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Cost Efficient Educational Multimedia Delivery

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DECLARATION

I, Andreea Maria Molnar, declare that this thesis is submitted by me in partial fulfilment of the requirement for the degree of Doctor in Philosophy, is entirely my own work except where otherwise accredited. It has not at any time either whole or in part, been submitted for any other educational award.

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LIST OF PUBLICATIONS

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ABSTRACT

Mobile device usage has increased both in developed and developing countries. The pervasiveness of cell phones has made them an ideal platform to cater educational content informally (anywhere, anytime). Although mobile devices offer different advantages compared with desktop PCs, several challenges need to be tackled such that students can effectively use them for learning. One of these is the cost of content delivery which is considered to be one of the most important issues that hinders the adoption of mobile devices. The cost of content delivery is particularly high when information is delivered over wireless networks. This is accentuated when heavy content, such as multimedia (understood in the context of this thesis as video in combination with audio and possible text), is delivered. With the further increase in heavy content, network providers have concerns that the infrastructure will not manage to cope with it and some of the network providers, that initially had flat rate plans, are considering charging extra fees for heavy data users.

Under these conditions reducing the cost of content delivery to suit the learners' budget, is necessary. Consequently, this research thesis proposes an adaptive mechanism that considers: learner willingness to pay for the multimedia content (and how it changes considering learner location, consumption history, billing plan, age and gender), learner device characteristics (resolution), and the wireless network type over which the multimedia content will be delivered, in order to personalise the cost of delivery for learners. The mechanism suggest to the learner unwilling to pay a high price, a lower quality (cheaper) version of the multimedia

clip, and higher quality version to the rest of the users, based on a new model of assessing the learner willingness to pay. As a part of this research significant other contributions were made: an analysis of the characteristics of feature of the feature phones and smartphones, an analysis of the mobile data billing plans that exists on the European market, a resolution based division of the mobile phones in four resolutions classes and proposing of suitable bitrate values for multimedia clips based on the resolution classes the device belongs to and wireless network over which the multimedia will be delivered.

The evaluation of the proposed mechanism has assessed the learner perceived multimedia quality, learning achievements, and the various savings obtained when the adaptive mechanism is used. The results have showed that the perceived quality and learning achievements have not been negatively affected for the learners who received the lower quality content. Moreover, savings are obtained in terms of amount of remaining data when a bundle based billing plan is used, and/or monetary cost.

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1 INTRODUCTION

Mobile device usage has increased both in the developed and developing countries. In particular developing countries, where the number of children who have access to a computer is small, mobile devices have the potential of alienating the digital divide. According to ITU-T, mobile network coverage will be 100% by 2015 (ITU-T WSIS, 2010). This implies *anytime, anywhere* access to information even in the most remote areas, leapfrogging landlines, leading to an advent of different mobile services, among them mobile learning.

Given the individuality of the mobile learner, personalization may be considered as a pre-requisite in mobile learning systems (Marin & Mohan, 2009). The diversity of mobile devices makes personalisation necessary, since content developed for one device may not be functional for another. From an educational point of view, it has been shown that personalised content is more effective (Spech, 2009), improving evaluations results and learning goal achievement (Chen et al. 2008a).

At the same time, multimedia is increasingly used in education, educational multimedia distribution systems such as iTunes U[niversity] (iTunes U, n.d.), Next Vista (NextVista, 2011), Schools Tube (Schools Tube, 2010), Teacher Tube (Teacher Tube, 2010) gaining popularity. Different studies have tried to determine the potential of using multimedia in education. It has been found that multimedia content enhances students’ interest (Dickinson & Summers, 2010), has the potential to enhance students’ performance (Fritsch, 2009; Smith et al., 2008), can help students with high absenteeism (Dickinson & Summers, 2010), and can be used to promote an inquisitive environment (Park, 2010). It is the most effective way of delivering the educational content to mobile devices (Macdonald & Chiu, 2011), and with the advent of mobile devices multimedia “is becoming casual and conversational”, a “primary form of communication” between many young people (Bell & Bull, 2010). Sometimes, it is also used as an initial point of reference when information is searched online (Iskold, 2008).

Unfortunately, multimedia has various characteristics which make it different to other types of content (e.g. text) mainly in terms of size and continuity. Size can lead to a higher cost of delivery, as an unlimited flat rate pricing for cellular network is not yet a norm (Telecoms Pricing, 2009; Telecoms Prepaid Services, 2009). Margrit Sessions, one of the world’s leading specialists in pricing, tariffing and billing analysis, as cited by Telecoms Pricing (2010) commented: “Overall, there are signs of more rational pricing being adopted, after the initial flurry of "all you can eat" data plans”. This can be noticed for some mobile operators, such as AT&T and Verizon, who initially offered flat rate plans but afterwards backed-up (Hamblen, 2009; Goldman, 2011).

1.1 CONTRIBUTIONS

This research makes the following contributions to the state of art:

- Proposes an adaptation mechanism that considers:
  - Learner risk attitude.
  - Learner device characteristics (resolution).
  - Wireless network type over which the multimedia is delivered.
- Models the learner willingness to pay (risk attitude) by taking into account:
  - Differences between gender and age that exist in terms of risk attitude
  - Learner own assessment regarding willingness to pay.
  - Changes in learner location (whether s/he is in the country in which s/he has the subscription or roaming).
  - Data usage history, when the learner has a data bundle billing plan.
- Performs an analysis of the mobile data billing plans that exit in five European countries: Ireland, Germany, United Kingdom, France, and Italy. The selection was selected based on their big population and high mobile subscriptions penetration rate.
- Performs a detailed analysis of the features phones and smartphones that exist on the market during the period 2008 - 2011[1]. Four device parameters have been considered

[1] Up to 14 June 2011

during the analysis: resolution, screen size, supported multimedia content, and supported wireless networks.

- Classifies the multitude of mobile phones based on their resolutions in four classes and proposes a set of suitable bitrate values for the multimedia clips for each class such as the video quality is not affected. The proposed bitrate values also take into consideration wireless network over which the multimedia content is delivered.

1.2 THESIS OUTLINE

The rest of this thesis is organised as follows:

Chapter 1.3 presents the related work in the context of this research. The chapter addresses mobile learning focusing on personalised mobile learning systems, multimedia adaptations techniques, usage of multimedia content in mobile learning, cost of the content delivery issues related to mobile learning, and consumer behaviour focusing on user risk attitude.

Chapter 3 starts with a classification of existing mobile devices. It continues with an analysis of the characteristics of feature phones and smartphones existent on the market between 2008 and 2011[1]. The analysis focuses on their resolution, screen size, supported multimedia format, and supported wireless networks.

Chapter 4 presents an analysis of the mobile data billing plans that exist in five European countries. The analysis presents both the national, as well as the roaming mobile Internet billing plans, for both pre-paid and contract based users.

Chapter 5 presents the adaptive multimedia mechanism that takes into account user risk attitude, mobile device resolution, and wireless network over which the multimedia content will to be delivered, and suggests intervals of bitrate values to be used for multimedia delivery.

Chapter 6 evaluates the proposed adaptive mechanism, both through objective and subjective assessment, and discusses the results.

Chapter 7 concludes the thesis by summarising the research findings and presents future work directions.

1.3 RESEARCH MOTIVATION AND PROBLEM

The monetary cost for accessing educational content through mobile networks is considered to be one of the most important problems hindering the widespread adoption of mobile learning (Dyson et al., 2009). Accessing the Internet on mobile devices is normally more expensive than accessing the same information via personal computers (PCs), and billing plans that allow unlimited Internet access without any restrictions are not common. This problem is aggravated by the scarce resources of wireless networks as compared with wired ones, and the exponential increase of multimedia content delivery over cellular networks (Yottabyte Era, n.d.). This poses problems to network providers (AT&T Overloaded, 2009; Consumer Electronic Association, 2010), and leads to doubts on whether the cellular infrastructure will manage to cope with it (Donoghue, 2008).

Concerns related to the cost of accessing the Internet from mobile devices have been raised in various contexts in mobile learning (Dyson et al., 2009; Koole et al., 2010; Lindquist et al., 2007; Min & Xiaoqing, 2010). Research done so far has proposed to reduce (Tan & Kinshuk, 2009), postpone (García et al., 2009) or have no communication (Gregson & Jordaan, 2009) over Internet between the mobile device and server. To the best of my knowledge, research which addressed the cost of delivery without affecting the possibility of interaction, has analysed the cost of delivery for text-only content (Dyson et al., 2009; Butgereit et al., 2010). However, multimedia is the preferred form for delivering educational content to mobile devices (Macdonald & Chiu, 2011; Gregson & Jordaan, 2009), since it compensates for the small screen mobile devices have, and reduces the necessity of scrolling. However, as it is, is also larger in size than text, it can be prone to higher costs to be paid for its delivery over wireless networks. Therefore, there is a need to address the cost of content delivery over mobile networks when multimedia educational content is involved.

The goal of this research is to address the problem of balancing the desire for multimedia based content access via wireless networks (Wi-Fi, 3G and 3G transitional) with the cost of content delivery in the context of user willingness to pay during learning. This thesis proposes an adaptive mechanism which reduces the delivery cost to the learners who are not willing to pay high price by decreasing the quality of the delivered multimedia content and provides high quality multimedia for learners who are willing to pay, or have access to free Internet connectivity. In order to assess the learner willingness to pay, research done in the consumer behaviour area was taken into account. In this space, the consumer attitude towards risk may predict the economic behaviour of the person (Dohmen et al., 2011).

The proposed adaptive mechanism takes into account learner risk attitude (and how its changes considering learner location, consumption history, billing plan, user feedback, age and gender), learner device characteristics (resolution), and the type of wireless network over which the multimedia content is to be delivered, as well as user feedback.

2 RELATED WORK

This research addresses the problem of high delivery cost over the cellular networks for mobile learning users, when multimedia educational content is used. The proposed solution for reducing the cost is an adaptive multimedia mechanism which takes into account the consumer behaviour. In this context, this state of art will cover the following areas of research: adaptive and personalised mobile learning solutions, adaptive multimedia delivery, multimedia usage in the mobile learning context, cost of delivery in mobile learning, and consumer behaviour.

2.1 MOBILE LEARNING

2.1.1 Mobile Learning Definition

There is no clear definition of what mobile learning is (Belshaw, 2010). Differences are related both to translation issues, as well as to cultural differences (Sharples, 2011). A generally accepted definition is:

"Any sort of [technology enhanced] learning that happens when the learner is not at a fixed, predetermined location or learning that happens when the learner takes advantage of the learning opportunities offered by mobile technologies. (Adapted from (O'Malley et al., 2003)).", as cited in (Sharples, 2011).

It the context of this thesis, mobile learning will be understood as learning with mobile technologies.

Mobile learning has several advantages over other forms of learning, such as:

- A high penetration rate both in developed and developing countries (ITU-T WSIS, 2010).
- Access to mobile networks is expected to have 100% world coverage by 2015 (ITU-T WSIS, 2010).
- Facilitates learning for the students that do not have that much time for home studying and hence they learn in unpredictable situations such as the time used while commuting (Ogawa, 2010; McElvaney & Berge, 2009; Tabata et al., 2010), waiting for public transport (Ogawa, 2010; Tabata et al., 2010), waiting while in line at the grocery store (McElvaney & Berge, 2009), waiting at the doctor's office (McElvaney & Berge, 2009), etc.
- Facilitate contextual learning (Tangney, et al., 2010; Patten et al., 2006; Ogata et al., 2010).
- Provides suitable information when it is needed (Yin et al., 2010).

Several mobile learning projects have been successfully developed, in the last years, showing positive results when using mobile devices in education (Tian et al., 2010; Daher, 2010; Butgereit et al., 2010; Butgereit & Botha, 2010; Kam et al., 2009).

Tian et al. (2010), studied how culturally inspired mobile learning games could help to improve Chinese literacy. The paper analyses different traditional Chinese games, and uses them as a motivation to design cell phone games that follow similar rules. The authors show that mobile learning has the potential to improve Chinese literacy and culturally inspired games have more potential than western games to attract the interest of children-students in China.

Daher (2010) examined how middle school students use mobile devices outside the classroom. Students were provided with the mobile application Fit2Go (a graphic tool that allows drawing linear and quadratic functions) to perform activities related to real world phenomena (Daher, 2010). The author concludes that the use of mobile phones while carrying out real world activities can enrich students' knowledge.

MobileMath (Butgereit et al., 2010) is an application that provides games, lessons, tutorials, examples, and quizzes as separate entities for students to practice concepts in algebra. Students used their own mobile phones, to get help with their mathematics during their free time (Butgereit & Botha, 2010). The system has been successful and it attracted 6000 participants since 2007, when it was launched (Butgereit et al., 2010).

Chen et al. (2008) proposed a ubiquitous learning system. On the mobile side, students will receive messages about what they should learn, updates about changes in the schedule, and help in finding peers to help them. The system has been shown to improve testing results, the task accomplished rate and learning-goal achievement.

Kam et al. (2009) explored the potential of mobile games for improving English literacy. The results of their pilot study have shown that mobile phones have the potential to improve English literacy. However, the results were uneven among the participants: the students that had a higher English level at the beginning of the pilot benefited more from the use of the mobile learning application. In order to solve this discrepancy, the authors proposed as a solution the creation of adaptive mobile learning games that offer personalised content depending on the student's knowledge.

These studies covered different countries. The mobile applications deployed in developing countries were mostly aimed at improving different skills out of school (e.g. literacy (Tian et al., 2010; Kam et al. 2009), mathematics (Butgereit et al., 2010)). For developing counties, they were focused on creating a contextualised environment (Daher, 2010; Chen et al., 2008b). Some of these studies also outline the necessity (Kam et al., 2009) and benefits of having an adaptive learning environment (Chen et al., 2008b).

2.1.2 Adaptation and Personalisation in Mobile Learning

Personalisation is both necessary and desirable in mobile learning. It is desirable because it has been shown that personalised content is more efficient and effective for learning support (Spech, 2009). It can improve testing results, task-accomplished by rating, and learning goal achievement (Chen et al., 2008a). It is necessary because the diversity of mobile devices makes difficult to design a content without keeping this in mind, a content that is not adapted to the mobile devices the learner uses, could be non-aesthetically looking or even non-functional. Personalisation in mobile learning covers several aspects such as: learner profile, learner device, and learning context.

2.1.2.1 Learner Profile Personalisation

The learner profile stores characteristics about the learner such as: the learner's knowledge, background, past interaction, preferred media type, learning styles etc. Different mobile projects have exploited these characteristics in various ways. For example, JPELAS2 (Yin et al., 2010) stored information about the learner such as: name, gender, year in school, friends and relatives. These are all introduced by the learner when s/he first enters into the system. In addition, the system will automatically detect the learner comprehension.

A ubiquitous learning system in which the students can access educational content from desktop PCs, laptops, PDAs or cell phones has been proposed by Chen et al. (2008a). The personalisation is done based on the learner's knowledge, personal schedule and learning goals. The system has been shown to improve the students testing results, task accomplishment rate, and learning-goal achievement rate.

Soliman & Guizani (2010) propose the usage of Radio Frequency Identification (RFID) technologies in order to match students based on their learning styles.

Yau & Joy (Yau & Joy, 2010) propose a model which incorporates five characteristics: location, level of distraction, time of the day, level of motivation and available time.

Graf et al. (2009) proposes to create automatically and dynamically a rich user model. The characteristics kept about the student are: profile, system usage (how do they use the system, when and what services they use for learning), student progress (what learning material and activities they view as well as the questions asked), interest and knowledge level, social closeness (what is the level of familiarity that exists between students and what are their genders and preferences for collaboration), problem solving abilities, learning styles and their location.

Frias-Martinez & Viserda (2011), show that for their sample, different learning behaviours exists across genders and ages, and propose to personalise mobile learning systems, based also on these components among others previously taken into consideration (e.g. time for answering the question, number of correct answered questions).

It can be seen that as opposed to the previous models who were incorporating only few factors in the adaptation, the newly proposed models incorporate more factors (Graf et al., 2009; Yau & Joy, 2010), that are automatically added.

In order to construct learner models with adaptive systems, different methods have been used such as: stereotype method, overlay method, and Bayesian method etc.

<u>Stereotype method</u>

In the stereotype based model the users are grouped in categories, based on their characteristics such as knowledge (Beaumont, 1994; Boyle & Encarnacion, 1994; Frias-Martinez & Viserda, 2011). The user classification can be done through binary values (the user belongs or not to a certain group) or through probabilistic values (represents the probability that a certain user belongs to a certain stereotype). Users can belong to one category (pure stereotype model) or to multiple categories (multiple stereotypes model).

<u>Overlay method</u>

Overlay method is used by most of the Educational Adaptive Hypermedia Systems, for user modelling (Brusilovsky & Millán, 2007). The user/learner model is represented relative to the expert model. Although the overlay method was initially a method used for representing the user knowledge in Intelligent Tutoring Systems (ITS), it emerged and is used today in Educational Adaptive Hypermedia Systems to model also other characteristics of the user, such as their interest, goals, etc. (Brusilovsky & Millán, 2007).

<u>Bayesian method</u>

The Bayesian method, like Bayesian networks, supports probabilistic inference in order to identify the best actions to take in case of uncertainty. Bayesian networks are directed acyclic graphs where nodes correspond to random variables. In a Bayesian based user model nodes correspond to user properties. The nodes are connected by directed arcs representing links from parent nodes to their children. For every node, a conditional probability distribution is associated. This assigns a probability to each value of the associated node, for each combination of the values of its parent nodes.

2.1.2.2 Learner Device based Personalisation

The diversity of mobile devices has been always considered a challenge in the area of mobile learning. Learners may have a diversity of devices, all with different characteristics such as:

- Screen size: width and height expressed in pixels;
- Screen colour depth: bits/pixel;
- Screen mode: it refers to whether the screen has portrait or landscape mode and if it supports switching between them;
- Capabilities: whether the device is capable of displaying multimedia, audio or images, etc.;

- Supported mark-up or scripting language: e.g. not all mobile devices support all JavaScript functions;
- Memory: capacity;
- Type of network connection (WiMAX, 3G, 802.11, etc.).

The screen size is the main device property taken into account by most of the personalised mobile learning systems in particular in the authoring process. For example, MEAT– Mobile E-learning Authoring Tool (Kuo & Huang, 2009) helps single authoring of multimodal interfaces. It produces SCORM (Sharable Content Object Reference Model) conformable learning objects such that the content may be re-used between different m-learning systems. Since this tool does not support content adaptation based on the learner profile, the content generated by the tool may be used by other applications that support content adaptation under the condition that the application supports SCORM objects.

In order to adapt the content to be suitable for mobile devices a solution is to write the content in XML format using the IMS Learning Design Specifications. This allows the separation of content from presentation style. It also gives the ability to display the content on a variety of devices and layouts. Ally et al. (2005) have proposed a system that gathers information about the learner device by asking the learner to complete a questionnaire when they use the device for the first time with the learning application. The questions are designed such that every learner should know the answer regardless of their background (the example given by them is that of a learner that will not be asked whether his device supports HTML because it cannot be assumed that all the learners know the meaning of HTML). Their solution uses a resource description framework CC/PP- Composite Capabilities/Preferences Profile promoted by W3C. They keep information about the learner processor type, amount of memory, OS version, and sound and image capabilities, based on which the server will transmit adequate content to the learner. The personalisation is done by using an agent which searches for conversion tools, in order to adapt the educational content to the learner mobile device. Personalisation is done based on a set of predefined rules.

Unfortunately, most mobile applications are created and tested just for a limited number of mobile devices, limiting the learner access to adequate information. If the learner accesses an application designed for a given mobile device by using a new model, there are chances that what s/he sees is not esthetical and difficult to follow (for example s/he should scroll a lot in order to arrive to the relevant information when the course is conceived for a bigger screen device than the learner has) when the devices vary in screen size or non-functional for devices which have different software capabilities.

2.1.2.3 Learning Context based Personalisation

Mobile learning is different from traditional learning on desktop computers, by the fact that learners could be anywhere and the learning may occur in any circumstance. The learning context refers to the location of the learner and the environment in which the learner is performing a learning session. Examples of context aware personalised m-learning systems are JAPELAS2 - Japanese Polite-Expressions Learning Assisting System (Yin et al., 2010), TANGO - Tag Added learNing Objects (Ogata & Akamatsu, 2004), and USL (Hwang et al., 2008).

JAPELAS aims at suggesting which Japanese polite expression may be used in a given context. The learners have a PDA equipped with IR (infrared), RFID (Radio Frequency Identification) tag, GPS and wireless LAN. Information about the learner location is obtained through the RFID tag attached to the doors when the learner is located inside the building, or by using GPS when the learner is located outside. IR is used for simplifying the communication targets; instead of entering the interlocutor name, the learner just points to him. The learners are required to introduce information about them when they use the system for the first time. Based on this information, the system suggests the appropriate “level of politeness”. Four “levels of politeness” were considered: casual, basic, formal, more formal. The level the learner needs changes according to hyponymy (e.g. age, position, etc), social distance (e.g. family, colleagues, etc), and formality of the situation (e.g. meeting).

TANGO recognizes the objects around the learner if they have a RFID tag. Based on these objects, different activities are suggested for the learner (e.g. the learner is asked where the microware is, etc.). Using RFID technologies with indoor or outdoor objects is also discussed in (Solimani & Guizani, 2010).

The USL system scope is twofold: to help the learner in finding peers which may answer his/her questions, as well as helping them to form groups based on their location and characteristics.

Different methods have been suggested in order to acquire the learner location:

- Goggle equipped with a special camera was used in MARS-Mobile Augmented Reality System (Doswell, 2006). The camera captures information about the learner’s current environment.
- Ekahau position engine computes the user’s relative position, with an accuracy of 3-5m. It uses WiFi signals as inputs for an algorithm that estimates the user position.

- GPS-Global Positioning System is utilised on a much bigger scale. It gives the position with an accuracy of 3m (Brown et al., 2006; Ogata et al., 2006).

2.1.3 Summary

Mobile learning, as understood in the context of this thesis, is defined as learning with mobile devices. It has several advantages such as a high penetration for mobile devices in both developed and developing world (ITU-T WSIS, 2010), it facilitates learning in different situations Ogawa, 2010; McElvaney & Berge, 2009; Tabata et al., 2010), it facilitates contextual learning (Tangney, et al., 2010; Patten et al., 2006; Ogata et al., 2010), etc. Different mobile projects have shown the benefits of using mobile devics in mobile learning (Tian et al., 2010; Daher, 2010; Butgereit et al., 2010; Butgereit & Botha, 2010), but also the neccessity for adaptation and personalisation (Kam et al., 2009). Adaptation has been done taking into account the learner profile (Frias-Martinez & Viserda, 2011; Yin et al., 2010), learner device (Kuo & Huang, 2009; Ally et al., 2005), and/or learner context (Yin et al., 2010; Solimani & Guizani, 2010).

2.2 ADAPTIVE MULTIMEDIA

As more and more mobile learning systems provide multimedia type educational content, this section presents an introduction on how multimedia adaptation has been done, and with what aims. Multimedia has been defined as "any combination of text, graphic art, sound, animation, and video that is delivered by computer" (Vaughan, 1993). In the context of this thesis multimedia refers to video in combination with audio and possible text.

Multimedia adaptation here refers to changing multimedia parameters, such as the bit rate, frame rate, resolution or colour depth. The adaptation of multimedia content has been performed for different purposes, such as adapting the content to the mobile device characteristics (Kopf & Effelsberg, 2008), optimising the delivery bandwidth (Muntean & Cranley, 2007) or increasing the battery life (Tsai et al., 2011).

Mobile Cinema (Kopf & Effelsberg, 2008) is an application that adapts high resolution multimedia content to mobile devices by considering the screen resolution, the bitrate or the colour depth of the mobile device when performing the adaptation. The disadvantage of the proposed adaptation is that the adaptation process might lead to loose in the semantic information when the video is cropped (Kopf & Effelsberg, 2008).

Quality-Oriented Adaptive Scheme (QOAS) adapts the multimedia content by using Moving Picture Quality Motion (MPQM) to estimate user perceived quality (Muntean & Cranley, 2007). The proposed mechanism is compared with other non-adaptive solutions and shows that by using it, higher number of simultaneously clients can connect to a Wi-Fi network.

Tsai et al. (2011) propose a system which adapts the multimedia streams based on their importance with the aim of improving the battery lifetime. They have shown positive results when testing the system through simulations.

2.2.1 Multimedia Adaptation Techniques

There are different ways of adapting multimedia content: entirely - focusing on the entire area of the picture; or partially - focusing on specific areas (ROI - "regions of interest") identified as important for the users. Multimedia adaptation is based on the fact that people prefer reduced bitrates to packet losses (Verscheure et al, 2008).

By *adapting the multimedia content entirely*, a more uniform adaptation is possible. Different adaptation solutions have been proposed with different aims. Khan et al. (2010) changed the bit rate and the frame rate of multimedia files with the aim of reducing the bandwidth necessary for the transmission of multimedia content. The study classifies the content in three categories: slight movement, gentle walking, and rapid movement, based on the spatial and temporal features of a multimedia file. Based on these categories the study determines the necessary bit rate and frame rate for different multimedia files. The acceptable quality is determined based on the PSNR metric's values mapped on the 1 to 5 MOS scale. Multimedia clips used in the study have a resolution of 176 x 144 and a frame rate of 10. The Jeong (2010) study addressed the battery power problem on mobile devices, when the multimedia content is presented on heterogamous devices. The research shows that by reducing the colour depth of the multimedia file to match the mobile device one, mobile devices drain considerably less battery and the video distortion is not considerable.

Gulliver & Ghinea (2004) showed that on a multimedia image, specific regions can be identified, on which the users are more interested in. Based on this approach, different adaptation schemes have been proposed (Ciubotaru et al., 2009; Muntean et al., 2008; Song et al., 2010). These schemes aim to reduce the quality for regions that are of little or no interest for the user and increase the focus on the "*region of interest*" (ROI). The idea is based on the human visual system that has different sensitivity to different visual areas (Sun et al., 2006). Adaptation based on ROI can deliver better perceived quality, especially for mobile users, where the resources are quite limited (Song et al., 2010). However, this solution might not be suitable in all contexts such as low bitrate multimedia with high movement (Song et al., 2010), or multimedia with frame rates less than 15 frames per second (Gulliver & Ghinea, 2009).

The above mentioned adaptive multimedia solutions can be applied also on educational content that consists of multimedia clips. For example, Ghinea & Chen (2008) focused on how changing the frame rate and colour depth of the multimedia clip is influenced considering users with different cognitive styles (Verbalizer, Bimodal, Imager). Results have shown that frame rates affect the information assimilation for Imagers, on different multimedia content types (high and low dynamism clips), that Imagers prefer 24 bit colours clips, and black and white movies are suitable to enhance their information assimilation. The last holds true also for Bimodal subjects.

2.2.2 Location of the Adaptive Mechanism

Multimedia adaptation can take place in different places: server side, intermediary proxy, or client side.

Server side

In this case, the adaptation is done on the server which stores the content. The main advantage is that the content is sent to the client, already fitting the requirements. This involves fewer resources necessary on the client side, which could be important when it comes to devices with limited resource power (e.g. mobile devices). There is also typically less bandwidth consumed, as the content scaled to the requirements of the client (for example, a clip to be sent to a mobile device, will be sent in that format, rather than a higher definition that has to be scaled down on the device). There are also other advantages in the sense that the content provider controls the content, and they keep their copyright. Among the drawbacks of this approach are all the traffic and the power that the server has to support since all the clients connect to the server; the necessity to keep track of all the clients' specifications. Among the research studies that follow this approach are: Van Deursen et al. (2010), and Arsov et al. (2010).

Client side

In this case the adaptation is done on the user device. Among the advantages of this approach one can count a more granular adaptation, and a better flexibility in involving the user during the adaptation process. However, this kind of adaptation would not be possible when the users do not have powerful devices (in terms of memory, and processor). There is a need as well that the users have installed applications that adapt the content, and this can be a tedious process both for programmers (taking into account the diversity of mobile devices that need to support the application), and for the users (it makes things harder for them, since they need to install applications). Among the studies that use this kind of adaptation are Davis et al. (2010) and Vaishnavi et al. (2010).

Intermediary Proxy

A proxy acts as an intermediate between the client and the server. The advantages of using this approach are that not all the processing is done on the server, which reduces the pressure put on the server; and not all the traffic is directed towards the server which may ease the communication, might avoid bottlenecks, and long delays. Among the disadvantages are that the proxy should be available through the Internet, since there should be communication at all times between the server and proxy and proxy and client. This implies that the proxy needs a public IP address. Among the studies that used this approach are: Ma et al. (2011) and Kofler et al. (2011).

2.2.3 Timing Multimedia Adaptation

Taking into account the moment when the adaptation is performed, the adaptation can be either online (dynamic mode) or offline (static mode). A hybrid approach is possible by using caching: the content is adapted online, but some of the versions are cached for further used.

Offline Adaptation (Static Mode)

Offline adaptation is performed before the content is send to the client. After the adaptation, the content is stored for future use. Offline adaptation can be done only on the server side. Among the advantages of this kind of adaptation one can count: the fact that the there is no latency involved with adaptation when the content is requested by the user; the content is transformed only once, at the beginning and then used as it is. There are other advantages inherent from the server side adaptation; such as the fact that the content is adapted only in one place, etc. Among the disadvantages are the diversity of the content that has to be stored on the server, since one version for each client (class of clients) has to be stored, not possible to serve live video (Zhu et al., 2011; Sun et al., 2008; Arachi et al., 2007).

Online Adaptation (Dynamic Mode)

Online adaptation is performed when the content is requested and can be done in any of the three locations. The main advantage is in terms of storage space, as a single version of multimedia has to be stored not all the adapted versions. Among the disadvantages are: the latency involved in adapting multimedia on the fly, and the fact that some content/adaptation cannot be done in real time, and at least some sort of multimedia pre-processing has to be done. Silvestre-Blanes et al. (2011) and Mastronarde & van der Schaar (2010) are two studies which used online multimedia adaptation.

2.2.4 Summary

Multimedia adaptation has been done with different aims and considering different factors. Multimedia adaptation can be done on the server side, client side or proxy side. It can be done either online or offline. It can consider all the multimedia when the adaptation is performed or only certain parts of the video.

2.3 MULTIMEDIA USAGE IN MOBILE LEARNING

Study habits are changing. Some students are using multimedia as an initial point of reference when they have questions related to a topic (Helft, 2009). Multimedia usage “is becoming casual and conversational”, a “primary form of communication” between many young people (Bell & Bull, 2010). In education, multimedia can be used among others to promote an enquiry environment (Park, 2010), to facilitate the comprehension of abstract concepts (Bravo et al., 2010), and to help students with high absenteeism (Dickinson & Summers, 2010). Also, according to the cognitive theory of multimedia learning (Mayer, 2001), presenting content both audio and visually can result in a better learning, by increasing the capacity to remember and transfer of information.

Multimedia has been used in mobile learning systems for different purposes such as: to enable access to education to a large number of students (Ullrich et al., 2010; Deb, 2011), to improve interactivity (Wang et al., 2009), to compensate for the small size of mobile devices (Gregson & Jordaan, 2009), to investigate different solutions for mobile learning educational content (Rekkedal & Dye, 2007; Macdonald & Chiu, 2011), to personalise the content based on learning styles (Al-Hmouz & Freeman, 2010), to investigate solutions for creating educational content which will be suitable for any device, regardless that it is a mobile device or a desktop computer (Dye & Rekkedal, 2008), investigate students preferences (Ogawa, 2009).

Mobile Live Video Learning System, MLVLS (Ullrich et al., 2010) is presented as “the first learning system that streams video lecturers to mobile devices”. The system is designed to work with Symbian OS smartphones. The multimedia resolution at which the lectures were broadcasted was 320 x 240. Difficulties were noticed during the study due to the GPRS connection bandwidth that is low or unstable, leading to frame drops and distorted video and audio. The results of the evaluation have shown that students liked the introduction of the system.

Wang et al. (2009) proposed a mobile learning system in which students have accesses to educational content both synchronously and asynchronously. As in previous case the students used their smartphones to access educational content. The students could select the content type they receive taking into account the network conditions (the content was designed for GPRS) and their preferences towards a media. The system is reported to enhance the students' interaction, but not for the courses broadcasted live since the students could not ask questions.

Gregson & Jordaan (2009) presented the challenges in creating a mobile learning system. The system was designed for postgraduate students in South Africa. They used video and audio content whenever possible to compensate for the small screen of the mobile device. Due to the delivery cost, they give the students the content from other sources (e.g. external card), rather than delivering it over the web. They noticed that the video, launched on the browser from the external card has a slow performance. In this case, the videos were short, aiming among others to supplement the course material. Students reported to be satisfied with the introduction of audio and video.

Rekkedal & Dye (2007) investigated among others the usage of small video clips on PDAs (Compaq iPAQ). They assume a cost free environment and the content was mostly used offline. The research did not find any problems when the content was accessed using the player supported by the device, but reported difficulty when trying to use the web browser. It was cumbersome for students to play multimedia content from the web browser, because the browser did not directly support playing video, or opening the player. The students found the video used of good quality, but negative comments were reported due to the technical difficulties encountered, with technical students being more critical than non-technical ones.

Macdonald & Chiu (2011) investigate the viability of using mobile learning for workplace learners. They did a pilot study which contained different media: text (as a PDF), video and audio. The content was both stored on the mobile phone, and part of it was streamed. The students were provided with a Nokia N96, a Symbian S60 mobile phone, with a resolution of 240 x 320 pixels. The results of the study have shown that video was the most effective way of delivering content for mobile devices. At the opposite side were text files that were found cumbersome to use, and students reported eye strains while reading.

Palmer & Dodson (2011) describe the results of a pilot study using both synchronous and asynchronous multimedia delivery, for ease of access to education for rural students. The students were provided with an Asus EEE notebook with 3G mobile data broadband. The notebook was chosen based on the consumer rating, battery life, and low cost. The video bitrate they streamed was maintained up to 256kbps, due to excessive buffering and delays noticed during field testing, for higher bitrate values. Difficulties were reported in poor sound connectivity and delays during synchronous discussions. However, most of the students (95%), preferred to continue with the courses in this format rather than commuting to the campus.

Ogawa (2009) researched whether students preferred face to face lecturers to podcasts when the content was complementary and taught by the same instructor. The study mentioned that the students had iPods given by the university, but does not specify if these were used during the study. The results of the study have shown that most students preferred face-to-face lectures but would prefer the podcast to be also used.

It can be noticed that few studies actually reported the usage of multimedia online. When it was reported, this is done mostly for GPRS (Ullrich et al., 2010; Wang et al. 2009), due to the popularity of this network type at the time when the research in question was done. Difficulties were reported on this network due to the low and unstable bandwidth. However, with the today increased presence of 3G and 3.5G networks this problem can be alleviated, Considering that multimedia content is shown to be the preferred one for mobile learning (Macdonald & Chiu, 2011), and the learners preference for accessing conveniently educational content even when they are not able to attend a lecture (Ullrich et al., 2010; Palmer & Dodson, 2011), its presence in mobile learning will most probably became popular. However, the cost of delivery is still a problem as reported (Gregson & Jordaan, 2009), and a solution for addressing it is necessary.

2.4 COST OF CONTENT DELIVERY

The monetary cost for accessing educational content through mobile networks (Dyson et al., 2009) is considered to be one of the most important problem hindering the widespread adoption of mobile learning (Dyson et al., 2009). Accessing data over mobile devices is normally more expensive than accessing the same information via personal computers (PCs). Concerns related to the cost of accessing the Internet from mobile devices have been raised in various mobile learning projects (Dyson et al., 2009; Lindquist et al., 2009; Min & Xiaoqing, 2010; Koole et al., 2010). The fact that the mobile data downloaded is limited is also an issue impacting mobile data adoption among some learners (Koole et al., 2010).

Chen et al. (2008b) reported that for 58% of survey participants the most important concern when using mobile phones for learning purposes was the overall high cost. This concern significantly surpassed any other concerns such as the educational content, multimedia effects or downloading speed. A study done on students' perception and potential impact on mobile learning in Thailand concluded that there are still "crucial" technological constraints related to mobile learning. Among the issues mentioned was the "huge" cost of always being connected to a mobile (James, 2011). Tan and Kinshuk (2009) suggest that when designing mobile learning systems, there should not be too much communication between the mobile device and the server. The reason given was that the cost of communication on mobile networks was "paramount".

Alternatively, Garcia et al. (2009) proposed the use of a mobile application that can work online as well as offline. The application stores the relevant server data directly on the learner's device. Updates are sent from the server when the learner is online using a low cost or free connection. Having the information stored on the mobile device, the learner can access it also while being offline. When s/he finds a suitable free or low cost network, the device will synchronise the content from the terminal with the one on the server. This solution allows mobile learners not to depend on Internet connectivity all the time. However, the learner still needs to connect at a certain point to the Internet in order to update the educational content, which in the case of multimedia content, can be quite heavy.

Gregson & Jordaan (2009) propose to distribute the content using external storage, such that the students will not have to pay for mobile data. The system is synchronised through a PC.

Dyson et al. (2009) proposed mInteract, a tool that allows students to use the mobile Internet, rather than sending messages. In this way the price the learner has to pay for downloading the educational content is reduced from 20-25c/SMS to 2c/interaction. This system is used for interaction in the class and does not consider high bandwidth multimedia clips. A similar approach is presented also in Butgereit et al. (2010). There MXit application (MXit, 2011), a text based chat is used for communication between the students and tutor, due to the lower cost of sending text messages through MXit rather than SMS messages. The limitations and advantages are the same as in the previous approach, the system allowing just text delivery and not catering for multimedia delivery.

It can be seen that students still perceive mobile data usage as expensive. Few solutions have been proposed probably due to expectation that cost will not be a problem in time (Kukulska-Hulme, et al., 2011). Four main directions for cost reduction are noticed: maintaining very little communication between the client and the server (Tan & Kinshuk, 2009), no communication via mobile networks, synchronisation being done via PC (Gregson & Jordaan, 2009), postponing the communication by having mobile applications that work as well offline and online (García et al., 2009), and using mobile data instead of SMS communication (Dyson et al., 2009; Butgereit et al., 2010). All these solutions partially address the problem.

Maintaining very little communication would reduce the cost, but at a certain moment students would still need to get new content, since the memory of mobile phones is an issue itself. The little communication could lead to mobile learning applications where collaboration between learners is not encouraged, increasing a sense of isolation for mobile learning students.

Moreover, by synchronising the content through a PC forces the students to have access to a PC every time when they need new content.

Applications which work offline as well as online, enssure that the learner could use the mobile application regardless or not if a mobile network is available. However, at a certain point the student still needs to connect to the network in order to synchronise the application with the server.

The usage of mobile data, instead of SMSs, for reducing the cost has shown to considerably reduce the monetary cost for the learner Dyson et al., 2009; Butgereit et al., 2010). It has been also successful, since MobileMath (Butgereit et al., 2010) is running since 2007 and it is having more than 6000 students, who voluntarily use it during their free time.

2.5 CONSUMER BEHAVIOUR

Behavioural economics area is a branch of economics that integrates psychology with neo-classical economics. It identifies ways in which the people's behaviour is different from the standard model that is based on rationality. Behavioural economics is concerned mostly with the bounds of rationality and what effects the emotional, cognitive and social factors have on human decisions directly and on the market indirectly.

Some of the arenas in which behavioural economics differentiates from neo-classical economics, as presented in Mullainathan & Thaler (2000) are:

- Neo-classical economics assumes that investors are always taking the most rational decisions, while in practice investor overconfidence, could lead them to making decisions even when the information s/he has is incomplete.
- Neo-classical theory stresses on people being concerned mostly with their self-interests but in practice people behave many times in a non-selfish manner.
- Neo-classical sustained that people have the same attitude towards information no matter of the time when it is received, while it has been shown that people tend to overreact to new information.

- Neo-classical economics assumes that the willingness to take risk is constant across the context. Although there is a stable risk attitude, it can vary across different contexts (Dohmen et al., 2011).

2.5.1 Risk Aversion

One of the dispositions that drive economic decisions is the human attitude towards risk. Risk is considered “the pivotal element in consumer behaviour” (Taylor, 1974). It is most often associated with uncertainty (e.g. missing information – making decisions about an unfamiliar brand, however “full information” contexts do not imply missing uncertainty (Bruke, 2010)).

It has been found that risk attitude has a great impact on many of person’s decisions such as those involving stock investment, educational attainment, ownership of a home and occupational choices (Dohmen et al., 2008). Understanding people’s attitude towards risk is linked to predicting the consumer behaviour (Dohmen et al., 2011).

Purchase decisions are one of the arenas which involve perceived risk. In Solomon et al. (2010), five kinds of risks that affect purchase decisions are presented: monetary risk, functional risk, physical risk, social risk and psychological risk. Items which are perceived as having a high price are more susceptible to monetary risk. Functional risk refers to the performance of the product. The physical risk is greater when the accident is bigger. Social risk involves the pressure put by the peers when buying visible goods (e.g. when the choice is visible to other peers, there is a risk of embarrassment if the decision is made). Psychological risk refers with how satisfied the consumer will be with acquiring a certain product. Risk is perceived different by different consumers. For example, a self-confident consumer will not be so much affected by peer choices; wealth can influence how monetary risk is perceived etc.

Based on people’s attitude towards risk, previous studies have shown that certain categories of people tend to be more risk adverse than others, e.g.:

- teachers are less willing to take risks than people involved in other professions (Dohment & Falk, 2010)
- women are less willing to take risks than men in general (Dohmen et al., 2011; Ding et al., 2010) and in different contexts (Dohmen & Falk, 2011; Niederle & Vesterlund, 2007; Karhunen & Ledyaeva, 2010)
- people with high-educated parents are more willing to take risks (Dohmen et al., 2011)
- high educated people are more willing to take risks than the ones with less education (Donkers et al., 2001; Rosen et al., 2003).

- older people are less willing to take risks (Dohmen et al., 2011)
- taller people are more willing to take risks than shorter people (Dohmen et al., 2011)
- risk aversion is negatively related to family income (Ding et al., 2010).

Based on their attitudes towards risk people can be classified into:

- Risk averse – they prefer not to assume risks;
- Risk neutral – who are neutral to risk;
- Risk seekers –they love risk.

However, these three categories are not always used as they are, sometimes only the first and last one are being used, risk neutral people being included in any of the previous two categories. This depends on the relevance of all three categories to the experiment, or whether or not the method used is able to determine the risk neutral category. Experimental studies involving lottery and hypothetical questions are typically able to determine a risk neutral person, while studies in which people are asked to assess on a scale their attitude towards risk in general or in different contexts, cannot be determined where on the given scale the risk neutral persons are). These categories were used to determine the user attitude towards risk across different contexts such as health, financial matters, career, in order to predict the economic behaviour or to explain different decisions (Hammitt & Haninger, 2010; Dohmen et al., 2011; Niederle & Vesterlund, 2007).

Concerning the distribution of risk attitudes, studies have shown that people are mostly risk averse, and this seems to be maintained across cultures (Dohmen et al., 2011; Holt & Laury, 2002; Ding et al., 2010). The study performed by Dohmen et al. (2011) with a sample of approximately 22 000 people (selected such that they are a representative sample from the German population) has shown that 78% of the participants are risk averse, 13% arguably risk neutral and 9% are risk loving. Similar results have been obtained by Holt and Laury (2002): 81% of the subjects were risk averse, 13% risk neutral and 6% risk loving. The former study sample consisted of 175 subjects (approximately, 50% undergraduate students, 33% MBA students and 17% business school faculty), from two universities (Georgia State University and University of Central Florida). Research done on a sample of 121 Chinese students has also shown that the subjects are mostly risk averse with over 20% risk lovers (Ding et al., 2010).

2.5.2 Risk Attitude across Different Contexts

A controversy concerning whether the people's risk attitudes are constant or not across different contexts, exists among neo-classical economics and psychology. Neo-classical economics economists believe that risk preference is the same across all contexts, and psychology challenges this idea. More recent studies show that a stable risk attitude exists but it may vary across the contexts (Dohmen et al., 2011), therefore, when taking into account people's attitudes towards risk, the context should be also taken into account in order to obtain better results.

2.5.3 Risk Theory Critiques

The critique given to risk theory is that it does not explain user preferences for flat rate pricing when they can choose between flat rate type of tariff and pay-per-use. This phenomenon has been called "flat-rate bias" (Train, 1991). Lambrecht and Skiera (2006) found that over 50% of the customers of a German Internet provider used a flat rate service, when a measured one would have been more suitable for them in terms of monetary cost. They argued that the consumer attitude towards loss could potentially explain this flat-rate bias. A consumer is considered loss adverse if s/he does not like any augmentation in the bill from the reference point s/he established. Their argument is that loss-averse consumers will be more biased towards a flat-rate plan. The difference between the reference point and the bill value will be perceived as a loss, if it is negative.

Studies that document bias towards flat rate tariffs are also found in the mobile telephony area (Gerpott, 2009; Mitomo et al., 2009). Gerpott (2009) argued that the bias can be explained by people having difficulties in estimating how much they will spend. In this case, they tend to overestimate the amount they spend. Based on their erroneous assumptions, they believe that a flat-rate tariff will be the most suitable solution for them. This leads to subscribers having higher bills than if they had chosen the pay-per-use alternative. Other studies on mobile telephony show as well that people do not know how to estimate the cost associated with mobile data access for different billing plans (Isomursu et al., 2007; Roto et al., 2006). Roto et al. (2006) discuss how people use different types of mobile Internet billing plans, and how people behave when using them (e.g. people who are using a time-based billing plan are concerned with optimising their actions, to reduce the time spent on the Internet, whereas the ones who use a mobile data billing plan, are confused about how much they do spend).

2.5.4 Assessing Risk Aversion

Risk aversion can be measured by involving people in experiments or through questionnaires. During experiments, people play lottery with real money at stake. The main advantage of using experiments is that they offer a compatible incentive for measuring risk attitudes (Eckel & Grossman, 2007). However, experiments are usually lengthy and they necessitate real money that makes them costly. A cheaper alternative is to use questionnaires. The main advantage of the questionnaire is that it is a direct method as opposed to the experiments when behavioural parameters have to be taken into account (Dohmen et al., 2005).

There are two ways to determine a learner's attitude towards risk through questionnaires: either by using the so-called lottery question or asking the learner to rate its willingness to take risk on an 11-point scale (Dohmen et al., 2011). Based on the user answer to any of these two questions, the person is categorised.

The most common method is the *hypothetical lottery question*, where the subjects are presented with a set of lottery like choices and are asked to select the choice they prefer. An example of a lottery question is:

> "*Imagine you are at a community fair. You have just won a throwing game and are entitled to claim a $40 prize. The operator of the game offers a second follow up game with the prize money. In this game, you will spin a wheel with two colors, yellow and green. You final prize depends on which color an arrow on the side is pointing to when the wheel stops spinning. If the pointer is on yellow, you win $60. If it comes up green you get only $20. At what settings of the odds to win (percentage on the wheel that is yellow) would you agree to play the follow up game? Answers can range from 1% to 100%*" (Nunes, 2000).

Using the *hypothetical lottery question* is cheaper than experimental studies because they do not involve real money. However, even though a *hypothetical question* is a strong predictor for financial domains, they might not predict the actual behaviour in different contexts (Dohmen et al., 2011).

More recent studies, have found that asking users to rate themselves leads to a better prediction of the user attitude across various contexts such as financial attitudes, career, health, car driving, sports and leisure (Caliendo et al., 2009; Dohmen et al., 2011; Jaeger et al., 2010).

The *general risk question* (Dohmen et al., 2011), in which the subjects are asked to rate their willingness to take risk in general is "the only measure to predict all of the behaviours", being "the best all-around measure" (Dohmen et al., 2005). The study uses as well an experimental study and the *hypothetical lottery question*. The *general risk question* maps to the actual choices from the lottery experiment (Dohmen et al., 2011) and has the potential to incorporate both risk preferences and risk perception (Dohmen et al., 2005). Taking into account that the emotions and other perceptions play a role in their behaviour (Bechara & Damasio, 2005;

Camerer et al., 2005), being able to incorporate both risk perception and preferences can be considered an advantage.

The *general risk question* used in Dohment et al. (2011) is "*How willing are you to take risks in general*". A scale from 0 to 10 is given to the subjects to rate their willingness, where 0 means "not at all willing to take risks" and 10 means "very willing to take risks" (Dohmen et al., 2011).

The *general risk question* was initially tested with a representative sample of 22 000 people of German population that were answering as well hypothetical questions. It was tested both with general risk attitudes as well as with their attitudes across different contexts (holding stocks, sport, health, and self-employment) (Dohmen et al., 2005; Dohmen et al., 2011). Afterwards, the results were validated with experimental studies on 450 people, chosen in the same way as the initial sample of 22, 000 (Dohmen et al., 2011) . Since then different other studies have successfully used the *general risk question* (Caliendo et al., 2009; Jaege et al., 2010; Grund & Sliwka, 2010). Caliendo et al. (2009) used it to study the effects of risk aversion on the decision of becoming self-employed. The results of the study have shown that people who were previously a regular employee are more willing to take risks and to become an entrepreneur. For other the people attitudes towards risk have no effect. Their results are based on the same sample as in the Dohmen et al. (2011) study, by considering only the persons who were not self-employed the previous year but were in the current year (2005), when the data was collected. The sample consists of 147 subjects. The *general risk question* was used to classify the users in three categories:

- Low risk: those who answered between 0 – 2
- Medium risk: those who answered between 3-7
- High risk: those who answered between 8 – 10

However, the results were not sensitive to the previous classification. They also used the *hypothetical lottery question* as well as other two self-assessment questions regarding the willingness to take risks in "financial matters" and "occupational choices". Although different categories of users have been defined, usually persons are divided either in two categories: risk averse and risk loving, or in three by identifying risk neutrals from the previous two ones.

Deciding which method to use in assessing risk aversion will depend on the scope of the study. Experimental studies are generally considered the best, however, they are hard and costly to organise for a large sample. The questionnaire could easily cover a bigger sample, and it was shown to provide accurate results as well.

2.5.5 Summary

Consumer behaviour integrates psychology with economy in order to predict, explain and understand consumer behaviour. Different factors affect the decision of a person to purchase a product. One of these is the risk. Financial risk in particular has been extensively studied in economics. The consumer attitude towards risk varies from person to person based on different factors such as gender, age. The person attitude towards risk may vary based on the context in which s/he is. There are two methods to assess the user attitude towards risk: experimental studies and questionnaires. Experimental studies are considered the most accurate; however they have high cost both in terms of money and time. A cheaper alternative to experimental studies are questionnaires which are less costly and have been shown to be accurate. There are two ways of assessing risk through questionnaires: by using the *hypothetical lottery question* or the *general risk question*. The *general risk question* has been shown to have certain advantages compared to the *lottery question* such as better prediction across different domains (Dohmen et al., 2011), and test-re-test stability (Lönnqvist et al., 2011). However, so far there is no way to determine risk neutral person with the general risk question.

2.6 SUMMARY

This chapter started with defining what mobile learning is, and its advantages. It then continued with the necessity of adapting educational content for mobile learning courses. Three main aspects considered in the adaptation have been identified: learner profile, learner device and learner context.

Since more and more delivered educational content is multimedia based, the chapter continued with the work performed in multimedia adaptation communities. It explained how multimedia adaptation has been done and with what aims. It then presents the work done in multimedia adaptation for online learning.

Section 2.3 presented mobile learning systems that have used multimedia type content. Multimedia has been used with different purposes, and mostly stored on the learner device, due to cost and bandwidth issues. However, recently, streaming multimedia has been used as a solution to give access to education to as many students as possible.

The cost issues for delivering educational content over mobile networks were discussed in section 2.4. Although several solutions have been proposed, there are still issues to be discussed in this arena, especially concerning the cost of delivery for multimedia content.

Consumer behaviour could help in identifying the learner economic behaviour and providing personalised solution. The last section introduced consumer behaviour and discussed risk aversion as a means of predicting economic behaviour. It also presented how risk assessment can be done and discusses what the most suitable ways for doing it are.

Using consumer behaviour to find the learner risk attitude, and then adapt the multimedia content based on it, can help solve the problem of delivery cost in mobile learning.

3 MOBILE DEVICES

3.1 MOBILE DEVICES CLASSIFICATION

With the presence of a large number of mobile devices in the world and the ever increasing coverage of mobile cellular networks, by 2015 ubiquitous access to information (ITU-T WSIS, 2010) will be possible (no matter where on the globe one is). Many of these mobile devices, such as mobile phones, have accessible prices, and are increasingly present on developed and developing markets (Rashid & Elder, 2009). However, a multitude of devices exist on the market making the decision to select a particular one very difficult.

At the same time, multimedia (video) content is increasingly preferred both in the educational arena, as well as in the day to day life. Multimedia is used to such extent that people prefer to search for the desired information in a multimedia format

With regards to multimedia content, and not only, one of the main issues is the diversity of resolutions presented with the mobile devices and the lack of accessible statistics regarding the most used resolutions, screen sizes, network capabilities and multimedia formats provided by mobile devices. The aim of this chapter is to analyse the mobile devices that were launched in the period 2008-2011[2] and the new models that are/will be released on the market in the second half of 2011[2]. The analysis compares mobile devices in terms of resolution, screen size, network access, and multimedia format, and determines which, among these, are the most used characteristics for the mobile devices currently used worldwide and on the Irish market.

The rest of this chapter is organised as follows: the next section makes a general classification of mobile devices types, and briefly describes them. Then an analysis of mobile phones (feature phones and smartphones, in particular) that support multimedia, focusing on mobile phone's resolution, screen size, supported multimedia formats and access to wireless networks is performed. Section 3.3 aims to summarise the characteristics of a mobile device that is used for mobile learning. The last section draws the conclusions.

3.1.1 Mobile Devices Classes

Currently, there are different devices on the market that can be considered portable. The following classes of mobile devices have been identified:

- Mobile Phones
- Digital Assistants
- Ultra-Mobile Devices (UMDs)
- Laptops
- Wearable computers
- Portable digital media players
- Mobile gaming devices
- Removable storage format
- Pagers
- Global Position System (GPSs) devices

Although *wearable computers, portable digital media players, mobile gaming devices, removable storage format, pagers* and *GPSs* can be considered as "ultra-mobile", they are usually not included when one speaks of UMDs. It is the same case for *mobile phones* that are usually considered as a separate category.

3.1.1.1 Mobile Phones

Three main categories can be distinguished in the mobile phone category: *basic phones, feature phones (cellular phones)* and *smartphones*. All these devices are characterised by being mobile devices that allow placing calls.

[2] Up to 14 June 2011

Basic phones are mobile phones that allow users to place calls and have a basic functionality. Even though mobile devices were used even during the World War II, the first commercial cellular phone was made available in 1984, by Motorola. The name of the model was DynaTAC 8000x.

Feature phones (also called cellular phones) are mobile phones that allow users to place calls. They also have an enhanced functionality compared to a basic phone. They can offer Internet access; they have the capability of playing multimedia content, and can provide support for Java applications, and even multiple SIM cards.

Smartphones are mobile phones that apart from allowing users to make a call, they can also provide high functionality and run an Operating System (OS). They allow running multitask applications. The term smartphone was used for the first time to label GS88, a mobile phone produced by Ericsson in 1997. However, previous to this, in 1993, IMB Simon was considered to be an advanced phone sometimes included in the smartphone category due to its advanced features for that time, even though it had no OS. IMB Simon combined a mobile phone, a Personal Digital Assistant (PDA), a fax machine, and a pager features and had several applications such as calendar, address book, and e-mail. It also had a touch screen device. Another advanced mobile phone considered a smartphone was the Nokia 9000 released in 1996 belonging to the Nokia Communicator line. This mobile phone is a combination between the Nokia phone and the Hewlett Packard PDA. Although, there were few phones in the past that were considered smartphones due to the enhanced capabilities, nowadays a smartphone is considered a mobile phone that has an OS. This definition will be used from here on in this research.

Smartphones have high capabilities, the majority of them supporting multimedia, Internet access, and multiple network capabilities. Similar to feature phones, some of them even support multiple SIM cards. The smartphones provide the best combination between portability and functionality.

3.1.1.2 Digital Assistants

This category has two classes of devices: *Personal Digital Assistants (PDAs)* and *Enterprise Digital Assistants (EDAs)*.

Personal Digital Assistants - PDAs (also known as palmtop computers) are digital agendas that lately also allow Internet access. As compared to smartphones, PDAs cannot place calls but are considered as more advanced in terms of functionality than smartphones. However, recent advances in smartphone development make smartphones similar to PDAs in terms of functionality; with the advantage of also having mobile phone features on the same device.

Enterprise Digital Assistants – EDAs (also known as Data Capture Mobile Devices or Batch Terminals or Portables) are handheld devices, similar to PDAs but adapted for use in Small to Medium Enterprise and Enterprise business applications. The main difference between EDAs and PDAs is that EDAs include data capture technologies, such as barcode, magnetic stripes, and Radio Frequency Identification (RFID) technology. Both PDAs and EDAs can play multimedia files. Another difference is that EDAs, as opposed to PDAs are designed for the use of multiple users, while PDAs are usually personal devices. EDAs are typically more robust than PDAs and smartphones, being designed for use in rugged environments. An example of an EDA is MC70. It has a 3.5’’ (89mm) screen, 240 x 320 resolution, and access to the following networks: eGPRS, GSM, Wi-Fi a/b/g.

3.1.1.3 Ultra Mobile Devices (UMDs)

Ultra Mobile Devices (UMDs) devices include: *smartbooks, Mobile Internet Devices (MIDs), Ultra Mobile Personal Computers (UMPCs), Tablet Personal Computers (Tablet PCs), Tablet Computers (Tablets), subnotebooks* and *notebooks*. All these devices can be used to watch multimedia content.

Smartbooks are mobile devices, filling the niche between notebooks and smartphones. In terms of size, they are typically bigger than a smartphone and smaller than a notebook. They offer better functionality than a smartphone would, but lower than a notebook. As opposed to notebooks, smartbooks allow user to place calls.

Mobile Internet Devices (MIDs) are mobile devices that have multimedia capabilities and support wireless connections. They are larger than a smartphone and smaller than an UMPC. They are considered to bridge the niche between smartphones and Tablet PCs.

Ultra Mobile Personal Computers (UMPCs) are mobile devices, slightly larger than MIDs, which are typically optimised for office applications. The differences between MIDs and UMPCs lie in their size, portability and functionality. MIDs are typically smaller and more portable than UMPCs. In terms of functionality, the main differences between UMPCs and MIDs are shown in Table 3-1.

Table 3-1 UMPCs vs. MIDs Functionality Differences

UMPC	MID
Business class device, focusing on enterprise use	Consumer class device, for personal use
Full desktop class OS, such as Windows Vista	Runs a “lightweight” OS such as Linux
Optimised for productivity applications	Optimised for quick start up, web surfing and media applications

Tablet Personal Computers (Tablet PCs) are ultra-light personal computers, tablet-sized, usually having a touch screen but a keyboard may also be attached. The screen size is typically 12’’ (~30.5cm), but Tablet PCs with larger screens exist, such as the Acer TravelMate C300, that has 14.1’’ (~38.51cm), an 1024 x 768 resolution, 3D display capabilities etc.

Tablet Computers (Tablets) are tablet mobile devices, which emerged in the middle of 2010, with similar aims and functionality as a Tablet PC. However they are typically smaller than a Tablet PC and with longer battery lifetime. Examples of tablet computers are iPad, and Samsung Galaxy Tab. The main differences between a Tablet PC and tablet computers are presented in Table 3-2.

Table 3-2 Tablet Computers vs. Tablet PCs

Tablet Computers	Tablet PCs
Mobile OS	A modified desktop OS
Finger driven (multi-touch capacitive touchscreen)	Stylus driven (resistive touchscreen)
Not considered to be a personal computer due to the restrictions regarding software installation and lack of admin rights for the user	Personal computer
Screen size between the size of a PDA and the size of a Tablet PC (typically between 7’’-12’’)	The screen size is typically 12’’, however larger screens are possible

Subnotebooks (also called ultraportables or mini notebooks) are considered to be similar with notebooks but lighter and with a smaller keyboard and screen size. They usually weigh around 1kg, typically not more than 2kg and have a screen size less than 11''. They are optimised for use for accessing the Internet and in the same time being ultraportable. An example of a subnotebook is Macbook Air of 11.6''.

Notebooks are mobile computers, smaller and lighter than a laptop, but heavier and bigger than a subnotebook. They have a higher battery lifetime than a laptop (around 4 – 5 hours), no CD-ROM/DVD included, and the keyboard is smaller, in order to keep them light and small.

3.1.1.4 Laptops

Laptops are portable computers that are larger than notebooks and have more capabilities but typically smaller than deskbooks and not as capable. The battery has a smaller lifetime than the one of a notebook, usually lasting around 3 hours.

Deskbooks (also called Desktop replacement computer) are computers that offer higher functionality than a laptop as it trades-off portability. They are larger and heavier than a laptop. Among mobile devices, they are the closest in functionality to desktop computers. An example is DeskBook Pro.

3.1.1.5 Wearable Computers

Wearable computers may come in different shapes and forms. This section focuses on *wristwatch computers* and *head-mounted display*s.

Wristwatch computers can be used around one's wrist (typically looking as a wristwatch, they come also in other shapes, such as bracelets). It can offer different functionalities. For example, some of them are similar to a PDA (e.g. Fossil Abacus is a PDA, looking as a wristwatch, with a Palm OS, 8MB RAM, micro USB etc.), others to a tablet computer (e.g. ZYPAD WL 1000 has 64MB RAM, a screen size of 3.5'' (89mm), 320 x 240 resolution; supports Wi-Fi b/g, Bluetooth, GPS, ISDA; has an USB and it looks like a bracelet) or a mobile phone (e.g. LG GD910, has a screen size of 1.43'' and a resolution of 128 x 160, access to 3G networks). These devices are used for diving (e.g. Ocean OC1), doctor/patient communication (e.g. Zypad devices), kicking (e.g. Suunto M5), etc.

Head-mounted displays (HMD) are mounted usually on a helmet or on a set of goggles. An example is Wrap 1200 from Vuzix, which was announced in Spring 2011. This device looks like a pair of sun glasses, and provides the experience of a 16:9 widescreen 75'' display. It supports both 2D and 3D content. These devices are mostly designed to be used in aviation, medicine, gaming, training etc.

3.1.1.6 Portable digital media players

Portable digital media players are mobile devices capable of storing and displaying/playing media. Some of these devices are capable of recording videos and have Internet connection. They typically have a small screen and a keyboard to select the music. However, there are portable digital media players that have a touch screen (e.g. iPod touch). Most of the previous presented categories support media players; however this category is designed for those mobile devices that have only this functionality.

3.1.1.7 Mobile gaming devices

Mobile gaming devices are portable consoles that allow playing games. Although, most of the previously presented mobile devices will now support game playing, this category was necessary because of the mobile devices that are especially designed for game playing without having the functionality presented in the previous mobile devices (e.g. PSP go).

3.1.1.8 Removable storage format

Removable storage format are storage devices that allow the easy transport of data. They can be anything from a portable hard drive to a memory card.

3.1.1.9 Pagers

Pagers are mobile devices that enable the transmission of messages. One-way pagers allow only the reception of messages, while two-way pagers also allow replaying messages.

3.1.1.10 Global Positioning System (GPS) Devices

Global Positioning System (GPS) devices are portable mobile devices that show the current location of the user, based on the satellite localisation.

3.1.2 Mobile Devices with Access to Mobile Networks

The research presented in this thesis, addresses the high cost of delivery over wireless networks. However, cellular networks pose the greatest problems in terms of high cost of delivery. From this perspective, mobile devices that can access cellular networks are of particular interests. From this point of view, Table 3-3 presents, a classification of mobile devices with access to cellular networks.

The first column lists cellular network enabled mobile devices such as feature phones, smartphones, some laptops – e.g. Dell XPS M1730, and devices that are not cellular network enabled but may access the cellular networks with the help of external modems (e.g. by using a USB modem, or by using the mobile phone as a modem).

Table 3-3 Mobile Devices' Classification based on the Cellular Network Availability

Mobile Devices with Access to Cellular Networks	Mobile Devices without Access to Cellular Networks
Feature phones	PDAs
Feature phones	EDAs
Smartphones	Head-mounted displays
UMPCs	Portable digital media players
MIDs	Mobile gaming devices
Subnotebooks	Removable storage format
Notebooks	Pagers
Laptops	GPS
Tablet PCs	
Tablet computers	
Deskbooks	
Wristwatch computers	

Although the devices from the second column of the table do not have yet access to cellular networks, some of them will probably have it in the future (e.g. head-mounted displays). However, others will more likely not adopt cellular networks. One such example are pagers, that now are mostly used in places where there is no cellular network coverage because it is not possible to use a cellular phone due to interference with other electronic equipment (e.g. medical equipment). They can be used as well in places in which it is unsafe to wear other kind of communication equipment (e.g. mining buildings).

Among the devices presented in Table 3-3, almost all currently have access to Wi-Fi networks with the exception of the removable storage format and GPS systems.

3.1.3 Summary

This section presented an overview of the existing mobile devices on the market. They are different in terms of functionality and the purpose with whom they were created. However, one can notice a merging between different categories of devices such as smartphones having both the functionality of a feature phone, PDA, portable media player and game device. There is also a tendency towards devices being ubiquitously connected, by providing access in cellular networks to devices that traditionally did not have such connectivity, for example laptops.

3.2 MOBILE PHONES ANALYSIS

There is a plethora of mobile devices that have different resolutions. This make it is difficult to pin down these resolutions to a certain class of mobile devices, different classes having the same resolution. For example, LG enV Touch VX 11000 –is a feature phone, Sony Ericsson XPERIA X1 – which is a smartphone, and uSmart M1C Intel Atom UMPC, both have a resolution of 800 x 480. Although it is true that a bigger screen size supports a bigger resolution the available mobile devices support different resolutions on the same screen size. For example a device with a 3.5’’ supports both a 240 x 320 resolution (e.g. HTC Blue Angel) and a 640 x 960 resolution (e.g. Apple Iphone4). The year when the device is released does not help too much either as the HTC Wildfire and Apple IPhone 4 were both released in June 2010, the first one having a resolution of 240 x 320 while the last one having a resolution of 640 x 960. Even though the resolutions cannot be pinned down, there is a certain trend towards higher resolutions for all classes of devices. Feature phones can have lower resolutions than a smart phone or UMPC. However, this is not a rule. More and more feature phones offer the same resolutions, though not the same capabilities as a smart phone or UMPC. This suggests a convergence between different classes of devices, both in terms of resolution as well as in terms of functionality.

Since one needs to cover a wide range of mobile device parameters when designing a mobile application, it is more cost effective to cover a subset of mobile devices. In order to decide the most common characteristics of these devices, an analysis of the feature phones and smartphones was performed. The parameters taken into account in the analysis are resolution, screen size, access networks and multimedia format that can be used. Just feature phones and smartphones have been selected from the previous shown classes of devices due to their portability, multimedia capabilities and access to cellular networks, characteristics which are of particular interest for this research. This research focuses on the cost of delivery of multimedia content over mobile networks. Mobile phones taken into account are the ones announced between January 2008 and June 2011.

Due to the diversity of mobile devices resolutions and screen sizes, and in order to provide a better perspective of the device characteristics that exist on the market a division of mobile phone resolutions and screen sizes was performed.

3.2.1 Feature Phones and Smartphones Parameters

This section looks at various characteristics of the feature phones and smartphones and analyses them in terms of resolution, screen size, multimedia format supported by them, as well as supported wireless network types.

3.2.1.1 Resolution

A variety of resolutions exist among feature phones and smartphones. There are also various standards regarding resolutions (Sokol, 2004; equasys, 2010), each of them including just certain resolutions. This makes difficult to group devices in a certain category. Hence, with the aim of providing a better view of the capabilities of the mobile phones in terms of resolution, the resolutions of feature phones and smartphones were classified in four classes as presented in Table 3-5, by adapting the resolution classes found in (wowza, 2011; Media, 2011). Wowza (wowza, 2011) is a company specialised in multimedia streaming. Their media streaming server delivers multimedia to different platforms. Their server has been selected as the best media server for three years in the row starting with 2008 by the Streaming Media Magazine (wowza, 2011). Wowza has proposed five classes of resolutions. Table 3-4 presents them, with the second column presenting the resolution corresponding to the class.

Among the classes selected in Table 3-4, 1080p and 720p resolutions are not yet present on the mobile phones market. However, since resolutions bigger than 480p are already present with mobile devices (e.g. iPhone 4 has a resolution of 640 x 960), and probably even higher resolutions will be supported in the future, the 720p class was included in the proposed classification presented in Table 3-5. Unfortunately, taking into account only the previous four resolutions would not solve the problem, since there are many other resolutions. Therefore the proposed classification, groups all found resolutions around the proposed four classes. This is done by adding the resolution which does not exist in the table; in the class immediately higher in terms of resolution size (e.g. the 240p class is considered higher than the 360p class).

Table 3-4 Mobile Devices Classes Based on Resolution

Class	Resolution Characteristics
1080p	1920 x 1080
720p	1020 x 720
480p	800 x 480
360p	640 x 360
240p	320 x 240

Mobile Phones

Table 3-5 Mobile Phones Classes Based on Resolution

Class	Resolution Characteristics
720p	640 x 960
480p	480 x 800 480 x 854
360p	360 x 640 320 x 480 360 x 480 320 x 320
240p	240 x 320 120 x 160 128 x 160 176 x 220

3.2.1.2 Screen Size

The screen size of the mobile devices influences how much information can be displayed. To the best of my knowledge, there is no standard on dividing screen sizes into particular classes. As well as in the case of resolution, feature phones and smartphones have a variety of screen sizes, starting from 1.8'' (e.g. Samsung B2100 Xplorer) up to 4.3'' (e.g. HTC HD2). The GSM Arena website was used (Arena, 2011), as a source for the analysing the screen sizes of the devices released on the market. The website provides detailed information about mobile devices, taken mostly from the manufacturer's web site. It has also served more than 3 billion pages since 2000 (Statistics, 2011). It also has a big database of 3948 mobile devices as listed in 20th of June 2011. It is also considered the "ultimate resource for GSM handset information" (GSMArena, 2011). The screen sizes for worldwide mobile phones were divided in the following categories on the GSM arena website: [0'', 2''); [2'', 2.2''); [2.2'', 2.4''); [2.4'', 2.6''); [2.6'', 2.8''); [2.8'', 3''); [3'', 3.2''); [3.2'', 3.5''); [3.5'', 4''), and [4'', 4.5'').

Typically, feature phones will not have a screen size higher than 3.5'' (89mm), while smartphones will not have a screen size lower than 2'' (51mm).

3.2.1.3 Multimedia (Video) Support

Mobile devices that play videos/multimedia support various video codecs and containers. This section aims to briefly introduce them.

H.263 is a video compression standard created mostly for videoconferencing. It was first developed by the Telecommunication Standardization Sector (ITU-T) Video Coding Experts Group (VCEG) and then further on extended during different projects.

MPEG-4 is a standard that consists of a collection of techniques used for the compression of audio and visual data. It consists of a collection of parts, defining compression techniques. MPEG-4 Part 2, H.264, and MP4 are among the ones that are supported by the mobile devices included in this analysis.

MPEG-4 Part 2 is a video codec partially based on the H.263 codec by adding improvements to it.

H.264, also known as **MPEG-4 Part 10**, was jointly developed by ITU-T and MPEG. It is currently the most used format for high video distribution. It provides good quality at almost half of the bitrate required by MPEG-4 Part 2.

MP4, also known as **MPEG-4 Part 14**, is a video container. It is used to store MPEG video formats, but can support also other data such as subtitles.

WMV is a video container developed by Microsoft. It supports almost any format but H.264 (H.264 is partially supported).

DivX is developed by DivX Inc. It has become popular due to the ability to compress lengthy videos into small segments, while maintaining a high quality. It is composed of two main codecs, *DivX Codec* (*MPEG-4 Part 2*) and *DivX H.264 Codec* (*MPEG-4 Part 10*), however, only the first one is available for mobiles as well.

xVid is a codec that follows the MPEG-4 standard. It is available for a variety of platforms. Contrasted to DivX, which is a proprietary standard, xVid is open source.

RealVideo (RV) is developed by RealNetworks. It is a proprietary video format. It is supported by various platforms and some mobile phones.

3GP is a multimedia container developed especially for mobile phones by 3GPP. It was developed especially for 3G wireless network but it can be used both for 2G and 4G wireless networks. It supports the following video formats: *H.263*, *H.264*, and *MPEG4-Part 2*.

AVI (**Audio Video Interleave)** is a multimedia container developed by Microsoft and introduced in 1992. It supports among others *RV*, *MPEG-4* video and *Editable MPEG*.

M4V is a multimedia container developed by Apple and mostly used for Apple's iTunes applications. It is similar to MP4, but it offers Apple’s DRM copyright protection and support for AC3 audio.

3.2.1.4 Supported Mobile Networks

Mobile phone evolution is connected with the evolution of mobile networks. The first commercial mobile network, dated back in 1979. It supported the first generation (1G) wireless telephone technology that was launched in Japan by NTT. Twelve years later, in 1991, the 2G (e.g. Global System for Mobile Communications-GSM, CdmaOne) network was launched. 3G was launched in 2001 (e.g. Universal Mobile Telecommunications System – UMTS, CDMA2000 1xEV-DO) and in 2009, 4G networks were introduced through IEEE 802.16m and LTE (Advanced). These are all-IP networks. In between these generations, transition networks have been launched such as: 2G transitional (2.5G and 2.75G) and 3G transitional (3.5G, 3.75G, 3.9G). 2G transitional makes the transition between the 2G and 3G networks.

Similar, 3G transitional fills the gap between 3G and 4G networks. Examples of 2G transitional networks are: GRPS, EDGE, EGPRS, and CDMA2000 1xRTT. Examples of 3G transitional networks are HSPA, LTE (E-UTRA), EV-DO Rev. A, Mobile WiMAX, Flash-OFDM, and IEEE 802.20.

3G and 3.5 networks can deliver the radio signal on different bands, depending on the country. For example, UMTS uses the bands 850, 900, 1700 and 1900 while HSPA uses 850, 900, 1700, 1900 and 2100 bands. A mobile device can support one or multiple of these bands. Among the wireless networks supported by the mobile phones Wi-Fi can also be counted.

All these mobile networks have different bandwidth. Table 3-6 presents different examples of mobile networks and their bandwidth. The first column presents the mobile network standard. The second column presents the generation for the cellular network. The third column presents the bandwidth range and the last column presents the average bandwidth.

Table 3-6 Wireless Networks Bandwidth

Standard	**Generation**	**Bandwidth Range**	**Medium bandwidth**
GSM	2G	9.6 kbps	9.6 kbps
GPRS	2.5G (2G transitional)	21.4 – 171.2 kbps	48 kbps
EDGE	2.75G (2G transitional)	43.2 – 345.6 kbps	171 kbps
UMTS	3G	144 – 2000kbps	384 kbps
HSPA	3.5G (3G transitional)	1.8 – 4MB downlink; up to 5.8MB uplink	1200kbps
LTE	4G	50 MB downlink 100 MB uplink	-
Wi-Fi			5000kbps

3.2.2 Analysis of the Feature Phones

An analysis of feature phones available worldwide and on the Irish market and released between 2008 and 2011[3] is presented next. The analysis is performed in terms of resolution, screen size, mobile access networks and multimedia supported format. The analysis of the multimedia supported format was done only for the Irish market due to the difficulty of getting this information about all the worldwide feature phones.

3.2.2.1 Worldwide Feature Phones Analysis

The worldwide feature phones were collected from GSM Arena website (Arena, 2011), by selecting the phones announced among 2008-2011[3]. A total of 573 feature phones were found, being listed on the website, among which 31% were announced in 2008, 31% in 2009, 31% in 2010, and 7% in 2011. The distribution on years of the feature phones found is presented in Figure 3-1. The number of feature phones are equally distributed among 2008 (31%), 2009 (31%) and 2010 (31%). Only 7% of feature phones are from 2011, probably due to the fact that the feature phones from 2008-2010 were collected for the whole year, while for 2011, just until 14 June 2011 and probably there is a gap starting from the time when a feature phone is announced and until it reaches the market.

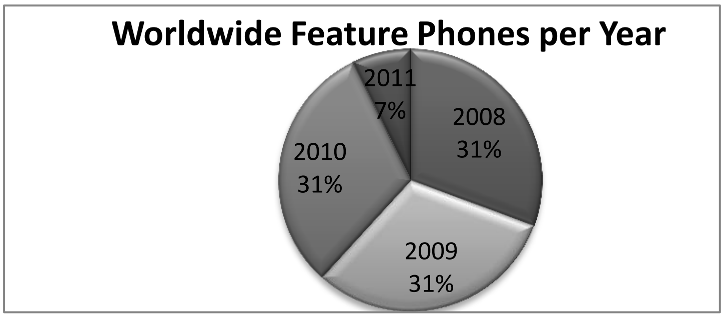

Figure 3-1 Worldwide Feature Phones' Distribution between 2008-2011

3.2.2.1.1 Worldwide Feature Phones Analysis based on Resolution

This section aims to determine which are the most used resolutions for feature phones announced worldwide for the period 2008-2011[4]. Because there are many resolutions, some of them very similar, a classification based on the classes defined in section 3.2.1.1 is presented.

<u>Year 2008</u>

The analysis for the year 2008 is presented in Figure 3-2, and it indicates what percentage of feature phones has certain resolutions. For example, 4% of the feature phones have a resolution of 240 x 400.

[3] As of 14th of June 2011
[4] As of the 14th of June 2011

It can be seen that the most common resolution for the feature phones in 2008 was 240 x 320 counting for 33%. The second most used resolution is 128 x 160 counting for 28% of the feature phones. The third most used resolution is 176 x 220, which counts for 19% of the feature phones. Relatively small resolutions are very common in 2008.

Table 3-7 presents the resolutions distributed based on the classes presented in section 3.2.1.1. It can be noticed that the resolutions included in the 240p category are the most present on the feature phone market in 2008. They count for 99% of the total number of feature phones. There are also a small number (1%) of feature phones with high resolutions, similar to those of smartphones or notebooks (480p class – 480 x 854 resolution).

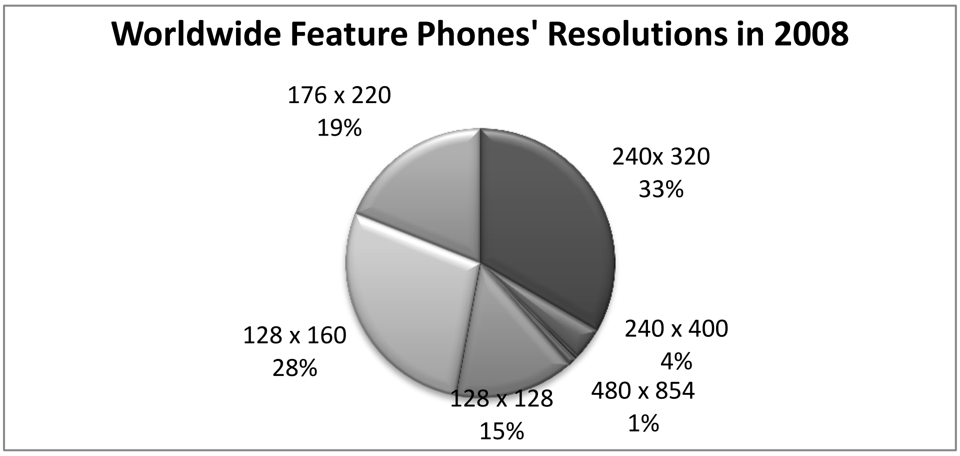

Figure 3-2 Distribution of the Resolutions for Worldwide Feature Phones Announced in 2008

Table 3-7 Feature Phones Classification in Resolution Classes (2008)

Resolution Class	**Percentage**
720p	0%
480p	1%
360p	0%
240p	**99%**

Year 2009

Figure 3-3 presents the feature phones distribution for 2009. As in 2008, the most used resolution is 240 x 320 counting for 48% of the feature phones. 176 x 220 is still a common resolution, being the second most used that year, counting for 15% Resolutions as 128 x 160 and 240 x 400 count each for 11%.

Table 3-8 presents the classification based on the resolution classes. The most common resolution is still 240 x 320 (96%), but an increase in the number of devices having higher resolutions (480p – 480 x 800, and 480 x 854 resolutions) can be noticed (4%).

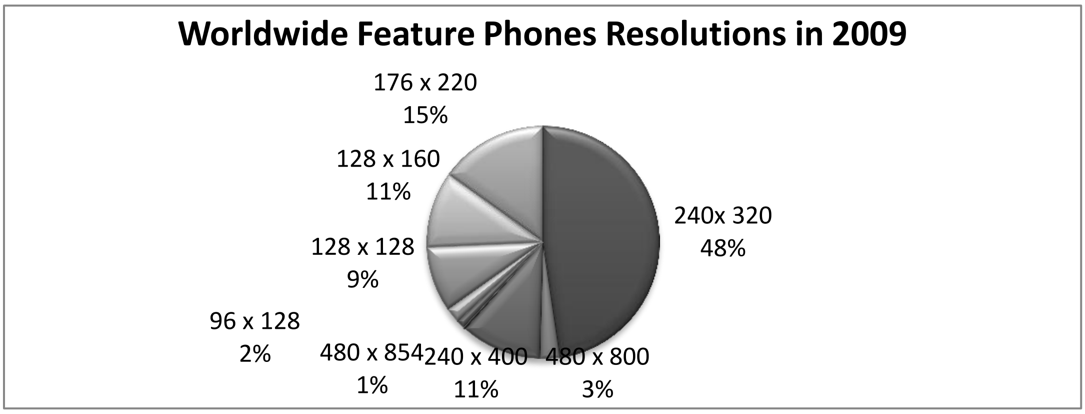

Figure 3-3 Distribution of the Resolutions Types for the Worldwide Feature Phones Announced in 2009

Table 3-8 Feature Phones Classification in Resolution Classes (2009)

Resolution Class	Percentage
720p	0%
480p	4%
360p	0%
240p	**96%**

Year 2010

240 x 320 is still the most common feature phone resolution even in 2010, counting for 40% of the feature phones (see Figure 3-4). There is an increase in higher resolutions; the second most used one being 240 x 400 which counts for 18% of the total of feature phones. The third most used resolution continues to be 128 x 160 (counting for 16% of the feature phones).

Table 3-9 presents the division of the resolutions in classes. The 240p class has also the most of resolutions, 96%. The rest of 4% are evenly divided between the 360p class and the 480p class. 320 x 400 and 320 x 480 have been included in the 360p class and 480 x 800 and 400 x 800 have been included to the 480p class, as explained in section 3.2.1.1. This leads to 2% of the devices classified as having resolutions belonging to the 360p class and 2% having resolutions belonging to the 480p class.

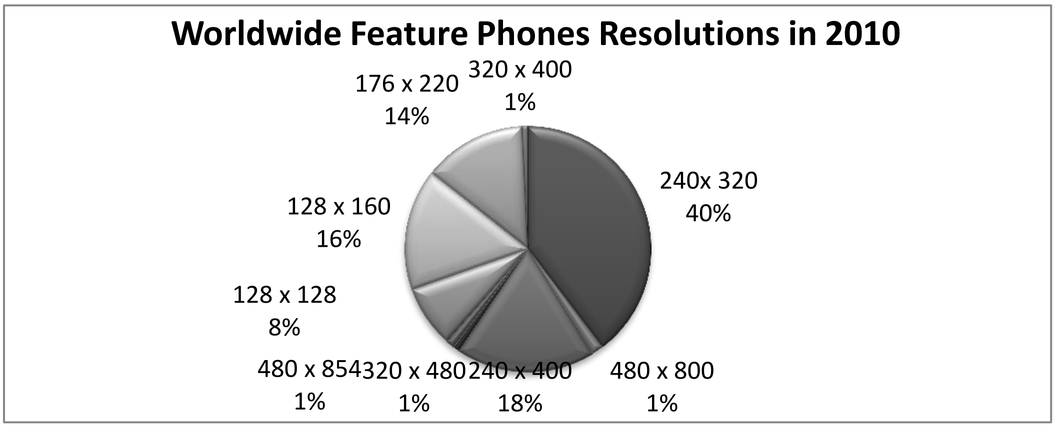

Figure 3-4 Distribution of the Resolutions Types for the Worldwide Feature Phones Announced in 2010

Table 3-9 Feature Phones Classification in Resolution Classes (2010)

Resolution Class	**Percentage**
720p	0%
480p	2%
360p	2%
240p	**96%**

Overview for the Period 2009-2010

The resolutions of the feature phones announced in 2009 and 2010 were analysed in order to provide a better view of the trends in feature phones resolutions. The results are presented in Figure 3-5. The three most used resolutions for feature phones in 2009-2010 are:

- 240 x 320 counting for 44% of feature phones
- 176 x 220 counting for 15% of feature phones
- 240 x 400 counting for 14% of feature phones

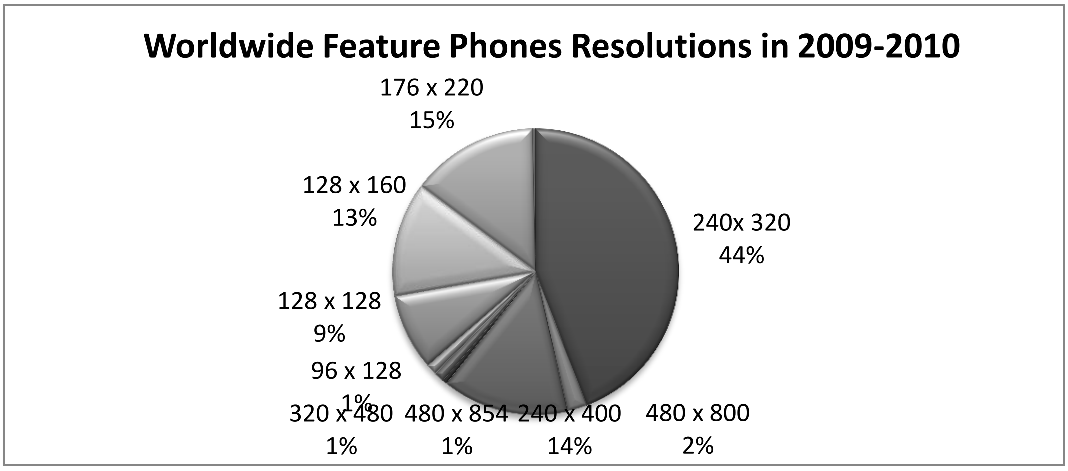

Figure 3-5 Distribution of the Resolutions Types for the Feature Phones Announced in the Period 2009-2010

These are all resolutions belonging to the 240p class. As it can be seen from Table 3-10, 97% of feature phones resolutions belong to this class. 1% belong to 360p and 3% to 480p.

Table 3-10 Feature Phones Classification in Resolution Classes (2009 -2010)

Resolution Class	Percentage
720p	0%
480p	3%
360p	1%
240p	**97%**

Figure 3-6 presents the distribution of the feature phones resolutions, for the feature phones released so far in 2011[5]. 240 x 320 resolution is still popular on feature phones, counting for 42%. The second most popular is 128 x 160 counting for 26%, and the third most used is 240 x 400 counting for 15%. As it can be seen from Table 3-11, from the feature phones analysed in 2011, all of them fit in the 240p class.

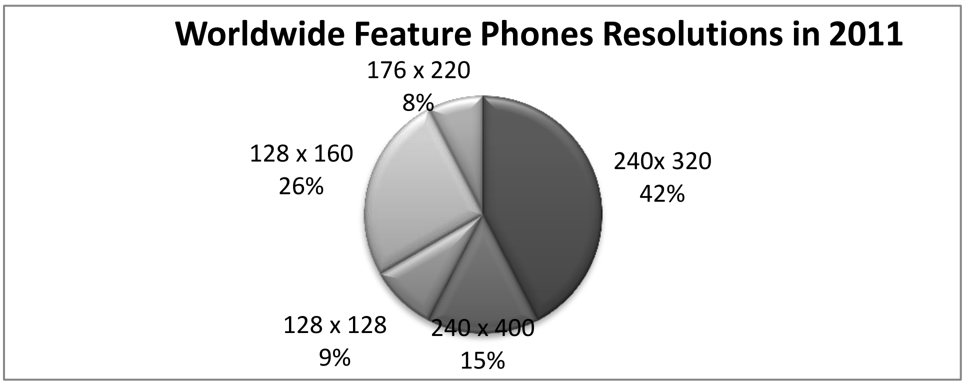

Figure 3-6 Distribution of the Resolution Types for Feature Phones Announced in 2011

Table 3-11 Feature Phones Classification in Resolution Classes (2011)

Resolution Class	**Percentage**
720p	0%
480p	0%
360p	0%
240p	**100%**

3.2.2.1.2 Worldwide Feature Phones Analysis based on the Screen Size

This section analyses the screen size of the feature phones announced between 2008 and 2011[6]. The analysis is done on screen size intervals rather than on exactly screen size, because of the way data was provided. However, this provides a better overview of the phones' screen size.

[5] Up to 14 June 2011
[6] Up to 14 June 2011, as taken from GSM Arena website (Arena, 2011)

Year 2008

Figure 3-7 presents the division of the screen size intervals supported by feature phones announced in 2008. The most common screen size interval is from 2’’ up to 2.2’’ (36% of the feature phones). The second most common screen sizes are in the interval 2.2’’ up to 2.4’’ (20%), and the third most common between 3.2’’ up to 3.5’’ (15%). It can be noticed that from the sample of feature phones provided on the GSM Arena website, no one had a screen size greater than 3.5’’ in 2008.

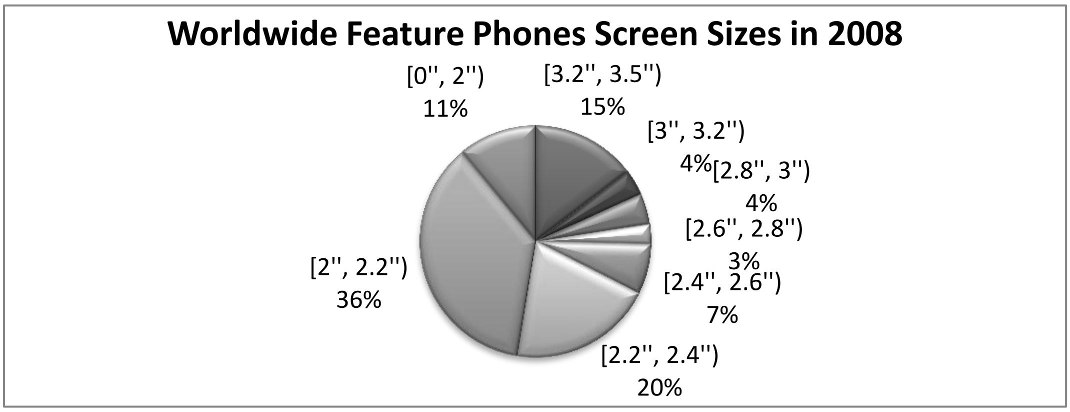

Figure 3-7 Distribution of the Screen Sizes Types for the Worldwide Feature Phones Announced in 2008

Year 2009

The screen sizes intervals from 2009 are presented in Figure 3-8. The first two most used screen size intervals remain the same as in 2008, with the only difference that the smaller screen sizes (2’’ up to 2.2’’) decreased in percentage (from 36% in 2008 to 26% in 2009), and bigger screen sizes (2.2’’ up to 2.4’’) increased in percentage points (from 20% in 2008 to 23%) in 2009. The third most used screen size interval is 2.8’’ up to 3’’, counting for 13% of the feature phones. As opposed to the previous year (2008) it can be noticed that in this year there are feature phones with bigger screen sizes, some of them having even more than 4’’.

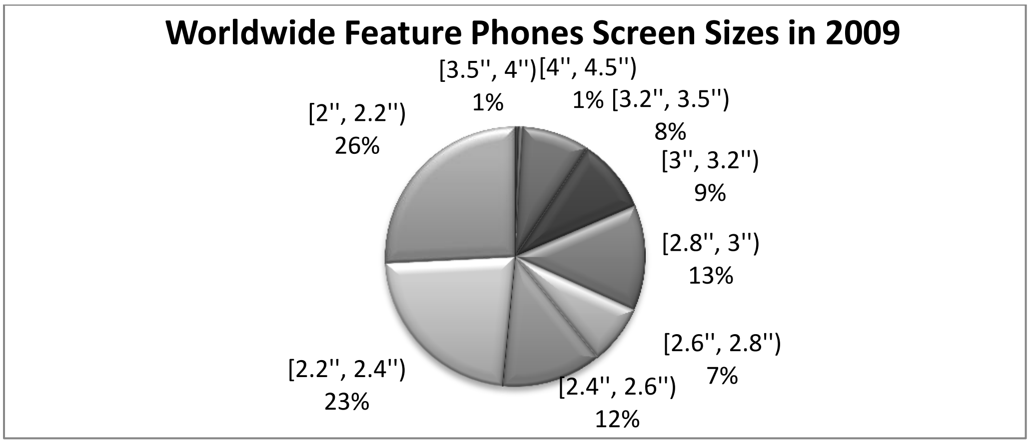

Figure 3-8 Distribution of the Resolutions Types for the Worldwide Feature Phones Announced in 2009

Year 2010

In 2010 (Figure 3-9), feature phones with a resolution between 2’’ and 2.2’’ continue to decrease in percentage in 2010 representing only 20% of the feature phones. This makes them the second most used screen size, the most used one being between 2.2’’ up to 2.4’’ (22%). The third most used screen size intervals are from 2.8’’ up to 3’’ and from 2.4’’ up to 2.6’’ counting for 15% of the feature phones.

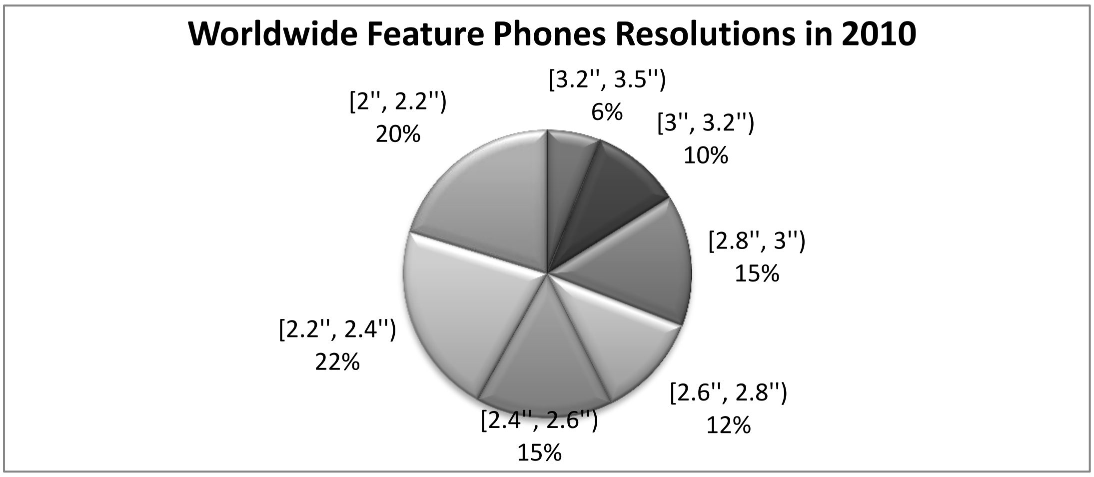

Figure 3-9 2010 Distribution of the Resolutions Types for the Worldwide Feature Phones Announced in 2010

Period 2009-2010

Similar to the resolution analysis, an analysis of the screen sizes for the period 2009 – 2010 was performed (Figure 3-10) in order to provide a better overview of trends of the existing feature phones on the market. Based on this data, the following screen size intervals are common:

- [2’’, 2.2’’) which counts for 23% of the feature phone
- [2.2’’, 2.4’’) which counts for 22% of the feature phone
- [2.4’’, 2.6’’) and [2.8’’, 3’’) which counts each for 14% of the feature phone.

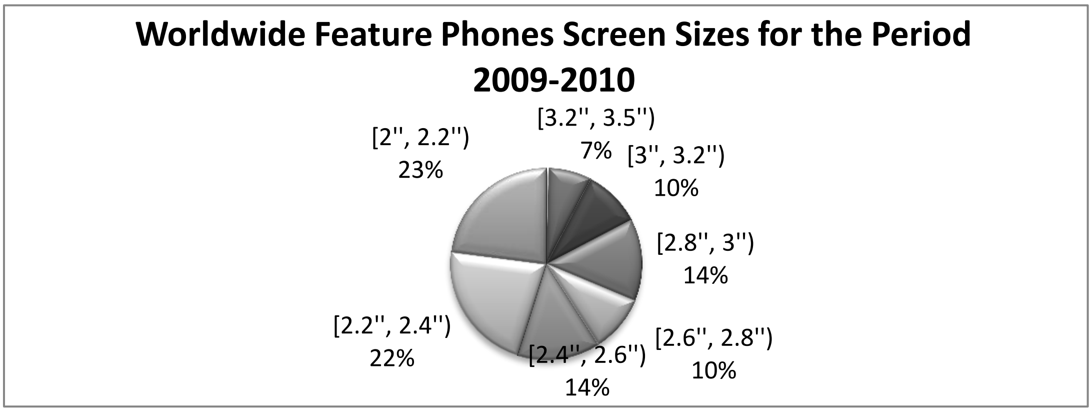

Figure 3-10 Distribution of the Screen Sizes for the Worldwide Feature Phones Announced in the Period 2009-2011

Year 2011

An analysis of the feature phones screen sizes released in 2011[7] is presented in Figure 3-11. The most common screen sizes are in the interval 2.2’’ up to 2.4’’ counting for 21% of the feature phones. This interval is the same as the one obtained from the 2009-2010, and the percentages are very similar (22% for the data from 2009-2010 and 21% for 2011). The second most used screen size is between 2.4’’ up to 2.6’’ counting for 18% of the feature phones, which is the third most used for the period from 2009-2010, leading maybe to an increase in the screen sizes from 2011. The third most used screen sizes are between 2’’ and 2.2’’, counting for 15% of the total number of devices, which is the second most used screen sizes for the period 2009-2010.

[7] Up to 14 June 2011

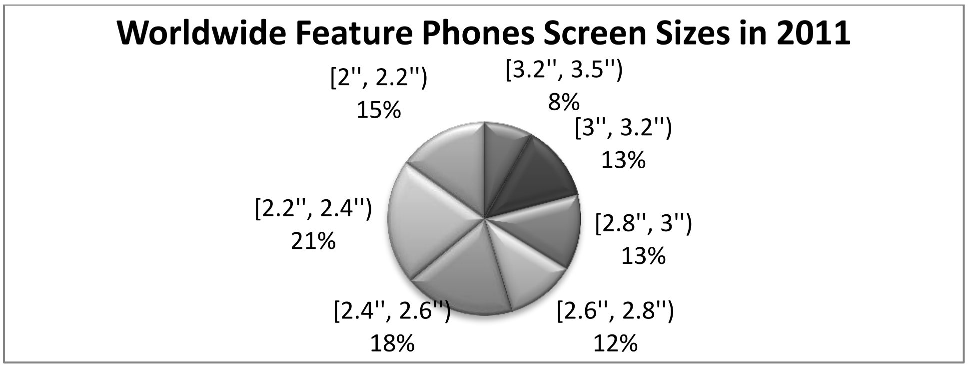

Figure 3-11 Distribution of the Screen Sizes for Worldwide Feature Phones Released in 2011

3.2.2.1.3 Worldwide Feature Phones Analysis based on the Mobile Network Access

This section presents an analysis of feature phone networks from 2008-2011[8], focusing on Wi-Fi, and cellular networks (HSDPA, UMTS, EDGE, GPRS and GSM). The last ones are divided based on the generation to which they belong to. The HSDPA, UMTS and GSM networks are divided based on the channel in which they transmit.

Year 2008

Figure 3-12 presents the mobile networks the feature phones had access to in 2008. Only 4.59% of the feature phones in 2008 had a Wi-Fi connection. At least 15.29% of the feature phones had 3G transitional (HSDPA in this case), and 23.55% had access to a 3G network (UMTS in this case represented). 48.62% of the feature phones can access the EDGE network and 87.77% have access to the GPRS network, this being part of the 2G transitional networks. The last part of the graph represents the 2G networks. 73% of the feature phones had Bluetooth.

[8] Up to 14 June 2011

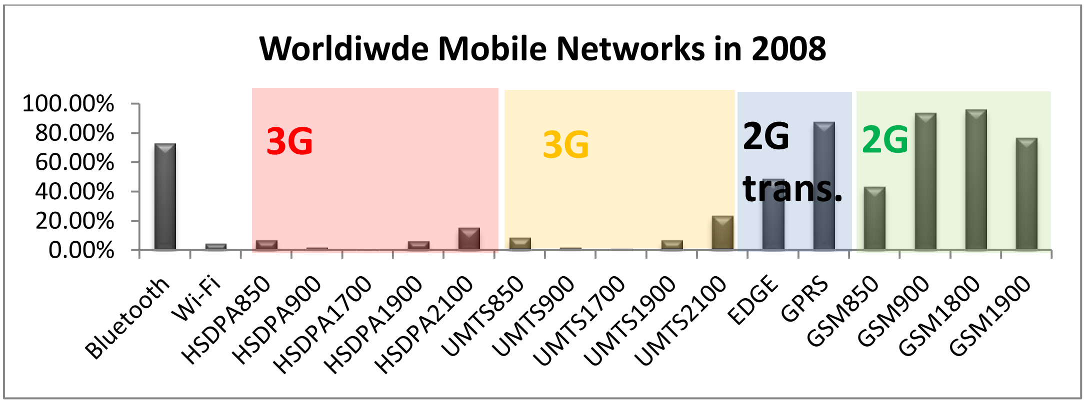

Figure 3-12 Distribution of the Mobile Networks for the Worldwide Feature Phones in 2008

<u>Year 2009</u>

Figure 3-13 presents the available mobile networks on the feature phones released in 2009. 7.23% of the feature phones can access the Wi-Fi network, an increase of over 50% from 2008. 3.5G networks are supported by at least 20.78% of the feature phones while 3G network by at least 29.52%. 66.27% of the feature phones can access the EDGE networks (comparing with 48.62% in 2008) and 88.25% can access GPRS. 83.73% of the feature phones can use Bluetooth.

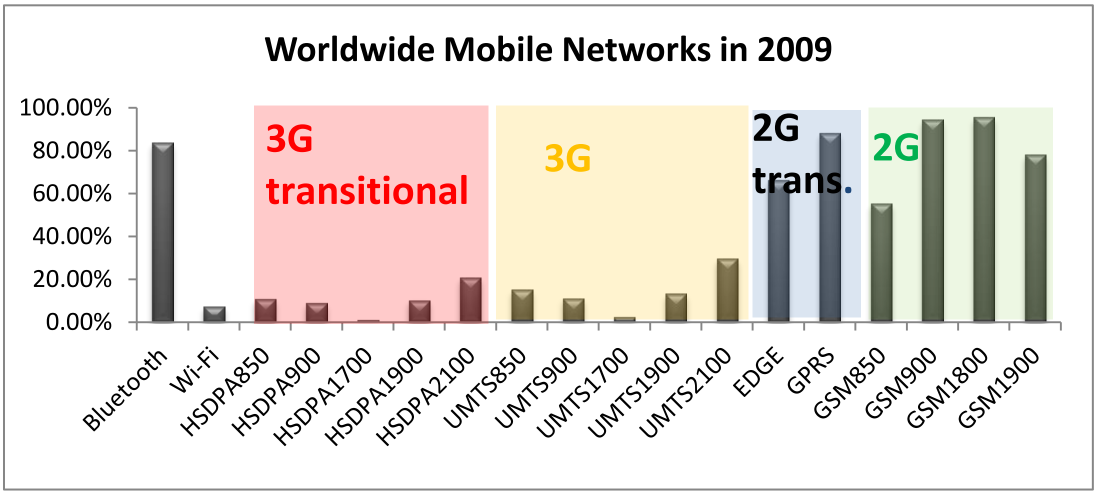

Figure 3-13 Distribution of the Mobile Networks for the Worldwide Feature Phones in 2009

<u>Year 2010</u>

16.88% of the feature phones have Wi-Fi connection in 2010, as it can be seen from Figure 3-14. At least 12.08% of the feature phones have 3G transitional access. 50.45% of the feature phones from 2010 can access EDGE network and 84.89% can access GPRS network. 81.87% of the feature phones have Bluetooth.

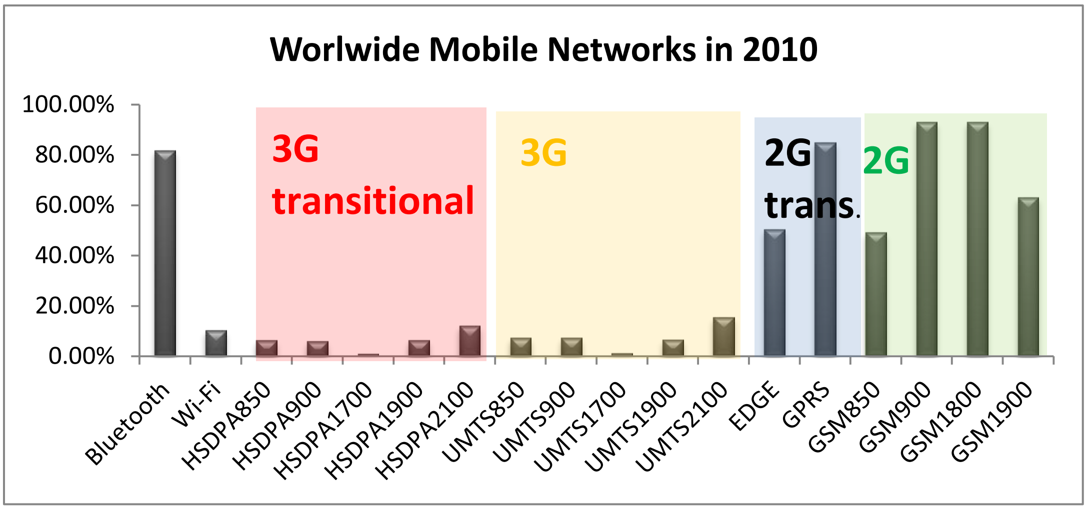

Figure 3-14 Distribution of the Mobile Networks for the Worldwide Feature Phones in 2010

<u>Period 2009-2010</u>

Figure 3-15 presents an analysis of feature phones networks from 2009-2010. As it can be seen in Figure 3-15 16.88% of the feature phones can access Wi-Fi networks. At least 16.54% can access 3G transitional network and 22.61% access 3G network. 58.73% of the feature phones can access EGDE network and 87.10% can access a GPRS network. 82.81% of the feature phones have Bluetooth.

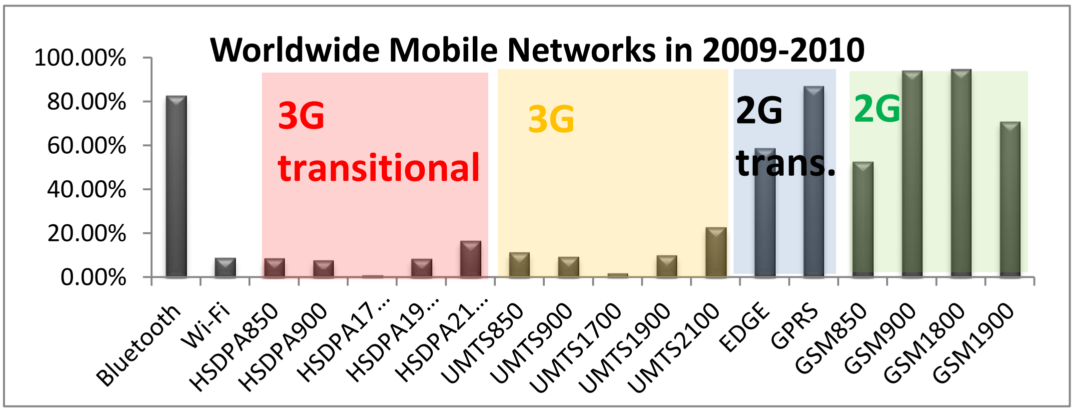

Figure 3-15 Distribution of the Mobile Networks for the Worldwide Feature Phones Announced in the Period 2009-2010

Year 2011

Figure 3-16 presents the mobile networks supported by the feature phones announced in 2011 listed on the GSM arena website (Arena, 2011). 16.88% of the released feature phones can access a Wi-Fi network, an increase from 10.27% in 2010. At least 16.54%, of the feature phones have access to 3.5G transitional network, and 9.09% can access 3G network. 40.26% of the feature phones have access to the EDGE network, and 76.62% of the GPRS network. 77.92% have Bluetooth.

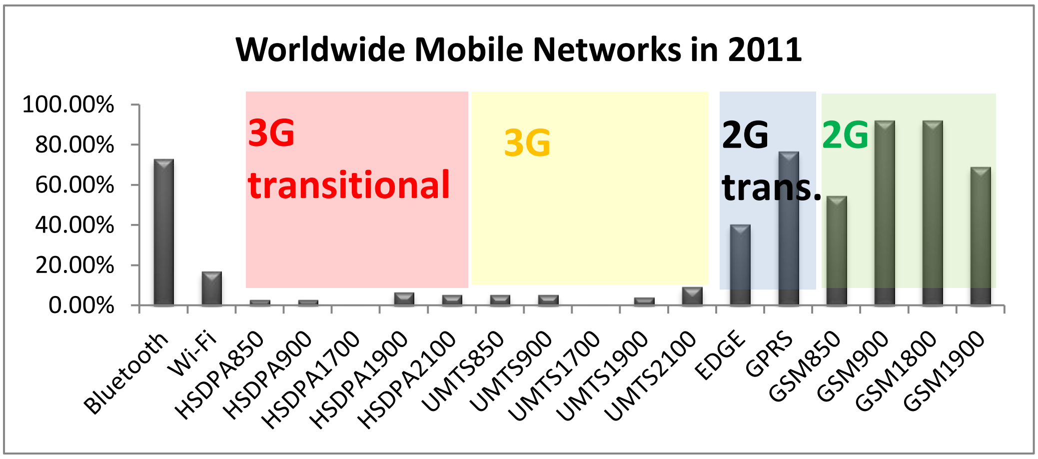

Figure 3-16 Distribution of the Mobile Networks for the Worldwide Feature Phones Announced in 2011

3.2.2.2 Feature Phones on the Irish Market

Table 3-12, Table 3-13, Table 3-14 and Table 3-15 present details about the feature phones available on the Irish market between 2008 and 2011[13]. The Irish mobile operators are O2[9], Vodafone[10], Meteor[11], and Three[12]. Feature phones offered for sale by these mobile operators were considered. Among those, we selected the ones that were released since 2008[13] (2008 included) and that support multimedia playing.

9 http://www.o2online.ie/o2/
10 http://www.vodafone.ie/
11 http://www.meteor.ie/
12 http://www.three.ie/
13 Until 14 June 2011

Table 3-12 Feature Phones Released on the Irish Market in 2008

Device	Released	Resolution	Screen Size	Supported Mobile Networks	Supported Multimedia (Video) Formats
Nokia 2330	2008	128 x 160	1.8" (46mm)	GSM, GPRS	H.263

Table 3-13 Feature Phones Released on the Irish Market in 2009

Device	Released	Resolution	Screen Size	Supported Mobile Networks	Supported Multimedia (Video) Formats
120 x 160					
Samsung B2100 Xplorer (Samsung Solid Extreme, Samsung Marine)	2009	120 x 160	1.8" (46mm)	GSM, GPRS, EDGE	MP4, 3GP, M4V
128 x 160					
Nokia 2220 slide	2009	128 x 160	1.8" (46mm)	GSM, GPRS, EDGE	MP4, H.263
240 x 320					
Samsung B3310 (Samsung B3313 Corby Mate)	2009	240 x 320	2.0" (51mm)	GSM, GPRS, EDGE	MP4/H.263/H.264

Nokia 2730 classic	2009	240 x 320	2.0" (51mm)	GSM, GPRS, EDGE, UMTS	MP4/H.263
Nokia 6700 classic	2009	240 x 320	2.2" (56mm)	GSM, GPRS, EDGE, HSDPA, HSUPA	H.263, H.264
Nokia 6700 Slide	2009	240 x 320	2.2" (56mm)	GSM, GPRS, EDGE, HSDPA, HSUPA	WMV, RV, MP4, 3GP
Sony Ericsson Elm	2009	240 x 320	2.2" (56mm)	GSM, GPRS, EDGE , HSDPA, HSUPA, Wi-Fi b/g	MP4, H.263, H.264
Nokia 7230	2009	240 x 320	2.4" (61mm)	GSM, GPRS, EDGE, UMTS	MP4, H.263, H.264, WMV
Nokia C3	2009	240 x 320	2.4" (61mm)	GSM, GPRS, EDGE, Wi-Fi b/g	MP4, AVI, H.264, H.263, WMV
Samsung B3410	2009	240 x 320	2.6" (66mm)	GSM, GPRS, EDGE	MP4, H.263, H.264

Sony Ericsson W995	2009	240 x 320	2.6" (66mm)	GSM, GPRS, EDGE , HSDPA, HSUPA, Wi-Fi b/g	MP4
Samsung S7070 Diva (Samsung La Fleur S7070, Samsung S7070 Marina)	2009	240 x 320	2.8" (71mm)	GSM, GPRS, EDGE	MP4, H.263, H.264
240 x 400					
Samsung S5230 Star (Samsung Tocco Lite, Samsung Player One, Samsung S5233, Samsung Avila)	2009	240 x 400	3.0’’ (81mm)	GSM, GPRS, EDGE	H.263, H.264, MP4
400 x 800					
LG GD900 Crystal	2009	400 x 800	3.0" (81mm)	GSM, GPRS, HSDPA, Wi-Fi b/g	DivX, XviD, MP4

Table 3-14 Feature Phones Released on the Irish Market in 2010

Device	Released	Resolution	Screen Size	Supported Mobile Networks	Supported Multimedia (Video) Formats
128 x 160					
Samsung C5010 Squash	2010	128 x 160	2.0" (51mm)	GSM, GPRS, EDGE, UMTS	MP4/H.264/H.263
Samsung E2550 Monte Slider	2010	128 x 160	2.0" (51mm)	GSM, GPRS, EDGE	MP4/H.263/H.264
176 x 220					
LG A133	2010	176 x 220	2.0" (51mm)	GSM, GPRS, EDGE	H.263/ MPEG4/WMV
240 x 320					
Samsung B2710	2010	240 x 320	2.0" (51mm)	GSM, GPRS, EDGE, UMTS	MP4/H.263

Nokia 2710 Navigation Edition	2010	240 x 320	2.2" (56mm)	GSM, GPRS, EDGE	MP4/H.263/H.264/WMV
Nokia 6303i classic	2010	240 x 320	2.2" (56mm)	GSM, GPRS, EDGE	H.263/H.264
Nokia X2	2010	240 x 320	2.2" (56mm)	GSM, GPRS, EDGE	MP4/H.263
Samsung S5350 Shark	2010	240 x 320	2.2" (56mm)	GSM, GPRS, EDGE, HSDPA	MP4/H.264/H.263/WMV
Sony Ericsson Cedar	2010	240 x 320	2.2" (56mm)	GSM, GPRS, EDGE , HSDPA, HSUPA	MP4/H.263/H.264
Sony Ericsson Spiro	2010	240 x 320	2.2" (56mm)	GSM, GPRS, EDGE	MP4/H.263/H.264
LG Town C300	2010	240 x 320	2.4" (61mm)	GSM, GPRS, EDGE	MP4/H.263
Nokia X3-02 Touch and Type	2010	240 x 320	2.4" (61mm)	GSM, GPRS, EDGE , HSDPA, HSUPA, Wi-Fi b/g/n	XviD/MP4/H.264/H.263/ WMV

Samsung C3300K Champ (Samsung Libre, Samsung C3303 Champ)	2010	240 x 320	2.4" (61mm)	GSM, GPRS, EDGE	MP4/H.263
Samsung S3370 (Samsung Corby 3G, Samsung Acton, Samsung Pocket3G)	2010	240 x 320	2.6" (61mm)	GSM, GPRS, EDGE, UMTS	MP4/H.263
Sony Ericsson Zylo	2010	240 x 320	2.6" (61mm)	GSM, GPRS,EDGE , HSDPA, HSUPA	MP4/H.263/H.264
240 x 400					
LG GM360 Viewty Snap	2010	240 x 400	3.0" (76mm)	GSM, GPRS, EDGE	MP4/H.264/H.263/WMV
LG GT400 Viewty Smile	2010	240 x 400	3.0" (76mm)	GSM, GPRS, EDGE, HSDPA	MP4/H.264/H.263/WMV
LG GT405 (LG Viewty GT)	2010	240 x 400	3.0" (76mm)	GSM, GPRS, EDGE, HSDPA	MP4/H.264

LG GS290 Cookie Fresh	2010	240 x 400	3.0" (76mm)	GSM, GPRS, EDGE	MP4/H.263
480 x 854					
LG GD880 Mini	2010	480 x 854	3.2" (81mm)	GSM, GPRS, EDGE , HSDPA, HSUPA, Wi-Fi b/g	MP4/DivX/XviD/H.264/H.263

Table 3-15 Feature Phones Released on the Market 2011[14]

Device	Released	Resolution	Screen Size	Supported Mobile Networks	Supported Multimedia (Video) Formats
Nokia C2-00	2011	128 x 160	1.8’’ (46mm)	GSM, GPRS	Not specified
Samsung E2530	2011	128 x 160	2.0’’ (51mm)	GSM, GPRS, EDGE	MP4
Nokia C2-01	2011	240 x 320	2.0’’ (51mm)	GSM, GPRS, EDGE, U MTS	MP4, H.264, H.263
Vertu Ascent Ferrari GT	2011	240 x 320	2.0’’ (51mm)	GSM, GPRS, EDGE, HSDPA, HSUPA	MP4, H.263
Samsung R710 Suede	2011	240 x 400	3.0’’ (76mm)	CDMA 800/1900, CDMA2000 1xEV-DO, Wi-Fi b/g	MP4, H.264, H.263
Samsung S5260 Star II	2011	240 x 400	3.0’’ (76mm)	GSM, GPRS, EDGE, Wi-Fi b/g/n	MP4, H.264, H.263
Philips Xenium X713	2011	240 x 400	3.2’’ (81mm)	GSM, GPRS, EDGE	MP4, H.263

[14] Up to 14 June 2011

42 feature phones were released on the Irish market in the period 2008-2011. Among these (Figure 3-17), 2% are from 2008, 33% from 2009, 48% from 2010 and 17% from 2011.

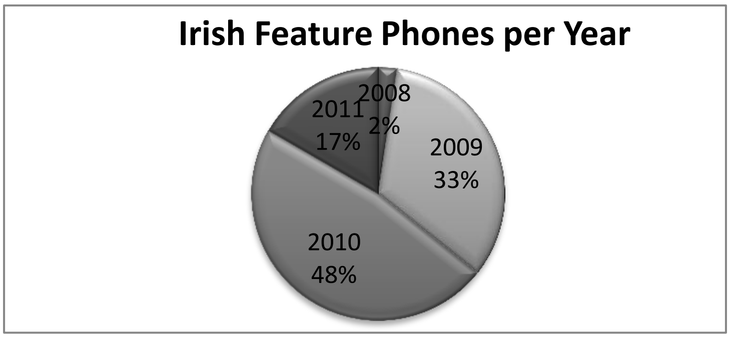

Figure 3-17 Irish Feature Phones' Distribution between 2008-2011

3.2.2.2.1 Irish Feature Phones Analysis based on the Resolution

The aim of this section is do determine which are the most used resolutions in the 2008-2011 for feature phones released on the Irish market that support multimedia. Because there are many resolutions, some of them very similar but belonging to different resolution standards, a classification in different classes is presented (see 3.2.1.1).

Year 2008

In 2008, due to the small sample of devices were found (Table 3-12), the only resolution is 128 x 160, which will fit in the 240p class. The small number of feature phones can be to the fact that feature phones that supported playing video just started to be released.

Year 2009

The analysis of the resolutions of the feature phones (Table 3-13) is presented in Figure 3-18. For example, 7% of the feature phones have a resolution of 240 x 400. It can be seen that the most common resolution in 2009 is 240 x 320, counting for 61% of the feature phones. The rest of the resolutions are evenly distributed, with 7% each. Table 3-16 presents the resolutions distributed based on the resolution classes presented in section 3.2.1.1. It can be noticed that resolutions included in the 240p class are the most present on the Irish feature phones market in 2009. They count for 86% of the total number of feature phones.

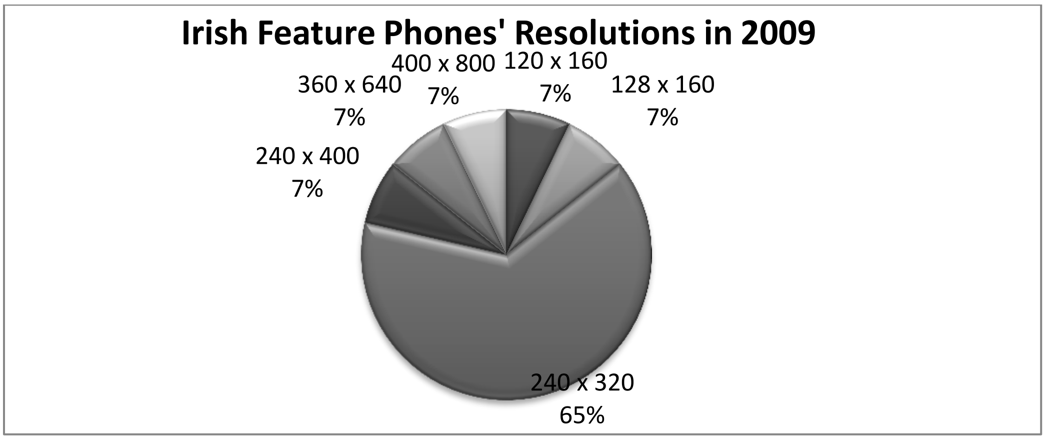

Figure 3-18 Distribution of the Resolutions for Irish Feature Phones Released in 2009

Table 3-16 Feature Phones Classification in Resolution Classes (2009)

Feature Phone Class	**Percentage**
720p	0%
480p	7%
360p	7%
240p	**86%**

Year 2010

The resolutions of the Irish feature phones from 2010 (Table 3-14), are presented in Figure 3-19. As in the previous year, the predominant resolution is still 240 x 320 counting for 60% of all feature phones. There is a clearer difference between feature phones resolutions; the second most used being 240 x 400 counting only for 20% of the feature phones. Small resolution devices, with a resolution of 128 x 160 count for 10% of the feature phones. This resolution is the third most used resolution for feature phones in 2010. As in 2009 the classification in resolution classes of the feature phones is presented in Table 3-17. As in 2009, feature phones from the 240p class are predominant (95%).

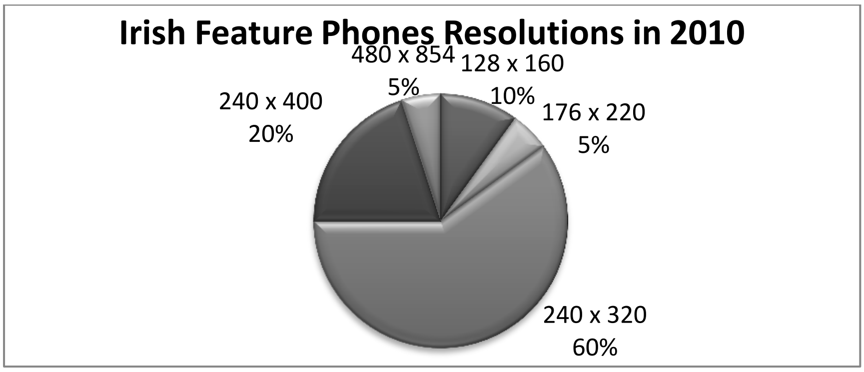

Figure 3-19 Distribution of the Resolutions for Irish Feature Phones Released in 2010

Table 3-17 Feature Phones Classification in Resolution Classes (2010)

Feature Phone Class	**Percentage**
720p	0%
480p	5%
360p	0%
240p	**95%**

Period 2009-2010

To better understand the resolution of the feature phones that exist on the Irish market in the last two years, an analysis of the devices released between 2009 and 2010 was performed (Figure 3-20). The three most used resolutions among the Irish feature phones released in the period 2009-2010 are:

- 240 x 320 counting for 62% of the feature phones
- 240 x 400 counting for 14% of the feature phones
- 128 x 160 counting for 9% of the feature phones

The rest of the resolutions were evenly distributed, counting each of them for 3%. The distribution of resolutions based on the resolution classes is presented in Table 3-18. Most of the feature phones resolutions are in the class 240p (91%). 480p counts for 6%, and 360p count for 3%.

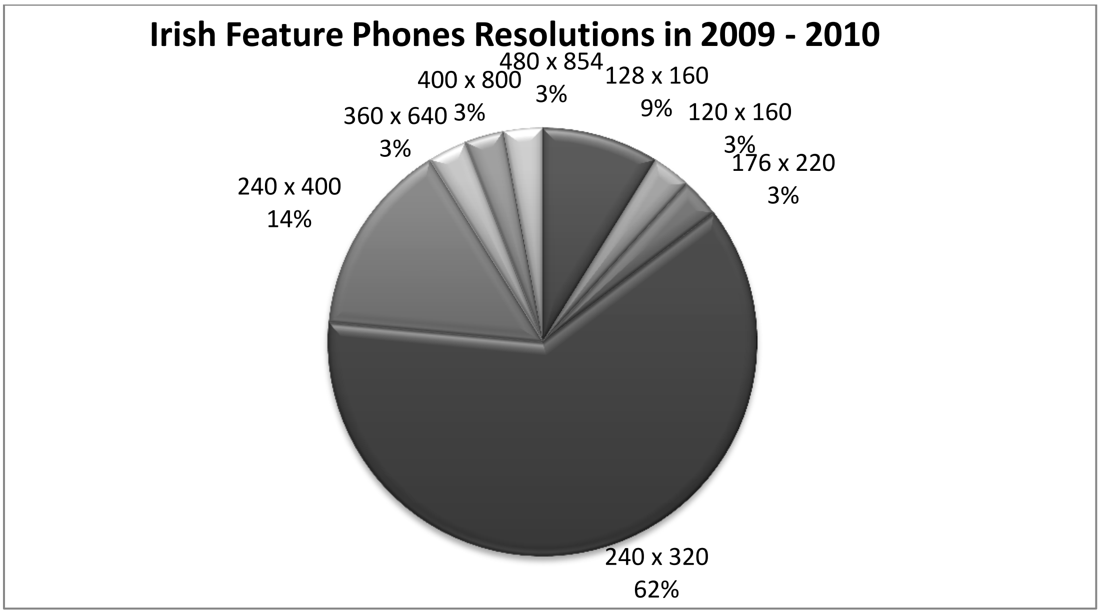

Figure 3-20 Distribution of the Resolutions for Irish Feature Phones in 2009-2010

Table 3-18 Feature Phones' Classification in Resolution Classes (2009-2010)

Feature Phone Class	Percentage
720p	0%
480p	6%
360p	3%
240p	**91%**

Year 2011

Figure 3-21 shows the resolutions from the feature phones released in 2011 that support multimedia, and are present on the Irish market. There are three resolutions: 240 x 400 (43%), 240 x 320 (29%) and 128 x 160 (28%). All these resolutions fit in the 240p class.

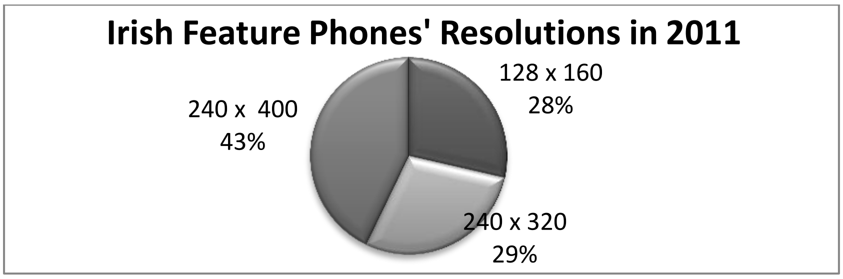

Figure 3-21 Distribution of the Resolutions for Irish Feature Phones in 2011

Table 3-19 Feature Phones Classification in Resolution Classes (2011)

Feature Phone Class	Percentage
720p	0%
480p	0%
360p	0%
240p	**100%**

3.2.2.2.2 Irish Feature Phones Analysis based on the Screen Size

This section analyses the screen sizes of the feature phones released on the Irish market between 2008 and 2011[15].

Year 2008

In 2008, the screen size is 1.8’’ (46mm) in 2008.

Year 2009

The distribution of screen sizes in 2009 is presented in Figure 3-22. Each slice of the pie represents a screen size and the percentage of feature phones having that size. The most used screen size in 2009 is 2.2’’ (56mm), counting for 23% of the feature phones presented in Table 3-13. The second most used screen size is 1.8’’ (46mm) counting for 16% of the total feature phones. The third most used screen size are 2.4’’ (61mm), 2.6’’ (66mm) and 3’’ (81mm), counting each for 15% of the Irish feature phones released in 2009.

[15] Up to 14 June 2011

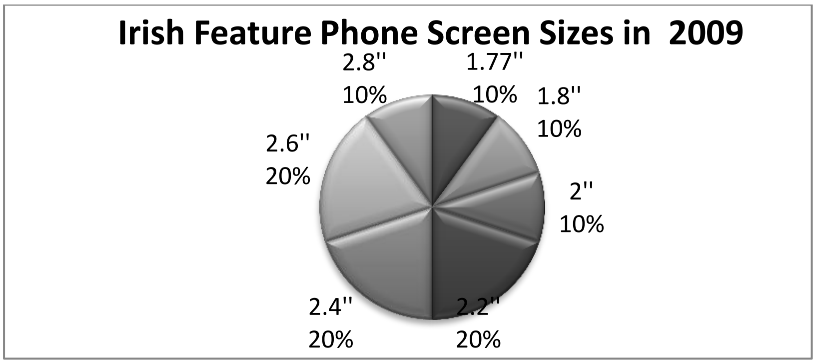

Figure 3-22 Distribution of the Screen Sizes for Irish Feature Phones in 2009

Year 2010

The distribution of screen sizes in 2010 is presented in Figure 3-23. Similar to 2009, the most frequent screen size was 2.2'' (56mm). It increased in popularity from 23% in 2009, to 30% in 2010. The second most used screen sizes are 2'' (51mm) and 3'' (76mm) counting each for 30% of feature phones. The 3'' screen size is the second most popular in 2009, but counting only for 15%. 2.4'' (61mm), which was the most popular in 2009, is still counting for 15%, but is only the third most used screen size in 2010.

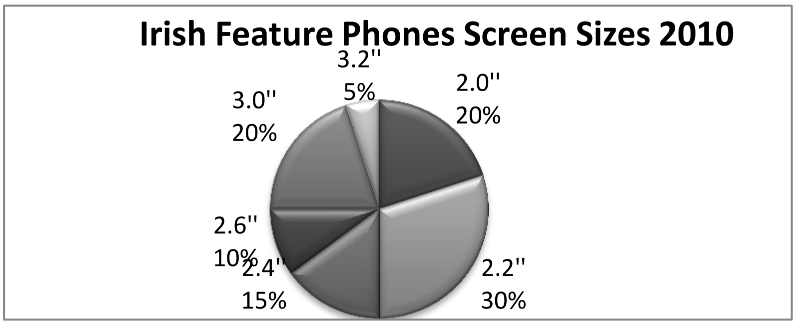

Figure 3-23 Distribution of the Screen Sizes for Irish Feature Phones in 2010

Period 2009-2010

As previously performed for the resolution analysis, this section also analyses which are the most used feature phone screen sizes for the period 2009-2010. Based on the data from Table 3-13 and Table 3-14, the three most used screen sizes for the Irish feature phones are:

- 2.2'' (56mm) that counts for 28% of the feature phones
- 3'' (76mm) that counts for 18% of the feature phones
- 2.4'' (51mm) and 2'' (51mm) that count each of them for 15%.

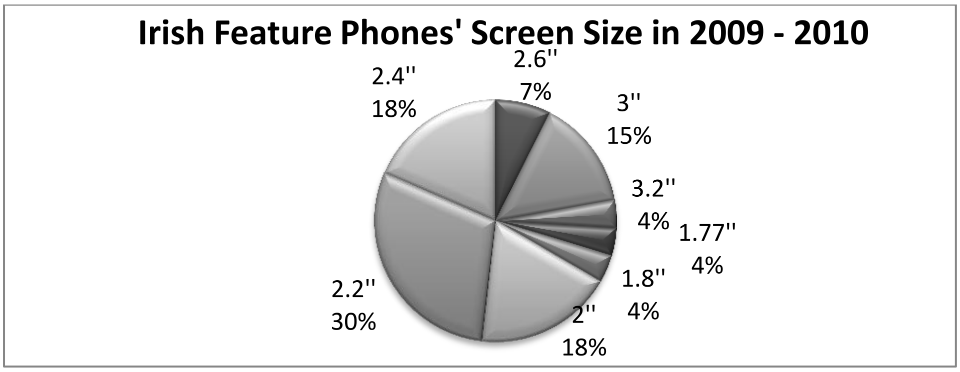

Figure 3-24 Distribution of the Screen Sizes for the Feature Phones in 2009-2010

Period 2011

Figure 3-25 presents the screen sizes of the feature phones that support multimedia, present on the Irish market in 2011[16]. 2'' (51mm) is the most used screen size, counting for 43% of the feature phones screen sizes. 3'' (76mm) is the second most used screen size (as in the analysis of the 2009-2010 period), counting for 29% of the total feature phones. 3.2'' (81mm) and 1.8'' (46mm) are equally distributed, counting for 14%.

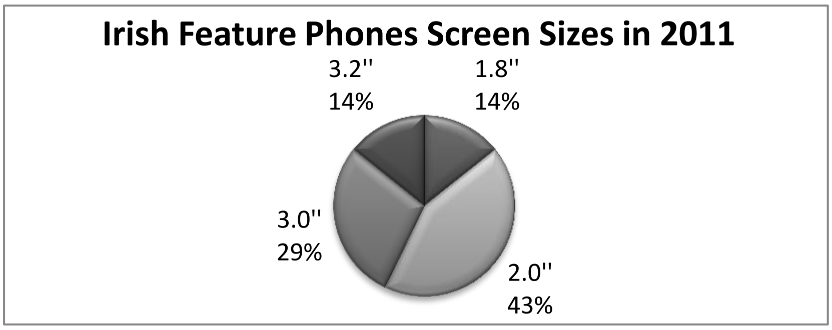

Figure 3-25 Distribution of the Screen Sizes for the Feature Phones in 2011

3.2.2.2.3 Irish Feature Phones providing Multimedia Support

Year 2008

The most common used video codec was H.263 in 2008.

Year 20009

Figure 3-26 presents the distribution of multimedia formats supported by feature phones released in 2009. The supported multimedia format is on the horizontal axis, and the percentage of feature phones who offer that format on the horizontal axis. As it can be noticed,

[16] Up to 14 June 2011

there is large support for MP4 multimedia files, with 92.86% of feature phone offering it. The H.263 and H.264 standards are as well widely supported, counting for 71.43% and 57.14% respectively from the total number of feature phones.

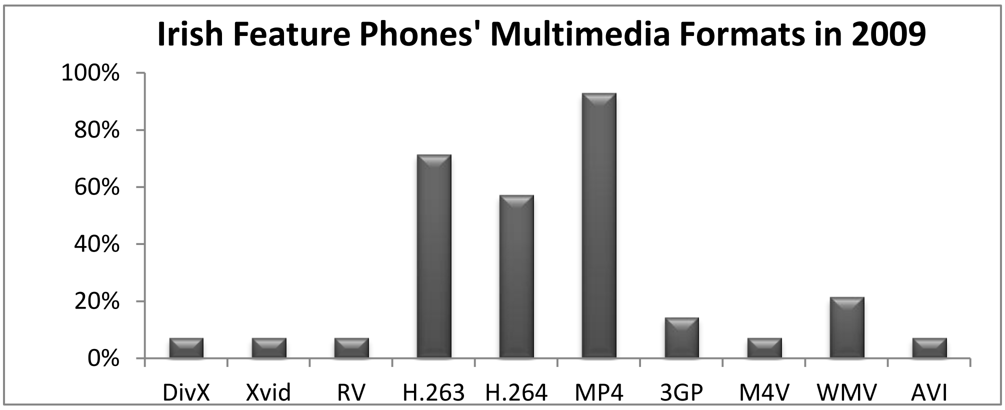

Figure 3-26 Distribution of the Multimedia Formats Supported by Feature Phones in 2009

<u>Year 2010</u>

As it can be seen from Figure 3-27 the same top three multimedia formats are popular in 2010 too, but with the distribution slightly changed. In 2010, the most common video codec is H.263 counting for 95%, followed by MP4 with 90%. H.264 support was increased 60% of the feature phones being able to play a H.264 video format.

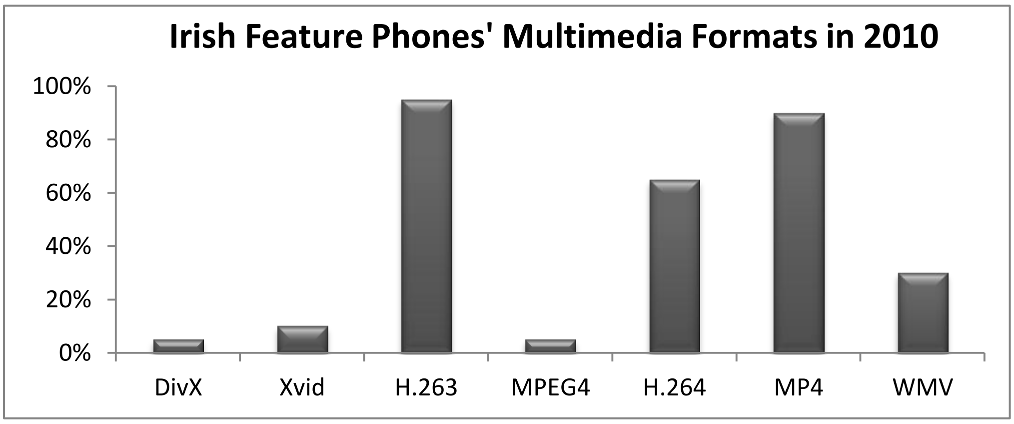

Figure 3-27 Distribution of the Multimedia Formats Supported by Feature Phones in 2010

Period 2009-2010

The top three supported multimedia formats by the Irish feature phones during 2009-2010 are (Figure 3-28):

1. MP4 by 91.18% of the feature phones
2. H.263 by 85.29% of the feature phones
3. H.264 by 61.76% of the feature phones

Among other multimedia (video) formats, WMV is increasingly supported by feature phones from 2010, 26.47% of feature phones supporting this format.

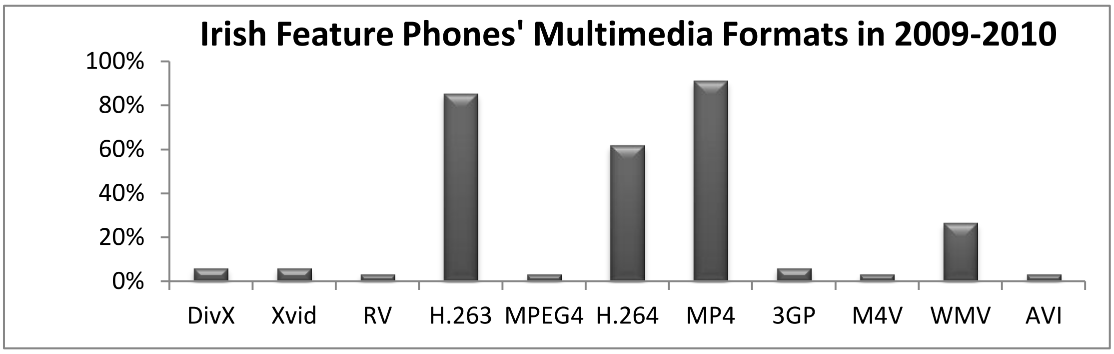

Figure 3-28 Distribution of the Multimedia Formats Supported by Feature Phones Released in the Period 2009 – 2010

Year 2011

Figure 3-29 presents the multimedia formats supported in 2011. There are three formats supported on the available Irish feature phones: MP4 (85.71%), H.263 (71.43%) and H.264 (42.86%).

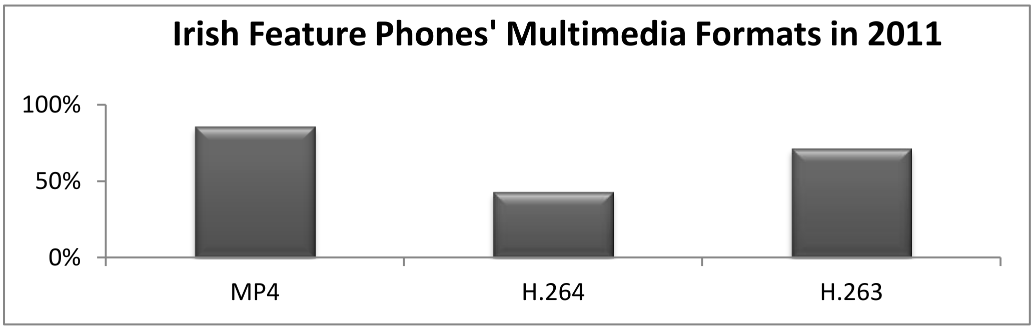

Figure 3-29 Distribution of the Multimedia Formats Supported by Feature Phones in 2011

3.2.2.2.4 Irish Feature Phones Analysis based on the Mobile Network Access

Taking into account that the mobile telephony standards can differ among regions (e.g. GSM being the most used in Europe, while CDMA being more popular in USA), the analysis was done based on the generation of cellular networks with mobile support.

Year 2008

In 2008, the Irish feature phones supported 2G and 2G transitional networks.

Year 2009

The generation of cellular networks supported by the feature phones in 2009 is presented in Figure 3-30. All feature phones supported 2G (e.g. GSM) and 2G transitional cellular networks (e.g. GPRS, EDGE). 3G and 3G transitional are also supported by some of the feature phones released in 2009. 3G transitional is supported by 35.71% of the feature phones, while 3G by 13.29%.

Although not directly related to this research, it is interesting to note, that among these devices, 21.43% of them have Wi-Fi (b/g) access and 92.86% have Bluetooth access.

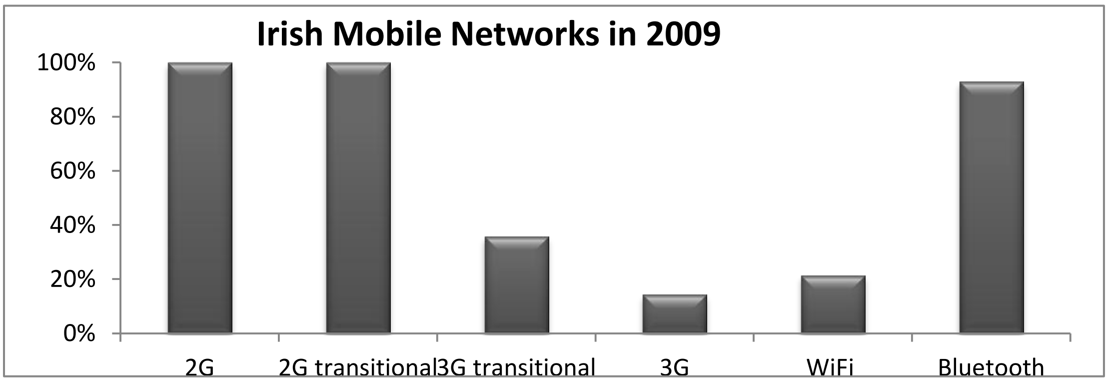

Figure 3-30 Distribution of the Mobile Networks for the Irish Feature Phones in 2009

Year 2010

The released Irish feature phones in 2010 (Figure 3-31) provide similar network support as the ones from 2009. The 2G and 2.5 G networks are, 100% supported. 3G and 3G transitional networks are supported approximately in the same percentage as in the previous year, 3G transitional is supported by 35% of the feature phones, while 3G by 15% of the feature phones.

All the feature phones released in 2010 had Bluetooth and only 10% had Wi-Fi access.

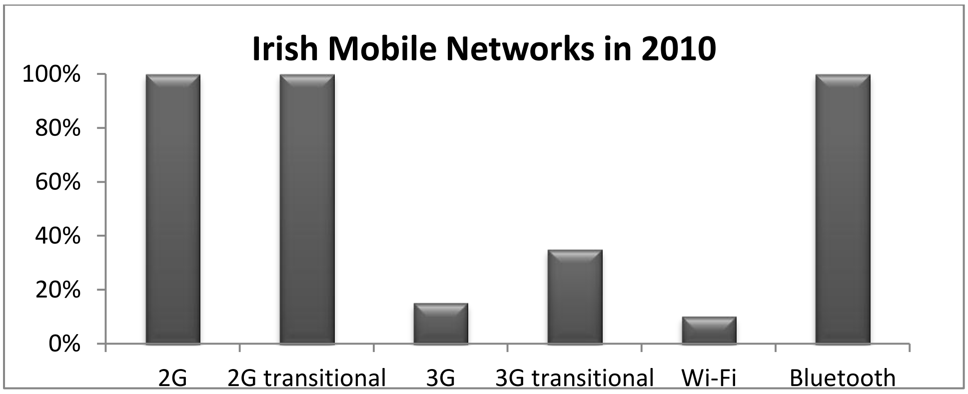

Figure 3-31 Distribution of the Mobile Networks for the Irish Feature Phones in 2010

<u>Period 2009-2010</u>

The most supported networks for 2009-2010 are obviously, 2G and 2G transitional, which are fully supported, while 3G and 3.5G (3G transitional) are being supported by approximately half of the mobile phones (Figure 3-32). 14.71% of the Irish feature phones had Wi-Fi access and 97.06% Bluetooth.

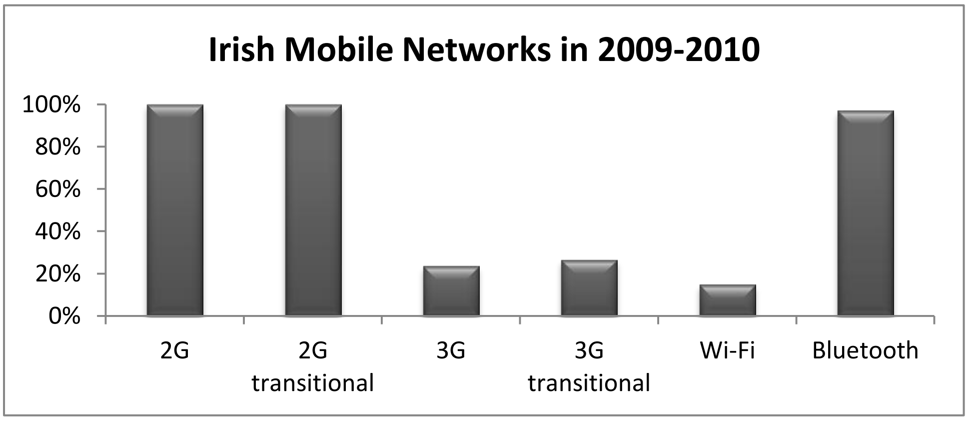

Figure 3-32 Distribution of the Mobile Networks for the Irish Feature Phones in 2009-2010

<u>Period 2011</u>

Figure 3-33 presents the mobile networks for the feature phones released on the Irish market in 2011. All the feature phones have 2G and 2G transitional networks. 28.57% can access 3G networks and 14.29% can access 3G transitional networks. 28.57% have access to Wi-Fi networks and 100% have Bluetooth.

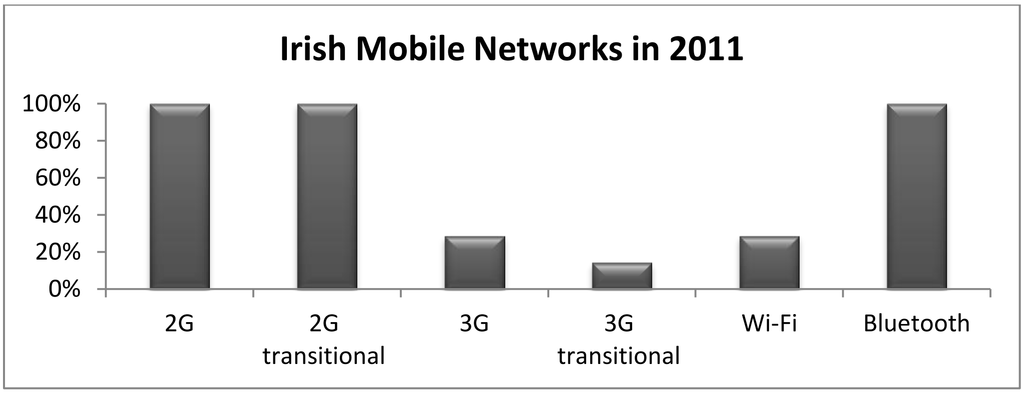

Figure 3-33 Distribution of the Mobile Networks for the Irish Feature Phones in 2011

3.2.3 Analysis of the Smartphones

3.2.3.1 Worldwide Smartphones Analysis

This section presents an analysis of the smartphones: published on the GSM Arena (Arena, 2011) website, and announced starting with 2008. A total of 530 models were analysed. Among these 90 (17%) of them were announced in 2008, 128 (24%) were announced in 2009, 210 (40%) were announced in 2010 and 102 (19%) announced in 2011 (Figure 3-34).

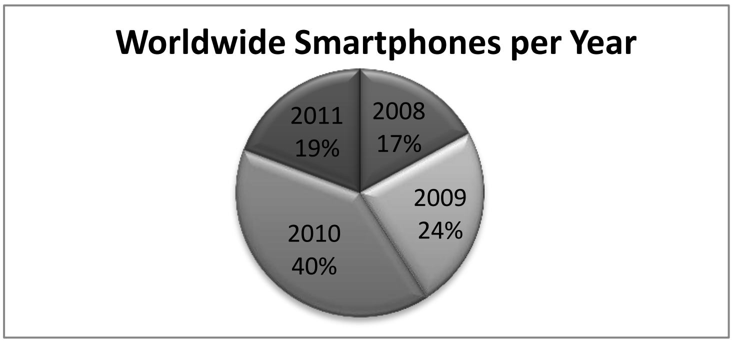

Figure 3-34 Worldwide Smartphones' Distribution between 2008-2011

3.2.3.1.1 Analysis of the Smartphones Resolutions

Year 2008

The analysis of the smartphones released in 2008 is presented in Figure 3-35. The most common resolution in 2008 is 240 x 320 counting for 65.56% of smartphones. Another relatively common resolution is 480 x 640 that counts for 18.89%. The other resolutions count fewer than 10% of the total smartphones. Table 3-25 presents the division of devices in the defined resolutions classes. Most of the smartphones resolutions in 2008 fit into the 240p class.

The next most used resolution class is 480p (24.45%), and the third most used is 360p (5.55%). In 2008 there are still no smartphones having a resolution that fits the 720p class.

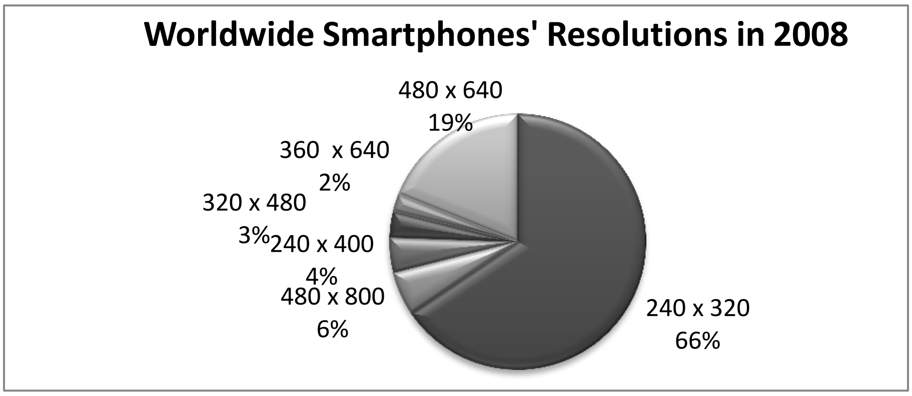

Figure 3-35 Distribution of the Resolutions for Worldwide Smartphones Released in 2008

Table 3-20 Smartphones' Classification in Resolution Classes (2008)

Resolution Class	**Percentage**
720p	0%
480p	24.45%
360p	5.55%
240p	**70%**

Year 2009

In 2009 (Figure 3-36), there is a considerable decrease among the smartphones which have a resolution of 240 x 320 (only 34.13% relative to 65.56% in 2008). However, this resolution is still the dominant resolution. An increase in the devices with a resolution of 480 x 800 can be noticed, which counts for 20.63% in 2009 (as opposed to 5.56% in 2008). The third most used resolution is 320 x 480 that counts for 15.87% of the smartphones, and in 2008 was 3.33%. The rest of the resolutions are present in fewer than 10% of the smartphones taken into consideration in this study.

Table 3-21 presents the division of the smartphones resolution classes in 2009. Since the resolutions belonging to other categories were not taken into consideration there might be a plus of up to 5.56% in any resolution class. The 240p resolution class is still the predominant resolution class, however it decreases from 70% in the previous year to at least 43.65% in 2009. It can be noticed an increase in resolutions belonging to both classes 360p (from 5.55% to at least 23.81%) and 480p (from 24.45% to at least 26.98%).

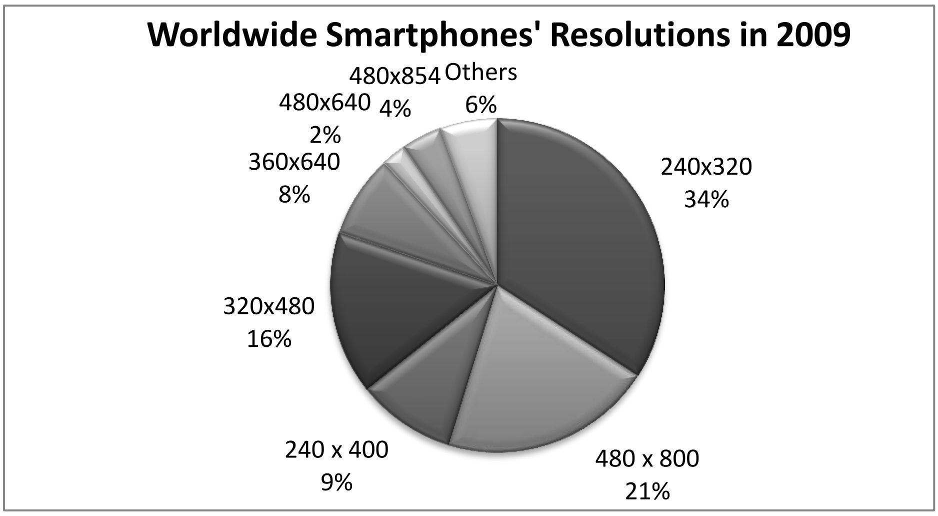

Figure 3-36 Distribution of the Resolutions for Worldwide Smartphones Released in 2009

Table 3-21 Smartphones' Classification in Resolution Classes (2009)

Resolution Class	Percentage
720p	0%
480p	26.98%
360p	23.81%
240p	**43.65%**

Year 2010

A considerable increase in the smartphones having higher resolutions, such as 480 x 800, can be noticed in 2010 (Figure 3-37). This is the dominant resolution in 2010, counting for 31.43% of the smartphones. The smartphones having a 240 x 320 resolution is still present (20.95%). 320 x 480 is still the third most used resolution for smartphones in 2010, counting for 17.14% of the smartphones. Overall it can be notice a significant increase in high resolutions for smartphones, especially comparative to 2010. Small resolutions are still present but their usage declines slowly.

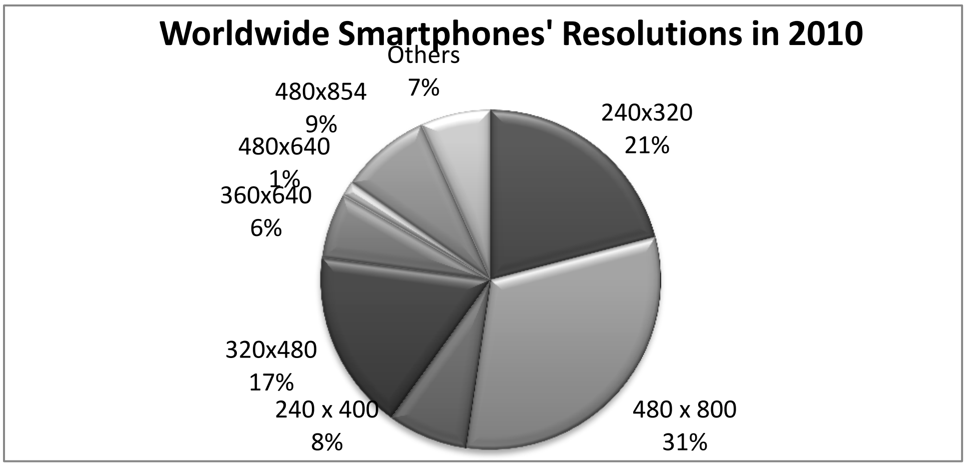

Figure 3-37 Distribution of the Resolutions for Worldwide Smartphones Released in 2010

Table 3-22 presents the devices resolutions' divided in resolution classes for 2010. As for 2009, the other resolutions, which count for (6.74%) were not considered, therefore they can belong to any of these classes. This year the most smartphones belong to the 480p class (at least 41.43%). The second most used resolution class continues to be 240p with at least 28.57% of the smartphones, and the third most used is 360p with at least 23.33% of the smartphones.

Table 3-22 Smartphones' Classification in Resolution Classes (2010)

Resolution Class	Percentage
720p	0%
480p	**41.43%**
360p	23.33%
240p	28.57%

Period 2009-2010

In the last two years the dominant resolutions are 480 x 800 with 27% of the smartphones, closely followed by 240 x 320 with 26% of the smartphones. 320 x 480 counts for 16% of the smartphones (Figure 3-38).

Table 3-23 presents the resolution classes for the 2009-2010. As well as before, the other resolutions are not taken into account, therefore there are 6.80% of the smartphones whose resolutions were not shown in the graph, and not taken into account in the class division. Overall, in 2009-2010, the most common resolution class seems to be 480p, with at least 36.02% of the resolutions belonging to this class. Closely, the 240p class has at least 34.22% of the smartphones. The third most used smartphones resolutions belong to the 360p class (at least 23.52%).

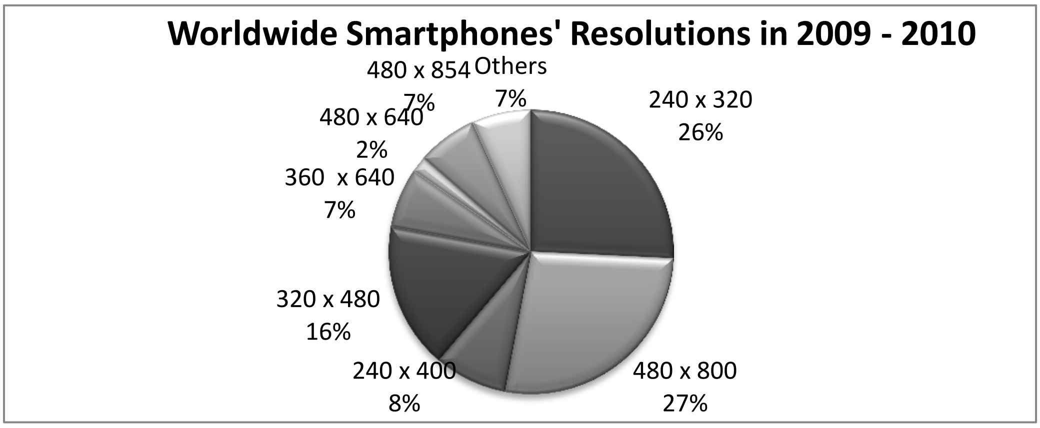

Figure 3-38 Distribution of the Resolutions for Worldwide Smartphones Released in 2008

Table 3-23 Smartphones Classification in Resolution Classes (2009-2010)

Resolution Class	**Percentage**
720p	0%
480p	**36.02%**
360p	23.52%
240p	34.22%

Year 2011

Figure 3-39 presents the smartphones' resolutions released in 2011. The most used resolution is 480 x 800 counting for 41% of the all considered smartphones. The second most used resolution is 320 x 480 that counts for 26% of all smartphones, and the third most used is 240 x 320. As it can be seen from Table 3-24, 480p class resolutions are used by 51% of all smartphones, 360p class is the second most used with 29% of all resolutions smartphones, and 240p is the third most used (17% of all smartphones' resolutions).

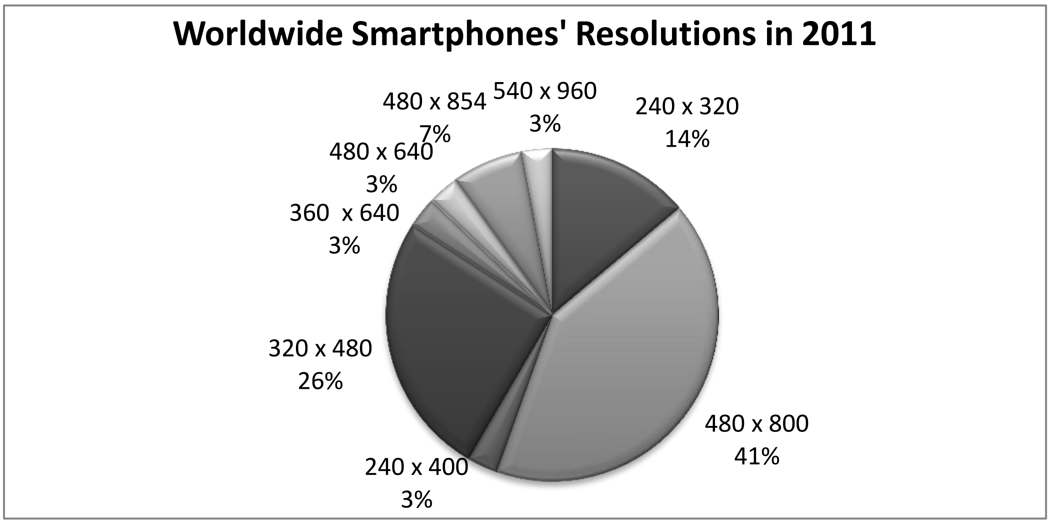

Figure 3-39 Distribution of the Resolutions for Worldwide Smartphones Released in 2011

Table 3-24 Smartphones' Classification in Resolution Classes (2011)

Resolution Class	Percentage
720p	3%
480p	**51%**
360p	29%
240p	17%

3.2.3.1.2 Analysis of the Smartphones' Screen Sizes

This subsection presents an analysis of smartphones in term of their screen size. The analysis is done for the period 2008-2011[17].

Year 2008

The distribution of screen sizes in 2008 is presented in Figure 3-40. The most used screen sizes are between 2.4'' and up to 2.6'', counting for 36.67% of the smartphones. Screen sizes between 2.8'' and up to 3'' are the second most used, counting for 25.56% of the total smartphones. The third most used screen sizes are between 3'' and up to 3.2''.

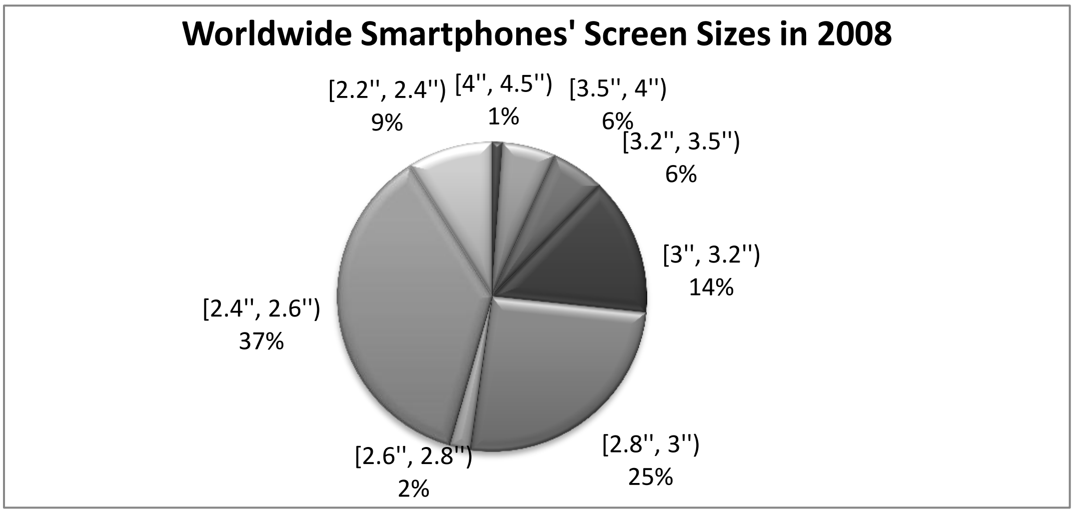

Figure 3-40 Distribution of the Screen Sizes for Worldwide Smartphones Announced in 2008

Year 2009

Figure 3-41 shows that the most used screen sizes are between 3.5'' and up to 4'', counting for 26.98% of the smartphones in 2009. It is closely followed by smartphones having screen sizes between 3.2'' and up to 3.5'' counting for 24.60%. The most used screen sizes in 2008 are still present on a considerable part of the devices (screen sizes between 2.4'' and 2.6'' count for 15.87% of the smartphones) but they are decreasing.

[17] Up to 14 June 2011

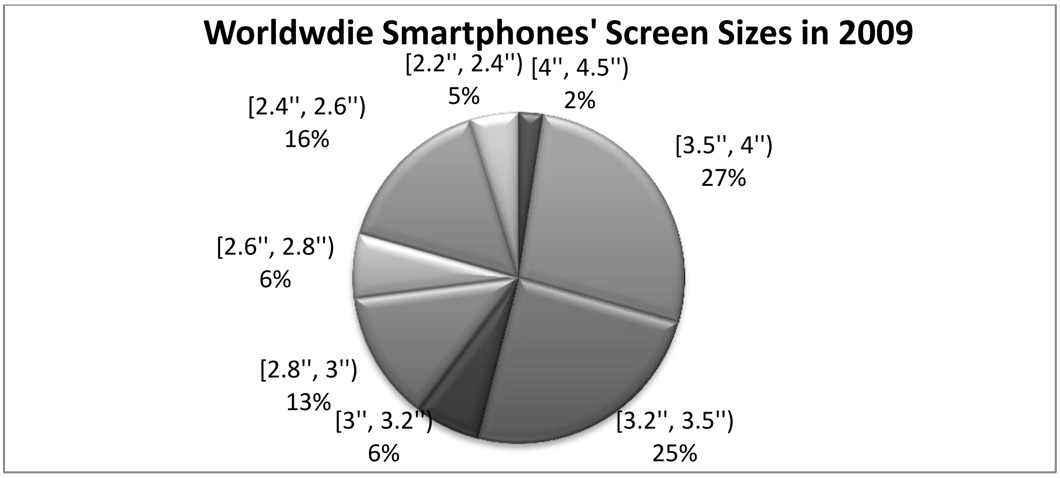

Figure 3-41 Distribution of the Screen Sizes for Worldwide Smartphones Announced in 2009

<u>Year 2010</u>

Figure 3-42 shows that there is an increase, especially in the number of devices that have screen sizes greater than 4'' for 2010(18.57% compared with 2.38% in 2009 and 1.11% in 2008). The most used screen sizes are between 3.2'' and 3.5'', the smartphones with these screen sizes counting for 26.19% of the smartphones.23.81% of the smartphones included in this study have screen sizes between 3.5'' and 4''.

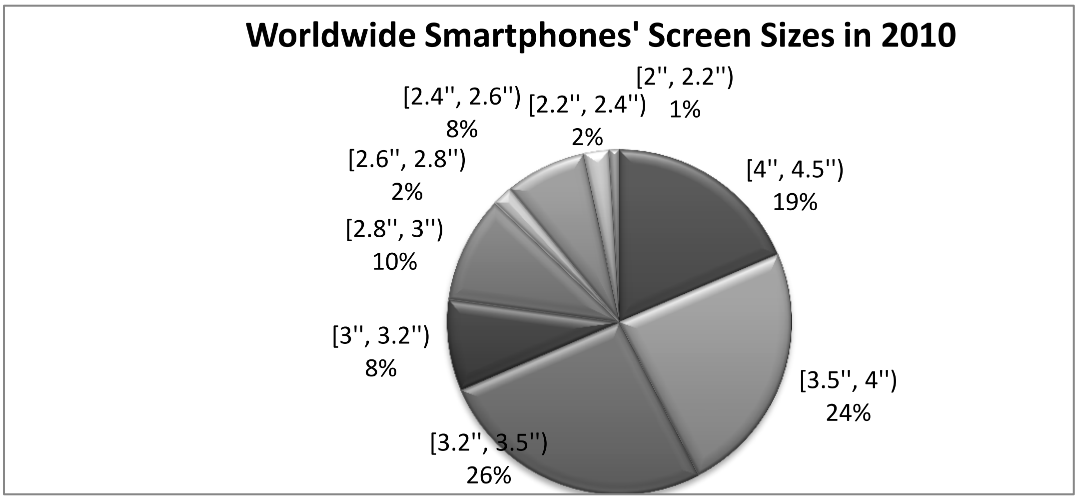

Figure 3-42 Distribution of the Screen Sizes for Worldwide Smartphones Announced in 2008

Period 2009-2010

Overall, the division of smartphones based on their screen sizes in 2009- 2010 is presented in Figure 3-43. Screen sizes over 4'' are predominant (30.13% of the total smartphones). Screen sizes between 3.5'' and 4'' or 3.2'' and 3.5'' are almost equally predominant in smartphones, with 22.12% and 22.44% respectively.

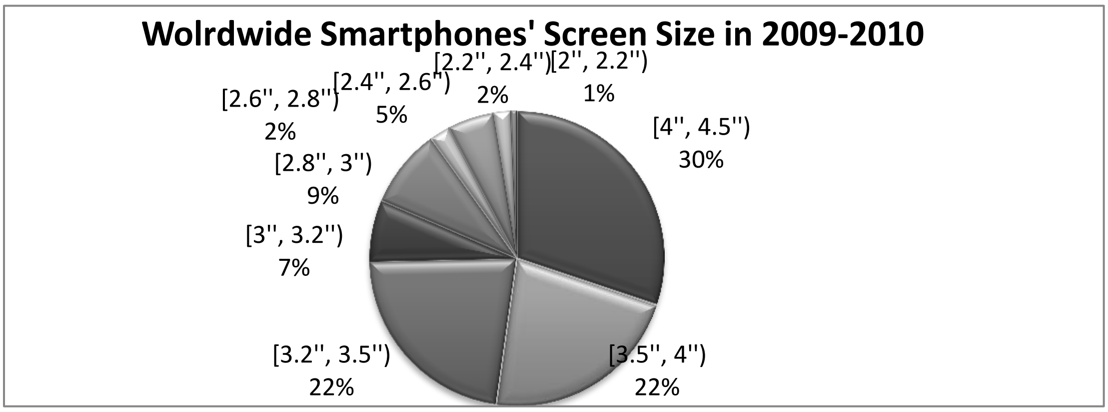

Figure 3-43 Distribution of the Screen Sizes for the Worldwide Smartphones Announced in the Period 2009-2010

Figure 3-44 represents the smartphones' screen sizes from 2011. As it can be seen, many screen sizes are equal or exceed 4'' (54%) of the smartphones. The second most used screen sizes are between 3.5'' (inclusive) and 4'' (18%) and the third most used among 3'' (inclusive) and 3.2'' (15%).

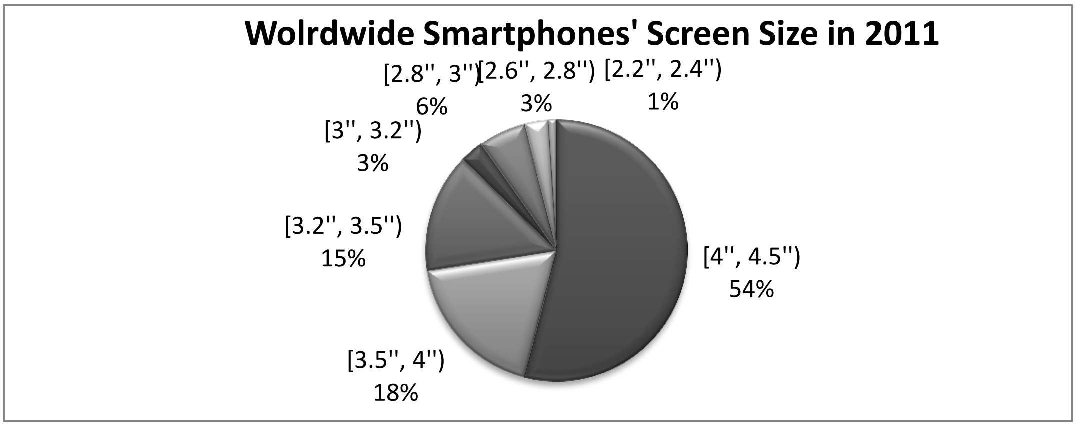

Figure 3-44 Distribution of the Screen Sizes for the Worldwide Smartphones in 2011

3.2.3.1.3 Analysis of the Smartphones based on the Mobile Networks Supported

In 2008-2011[18] (Figure 3-45, Figure 3-46, Figure 3-47, and Figure 3-49), most of the smartphones have access to 2G networks (GSM). Data based on the supported bands is given GSM 850, GSM 900, GSM 1800 and GSM 1900.

<u>Year 2008</u>

2.5G network is also popular (EDGE, GPRS) and an increase in the number of devices supporting one of them or both is noticed in 2009 and 2010 comparatively with 2008. However, the support for 3G network (UMTS), 3.5G (HSDPA) and Wi-Fi networks increases considerably from 2008. The 3G and UMTS networks are also represented based on the percentage of smartphones supporting a certain transmission band. In 2008 76.66% of the smartphones had access to Wi-Fi network, and all have Bluetooth access.

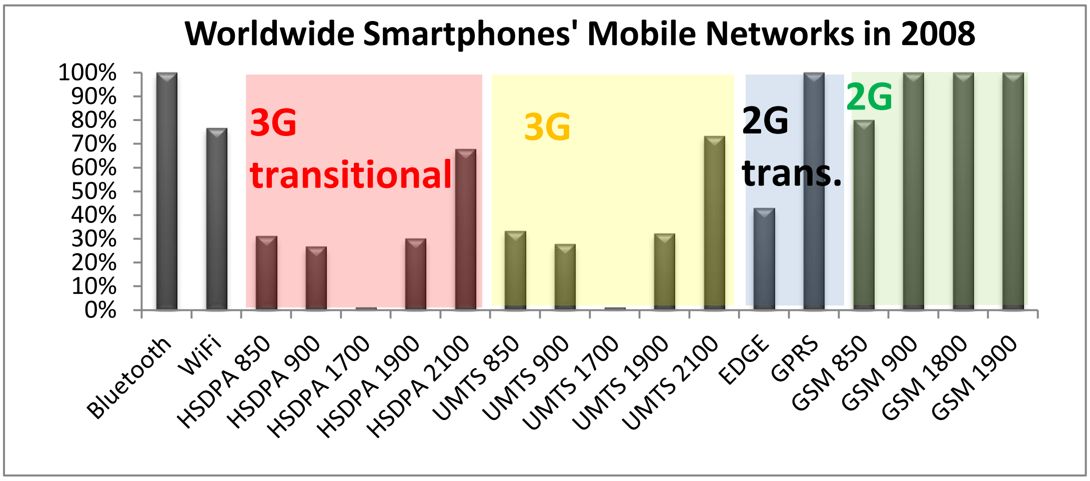

Figure 3-45 Distribution of the Mobile Networks for Worldwide Smartphones in 2008

<u>Year 2009</u>

In 2009 (Figure 3-46), the number of smartphones supporting Wi-Fi is 79.69%. Relative to 2008, there is an increase in the number of smartphones supporting 3G and 3.5G networks. All smartphones support Bluetooth.

[18] Up to 14 June 2011

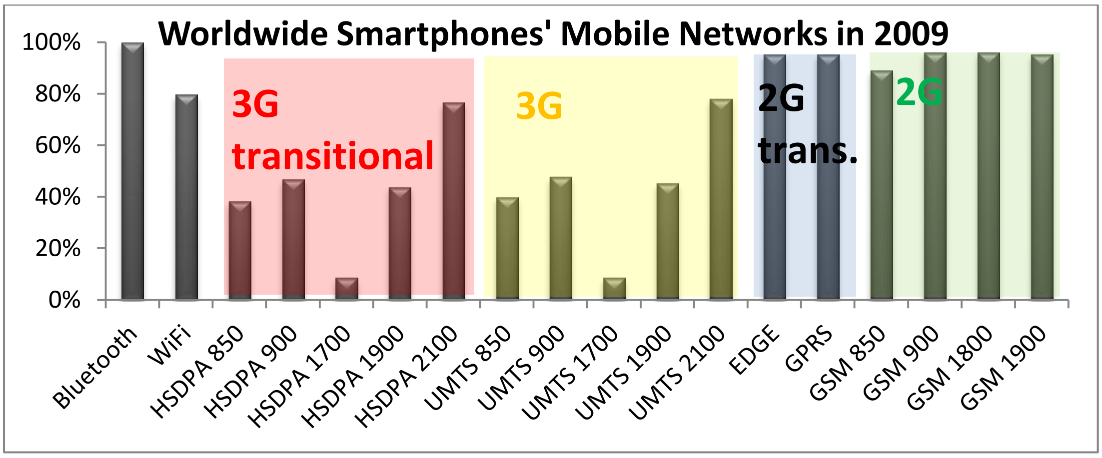

Figure 3-46 Distribution of the Mobile Networks for Worldwide Smartphones in 2009

<u>Year 2010</u>

In 2010, almost all of the produced smartphones allow access to Wi-Fi (92.86%), and all allow Bluetooth access. Support for 3G, 3.5G increases as well (Figure 3-47).

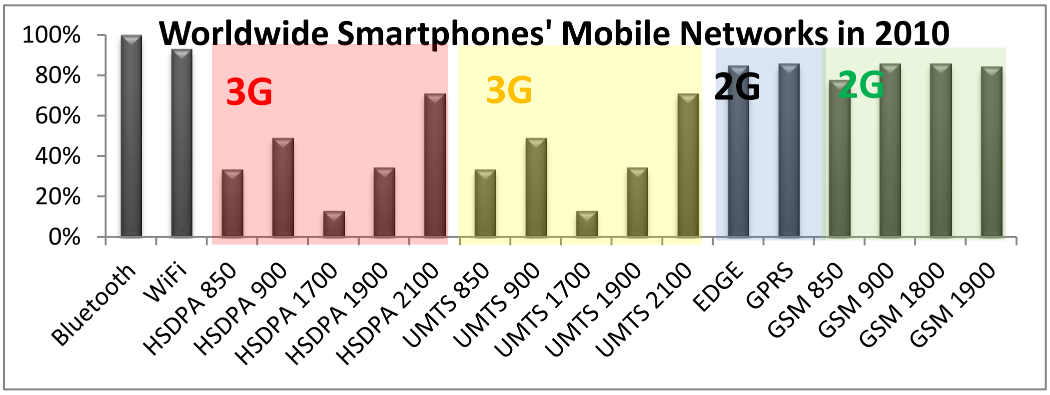

Figure 3-47 Distribution of the Mobile Networks for Worldwide Smartphones in 2010

<u>Period 2009-2010</u>

Figure 3-48 presents the percentage of the smartphones having access to particular type of network released in the period 2009-2010. 87.87% of the smartphones support Wi-Fi, at least 49.17% can access 3G transitional network, most of them (90.04%) can access EDGE network and/or GPRS network (90.51%). All can access Bluetooth.

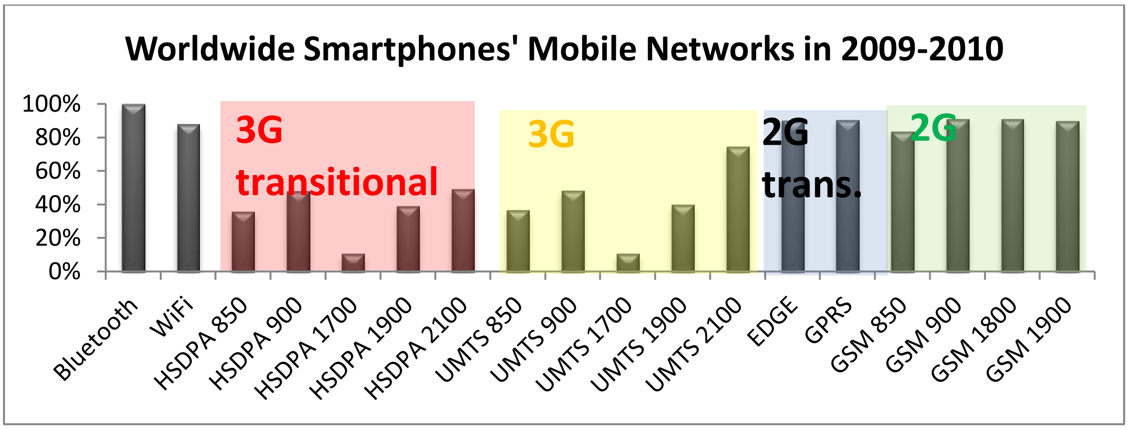

Figure 3-48 Distribution of the Mobile Networks for Worldwide Smartphones Announced in the Period 2009-2010

Year 2011

Figure 3-49 presents a distribution of mobile networks from 2011. Most of the smartphones (96.08%) are Wi-Fi enabled. At least 61.76% can access 3G transitional network, 61.76% 3G network, and 70.59% GPRS and/or EDGE network. All smartphones have Bluetooth access.

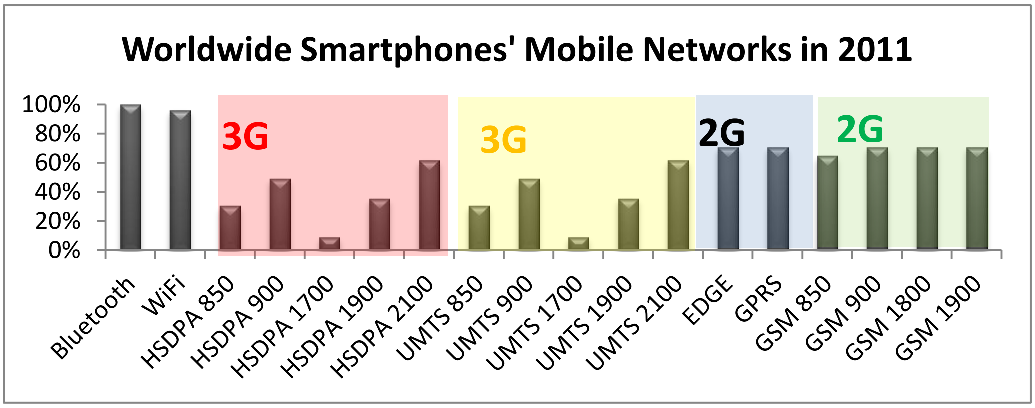

Figure 3-49 Distribution of the Mobile Networks for the Worldwide Smartphones in 2011

3.2.3.2 Smartphones Analysis: Ireland Case Study

An analysis of the smartphones released on the Irish market during the period 2008-2011 is performed in this section, focusing on their resolution, screen size, supported multimedia formats, and mobile networks access. The smartphones based on which this analysis is performed are presented in Table 3-25, Table 3-26 and Table 3-27. Table 3-28 presents the devices that appeared or are announced to appear in 2011.

Table 3-25 Irish Smartphones Released in 2008

Device	Released	Resolution	Screen Size	Supported Mobile Networks	Supported Multimedia Formats
240 x 320					
Motorola RIZR Z10	2008	240 x 320	2.2’’ (56mm)	GSM, GPRS, EDGE, HSDPA	MP4
Motorola MOTO Q11	2008	240 x 320	2.4’’ (61mm)	GSM, GPRS, EDGE, Wi-Fi b/g	MP4, 3GP, MWV, H.264
Nokia E63	2008	240 x 320	2.4’’ (61mm)	EGSM, WCDMA, GPRS, EDGE, UMTS Wi-Fi b/g	WMV, RV, MP4, 3GP
Nokia E71	2008	240 x 320	2.4’’ (61mm)	EGSM, WCDMA, GPRS, EDGE Wi-Fi b/g, HSDPA, UMTS	WMV, RV, MP4, 3GP
RIM BlackBerry Pearl Flip 8220	2008	240 x 320	2.6’’ (64mm)	GSM, GPRS, EDGE, Wi-Fi b/g	MP4, WMV, H.263, H.264

Nokia N96	2008	240 x 320	2.8’’ (71mm)	GSM, GPRS, EDGE, UMTS, HSDPA, Wi-Fi b/g	WMV, RV, MP4, 3GP
240 x 400					
LG CT810 Incite	2008	240 x 400	3’’ (76mm)	GSM, GPRS, EDGE, UMTS, HSDPA, Wi-Fi b/g	MP4, H.263, H.264
320 x 480					
Apple iPhone 3G	2008	320 x 480	3.5’’ (89mm)	GSM, UMTS, EDGE, GPRS, HSDPA, Wi-Fi b/g	H.264, MPEG-4
360 x 480					
Samsung SGH-i900 Omnia	2008	360 x 480	3.2’’ (81mm)	HSDPA, GSM, GPRS, EDGE, Wi-Fi b/g	DivX, XviD, WMV, MP4
RIM BlackBerry Storm 9500	2008	360 x 480	3.3’’ (84mm)	GSM, GPRS, EDGE, HSDPA, CDMA	MP4, H.264, H.263, WMV

360 x 640					
Nokia 5800 XpressMusic	2008	360 x 640	3.2’’ (81mm)	HSDPA, GSM, EGPRS, EDGE, Wi-Fi b/g	MP4, H.263, H.264, WMV
480 x 640					
E-TEN Glofiish V900	2008	480 x 640	2.8’’ (71mm)	GSM, GPRS, UMTS, Wi-Fi b/g, HSDPA	MP4, H.263, WMV
E-TEN Glofiish X650	2008	480 x 640	2.8’’ (71mm)	GSM, GPRS, EDGE, Wi-Fi b/g	WMV
E-TEN Glofiish X900	2008	480 x 640	2.8’’ (71mm)	GSM, HSDPA, GPRS, EDGE, Wi-Fi b/g	WMV
Gigabyte GSmart MS820	2008	480 x 640	2.8’’ (71mm)	GSM, HSDPA, GPRS, EDGE, Wi-Fi b/g	WMV, MP4, 3GP
480 x 800					

Samsung SCH-M495 T*OMNIA	2008	480 x 800	3.3’’ (84mm)	HSDPA, GSM, GPRS, EDGE, Wi-Fi b/g	MP4, H.263, H.264, WMV
HTC Max 4G	2008	480 x 800	3.8’’ (97mm)	Mobile WiMAX, GSM, GPRS, EDGE	MP4
HTC Touch HD	2008	480 x 800	3.8’’ (97mm)	GSM, GPRS, EDGE, UMTS, HSDPA, HSUPA, Wi-Fi b/g	MP4, H.264, H.263
Sony Ericsson XPERIA X1	2008	480 x 800	3’’ (76mm)	GSM, GPRS, EDGE, UMTS, HSDPA, HSUPA, Wi-Fi b/g	MP4

Table 3-26 Irish Smartphones Released in 2009

Device	Released	Resolution	Screen Size	Supported Mobile Networks	Supported Multimedia Formats
240 x 320					
Nokia 6700 slide	2009	240 x 320	2.2'' (56mm)	GSM, GPRS, EDGE, HSDPA, HSUPA	WMV, RV, MP4, 3GP
Nokia E52	2009	240 x 320	2.4'' (61mm)	GSM, GPRS, EDGE, HSDPA, HSUPA, Wi-Fi b/g	WMV, RV, MP4, 3GP
Nokia E72	2009	240 x 320	2.4'' (61mm)	EGSM, WCDMA, GSM, GPRS, EDGE Wi-Fi b/g, HSDPA	WMV, RV, MP4, 3GP
RIM BlackBerry Curve 8520	2009	240 x 320	2.5'' (62mm)	GSM, GPRS, EDGE, Wi-Fi b/g	MP4, H.263, H.264, WMV
HTC Tattoo	2009	240 x 320	2.8'' (71mm)	HSPA, WCDMA, GSM, GPRS, EDGE	MP4, H.263, H.264, WMV9
240 x 400					

Samsung Vodafone 360 M1	2009	240 x 400	3.2’’ (81mm)	GSM, UMTS, EDGE, HSDPA, Wi-Fi b/g	MPEG4, H.263, H.264, DivX, XViD, WMV
320 x 320					
Samsung B7330 OmniaPRO	2009	320 x 320	2.6’’ (67mm)	GSM, UMTS, EDGE, HSDPA, HSUPA, Wi-Fi b/g	MP4, WMV9, H.263, H.264
320 x 480					
Palm Pre	2009	320 x 480	3.1’’ (79mm)	GSM, CDMA, UMTS, HSDPA, Wi-Fi b/g, GPRS, EDGE	MP4, H.264, H.263
Apple iPhone 3GS	2009	320 x 480	3.5’’ (89mm)	GSM, UMTS, EDGE, GPRS, HSDPA, Wi-Fi b/g	H.264, MPEG-4
360 x 480					
RIM BlackBerry Bold 9700	2009	360 x 480	2.4’’ (62mm)	GSM, GPRS, EDGE, HSDPA, Wi-Fi b/g	DivX, WMV, XviD, 3GP

Nokia N97	2009	360 x 640	3.5’’ (89mm)	HSDPA, GSM, GPRS, EDGE, Wi-Fi, b/g	WMV, RV, MP4
Nokia X6	2009	360 x 640	3.2’’ (81mm)	GSM, HSDPA, GPRS, EDGE, Wi-Fi b/g	WMV, RV, MP4, 3GP
480 x 800					
Asus P835	2009	480 x 800	3.5’’ (89mm)	GSM, HSDPA, HSUPA, GPRS, EDGE, Wi-Fi b/g	MP4
Nokia N900	2009	480 x 800	3.5’’ (89mm)	GSM, GPRS, EDGE, UMTS, WCDMA, HSPA, Wi-Fi b/g	MP4, WMV, RV, H.264, xViD, DivX
Toshiba TG01	2009	480 x 800	4.1’’ (104mm)	GSM, GPRS, EDGE, HSPA, UMTS, Wi-Fi b/g	MP4, WMV, H.263, H.264
HTC HD2	2009	480 x 800	4.3’’ (109mm)	GSM, GPRS, EDGE, Wi-Fi b/g, HSPA, WCDMA	WMV, MP4, H.264, H.263
480 x 854					

Motorola Droid	2009	480 x 854	3.7’’ (94mm)	GSM, CDMA 2000, UMTS, Wi-Fi b/g	MP4, H.263, H.264, WMV
480 x 640					
Asus P565	2009	480 x 640	2.8’’ (71mm)	GSM, HSDPA, GPRS, EDGE, Wi-Fi b/g	WMV, MP4

Table 3-27 Irish Smartphones Released in 2010

Device	Released	Resolution	Screen Size	Supported Mobile Networks	Supported Multimedia Formats
240 x 320					
Nokia C5	2010	240 x 320	2.2'' (56mm)	GSM, EDGE, WCDMA, GPRS, HSDPA, HSUPA	MP4, H.264, H.263
Nokia X2	2010	240 x 320	2.2'' (56mm)	GSM, GPRS, EDGE	MP4, H.263
RIM BlackBerry Curve 3G 9300	2010	240 x 320	2.5'' (62mm)	GSM, GPRS, EDGE, HSDPA, Wi-Fi b/g/n	MP4, H.263, H.264, WMV
Sony Ericsson XPERIA X10 mini	2010	240 x 320	2.6'' (65mm)	GSM, UMTS, HSPA, Wi-Fi b/g	MP4, H.263, H.264, WMV
Sony Ericsson XPERIA X10 mini pro	2010	240 x 320	2.6'' (65mm)	GSM, UMTS, EDGE, HSDPA, HSUPA, Wi-Fi b/g	MP4, H.263, H.264, WMV9

HTC Smart	2010	240 x 320	2.8’’ (71mm)	GSM, GPRS, EDGE, HSDPA	MP4, H.263, H.264, WMV9
Samsung I5500 Galaxy 5	2010	240 x 320	2.8’’ (71mm)	GSM, UMTS, EDGE, HSDPA, Wi-Fi b/g	MP4, H.264, H.263
HTC Wildfire	2010	240 x 320	3.2’’ (81mm)	GSM, GPRS, EDGE, WCDMA, HSDPA, Wi-Fi (802.11b/g)	MP4, H.263, H.264, WMV9
240 x 400					
Samsung I5801 Galaxy Apollo	2010	240 x 400	3.2’’ (81mm)	GSM, HSDPA, GPRS, EDGE, Wi-Fi b/g/n	MP4, DivX, XviD, WMV, H.264, H.263
Samsung S7230E Wave 723	2010	240 x 400	3.2’’ (81mm)	GSM, HSDPA, GPRS, EDGE, Wi-Fi b/g/n	MP4, H.263, H.264
320 x 480					
LG P500 Optimus One	2010	320 x 480	3.2’’ (76mm)	GSM, UMTS, HSDPA, EDGE, Wi-Fi b/g	DivX, Xvid, MP4, H.264, H.263, WMV

LG GT540 Optimus	2010	320 x 480	3’’ (76mm)	GSM, GPRS, EDGE, HSDPA, Wi-Fi b/g	MP4, DivX, Xvid, H.264, H.263, WMV
Sony Ericsson XPERIA X8	2010	320 x 480	3’’ (76mm)	GSM, UMTS, EDGE, HSDPA, HSUPA, Wi-Fi b/g	MP4, H.263, H.264, WMV
360 x 400					
RIM BlackBerry Pearl 3G 9105	2010	360 x 400	2.3’’ (57mm)	GSM, GPRS, EDGE, HSDPA, HSUPA, Wi-Fi b/g/n	MP4, H.264, H.263, WMV
360 x 480					
RIM BlackBerry Torch 9800	2010	360 x 480	3.2’’ (81mm)	GSM, GPRS, EDGE, UMTS, HSDPA, HSUPA, Wi-Fi b/g/n	MP4, WMV, H.263, H.264
360 x 640					
Nokia C6	2010	360 x 640	3.2’’ (81mm)	GSM, HSDPA, GPRS, EDGE, Wi-Fi b/g	MP4, H.264, WMV

Sony Ericsson Vivaz	2010	360 x 640	3.2’’ (81mm)	GSM, HSDPA, HSUPA, GPRS, EDGE, Wi-Fi b/g	WMV, RV, MP4, 3GP
Nokia C7	2010	360 x 640	3.5’’ (89mm)	GSM, HSDPA, HSUPA, GPRS, EDGE, Wi-Fi b/g/n	DivX, XviD, MP4, H.264, H.263, WMV
Nokia N8	2010	360 x 640	3.5’’ (89mm)	GSM, GPRS, EDGEHSPA, Wi-Fi b/g/n	DivX, XviD, MP4, H.264, H.263, WMV
480 x 800					
Samsung S8500 Wave	2010	480 x 800	3.3’’ (84mm)	GSM, HSDPA, GPRS, EDGE, Wi-Fi b/g/n	MP4, H.263, H.264, WMV, Xvid, DivX
HTC Desire	2010	480 x 800	3.7’’ (94mm)	HSPA, WCDMA, GSM, GPRS, EDGE Wi-Fi (802.11b/g);	MP4, H.263, H.264, WMV9
HTC Desire Z	2010	480 x 800	3.7’’ (94mm)	GSM, HSDPA, HSUPA, GPRS, EDGE, Wi-Fi b/g/n	MP4, H.264, DivX, XviD
HTC Nexus One	2010	480 x 800	3.7’’ (94mm)	Wi-Fi (802.11b/g/n), GSM, GPRS, EDGE, UMTS, HSDPA, HSUPA	MP4, H.263, H.264

Samsung SGH-i8000 Omnia II	2010	480 x 800	3.7’’ (94mm)	GPRS, EDGE, HSUPA, HSDPA, UMTS, Wi-Fi b/g	DivX, XviD, MP4, H.263, H.264, WMV
LG Optimus 7	2010	480 x 800	3.8’’ (97mm)	GSM, HSDPA, GPRS, EDGE, Wi-Fi b/g/n	MP4, WMV
HTC Desire HD	2010	480 x 800	4.3’’ (109mm)	GPRS, EDGE, Wi-Fi b/g/n, HSPA, WCDMA	DivX, Xvid, MP4, H.263, H.264, WMV9
HTC HD7	2010	480 x 800	4.3’’ (109mm)	GSM, GPRS, EDGE, HSDPA, HSUPA, Wi-Fi b/g/n	MP4, WMV, H.264, H.263
Samsung I8700 Omnia 7	2010	480 x 800	4.0’’ (102 mm)	GSM, HSDPA, HSUPA, GPRS, EDGE, Wi-Fi b/g/n	MP4, WMV
Samsung Galaxy S	2010	480 x 800	4’’ (102mm)	GSM, GPRS, EDGE, HSDPA, Wi-Fi b/g	MP4, DivX, WMV, H.264, H.263
Samsung I9000 Galaxy S	2010	480 x 800	4.0’’ (102mm)	GSM, GPRS, EDGE, HSDPA, HSUPA, Wi-Fi b/g/n	MP4, DivX, WMV, H.264, H.263
480 x 854					

Sony Ericsson Xperia X10	2010	480 x 854	4.0’’ (102mm)	GSM, GPRS, EDGE, HSPA, UMTS, Wi-Fi b/g	MP4, H.263, H.264, WMV
640 x 960					
Apple iPhone 4	2010	640 x 960	3.5’’ (89mm)	GSM, UMTS, EDGE, GPRS, HSDPA, HSUPA, Wi-Fi b/g/n	H.264, MPEG-4

Table 3-28 Irish Smartphones Released in 2011[19]

Device	**Released**	**Resolution**	**Screen Size**	**Supported Mobile Networks**	**Supported Multimedia Formats**
240 x 320					
Samsung C3500 Ping Ch@t	2011	240 x 320	2.4" (71mm)	GSM, EDGE, GPRS	MP4,H.263
LG Optimus Me P350 (LG Pecan)	2011	240 x 320	2.8" (71mm)	GSM, EDGE, GPRS, HSDPA, HSUPA, Wi-Fi b/g	MP4, H.264, H.263, WMV
Samsung Galaxy Mini S5570	2011	240 x 320	3.14’’ (79.75mm)	GSM, EDGE, GPRS, HSDPA, HSUPA, Wi-Fi b/g/n	MP4, H.264, H.263
Samsung S3850 Corby II	2011	240 x 320	3.2’’ (81mm)	GSM, EDGE, GPRS, Wi-Fi b/g/n	MP4, H.264, H.263
240 x 400					
Samsung S5260 Star II	2011	240 x 400	3.0" (76mm)	GSM, EDGE, GPRS, Wi-Fi b/g/n	H.263, H.264, MP4

[19] As of 18 June 2011

320 x 480					
HTC Wildfire S	2011	320 x 480	3.2" (81mm)	GSM, EDGE, GPRS, HSDPA, HSUPA, Wi-Fi b/g/n	Xvid, MP4, H.264
Samsung Galaxy Ace S5830	2011	320 x 480	3.5" (89mm)	GSM, EDGE, GPRS, HSDPA, HSUPA Wi-Fi b/g/n	MP4, H.264, H.263
360 x 640					
Nokia E7	2011	360 x 640	4.0’’ (102mm)	GSM, EDGE, GPRS, HSDPA, HSUPA, Wi-Fi b/g/n	MP4, H.264, H.263, WMV
480 x 800					
HTC 7 Pro	2011	480 x 800	3.6" (91mm)	GSM, EDGE, GPRS, HSDPA, HSUPA, Wi-Fi b/g/n	MP4, WMV, H.264, H.263
HTC Desire S	2011	480 x 800	3.7’’ (94mm)	GSM, EDGE, GPRS, HSDPA, HSUPA, Wi-Fi b/g/n	MP4, H.263, H.264, WMV
Samsung Google Nexus S I9023	2011	480 x 800	4.0’’ (102mm)	GSM, EDGE, GPRS, HSDPA,	MP4, H.264, H.263

				HSUPA, Wi-Fi b/g/n	
LG Optimus	2011	480 x 800	4.0’’ (102mm)	GSM, EDGE, GPRS, HSDPA, HSUPA, Wi-Fi b/g/n	MP4, H.264, H.263, WMV
Samsung I9100 Galaxy S II	2011	480 x 800	4.3’’ (110mm)	GSM, EDGE, GPRS, HSDPA, HSUPA, Wi-Fi a/b/g/n	MP4, DivX, XviD, WMV, H.264, H.263
480 x 854					
Sony Ericsson XPERIA Arc	2011	480 x 854	4.2" (106mm)	GSM, EDGE, GPRS, HSDPA, HSUPA, Wi-Fi b/g/n	MP4, H.263, H.264, WMV
Sony Ericsson Xperia PLAY	2011	480 x 854	4.2" (106mm)	GSM, EDGE, GPRS, HSDPA, HSUPA, Wi-Fi b/g/n	MP4, H.263, H.264, WMV
540 x 960					
Motorola ATRIX	2011	540 x 960	4.0’’ (102mm)	GSM, EDGE, GPRS, HSDPA, HSUPA, Wi-Fi b/g/n	MP4, H.263, H.264, WMV, Xvid, DivX
HTC Sensation	2011	540 x 960	4.3’’ (110mm)	GSM, EDGE, GPRS, HSDPA, HSUPA, Wi-Fi b/g/n	XviD, MP4, H.263, H.264, WMV

Table 3-25, Table 3-26, Table 3-27, and Table 3-28 contained information about 86 smartphones. The distribution of these smartphones is presented in Figure 3-50. As in the case of feature phones, smartphones parameters were analysed for the 2008-2011[20] period. The data from 2009-2010 was aggregated, in order to determine which are the most common resolutions that are currently being offered on the market.

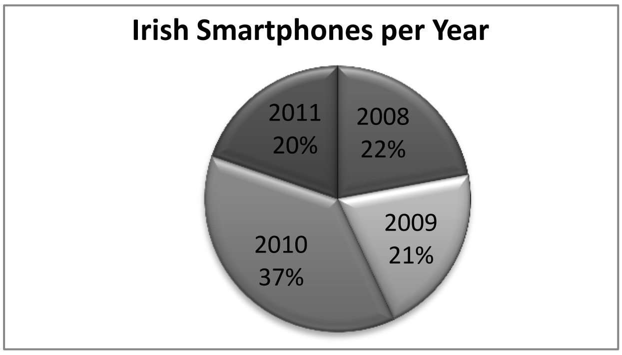

Figure 3-50 Irish Smartphones' Distribution between 2008-2011

3.2.3.2.1 Irish Smartphones Analysis based on Resolution

Year 2008

The resolutions of the smartphones from 2008 are presented in Figure 3-51. The most common resolution in 2008 is 240 x 320 with 32% from the total of devices. The second most used resolution is 480 x 800 counting for 21%, while the third 480 x 640 with 21%. Table 3-29 presents the division of smartphones resolutions in different resolution classes. The most used resolution class is 480p, counting for 42% of the smartphones. The second most used resolution class is 240p counting for 37% of the smartphones resolutions. The third most used resolution class is 360p, with 21% of the smartphones resolutions.

[20] Up to 14 June 2011

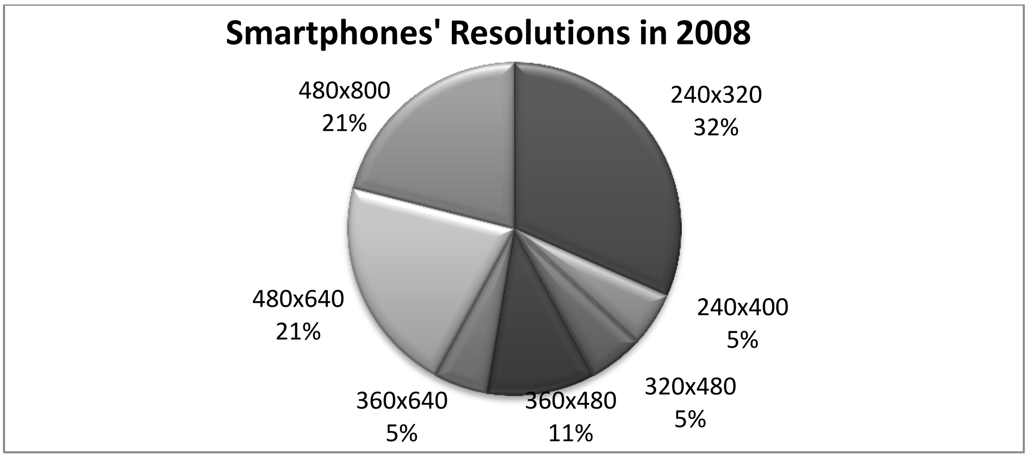

Figure 3-51 Distribution of the Resolutions for Irish Smartphones Released in 2008

Table 3-29 Irish Smartphones Classification in Resolution Classes (2008)

Resolution Class	**Percentage**
720p	0%
480p	**42%**
360p	21%
240p	37%

Year 2009

The analysis of the smartphones' resolutions from 2009 is presented in Figure 3-52. The most common resolution was 240 x 320, similar with 2008. However, the percentage of phones with this resolution decreased to 28%, while the devices with 480 x 800 increased to 22%, being the second most used resolution. The third most used resolution is 360 x 640, with 11% of the total smartphones having this resolution. The distribution of device resolutions in resolution classes is almost equally distributed among 240p, 360p and 480p classes (Table 3-30).

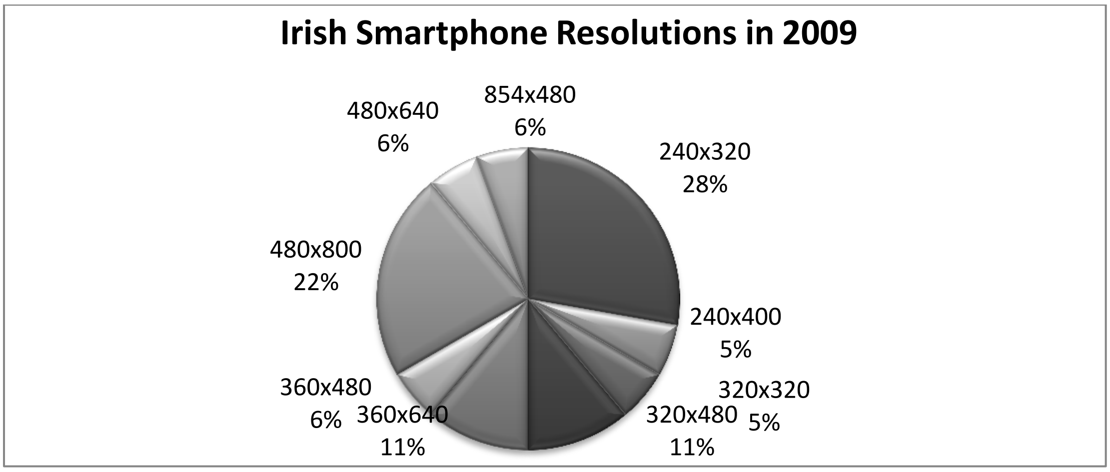

Figure 3-52 Distribution of the Resolutions for Irish Smartphones Released in 2009

Table 3-30 Irish Smartphones Classification in Resolution Classes (2009)

Resolution Class	**Percentage**
720p	0%
480p	**34%**
360p	33%
240p	33%

<u>Year 2010</u>

In 2010 (Figure 3-53), it can be notice an increase in the number of smartphones supporting bigger resolutions. The most used resolution is 400 x 800 counting for 34%. Smartphones having a resolution of 240 x 320 are still in a high percentage, 25% from the total number of smartphones, being the second most used resolution. The third most used resolution is 360 x 640 that corresponds to 13% of the total number of devices. It can be notice an increase in the number of resolutions on the Irish market, with resolutions such as 640 x 960 being presented, though not yet predominant. These resolutions fit into the 720p class (Table 3-31). The predominant resolution class continues to be 480p, with 37% of the smartphones, followed by 240p with 31% and then 360p with 29%.

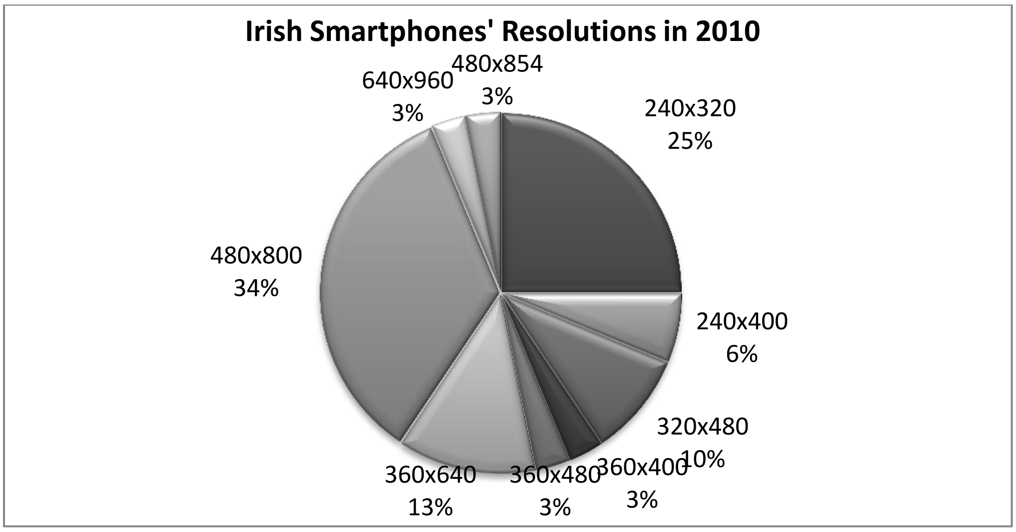

Figure 3-53 Distribution of the Resolutions for Irish Smartphones Released in 2010

Table 3-31 Irish Smartphones Classification in Resolution Classes (2010)

Resolution Class	Percentage
720p	3%
480p	**37%**
360p	29%
240p	31%

<u>Period 2009-2010</u>

I took the smartphones' from 2009 and 2010 and determined what are most used smartphones' resolutions in the last two years (Figure 3-54):

- 480 x 800 with 28% of the Irish smartphones
- 240 x 320 with 27% of the Irish smartphones
- 360 x 640 with 12% of the Irish smartphones

As it can be seen from the smartphones classes (Table 3-32), the predominant resolutions belong to the class 480p and 240p. The second most used, is the 360p class and then the 720p class resolution.

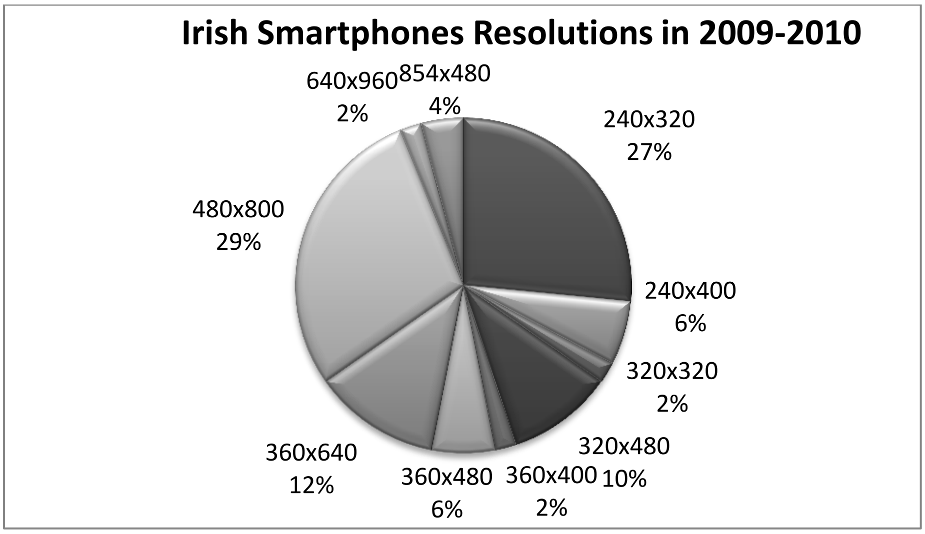

Figure 3-54 Distribution of the Resolutions for Irish Smartphones Released in 2009-2010

Table 3-32 Irish Smartphones Classification in Resolution Classes (2009-2010)

Resolution Class	**Percentage**
720p	2%
480p	**33%**
360p	32%
240p	**33%**

Year 2011

Figure 3-55 presents the smartphones resolutions released in 2011[21]. 480 x 800 is by far the most common resolution of the smartphones from the Irish market, counting for 33% of the smartphones resolutions for this year. The second most used resolution is 240 x 320 counting for 22%. The third most used resolutions are: 320 x 480, 480 x 854 and 540 x 960, counting each for 11%. Table 3-33 presents the devices resolution distribution in resolution classes. Most of the smartphones' resolutions are in the class 480p (44%). Resolutions from the class 240p are still popular among the Irish smartphones (28%). The third most used class resolution

[21] Up to 14 June 2011

is 360p, with 17% of the resolutions. It can be notice in 2011, an increase in the devices having high resolutions.

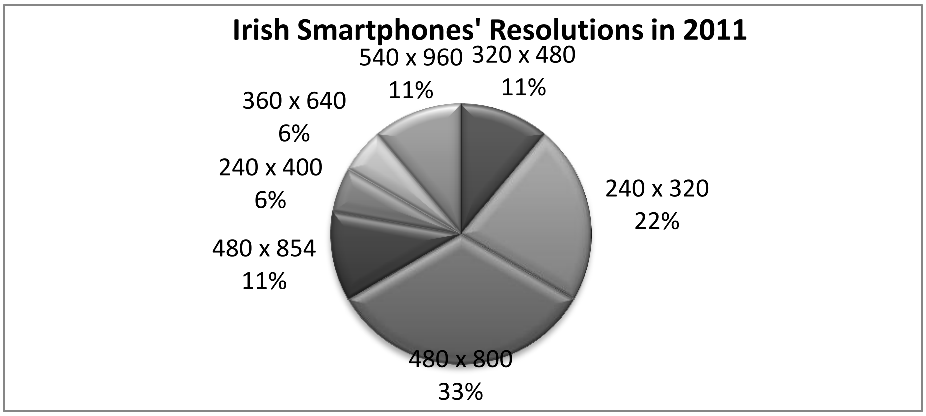

Figure 3-55 Distribution of the Resolutions for Irish Smartphones Released in 2011

Table 3-33 Irish Smartphones Classification in Resolution Classes (2011)

Resolution Class	Percentage
720p	11%
480p	**44%**
360p	17%
240p	28%

3.2.3.2.2 Irish Smartphones Analysis based on Screen Size

Same as for feature phones, the analysis of the smartphones' screen sizes is done based on their actual resolution, as well as taking into account the class in which the resolution falls. Irish smartphones released in the period 2008-2011 are analysed, and data from the 2009 and 2010 is aggregated in order to provide a better view on what are the characteristics in terms of screen size, for the smartphones that exist on the market, and what is the trend

<u>Year 2008</u>

In 2008 (Figure 3-56), the most used screen size was of 2.8'' (71mm), which counted for 26% of the smartphones. The second most used was 2.6'' (64mm), counting for 16% of the smartphones. The third most used resolutions are 3’’ (76mm), 3.2’’(81mm) and 3.8’’ (97mm) counting for 11% of the smartphones.

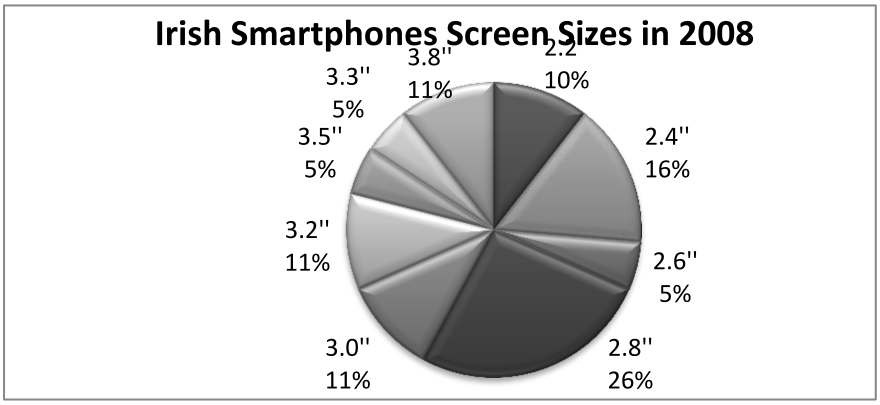

Figure 3-56 Distribution of the Screen Sizes for Irish Smartphones Released in 2008

Year 2009

In 2009 (Figure 3-57), the most used screen size for smartphones was 3.5’’ (89mm), counting for 22% of the smartphones. The second most used screen size was 3.2’’ (81mm), counting for 11% of the smartphones, while the third most used dimensions for screen sizes are 2.4’’(61mm) and 3.2’’(81mm). It can be noted an increase in screen sizes when comparing to 2008.

Compared to 2008, the screen sizes in 2009 increased in size. There are smartphones with screen sizes of over 4’’ (102mm), 4.3’’ (109mm) being the bigger screen size for smartphones in this year. It can be notice an increase in the overall resolutions, as well most smartphones (29%) having resolutions between 3.5’’ (89mm) and 4’’ (102mm).

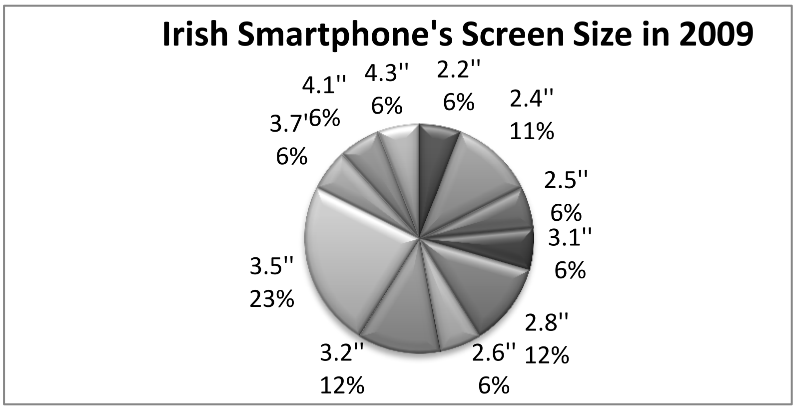

Figure 3-57 Distribution of the Screen Sizes for Irish Smartphones Released in 2009

Year 2010

In 2010 (Figure 3-58), the most used screen size is 3.2’’ (81mm), counting for 22% of the smartphones. The second most used screen sizes is 3.7’’ (94mm) and 4’’ (102mm), counting for 13% of smartphones each. The third most used screen size is 3.5’’ (89mm), counting for 10% of the smartphones. Overall, there is an increase in screen size, although the most used screen size decreased compared to the previous year.

In 2010, it can be seen an increase in the number of devices that have screen sizes over 4’’ (102mm) to 19%. However, the predominant screen size decreased for most devices having screen sizes between 3’’ (76mm) and 3.5’’ (89mm), probably due to the fact that larger resolutions are possible on smaller screens.

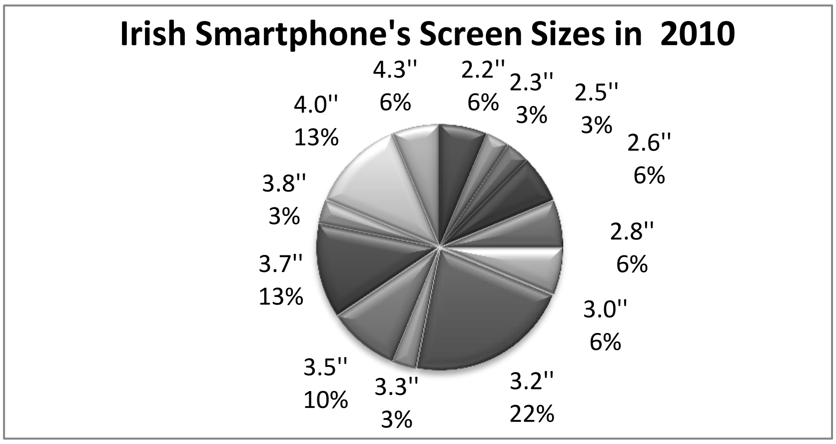

Figure 3-58 Distribution of the Screen Sizes for Irish Smartphones Released in 2010

Period 2009-2010

An analysis of screen sizes among 2009-2010 (Figure 3-59) smartphones shows that the most used screen sizes for smartphones in the last two years were:

- 3.2’’ (81mm) counting for 18% of the total number of smartphones
- 3.5’’ (89mm) counting for 14% of the total number of smartphones
- 3.7’’ (94mm) counting for 10% of the total number of smartphones

The most used resolutions range from 3’’ (76mm) and 4’’ (102mm), counting for 52% of the total number of feature phones. There are no smartphones with resolution under 2’’ (51mm). The smartphones are approximately equally distributed among the smaller screen size classes.

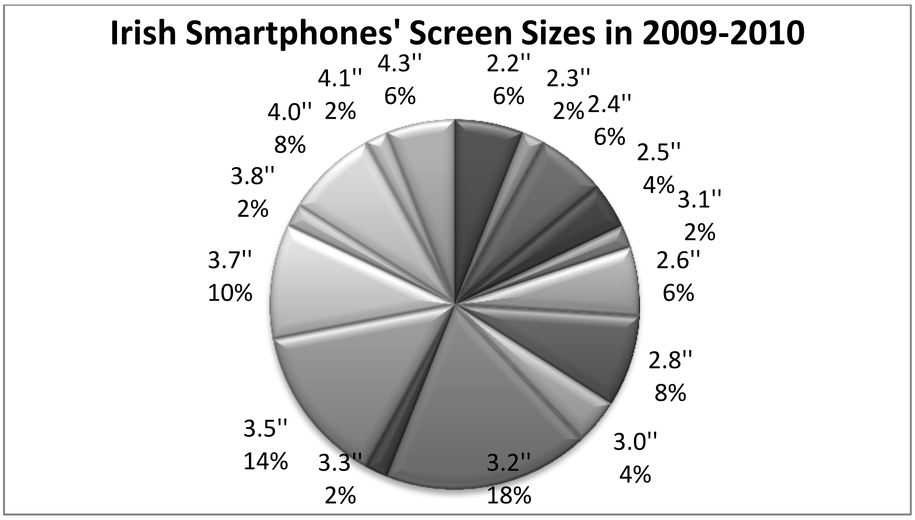

Figure 3-59 Distribution of the Screen Sizes for Irish Smartphones Released in 2009-2010

<u>Year 2011</u>

Figure 3-60 shows the screen sizes the smartphones' present on the Irish market. The most used screen size is 4'', counting for 37% of the smartphones. The second most used one is 4.3'' counting for 16% of the smartphones and the third most used one is 3.2'' counting for 11% of the smartphones. It can be noticed a considerable increase in the screen size from 2009/2010, this probably explaining also the increase in resolutions the smartphones that have during 2011 compared to 2009/2011. In 2011, 53% of the smartphones on the Irish market have a screen size of 4'' or over, and 15% have over 3.5'' up to 4'' screen size.

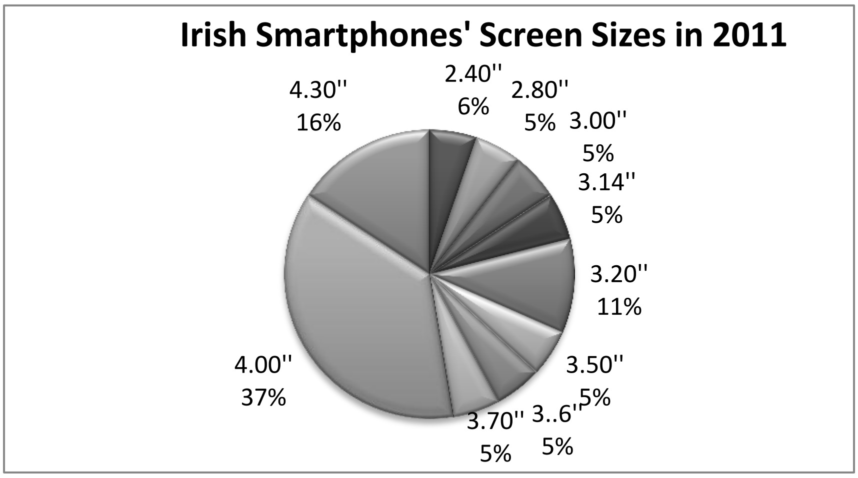

Figure 3-60 Distribution of the Screen Sizes for Irish Smartphones Released in 2011

3.2.3.2.3 Irish Smartphones Providing Multimedia Support

Year 2008

In 2008, Figure 3-61 shows the distribution of the multimedia formats supported by the smartphones. Most of the smartphones (94.45%) support MP4 multimedia files and WMV multimedia files (77.78%). Also, 50% of the smartphones offer support for the H.264 codec.

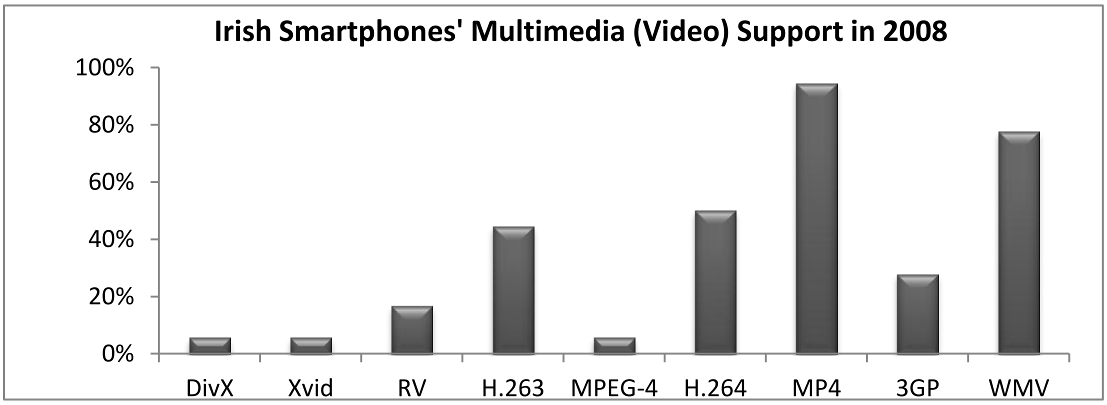

Figure 3-61 Distribution of the Multimedia Formats Supported by Irish Smartphones in 2008

Year 2009

As in the previous year, in 2009 (Figure 3-62), most phones offer support for WMV (88.89%) and MP4 (83.33%). An increasing support can be noticed for files in the H.264 format, 55.56% of the smartphones supporting this format.

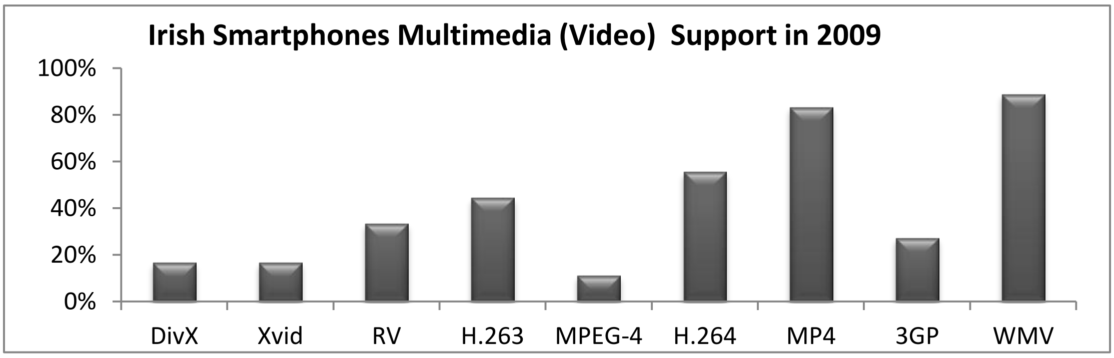

Figure 3-62 Distribution of the Multimedia Formats Supported by Irish Smartphones in 2009

Year 2010

In 2010 (Figure 3-63) similar to 2009, most smartphones provide support for MP4 files. These are being supported by 96.88% of the smartphones. Smartphones that provide support for H.264 increased to 87.50%. WMV support is slightly decreasing being supported by only 71.23% of the smartphones. There is an increasing support for H.363 files, this year being supported by 81.25% of the smartphones, as opposed to 2009 and 2008 when 44.44% of the smartphones were supporting it.

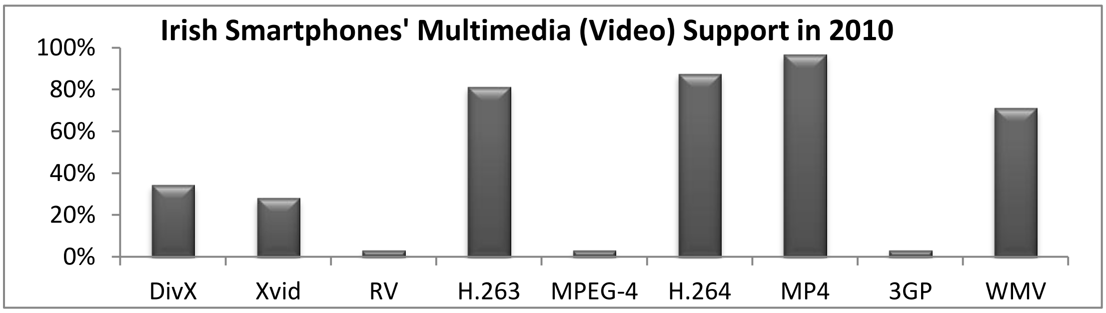

Figure 3-63 Distribution of the Multimedia Formats Supported by Irish Smartphones in 2010

Period 2009-2010

In the last two years, the most popular multimedia formats supported (Figure 3-64) have been:

- MP4 being supported by 92% of the smartphones
- VMW being supported by 82% of the smartphones
- H.264 being supported by 76% of the smartphones
- H.263 being supported by 68% of the smartphones

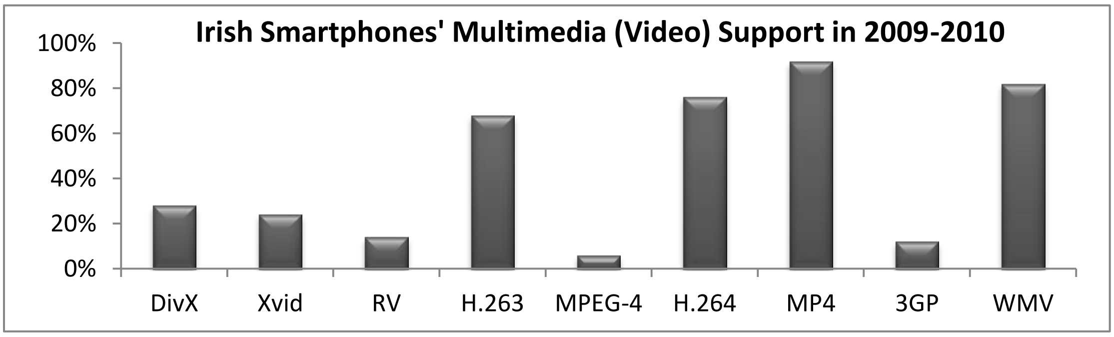

Figure 3-64 Distribution of the Multimedia Formats Supported by Irish Smartphones in the Period 2009-2010

Year 2011

Figure 3-65 presents the multimedia support for the smartphones present on the Irish market in 2011. All smartphones support the MP4 format, and the majority (94.44%) support H.263 and H.264.WMV is also a popular format counting for 61.11% of the smartphones.

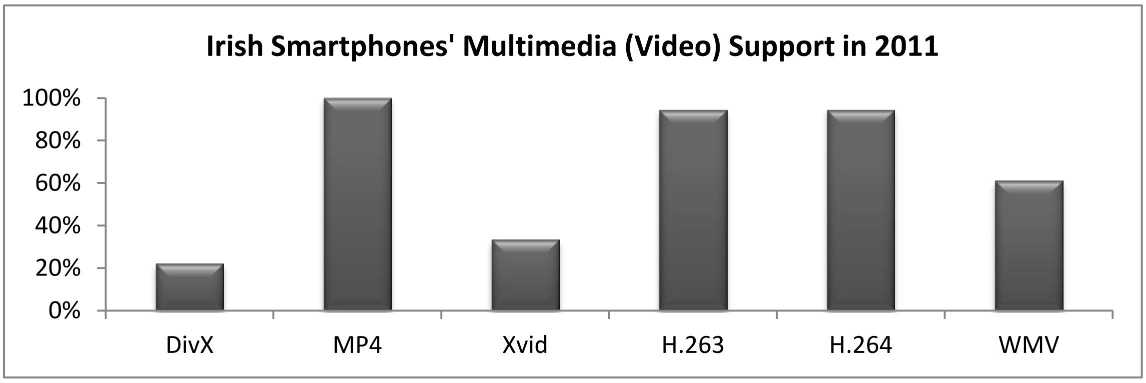

Figure 3-65 Distribution of the Multimedia Formats Supported by Irish Smartphones in 2011

3.2.3.2.4 Irish Smartphones Analysis based on the Mobile Network Access

Year 2008

In 2008 all the smartphones were able to access 2G, 2.5G and Bluetooth networks (Figure 3-66). 3G transitional network could be accessed from 72.95% of the smartphones and 3G network from 42.10% of the smartphones. Among the smartphones from 2008, 84.21% were able to access Wi-Fi.

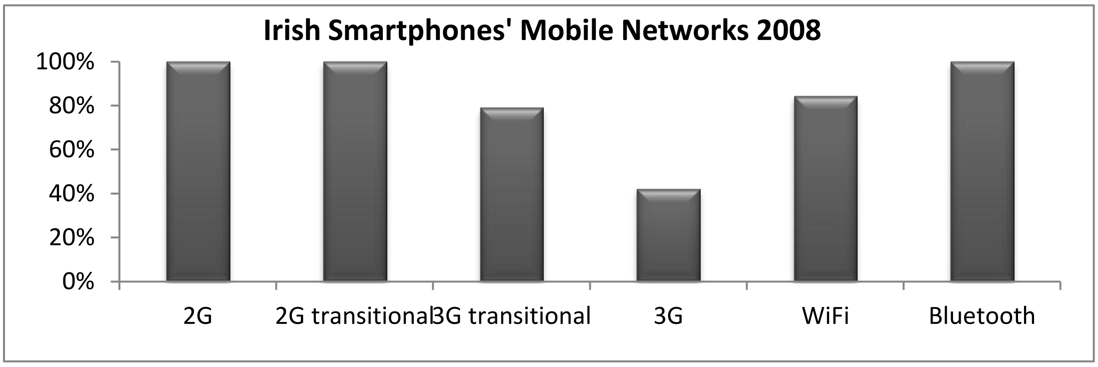

Figure 3-66 Distribution of the Mobile Networks for Irish Smartphones Released in 2008

Year 2009

Similar to the smartphones released in 2008, all the smartphones released in 2009 are able to access 2G, 2G transitional and Bluetooth networks (Figure 3-67). The number of smartphones able to access 3G transitional network increased to 83.33% from 72.95% in 2008. 33.33% of the smartphones are able to access 3G network. There has also been an increase in the number of smartphones enabled to access Wi-Fi, 94.44% of the smartphones being able to do so in 2009, as compared to 84.21% in 2008.

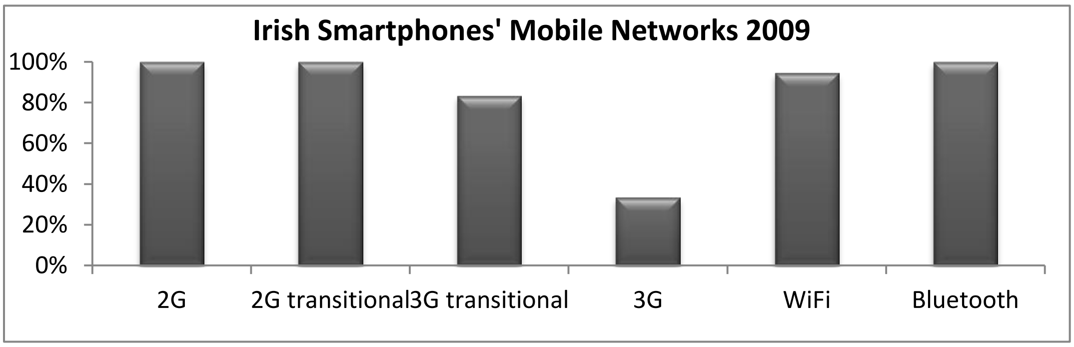

Figure 3-67 Distribution of the Mobile Networks for Irish Smartphones Released in 2009

Year 2010

In 2010, as well as in previous years, all the devices are able to access 2G and 2G transitional, and Bluetooth networks (Figure 3-68). The number of devices being able to access 3G transitional networks increased to 93.75% as compared to 83.33% in 2009, and the number of smartphones able to access 3G network is 31.25%. The number of smartphones able to connect to Wi-Fi has increased as well to 93.75%.

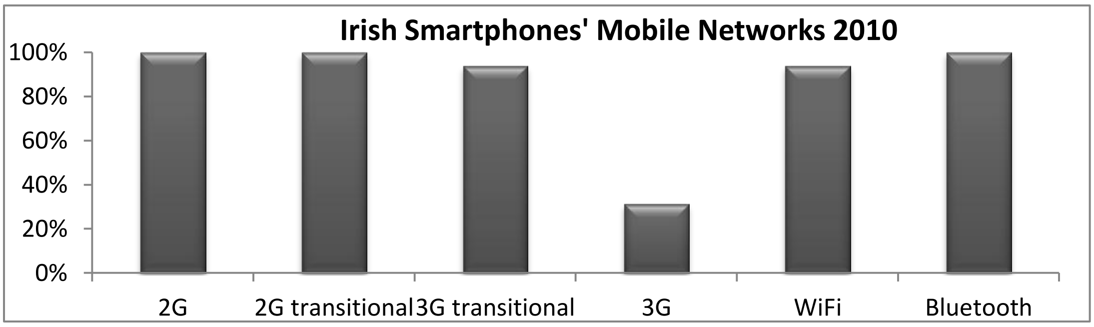

Figure 3-68 Distribution of the Mobile Networks for Irish Smartphones Released in 2010

Period 2009-2010

Overall it can be noted a continuously increasing number of mobile devices being able to access 3G or 3G transitional cellular networks (in the period 2009-2010 almost all being able to do so). This leads to the possibility of accessing video content, as these networks have a higher bandwidth capacity compared to the previous ones. In the period 2009-2010 (Figure 3-69), 3G network's supported by 32% of the smartphones and 3G transitional networks by 90% of them. Wi-Fi is supported by 94% of the smartphones on the Irish market. All smartphones can access Bluetooth networks.

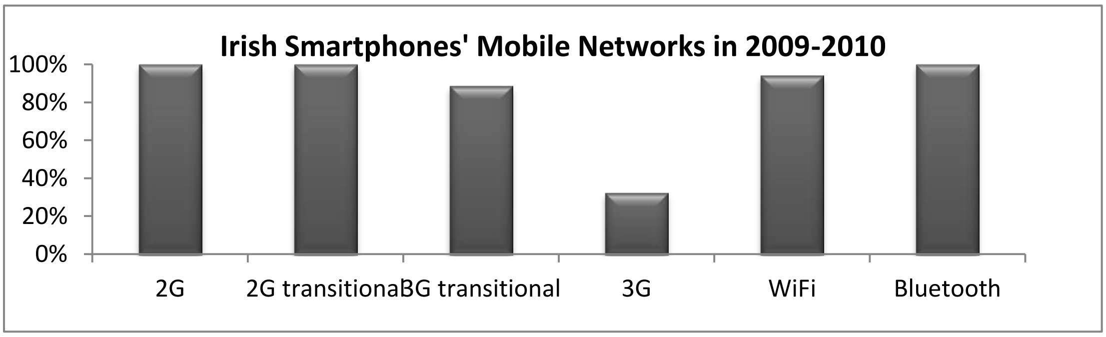

Figure 3-69 Distribution of the Mobile Networks for Irish Smartphones Released in 2009-2010

Year 2011

Figure 3-70 presents the mobile networks supported by the Irish smartphones in 2011. As in 2009/2010 all the smartphones can access 2G, 2G transitional, or Bluetooth networks. Wi-Fi is supported by 92.31% of the smartphones. 3G transitional by 84.62% of the smartphones while 3G by 15.38% of the smartphones.

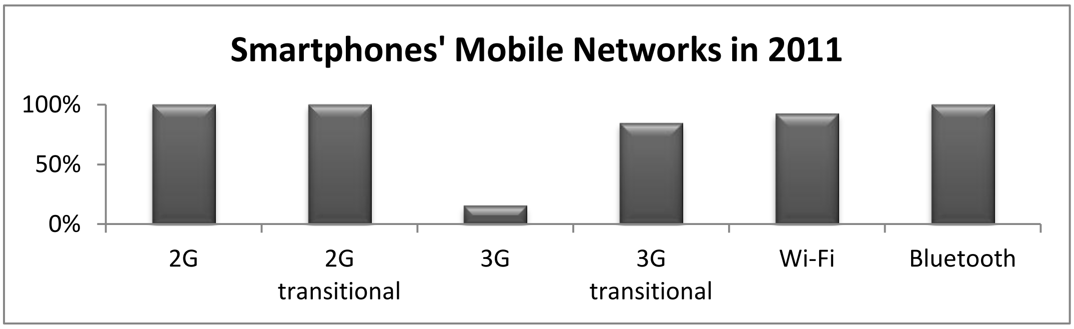

Figure 3-70 Distribution of the Mobile Networks for Irish Smartphones Released in 2011

3.2.4 Discussion on Feature Phones vs. Smartphones

Analysis of the feature phones and smartphones released worldwide and listed on the GSM Arena (Arena, 2011) website in the period 2008-2011[22] was performed. in particular I looked at the Irish market.

Resolution and Screen Size

Smartphones typically have a bigger resolutions and a larger screen size than feature phones. Feature phones released in the period 2009-2010, have 240 x 320 as a predominant resolution. In the smartphone arena, the most common resolution in the period 2009-2010 is 480 x 800, with high resolutions being predominant on the smartphones existent on the market in the last two years. Another difference between feature phones and smartphones is that on the smartphone market there are no resolutions smaller than 240 x 320. However, there are still many smartphones that have resolutions of 240 x 320, and there are as well feature phones that support a resolution of 480 x 800. It can be noted an increase in the capabilities of feature phones, however they are not yet as capable as a smartphone. The results obtained for the worldwide smartphones are the same for the Irish market.

Concerning the screen size, smartphones have definitely the biggest one, reaching 4.3'' (109mm). During the period 2009-2010 the biggest screen on a feature phone, to the best of my knowledge is 3.2'' (81mm). Smartphones do not have in the period 2009-2010 small screen sizes such as those under 2'' (51mm), a screen size that can be still found with the feature phones. This is the same for the worldwide and Irish mobile phones analysed. The difference in the screen size can explain the predominantly higher resolutions present in smartphones as opposed to feature phones.

In conclusion, the smartphones resolutions seem to increase towards the HD resolutions. While the feature phone resolutions increase, they seem to lag behind smartphones, probably due to the fact that feature phones tend also to be smaller and have smaller screen sizes.

Multimedia Capabilities

Both feature phones and smartphones offer very good support for MP4 and H.264. However, most smartphones will offer support for WMV as well, while only few feature phones do.

[22] Up to 14 June 2011

H.263 is more popular on feature phones than on smartphones, but it can be noticed that in 2010 the support for H.263 on smartphones increased.

Mobile Networks Access

Both feature phones and smartphones offer support for 2G or 2G transitional networks. What distinguishes smartphones from feature phones is that most smartphones provide support for 3G or 3G transitional networks, while only few feature phones do. 3G and 3G transitional networks provide a better quality of service and as a result the data transfer is speeded up and richer content can be accessed such as video (MOLeNET, 2010). According to Rhythm (Rhythm NewMedia, 2010), video is accessed 53% of the time from a 3G network and 47% of the time from a Wi-Fi network. Accessing video from a 3G network increases for the possessors of smartphones with Android OS by up to 72%. Trying to transmit multimedia content over lower capacity networks such as GPRS (2G transitional), has shown that the delivery is slow and not stable, an unstable network leading to dropped frames and distorted sound which lasts for several seconds (Ullrich et al., 2010).

More smartphones allow access to Wi-Fi networks than feature phones. For example, during the period 2009-2010 94% of the smartphones support Wi-Fi in comparison with 16.88% of the feature phones. All smartphones and 81.87% of the feature phones can access Bluetooth networks.

Market

The smartphones' market has increased with 95% in the third quarter of 2010 (Canalys Research, 2010) and it is expected to continue to increase (Canalys Smartphone, 2010; Ho, 2009), and eventually to overshadow feature phones (Ho, 2009).

According to AdMob's Mobile Metrics (Mobile, 2010) in Africa, Asia and Eastern Europe, Nokia is the leading device manufacturer, while in North America, Oceania and Western Europe the leader is Apple. The top three smartphones in May 2010 were Apple iPhone, Motorola Droid and HTC Magic, and the top three mobile phones were Apple iPhone, Apple iPod touch and Motorola Droid. These statistics are based on the advertisement requests.

Gartner (Gartner, 2010) cite that the top three companies based on their mobile devices sales are Nokia, Samsung and LG. The top three smartphone's operating systems based on smartphone's sales are: Symbian, RIM (Research In Motion) and Android. Based on the shipment volume and market share, the top three smartphones manufactures are Nokia, RIM and Apple (IDC, 2010).

3.2.5 Summary

This section presented an analysis of mobile phones, focusing on feature phones and smartphones, in terms of their resolution, screen size, access to mobile networks and multimedia format supported that were released during the period 2008-2011. A summary of the most popular resolutions, most used screen sizes for worldwide feature phones and smartphone in 2009-2010 are presented in Table 3-34. Table 3-5 presents the mobile networks access and the most supported video format for the Irish market. The resolution and screen size statistics are taken from the worldwide smartphones data, while the mobile networks and popular multimedia (video) formats are taken from the Irish market. The reason for doing so, laid in the difficulty to assess how many devices have a particular type of network since the worldwide smartphones data is divided based on the delivery channel for some of the cellular networks, while for the multimedia format, data was not collected for worldwide smartphones. However, for resolution and screen sizes, the results in terms of the most popular were the same for the Irish market and worldwide and very similar percentage were obtained in terms of the others resolutions. Therefore, it might be probably that the results from the Irish market can be applied as well for the worldwide mobile devices.

Table 3-34 Worldwide Feature Phones and Smartphones Statistics for Resolution and Screen Size in based on the Devices from GSM Arena Website in 2009-2010

	Feature Phone	**Smartphone**
Resolutions		
Most used resolution(s)	240 x 320 (44%)	480 x 800 (27%)
Most used resolution class	240p (97%)	480p (36.02%)
Screen Size		
Most used screen size interval	[2’’, 2.2’’) (23%)	size>=4’’ (30%)

Table 3-35 Irish Feature Phones and Smartphones Statistics for Mobile Networks Available and Multimedia Format Supported in 2009-2010

Mobile Networks		
2G	100%	100%
2G transitional	100%	100%
3G	14.70%	32%
3G transitional	35.29%	90%
Wi-Fi	15%	94%
Bluetooth	81.87%	100%
Popular Multimedia (Video) Format		
MP4	91.18%	92%
H.263	85.29%	68%
H.264	61.76%	76%
WMV	26.47%	82%

3.3 MOBILE DEVICES FOR MOBILE LEARNING

There is no accord on what device to be used for mobile learning (Moblearn, 2010; MOLeNET, 2010), the selection being dependent on the context in which they are used. Different devices have been used in mobile learning such as smartphones for multimedia delivery (Ullrich, 2010), wearable electronics (Ngai, 2010), tablets (Viswanathan & Blom, 2010), a combination between GPS devices, PDAs, mobile phones, MP3 players, camera and laptops (Clough, 2010), etc. As Belshaw (Belshaw, 2010) pointed out “There is, and never will be the ‘perfect’ mobile learning device”. Rekkedal & Dye (Rekkedal & Dye, 2007) pointed that “the answer will very likely rest with students' individual preferences”. However, certain devices might be more suitable than others for certain content. For text, a larger screen allows more information to be presented on the screen, and hence avoid scrolling etc. For video and images a larger screen allows more details to be visible. For an audio content even a smaller screen device can be used.

If the content is to be transmitted over cellular networks (in order to ensure that the content is accessible anywhere), mobile phones that have 3G or a better Internet connection are more suitable, since they provide a higher quality of service. A mobile phone with Wi-Fi can be considered as well, especially for heavy multimedia content, however, it is worth considering that Wi-Fi is not available everywhere.

Since multimedia content can be transcoded easily form a format to another, certain codecs provide better quality and require a smaller bandwidth than others, and this is worth considering when the data is delivered over a mobile network, on which the resources of the network are limited and the price of delivery still high.

If the choice is among mobile phones, an issue to consider when deciding which mobile phone to use is that smartphones are more likely to be similar with mobile phones that will be easily accessible by students in some time, hence they could be a better choice if it is envisioned that students will be able to use their own mobile phones for learning purposes (Moblearn, 2010). An example of a study that successfully used students’ smartphones is reported in Ullrich et al. (2010). The system is designed for Symbian OS smartphones and used for synchronous or asynchronous delivery of the multimedia content (the lecture taught in class).

3.4 SUMMARY

There are a variety of mobile devices, on the market. Among these, feature phones and smartphones allow multimedia delivery and are portable to the extent that they are almost embedded in their possessors’ life. They are analysed in terms of resolution, screen size, support for multimedia formats and mobile networks access. The performed analysis shows that smartphones have considerable bigger screen size (more than one inch bigger) than feature phones. They have as well bigger resolutions. In terms of supported multimedia(video) format supported there is not a big difference, with the exception of feature phones having usually support for H.263, which is increasingly present in the last year on smartphones as well. There is another difference; smartphones support WMV quite often, while it is more rarely supported by feature phones. In terms of mobile networks, smartphones detach themselves through the support of 3G or 3G transitional networks, which are very common for smartphones but not so common for feature phones. Also, most of them support Wi-Fi and all of them have access to Bluetooth. This give them access to mobile networks with a better performance, and more suitable for delivering multimedia content.

Smartphones can be better equipped for multimedia access, having access to wider range of mobile networks, a bigger resolution and screen size for multimedia playing, and support for various media formats.

4 MOBILE DATA BILLING PLANS

Data transmission over cellular networks suffers more from bandwidth scarceness than transmitting over other types of wireless or wired networks. This has led to several differences in how Internet is charged on cellular networks as opposed to other types of networks (e.g. wired networks) that have considerably higher bandwidth available and hence less chances for bottlenecks to occur.

Different types of billing plans have been used for mobile data pricing (Telecoms Pricing, 2009; Roto et al., 2006). Next, a brief description of each available billing plan is presented:

1. **Bundle billing**: The user pays for a specific amount of data in advance. The available data amount may be used in a given period of time. If the amount of data used is exceeded during the given period, some of the following options are available:
    - the user needs either to pay for the exceeding quantity with a different price. For example, the Vodafone Ireland daily billing plan for prepaid users, for €0.99 one gets a bundle of 50MB of data and, when the quantity is exceeded a charge of €1/MB is applied.

- to buy a new bundle at the same or different price. For example, the O2 Ireland monthly plan, for €9.99 one gets 700MB of data, and once the bundle quantity is exceeded the user has the option to buy another bundle; T-Mobile in Germany, has a roaming plan that for €1.95 one can get a bundle of 10MB of data and, once the quantity is exceeded the user can buy another 10MB for €2.95.
- the bandwidth is limited. For example, T-Mobile Germany for prepaid billing plans limits the bandwidth to 64kbps for download and 16kpbs for upload.

2. **Time based billing**. The user pays for the time s/he spends using the Internet. For example with the Bouygues Télécom, France, the prepaid users can opt for paying €0.15/minute when using mobile data. This type of billing plan is typical for 2G connections (Roto et al., 2006).
3. **Data based billing**. The user pays for the quantity of data downloaded or uploaded. It differs from the bundle billing plan by the fact that the user does not pay for the data they will consume in advance. For example, with the Bouygues Télécom, France, the prepaid users can opt for paying €0.01/KB when using mobile data. This type of billing plan was used starting with packet switched networks such as 2.5G and 3G (Roto et al., 2006).
4. **Flat rate**. The user has unlimited Internet access. In the context of this research a flat rate billing plan will be used as a billing plan in which no limitations are imposed on the user once a certain quantity has been reached. Usually in this case, a monthly fee is involved, but it could be unlimited for a shorter period of time such as a session. For example, the users of Three in UK can opt to pay £25 for a month of unlimited data access; in Germany T-Mobile offers an unlimited data session for €19.90.
5. **Free Internet access**. This is the most desirable case for the user, when s/he does not pay for the data. One example is a learner using the wireless network offered by the infrastructure of the school s/he is learning in; or when free Wi-Fi is included in the billing plan.

Billing plans can be also divided in **prepaid** and **contract based**. Either of previous presented billing plans are available either as prepaid or contract based.

The aim of this chapter is to analyse which are the most common billing plan in Europe. In order to do so, five European countries were selected. For each country billing plans for pre-paid, contract based, and data roaming were collected. The five countries are: Ireland, Germany, France, UK, and Italy. Except for Ireland, the last four were selected due to the fact that they have the biggest number of people in Europe, high penetration rate of mobile subscriptions (see Table 4-1), and consequently the largest number of mobile phones customers. Since this research is taking place in Ireland, the Irish billing plans were considered of particular importance, especially since the subjects that took part in the experimental evaluation were from Ireland, with people being either Irish or living in Ireland.

The data billing plan from non-virtual mobile operators were mainly taken into account. A virtual mobile operator is a mobile operator who does not necessarily have its own infrastructure and it is renting it from other operators. Virtual operators have usually a far lower number of subscriptions that non-virtual ones. This is the main reason for not considering virtual mobile operators in this study. The mobile operators taken into account are presented in Table 4-1. The first column presents the country from which the mobile operator is; the next column the country's population, the third column the percentage of subscriptions as percentage of population relative to the population, and the forth column the mobile network operators from the given country. For example Ireland that has a population of 4,100,000, the mobile subscription is of 106.63%, and the following mobile operators were taken into account in the performed analysis: Vodafone, O2, Meteor, and Three.

Table 4-1 Non Virtual Mobile Operators Analysed based on Country

Country	Population	Mobile Phones Subscription as Percentage of Population[23]	Mobile Network Operators
Ireland	4 100 000	106.63%	Vodafone, O2, Meteor, Three
Germany	82 600 000	127.42%	Vodafone, T-Mobile, E-Plus, O2
France	60 000 000	95.35%	Orange, SFR, Bouygues Télécom
UK	59 700 000	130.17%	T-Mobile/Orange, O2, Vodafone, Three
Italy	57 800 000	146.08%	TIM, Vodafone, Wind, Three

[23]http://www.itu.int/ITU-D/icteye/Reporting/ShowReportFrame.aspx?ReportName=/WTI/CellularSubscribersPublic&ReportFormat=HTML4.0&RP_intYear=2009&RP_intLanguageID=1&RP_bitLiveData=False

This analysis did not consider different offers that mobile operators have when buying a certain mobile (e.g. when you buy a BlackBerry you can get a different mobile data offer than when buying other types of mobile phones), or for a limited period of time (e.g. free Internet for a month when switching to the given mobile operator).

Some of the billing plans that exist on the market offer just data services, while others offer other services too (e.g. calls, texts). When two billing plans differ in price and the price, difference is based on the extra services provided and not on the included mobile data, the billing plan with the lower price was selected. For example, O2 Ireland, offers among others two contract based billing plans (from O2 Advance), one in which for €60 you get among other services 1GB data per month (it costs 2c/MB if the quantity is exceeded), 350 call minutes, and 150 SMSs; a second one that for €80 you get the same quantity of data (1GB included and 2c/MB if the quantity is exceeded) but 550 minute for voice call and 250 SMSs. Since mobile data is of particular importance here, just the first one with €60 was considered.

The chapter is organised as follows: the next section presents the prepaid data billing plans in the above countries; afterwards the contract based billing plans are presented, continuing with the billing plans for roaming for both prepaid and contract based users. The last section concludes the chapter.

4.1 PREPAID BILLING PLANS CATEOGY

A *prepaid* billing plan also called *pay as you go* is a billing plan in which the customer pays in advanced for the provided service. Table 4-2 presents the prepaid mobile Internet billing plans, available in the five countries mentioned in the previous section. The first column of the table, presents the country; the second column the Mobile Network Operator (MNO) for the given country; the third column shows the billing plan type (e.g. data based billing), the forth column presents the time limit for the bundle being used only for bundle based billing when the time spam is greater than one minute, otherwise the time is considered a time based billing plan and details about how much are presented in the last column; the fifth column has the bundle quantity of data included; the sixth column is the price paid for the bundle, and the last column contains information about what happens when the bundle quantity of data is exceeded.

The last column is used as well to provide details about the data billing plans and time based billing plans. For example, the first column of the table presents details about a billing plan from Vodafone Ireland. A bundle based billing plan that costs €0.99 provides 50MB of data that is available to be consumed for one day. If the 50MB is exceeded during the day the user pays 0.1c/KB or €1/MB. Three MNO from Ireland, has a data based billing plan, in which the user pays for the data consumed. This is a data based billing plan and details about it are presented in the last column, previous columns (*Time Limit, Bundle Data Included* and *Price Bundle*) are being kept empty. In this case the user pays €0.99/1MB (charged by KB). Bouygues Télécom in France, has a time based billing plan, in which the user pays for the time s/he spends using the Internet, either €0.11/30 seconds, or €0.15/minute. As in the previous case, details about the billing plan are presented in the last column of the table. An example of a flat rate billing plan, but in this case for a shorter period of time, a session is the one from Vodafone in Germany. The consumers pay €19.90, for a session, regardless on the consumed data quantity.

It can be noticed that all the billing plans presented before (time based billing, data based billing, bundle based billing and flat rate) are presented with the prepaid billing plan. Moreover, Bouygues Télécom, in France offered a layered billing plan, in which the user pays based on the data layer s/he is in (Figure 4-1). This is somehow similar to a bundle billing plan in which the user pays for a certain quantity of data and as he consumes he pays more (e.g. the user pays €0.50 for the first 20KB, then another €0.50 for the next 30KB and so on). One can also notice that a bundle based billing plan is by far the most used billing plan for the given country.

Table 4-2 Pre-Paid Mobile Data Billing Category

Country	MNO	Type of Billing Plan	Time Limit	Bundle Data Included	Price Bundle	Consequences on Exceeding Bundle
Ireland	Vodafone	Bundle based	Day	50MB	€0.99	0.1c/KB or €1/MB
Ireland	Vodafone	Bundle based	Month	1GB	€9.99	€1/MB
Ireland	O2	Bundle based	Day	50MB	€0.99	€0.99/MB
Ireland	O2	Bundle based	Month	700MB	€9.99	Buy another bundle, or by default get a daily bundle
Ireland	Meteor	Bundle based	Day	50MB	€0.69	2c/KB or €20.48/MB
Ireland	Three	Data based	-	-	-	€0.99/1MB (charged by KB)
Germany	Vodafone	Bundle based	15 minutes	1GB	€0.49	-

Germany	Vodafone	Bundle based	Day	1GB	€3.95	-
Germany	Vodafone	Bundle based	Week	1GB	€12.95	-
Germany	Vodafone	Bundle based	Month	3GB	€39.95	-
Germany	Vodafone	Flat rate	Session	Unlimited	€19.90	-
Germany	T-Mobile	Bundle based	Month	3.6GB	€19.95[24]	After 200MB, traffic limited to 64kbitps download and 16kbps upload[25]
Germany	T-Mobile	Bundle based	Month	7.2GB	€29.95[26]	After 300MB, traffic limited to 64kbitps download and 16kbps upload[27]
Germany	O2	Bundle based	Month	7.2MB	€10	After 300MB, traffic limited to 64kbitps download and 16kbps upload[28]

[24] Price may vary to €29.95, €39.95, €49.9, depending on other services included in the tariff
[25] This a reported as a smartphone tariff, and it contains other services included
[26] Price may vary to €39.95, €49.9, €99.95 depending on other data included in the tariff
[27] This a reported as a smartphone tariff, and it contains other services included

France	Orange	Bundle based	Month	200MB	€3	€3/100MB or €6/200MB
France	Orange	Bundle based	Month	500MB	€12	€3/100MB or €6/200MB
France	Orange	Bundle based	20 minutes	Unlimited	€0.50	-[29]
France	SFR	Bundle based	Month	250MB	€5	No more Internet[30]
France	Bouygues Télécom	Bundle based	Month	-[31]	€3.90	-
France	Bouygues Télécom	Bundle based	Month	500MB	€9.90	Limited bandwidth
France	Bouygues Télécom	Bundle based	Month	See Figure 4-1	See Figure 4-1	Limited bandwidth
France	Bouygues Télécom	Data based	-	-	-	€0.01/KB

[28] This reported as a smartphone tariff, and it contains other services included
[29] This is just for checking email, uses Orange Messenger or GPS service
[30] http://www.sfr.fr/telephonie-mobile/services-options/services-smartphones/recharge-internet-mobile/index.html
[31] Can be used for Windows Live TM Messenger and unlimited emails

France	Bouygues Télécom	Bundle based	Day	€2[32]	1MB	-
France	Bouygues Télécom	Time based	-	-	-	€0.11/30s[33]
France	Bouygues Télécom	Time based	-	-	-	€0.15/minute[34]
United Kingdom	T-Mobile/Orange	Bundle based	Month	500MB	£10.21[35]	-[36]
United Kingdom	O2	Bundle based	Month	500MB	£10[37]	-[38]
United Kingdom	Vodafone	Bundle based	Day	25MB	£1	Buy another bundle

[32] Charged by KB
[33] First minute is indivisible
[34] Charged by second; can be limited or not to €6/month
[35] Price may vary to £15.32, £20.42, £25.54, depending on other services included in the tariff
[36] Email and browsing is unlimited but streaming video, uploading and downloading files are not available after the 500MB limit is exceeded
[37] Price may vary to £15, £30, depending on other services included in the tariff
[38] Nothing specified

United Kingdom	Vodafone	Bundle based	Month	250MB	£5	Buy another bundle; you are able to have up to 5 bundles at a time
United Kingdom	Three	Bundle based	Month	1GB	£10[39]	10p/MB
Italy	TIM	Bundle based	Week	50MB	€2	€0.05/KB for email and 2000 instant messages every day, if those are exceeded it is 15c/message
Italy	Vodafone	Bundle based	Day	100MB	€1.5	0.1c/100KB
Italy	Vodafone	Bundle based	Week	250MB	€3	0.1c/100KB
Italy	Vodafone	Bundle based	Week	2GB	€8	0.1c/100KB
Italy	Wind	Bundle based	Month	14.4MB	€9	Traffic limited to 32kbps unless a new bundle is bought
Italy	Three	Bundle based	Month	3GB	€5	Charges depend on the plan ones have subscription to.

[39] Price may vary to £15, £20, depending on other services included in the tariff

Layered Tariff

Consumed (up to)	20 Kb	50Kb	150 Kb	300 Kb	1MB	3 MB	5 MB	7 MB	10 MB	100 MB
Level	1	2	3	4	5	6	7	8	9	10
Price	0,50€	+ 0,50€	+ 1€	+ 1€	+ 2€	+ 2€	+ 2€	+ 2€	+ 4€	+ 5€

Figure 4-1 Layered Tariff (Bouygues Télécom, 2011)

4.2 CONTRACT BASED BILLING CATEGORY

A *contract based* billing plan (also named as *bill paid* billing plan or *post-paid* billing plan) is a billing in which the user pays for the services after s/he has used them. The data regarding the billing plans offered to the customers by the five MNOs was collected and presented in Table 4-3. The table's columns are the same as in Table 4-2. The first column is the country, the second is the name of the MNO, the third shows the type of billing plan, the forth shows the time the contract is active, the fifth column contains the bundle data included or unlimited if the data is unlimited, the sixth one the price to be paid, and the seventh one the price to be paid in case that the bundle is exceeded, in case if this applies.

What is different from *prepaid* billing plans, is that time based, and data based billing plans are not present for the contract customers. Sometimes the contract customers are offered the same tariffs, or even better deals than the prepaid ones. It is also common that the contract based plans to contain other services, too. As for *prepaid* customers, bundle based billing is the most used billing plan.

Table 4-3 Contract Based Billing Category

Country	MNO	Type of Billing Plan	Time Limit	Bundle Data Included	Price Bundle	Consequences on Exceeding Bundle
Ireland	Vodafone	Bundle based	Day	50MB	€0.99	0.1c/KB or €1/MB
Ireland	Vodafone	Bundle based	Month	1GB	€9.99	€1/MB
Ireland	O2	Bundle based	Month	500MB	€45[40]	2c/MB
Ireland	O2	Bundle based	Day	50MB	€0.99	2c per KB
Ireland	O2	Bundle based	Month	500MB	€40	2c per MB
Ireland	Meteor	Bundle based	Day	50MB	€0.69	2c/MB
Ireland	Meteor	Bundle based	Month	250MB	€4.99	Charged using the day price bundle

[40] Price may vary depending on the number of months of contract; this is for 18 months contract and the price for 12 months contract is €50; Price may vary to €60, €80, €100 , for 18 months contract and €65, €85, €105 for 12 months contract, depending on other services included in the tariff

Ireland	Meteor	Bundle based	Month	1GB	€14.99	Charged using the day price bundle
Ireland	Three	Bundle based	Month	10GB	€30[41]	34c/500KB
Ireland	Three	Bundle based	Month	10GB	€60[42]	30c/500KB
Ireland	Three	Bundle based	Month	500MB	€4.99	34c/MB or 30c/MB depending on the billing plan[43]
Ireland	Three	Bundle based	Month	1GB	€9.99	34c/MB or 30c/MB depending on the billing plan[44]
Ireland	Three	Bundle based	Month	10GB	€19.99	34c/MB or 30c/MB depending on the billing plan[45]
Germany	Vodafone	Bundle based	Month	5GB	€29.99	-
Germany	Vodafone	Bundle based	Month	10GB	€39.99	-

[41] Price may vary to €40, €70, €80, €85, €95 depending on other services included in the tariff
[42] Price include other services that are better than for the €30billing plan; Price may vary to €50, €70, €80, €85, €95 depending on other services included in the tariff
[43] This is an Internet add on, to the bundle you already have
[44] This is an Internet add on, to the bundle you already have
[45] This is an Internet add on, to the bundle you already have

Germany	Vodafone	Bundle based	Month	15GB	€49.99	-
Germany	Vodafone	Bundle based	Month	30GB	€69.99	-
Germany	Vodafone	Bundle based	Month	1GB	€19.99	Traffic limited to 64kbps download and 16kbitps upload
Germany	Vodafone	Bundle based	Month	1GB	€19.99[46]	Traffic limited to 64kps download and 16kbitps upload
Germany	Vodafone	Bundle based	Month	5GB	€29.99[46]	Traffic limited to 64kbps download and 16kbitps upload
Germany	Vodafone	Bundle based	Month	1GB	€29.99[47][46]	Traffic limited to 64kbps download and 16kbitps upload or 500MB and pay extra €2.27/MB
Germany	T-Mobile	Bundle based	Month	300MB	€19.95	Traffic limited to 64kbps download and 16kbps

[46] Minimum 24 months contract
[47] €5 discount if you are a student

Germany	T-Mobile	Bundle based	Month	1GB	€29.95	Traffic limited to 64kbps download and 16kbps
Germany	E-Plus	Bundle based	Month	50MB	€5	-
Germany	E-Plus	Bundle based	Month	100MB	€10	-
Germany	E-Plus	Bundle based	Month	1GB	€15	-
Germany	O2	Bundle based	Month	300MB	€10	Traffic limited to 64kbps download and 16kbps
Germany	O2	Bundle based	Month	1GB	€15	Traffic limited to 64kbps download and 16kbps
France	Orange	Bundle based	Month	3GB	€59.90	After 2GB, bandwidth limited
France	SFR	Bundle based	Month	500MB	€34.90[48]	Bandwidth limited
France	SFR	Bundle based	Month	1GB	€42.30[49]	Bandwidth limited

[48] The price is given for a 24 months contract; for a 12 months contract the price is of €41.30.The price may vary depending on other services included in the tariff
[49] Price may vary depending on other services included in the tariff

France	SFR	Bundle based	Month	3GB	€106[50]	Bandwidth limited
France	Bouygues Télécom	Bundle based	Month	300MB	€9.90[49]	Bandwidth limited
France	Bouygues Télécom	Bundle based	Month	1GB	€19.90[49]	Bandwidth limited
France	Bouygues Télécom	Bundle based	Month	3GB	€29.90[49]	Bandwidth limited
United Kingdom	T-Mobile/Orange	Bundle based	Month	500MB[51]	£25	Restricted Internet access
United Kingdom	T-Mobile/Orange	Bundle based	Month	750MB	£45	Restricted Internet access
United Kingdom	T-Mobile/Orange	Bundle based	Month	1GB[52]	£25	Charged based on the daily billing plan

[50] The price is given for a 24 months contract; for a 12 months contract the price is of €112.40. Price may vary depending on other services included in the tariff
[51] The price may vary to £30, £35, £40, depending on the contract duration or on other services included in the tariff
[52] The price may vary to £30, £35, £40, £45, £55, depending on the contract duration or on other services included in the tariff

United Kingdom	T-Mobile/Orange	Bundle based	Month	1GB	£60	Restricted Internet access
United Kingdom	O2	Bundle based	Month	100MB	£3	-
United Kingdom	O2	Bundle based	Month	500MB	£6[53]	-
United Kingdom	O2	Bundle based	Month	1GB	£10[54]	-
United Kingdom	Vodafone	Bundle based	Day	100MB	£1	Buy another bundle
United Kingdom	Vodafone	Bundle based	Month	500MB	£5.11	Buy another bundle
United Kingdom	Vodafone	Bundle based	Month	500MB	£7.66[55]	Pay £5 for another 500MB

[53] 20 MMSes and free Wi-Fi included as well
[54] 50 MMSes and free Wi-Fi included as well
[55] This plan does not involve any commitment from the user

United Kingdom	Three	Bundle based	Month	10MB	£2.56	Plan dependent[56]
United Kingdom	Three	Bundle based	Month	2GB	£5.11	Plan dependent[57]
United Kingdom	Three	Flat rate	Month	unlimited	£25	-
United Kingdom	Three	Bundle based	Month	500MB	£12[58]	10p/MB
United Kingdom	Three	Bundle based	Month	1GB	£20[59]	10p/MB
Italy	TIM	Bundle based	Month	-	€9[60]	-

[56] This is an add on to an existing plan
[57] This is an add on to an existing plan
[58] The price may vary to £15, £18 depending on other services included in the tariff
[59] The price may vary to £23, £18 depending on other services included in the tariff
[60] Access to surfing Internet, access to Facebook, all emails and Windows Live Messenger

Italy	TIM	Bundle based	Month	1GB	€179[61]	0.05c/KB and 15c for each instant message sent
Italy	Vodafone	Bundle based	Day	100MB	€1.5	-[62]
Italy	Vodafone	Bundle based	Week	250MB	€3	-[63]
Italy	Vodafone	Bundle based	Week	2GB	€8	-[64]
Italy	Wind	Bundle based	Month	1GB	€9	Traffic limited to 32kbps
Italy	Three	Bundle based	Month	15GB	€19[65]	€0.2/MB

[61] Its only for smartphones, when you buy one
[62] It is not specified to this particular plan, but for BlackBerry users the price is 0.1c/100KB
[63] It is not specified to this particular plan, but for BlackBerry users the price is 0.1c/100KB
[64] It is not specified to this particular plan, but for BlackBerry users the price is 0.1c/100KB
[65] Can use a maximum of 500MB per day, and no more than 100MB per session

4.3 ROAMING

Roaming plans are used when the customer uses the mobile service(s) in another country/region or to another carrier than the one it had the subscription. This ensures that consumers have access to the services (Internet in this particular case) even outside the country in which the customer has subscription. Most of the times the MNOs consider different roaming zones (see Table 4-4), based on which the pricing differs (see Table 4-5). The roaming zones for making calls are not necessarily equivalent with the ones for data delivery. Also, sometimes the data roaming zones for *prepaid* customers are different from *contract* based customers (e.g. O2 Germany). Other times, *prepaid* users do not have access to roaming in the same number of countries as contract based users do.

4.3.1 Roaming Zones

Operators consider different roaming zones based on the distance. There is not a standard on delivery zones, and they differ among the MNOs. Table 4-4 presents the roaming zones for the operators taken into account in this study. The first column presents the country from which the MNO is, the second column the MNO, and the third one the roaming zones for mobile data access. As it can be seen the majority of MNOs define different roaming zones. Usually, Europe as a continent or EU would be a zone in itself. Sometimes, mobile operators would have special prices towards a different country (e.g. Ireland for UK). As it can be seen, majority of the mobile operators allocate a zone to Europe that may include all European countries or only some of them.

Table 4-4 Data Roaming Zones

Country	MNO	Roaming Zones
Ireland	Vodafone	1. Europe 2. US and Canada 3. The rest of the world
Ireland	O2	1. UK 2. EU 3. Far Europe, North America & South Africa 4. Australia & New Zealand 5. The rest of the world
Ireland	Three	1. Europe 2. Asia 3. Africa 4. Australia & New Zeeland 5. America
Ireland	Meteor	1. Europe [Zone1]: EU countries plus Andorra, Gibraltar, Iceland, Jersey, Lichtenstein, Norway. San Marino and Vatican City 2. Europe [Zone2]: rest of the Europe 3. Middle East, Asia & Australia 4. Africa 5. USA 6. Americas
Germany	Vodafone[66]	1. EU 2. Rest of Europe with the exception of Montenegro, Georgia, Cyprus, Ukraine, Russia; USA and Canada 3. Georgia, and Ukraine; rest of Americas with the exception of Cuba, Mexico, and Nicaragua; Africa with the exception of Mauritius and Kenya; Asia with the exception of Azerbaijan, Bangladesh, Cambodia, Maldivian, Mongolia, Philippines, and Uzbekistan 4. Rest of the world

[66] http://www.vodafone.de/infofaxe/486.pdf

Germany	T-Mobile	1. EU including Réunion, Gibraltar, French Caribbean's and Croatia 2. Rest of Europe, Canada, and USA 3. Rest of the world
Germany	E-Plus	1. EU 2. Travel Advantage countries[67] 3. Rest of Europe & North America 4. Rest of the world
Germany	O2	1. EU and selected countries in Europe 2. European Countries 3. Rest 4. Europe, United States, Canada and Turkey 5. Rest of World Alternatively (this one is used for pre-paid):[68] 1. Same as contract based excluding France Guinea, Isle of Man & La Reunion 2. Switzerland 3. Croatia, Tunisia, Turkey, and USA 4. Rest of the World
France	Orange	1. Europe 2. Maghreb, USA, Canada, Turkey 3. Rest of the world
France	SFR	1. Europe, DOM 2. Enlarged Europe Maghreb, North America 3. Rest of the world
France	Bouygues Télécom[69]	1. Europe 2. Rest of the world

[67] EU and travel advantage countries are not exclusive: Belgium, Bulgaria, Denmark, Estonia, Finland (including Aland Islands), France (incl. Monaco, French Guiana, Martinique, Guadeloupe and La Reunion), Gibraltar, Greece, Great Britain (including Channel Islands), Ireland, Italy (incl Vatican City and San Marino), Latvia, Lithuania, Luxembourg, Malta, Netherlands, Austria, Poland, Portugal (incl. Azores and Madeira), Romania, Slovak Republic, Slovenia, Spain (incl. Canary Islands), Czech Republic, Hungary, Cyprus, plus Iceland, Liechtenstein and Norway. http://www.eplus.de/Kontakt-und-Hilfe/Auslandstelefonate/Auslandstelefonate.asp

[68] http://o2online.de/nw/support/mobilfunk/ausland/prepaid/imausland/im-ausland-telefonieren.html

[69] Zones differ from other services, such as calling zones:
http://www.reseau.bouyguestelecom.fr/content/view/fond_blanc_haut/49911
http://www.reseau.bouyguestelecom.fr/content/view/fond_blanc_haut/49912

UK	T-Mobile/Orange	1. Zone 1: Eire, Channel Isles & Isle of Man • Zone 1A • Zone 1B 2. Zone 2: Europe 1 (EEA) • Zone 2A • Zone 2B 3. Zone 3: Europe 2 (Non EEA) 4. Zone 4: United States & Canada 5. Zone 5: Australia & New Zealand 6. Zone 6: Rest of the World
UK	O2	1. Europe 2. The rest of the world
UK	Vodafone	1. Europe 2. The rest of the world
UK	Tree	1. EU and selected European countries 2. Australia, Cyprus North, Israel, Japan, Philippines, Taiwan, Turkey, Puerto Rico, Virgin Islands (USA), USA, and Hong Kong 3. Rest of the world 4. India, Thailand, Canada, Croatia, Kenya, Malaysia, Oman, Korea
Italy	TIM[70]	1. Zone 1 – EU 2. Rest of Europe except Ukraine, Canada, USA, Virgin Islands, Tunis, Morocco, Turkey, 3. Ukraine, West Asia, Australia, New Zeeland, South America with the exception of Guyana and Paraguay, Niger, Burundi, Anguilla, Côte d'Ivoire, Egypt, Ghana, Guatemala, Mozambique, Sierra Leone, Madagascar, Mauritania, Namibia, Palestine, Senegal, Santa Lucia, Greenland, Nigeria, South Africa. 4. Rest of the world
Italy	Vodafone	1. Europe 2. Rest of the world
Italy	Wind	1. Europe & USA

[70] http://www.tim.it/consumer/o72832/infoutile.do

Italy	Three[71][72]	1. EU 2. Austria, Belgium, Bulgaria, Canada, Cyprus, Denmark, Estonia, Finland, France, Germany, Great Britain, Greece, Guernsey, Ireland, Luxembourg, Netherlands, Poland, Portugal, San Marino, Slovenia, Spain, Sweden, Switzerland, Hungary , USA 3. Albania, Andorra, Belarus, Bosnia and Herzegovina, Croatia, Greenland, Gibraltar, Kazakhstan, Iceland, Far Hours Islands, Latvia, Liechtenstein, Lithuania, Macedonia, Malta, Monaco, Norway, Czech Republic, Moldova, Slovakia, Romania, Russia, Serbia and Montenegro, Turkey, Ukraine 4. Australia, Bangladesh, China, Egypt, Philippines, Georgia, Japan, Ghana, Hong Kong, India, Marshall Islands, Malawi, Morocco, Mauritius, Micronesia, Mozambique, Myanmar, Namibia, Niger, Nigeria, Dominican Republic, Seychelles, Singapore, Syria, Taiwan, Thailand, Tunisia, Yemen 5. Rest of the world

4.3.2 Roaming Charges

Based on the defined roaming zones, each operator applies a different charge per zone. Table 4-5 presents the mobile data roaming charges applied by different operators. Since MNOs do not always differentiate between prepaid and contract based planes, it was decided to group the two categories into a single table. The first column of the table presents the country the MNO belongs to, the second column the MNO, the third one the plan type. the forth the zones for which the billing plan applies, the fifth column the billing type (e.g. prepaid or contract), the sixth column the plan’s limitation, next column indicates the data included in the bundle, then the price of the bundle, and the last column presents what is happening if the bundle is exceeded.

Concerning the zones, the price can be applied to one zone, multiple ones (in this case either all the zones to which it applies are included), it applies to all zones (*All* is written in the column), or nothing (-) is written, if the MNO does not specify the zone. For the last case, most probably

[71] http://www.tre.it/tariffe/estero/quando-sei-all-estero
[72] http://www.tre.it/tariffe/estero/internet-all-estero

the billing plan applies to either of the zones, described in Table 4-4, for the given mobile operator.

If no information is provided in the billing type column it means that the MNO did not specify it, and most probably it applies to all types of billing plans. It can be noticed that a considerable number of MNOs do not really make the difference between the *contract* based and *prepaid* plans.

The time limit is similar to the national data access, being a day, a month, a session, or unspecified, in which case probably there is no limit in which the data can be consumed. The bundle data contains the data included in the bundle (either in GB, MB or KB), however, when no information is specified, it means that the billing plan is not a bundle billing plan. In this case, if information is provided in the *Exceeding Bundle Consequence*s column, it implies that a different kind of data plan such as time based billing, data based limit or even unlimited one is available.

However, it can be noticed that only data based billing plans and bundle based billing plans are available. A considerable number of operators make use of first one, which is different from what were Internet billings at the national level. Although bundle based billing plans are still very popular for Irish customers roaming, other countries do not seem to have adopted them in such a big majority.

What distinguishes the roaming billing plan is that in neither of the presented countries, the billing plans contain other services, these billing plans being dedicated only for data billing. There are no unlimited data billing plans. Another difference is the more harsh limitations on the bandwidth when the limit is exceeded, going for some mobile operators to as low as 2kbps (e.g. O2 Germany, for Zone 1 and Zone 2 to bill pay customer, on 100MB daily plan).

MNOs offer for roaming users the possibility to cap their usage to a certain price limit. When this limit is reached the Internet access is being interrupted. However, the user can give up this option and use how much data as s/he wants.

Table 4-5 Roaming Billing Plans[73]

Country	MNO	Plan Type	Zone(s)	Billing Type	Time Limit	Bundle Data Included	Price Bundle	Exceeding Bundle Consequences
Ireland	Vodafone	Bundle based	All[74]	Prepaid	Day	50MB	€12	€6.05/MB
Ireland	Vodafone	Data based	All[75]	Prepaid	-	-	-	€6.05/MB (charged in KB increments).
Ireland	Vodafone	Bundle based	Europe	Prepaid	Day	50MB	Same as home + €2	€1/MB
Ireland	Vodafone	Bundle based	Rest of World	Prepaid	Day	10MB	€4.99	€3.63/MB

[73] Data Collected from 27 June to 2 July
[74] There are more countries for bill pay than for pre-paid users
[75] There are more countries for bill pay than for pre-paid users

Ireland	Vodafone	Bundle based	Europe	Contract	Day	50MB	Same as home + €2	€1/MB
Ireland	Vodafone	Bundle based	Rest of World	Contract	Day	10MB	€4.99	€3.63/MB
Ireland	Vodafone	Bundle based	Europe	Contract	Day	50MB	€14.52	€1.21/MB
Ireland	Vodafone	Bundle based	All	Contract	Day	50MB	€30.25	€6.05/MB
Ireland	Vodafone	Bundle based	Europe	Contract	Month	500MB	€54.45	€1.21/MB
Ireland	Vodafone	Bundle based	All	Contract	Day	500MB	€84.70	€1.21/MB in EU or €6.05/MB in Rest of the World
Ireland	O2	Bundle based	United Kingdom	Contract[76]	Day	50MB[77]	€4.98	€4.98/MB (paid by KB (0.0049 euro c = 1KB)
Ireland	O2	Bundle based	Other EU destinations (Zone 2)	Contract[78]	Day	50MB[79]	€4.98	€4.98/ MB (paid by KB (0.0049 euro c = 1KB)

[76] http://help.o2online.ie/kb/ps?type=search&search=1&searchtype=2&c=12&cid=21&cpc=&searchstring=3970
[77] €4.98 Inc Vat Per MB and only the first 4 MB will be charged for in per KB increments (0.0049c = 1KB).
[78] http://help.o2online.ie/kb/ps?type=search&search=1&searchtype=2&c=12&cid=21&cpc=&searchstring=3970

Ireland	O2	Bundle based	Far Europe, North America & South Africa	Contract[80]	Day	50MB[81]	€9.95	€9.95/MB (paid by KB (0.0098 euro c = 1 KB)
Ireland	O2	Bundle based	Australia & New Zealand	Contract[82]	Day	50MB[83]	€9.95	€9.95/MB (paid by KB (0.0098 euro c = 1KB)
Ireland	O2[84]	Bundle based	The rest of the world	Contract[85]	Day	50MB[86]	€9.95	€9.95/MB (paid by KB (0.0098 euro c = 1KB)
Ireland	O2	Bundle based	All	Contract	Month	5GB, 7.5GB, 10GB or 15GB[87]	-[88]	€0.02/MB

[79] €4.98 Inc Vat Per MB and only the first 4 MB will be charged for in per KB increments (0.0049c = 1KB).
[80] http://help.o2online.ie/kb/ps?type=search&search=1&searchtype=2&c=12&cid=21&cpc=&searchstring=3970
[81] €4.98 Inc Vat Per MB and only the first 3MB will be charged for in per KB increments (0.0098c = 1KB).
[82] http://help.o2online.ie/kb/ps?type=search&search=1&searchtype=2&c=12&cid=21&cpc=&searchstring=3970
[83] €4.98 Inc Vat Per MB and only the first 3MB will be charged for in per KB increments (0.0098c = 1KB).
[84] Roaming CAP in Europe: http://help.o2online.ie/kb/ps?type=search&search=1&searchtype=2&c=12&cid=21&cpc=&searchstring=10640; http://help.o2online.ie/kb/ps?type=search&search=1&searchtype=2&c=12&cid=21&cpc=&searchstring=55726
[85] http://help.o2online.ie/kb/ps?type=search&search=1&searchtype=2&c=12&cid=21&cpc=&searchstring=3970
[86] €4.98 Inc Vat Per MB and only the first 3MB will be charged for in per KB increments (0.0098c = 1KB).
[87] Depends on the price plan
[88] Depends on the price plan

Ireland	O2	Bundle based	All	Prepaid	Day	500MB	-[89]	€0.02/MB
Ireland	O2	Bundle based	All	Prepaid	Month	5GB	-[90]	€0.02/MB
Ireland	Meteor[91]	Bundle based	-	-	-	-	-	-
Ireland	Three[92]	Bundle based	-	-	-	-	-	-
Germany	Vodafone	Bundle based	EU and Switzerland	Prepaid	Day	25MB	€2	-
Germany	Vodafone	Bundle based	EU and Switzerland	Prepaid	Session	50MB	€14.95	-
Germany	Vodafone	Data based	EU	All	-	-	-	€0.17/50MB
Germany	Vodafone	Data based	Zone 2	All	-	-	-	€0.49/50MB
Germany	Vodafone	Data based	Zone 3	All	-	-	-	€0.79/50MB

[89] It is not specified
[90] It is not specified
[91] No data roaming
[92] No data roaming

Germany	Vodafone	Data based	Zone 4	All	-	-	-	€0.99/50MB[93]
Germany	Vodafone	Bundle based	-	Contract	Month	30MB	€9.95	€1.90/MB
Germany	Vodafone	Bundle based	-	Contract	Month[94]	1GB	€19.99	Traffic limited to 64kbps
Germany	Vodafone	Bundle based	-	Contract	Month[94]	5GB	€29.99	Traffic limited to 64kbps
Germany	Vodafone	Bundle based	-	Contract	Month[94]	7.5GB	€39.99	Traffic limited to 64kbps
Germany	Vodafone[95]	Bundle based	-	Contract	Month[94]	10GB	€49.99	Traffic limited to 64kbps
Germany	T-Mobile	Bundle based	Zone 1	-	Day	10MB	€1.95	€2.95/10MB
Germany	T-Mobile	Bundle based	Zone 2	-	Day	10MB	€14.95	€14.95/10MB
Germany	T-Mobile	Bundle based	Zone 3	-	Day	10MB	€24.95	€2.95/10MB
Germany	T-Mobile	Bundle based	Zone 1	-	Day	50MB	€4.95	€6.95/50MB

[93] Without Vodafone World Data tariffs are higher: http://www.vodafone.de/infofaxe/428.pdf
[94] Min 24 months
[95] There is also a tariff just for email: http://www.vodafone.de/privat/tarife/datentarife-email-connect.html

Germany	T-Mobile	Bundle based	Zone 1	-	Week	-	€14.95	Bandwidth limited after 100MB
Germany	E-Plus	Data based	EU	Prepaid	-	-	-	€0.49/10 KB
Germany	E-Plus	Data based	Rest of Europe, North America	Prepaid	-	-	-	€2.49/10 KB
Germany	E-Plus	Data based	Rest of World	Prepaid	-	-	-	€4.49/10 KB
Germany	E-Plus	Data based	EU	Contract	-	-	-	€0.0586 / 10KB[96]
Germany	E-Plus	Data based	Travel Advantage countries	Contract	-	-	-	€0.06/10KB
Germany	E-Plus	Data based	Rest of Europe, North America	Contract	-	-	-	€0.15/10KB
Germany	E-Plus	Data based	The rest of world	Contract	-	-	-	€0.20/10KB
Germany	E-Plus	Data based	EU	Contract	-	-	-	€0.59/50KB

[96] http://www.eplus.de/Kontakt-und-Hilfe/Auslandstelefonate/Auslandstelefonate.asp

Germany	E-Plus	Data based	Rest of Europe, North America	Contract	-	-	-	€0.79/50KB
Germany	E-Plus	Data based	The rest of world	Contract	-	-	-	€0.99/50KB
Germany	E-Plus	Data based	Travel Advantage countries	Contract	-	-	-	€0.49/MB
Germany	E-Plus	Data based	Rest of Europe, North America	Contract		-	-	€2.49/MB
Germany	E-Plus	Data based	The rest of world	Contract	-	-	-	€4.49/MB
Germany	O2[97]	Data based	Zone 1, & Zone 2	-	-	-	-	€0.15/100 KB
Germany	O2[98]	Data based	Zone 1, & Zone 2	-	-	-	-	€0.12/10 KB
Germany	O2[99]	Data based	Zone 1 & Zone 2[100]	Contract	-	-	-	0.15€/100 KB

97 http://o2online.de/nw/support/mobilfunk/ausland/prepaid/imausland/im-ausland-telefonieren.html
98 http://o2online.de/nw/support/mobilfunk/ausland/prepaid/imausland/im-ausland-telefonieren.html
99 Max invoice € 59.50 per billing period
100h ttp://o2online.de/nw/support/mobilfunk/ausland/postpaid/roaming/international-roaming.html

Germany	O2	Data based	Zone 3 & Zone 4	Contract	-	-	-	0.12€/10 KB
Germany	O2	Bundle based	Zone 1 & Zone 2[101]	Contract	Day	100MB	€10	Limited to GPRS bandwidth, and after 103MB to 2kbps
Germany	O2	Data based	Zone 1, & Zone 2	Contract	-	-	-	€0.05/10KB[102]
France	Orange	Bundle based	Europe	-	-	10MB	€5	€0,05/10KB
France	Orange	Data based	Europe	-	-	-	-	€0,05/10KB
France	Orange	Data based	Maghreb, USA, Canada, Turkey, & Rest of the world	-	-	-	-	€0,13/10KB
France	Orange	Data based	All	-	-	-	-	€0,25/min
France	SFR	Bundle based	Europe, DOM, North America[103]	-	-	15MB	€5	€1/MB[104]

[101] h ttp://o2online.de/nw/support/mobilfunk/ausland/postpaid/roaming/international-roaming.html
[102] Applies only for packet switched data usage (no VoIP or video). From 30MB the bandwidth is limited to 64kbps and from 200MB to 2kbps
[103] http://translate.google.ie/translate?hl=en&sl=fr&tl=en&u=http%3A%2F%2Fwww.sfr.fr%2Finternational

France	SFR	Data based	Rest of the world [105]	-	-	-	-	€10[106]
France	Bouygues Télécom	Data based	All	-	-	-	-	Price charged at national rates + €0,001/KB
UK	T-Mobile/ Orange	Data based	Zone 1A, & Zone2A	-	-	-	-	£1.28/MB
UK	T-Mobile/ Orange	Data based	Zone 1B, Zone2B, & Zone 3 to Zone6	-	-	-	-	£7.50/MB
UK	T-Mobile/ Orange	Data based	Zone 3 to Zone 6	-	-	-	-	£7.50/MB
UK	O2	Data based	Europe	Prepaid	-	-	-	£3/MB
UK	O2	Data based	Rest of the world	Prepaid	-	-	-	£6/MB
UK	O2	Bundle based	Europe	Contract	Month	50MB	£40[107]	-[108]

[104] Charged in chunks of 10KB
[105] http://translate.google.ie/translate?hl=en&sl=fr&tl=en&u=http%3A%2F%2Fwww.sfr.fr%2Finternational
[106] Charged in chunks of 10KB, charged in minimum 30KB per connection
[107] £3.07/MB, until you reach £40, afterwards free up to 50MB

UK	O2	Bundle based	Rest of World	Contract	Month	50MB	£40[109]	-
UK	O2	Bundle based	Europe	Contract	Month	200MB	£120[110]	-[111]
UK	O2	Bundle based	Rest of World	Contract	Month	200MB	£120[112]	-
UK	Vodafone	Data based	Europe	-	-	-	-	85p a MB up to 5MB, then £4.25 for each 5MB[113]
UK	Vodafone	Data based	Europe	-	-	-	-	£3 a MB up to 5MB, then £15 for every 5MB after that.[113]
UK	Three[114]	Data based	Zone 1	-	-	-	-	£1.28/MB
UK	Three	Data based	Zone 2	-	-	-	-	£3/MB

108 Not sprecified
109 £6/MB, until you reach £40, afterwards free up to 50MB
110 £3.07/MB, until you reach £40, afterwards free up to 50MB
111 Not sprecified
112 £6/MB, until you reach £40, afterwards free up to 50MB
113 It is capped to £43
114 http://www.three.co.uk/_standalone/Link_Document?content_aid=1220455423498

UK	Three	Data based	Zone 3	-	-	-	-	£6/MB
UK	Three	Data based	Zone 4	-	-	-	-	£10/MB
Italy	TIM	Data based	Zone 1	-	-	-	-	0.8c/KB
Italy	TIM	Data based	Zone 2	-	-	-	-	1.8c/KB
Italy	TIM	Data based	Zone 3, & Zone 4	-	-	-	-	3.6c/KB
Italy	Vodafone	Bundle based	Zone A, & Zone B	-	Day	1MB	€1	-
Italy	Vodafone	Bundle based	Zone 2	-	Day	1MB	€2	-
Italy	Vodafone	Bundle based	Zone 1	-	Day	5MB	€5	0.1c/KB
Italy	Vodafone	Bundle based	Zone 2	-	Day	5MB	€8	0.29c/KB
Italy	Wind	Bundle based	Europe & USA	All[115]	Week	100MB	€15	€0.9/MB

[115] http://www.wind.it/it/opzioni/pagina114.phtml?sez=Eprivati

Italy	Wind	Data based	Europe & USA	-	-	-	-[116]	€0.9/MB
Italy	Tree	Data based	Zone EU	-	-	-	-	2 €/MB
Italy	Tree	Data based	Zone 2	-	-	-	-	0.015€/KB
Italy	Tree	Data based	Zone 3	-	-	-	-	0.020 €/ KB
Italy	Tree	Data based	Zone 4	-	-	-	-	0.040 €/ KB
Italy	Tree	Data based	Zone 5	-	-	-	-	0.050 €/ KB

[116] There is a €3 activation tariff: http://www.wind.it/it/opzioni/pagina54.phtml?sez=Eprivati

4.4 SUMMARY

Various billing plans exist on the market for mobile Internet access such as: bundle based billing, data based billing, time based billing, flat rate etc. This chapter presented the billing plans for mobile Internet from five European countries. The billing plans taken into account are both from national and international browsing. Billing plans are considered for both prepaid and contract based customers.

It can be seen that the real unlimited billing plans are not that common for mobile data. Usually plans are capped, and after exceeding the cap the consumer has to pay again (either a new price which is usually higher, or for a new bundle), or the plan is bandwidth limited, in order to discourage heavy traffic. Data based billing plans and time based billing plans are still present on the mobile data market, however bundle based billing is the most common billing plan when the customer is not in roaming.

Analysis of the roaming charges was also performed. The roaming plans are more expensive than the national plans, and usually prices differ by zones. The zones are not the same for each operator, and sometimes they are different from the roaming calling zones or there could be different roaming zones for prepaid and contract customers. The bundle based billing plans and data based billing plans are equally present. Roaming plans for Internet access cater only for data based billing and do not include other services. There is no unlimited billing plan present for roaming, and the MNOs allow the customer the possibility to cap their usage up to a certain price limit. When this limit is reached the Internet access is being interrupted.

Overall, bundle based billing is the most common billing plan regardless if the consumer has a prepaid subscription or a contract based one, and regardless if the user is or not using mobile Internet in the country s/he has the subscription or in roaming. Roaming billing plan depends on zones, and they are usually more expensive.

5 USER’S RISK AVERSION BASED ADAPTATION MECHANISM

This chapter proposes an adaptive mechanism that takes into account the user’s attitude towards risk and adapts multimedia content based on it. The user risk attitude can predict economic behaviour, also it can change based on the context the user is in (Dohmen et al., 2011).

Next section presents how the user attitude can be computed. It also presents how it is affected by age and gender by analysing data from a very large sample (more than 22, 000 people). Implicit (how much data the user consumes, whether the user is roaming or not), and explicit feedback (when the user explicitly changes the computed risk attitude), is taken also into account in order to determine changes in user risk attitude.

Section 5.2 presents the adaptation mechanism that takes into account the user risk aversion. In order to do so, other factors had to be considered as well, such as the diversity of the mobile device resolutions, the bit rate at which the multimedia content can be delivered, and the bandwidth of the network over which the multimedia content is to be delivered. First, this section proposes a classification of the resolutions in different classes. Second, based on the resolution classes, multimedia bitrate values are proposed such that they match the proposed resolution class, and the proposed bitrate values are then adapted to the cellular network over which the multimedia content is to be delivered. The last step was necessary because of the high difference in bandwidth among the wireless networks. This chapter concludes with the proposed adaptation mechanism.

5.1 USER'S RISK AVERSION

The research presented in this section aims to determine the user attitude towards risk, and how it changes based on the age and gender, quantity of data consumed (for bundle based billing users) and whether the user is in roaming or not. The risk value consists of two components. The first component, *Risk Value Stable* (RV_{Stable}), is computed at the beginning after the user registration is done, and its value changes only when the user ages. This assumes that during the registration process the user is asked to answer the general risk question (Dohmen et al., 2011), and to provide their gender and date of birth. Based on this data, the users are classified as being either risk averse or risk seekers. The second component, *Risk Value in Real Time* ($RV_{RealTime}$), is computed in real time and consists on the following three factors: user explicit feedback, user billing plan consumption for bundle based billing users, and user roaming.

5.1.1 User's General Risk Assessment

User's general risk assessment is computed based on both users' own assessment towards risk, and based on user's gender and age.

5.1.1.1 User's Own Assessment based on the General Risk Question

During the registration process users are asked to assess their attitude towards taking risk, for example they can answer the question presented in Figure 5-1. The question is called the *general risk question* (Dohmen et al., 2011), and was used in the Socio-Economic Panel (SOEP, v26) questionnaire.

This question asks users to assess their attitude towards risk on a 0 (risk averse) to 10 (fully prepared to take risks) scale. Users who pick a value among 0 and 5 (inclusive) are classified as risk averse, and the ones that select a value higher than 5 are classified as risk seekers (Dohmen et al., 2011). For example, a learner who ticks the box with the value 3 is considered risk averse, and one who ticks the box with the value 7 is considered a risk seeker. Other researchers have also classified the users as being risk neutral, but it has not yet been agreed where on this scale the risk neutral users are (Dohmen, 2011).

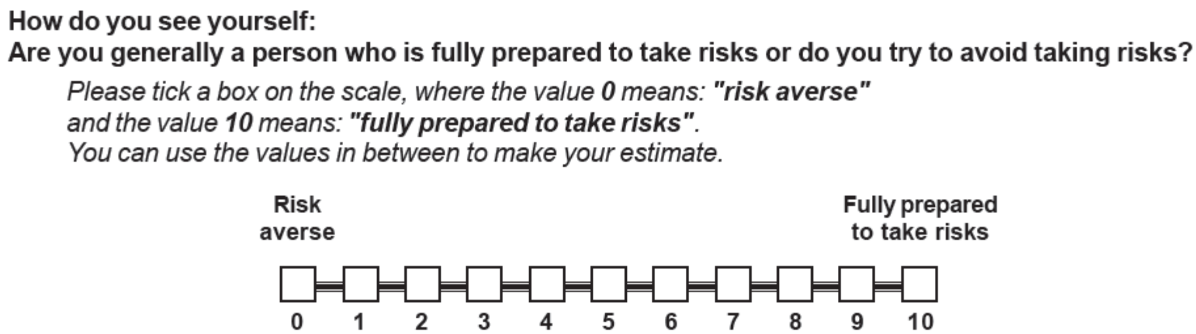
How do you see yourself:
Are you generally a person who is fully prepared to take risks or do you try to avoid taking risks?
*Please tick a box on the scale, where the value **0** means: **"risk averse"***
*and the value **10** means: **"fully prepared to take risks"**.*
You can use the values in between to make your estimate.

Figure 5-1 User's Risk Attitudes based on the General Risk Question (SOEP, v26)

Another way of assessing the user attitude towards risk (see section 2.5.4) consists of using *experimental studies* or questionnaires that make use of the *hypothetical lottery question*. During *experimental studies* subjects play lottery with real money at stake. The *hypothetical lottery question* presents subjects with lottery like choices.

The advantages of using the *general risk question* as compared to the previous two solutions are described in Table 5-1. The first column indicates the advantages of using the general risk question compared to *experimental studies,* whereas the second column presents the advantages of this technique compared to the *hypothetical lottery question*. As it can be remarked from Table 5-1, the *general risk question* is easier to administer especially in online learning environments. It also offers several advantages compared to the *hypothetical lottery questions*, such as a better prediction across domains. Even though *general risk question* is a recently used assessment method, it has already been tested and validated through lottery question or experimental study, in several studies (Caliendo et al., 2009; Grund & Sliwka, 2010; Jaeger et al., 2010) making it a very good candidate for use in assessing the user attitude towards risk in the e-learning area.

Table 5-1 Advantages of Using the General Risk Question Compared to Experimental Studies and the Hypothetical Lottery Question

General Risk Question vs. Experimental Studies	General Risk Question vs. Hypothetical Lottery Question
With the general risk question there is no need for an experimental study every time a new user joins the system	The general risk question offers better prediction across different domains (Dohmen et al., 2011)
The general risk question is cheaper in terms of money since it does not involve bets with money at stake	The general risk question has test-re-test stability, which is not present in the lottery question (Lönnqvist, 2011)
The general risk question is less time consuming, it is faster to answer a question than to participate in a whole experiment	

5.1.1.2 User Attitude towards Risk based on Gender and Age

Users' risk aversion differs with age and between the two genders. How it differs was analysed in this research using the results of the SOEP (SOEP, v26) survey administered to 20,869 people, selected to be a large sample that might be representative. The survey was performed by the German Institute for Economic Research in 2009.

Among the subjects that took the survey 20,533 were Germans, 333 belonged to 41 other nationalities and 3 did not declare their nationality. The subjects who filled in the survey had ages varying from 17 up to 100 years old. For the research presented in this thesis, the subjects' with the age less than 18 (the sample contained only females) and subjects whose age is over 90 (due to the low number of people– e.g. there were only 14 people that were over 90 years old) were eliminated. I also eliminated entries that did not provide information about their gender. As a result, a total of 20,686 people were used in the performed analysis.

The distribution based on gender is presented in Figure 5-2. There are 10,820 (52%) women, and 9866 (48%) men.

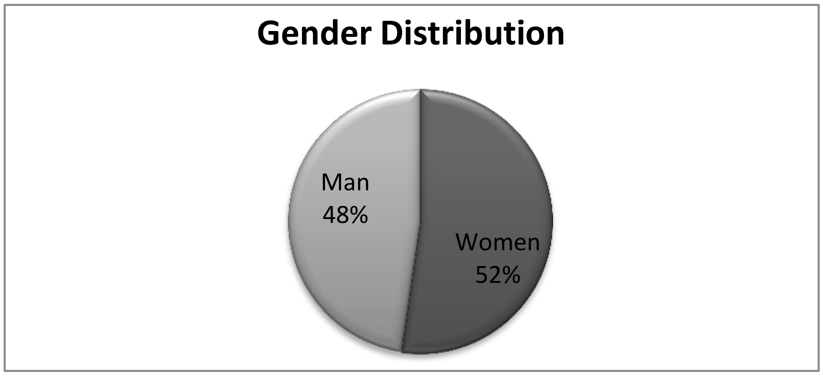

Figure 5-2 Gender Distribution

Figure 5-3 presents the distribution of the subjects' age. 20% of the subjects are between 18 and 30 years old, 42% are 31 to 50 years old, 22% are 51 to 70 years old and 16% are 71 to 90 years old.

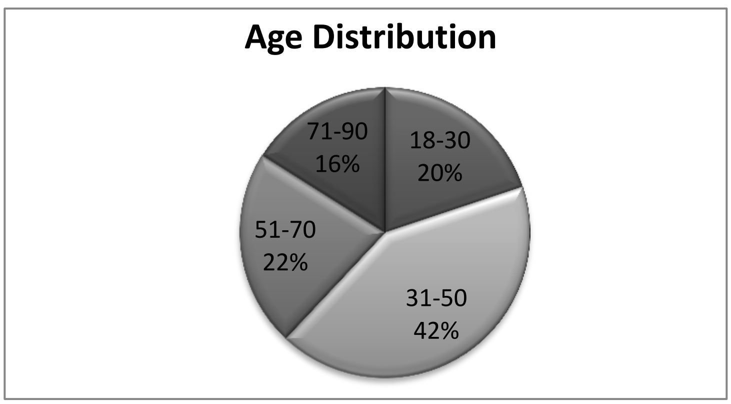

Figure 5-3 Age Distribution

SEOP survey subjects were asked to provide, among other, information/data about their gender, year in which they were born, and the answer to the general risk question. Based on the answer provided in the SOEP survey, the probability to be in a certain risk category for a certain gender and age was computed. Figure 5-4, Figure 5-5, Figure 5-6, Figure 5-7, and Figure 5-8 show the risk distribution probabilities on the 0-10 risk scale for females in different age ranges, between 18 to 90 years old. Figure 5-9, Figure 5-10, Figure 5-11, Figure 5-12, and Figure 5-13, show the distribution probabilities on the 0-10 risk scale for males in different age groups between 18-90 years old.

The data in the figures was grouped based on the gender and age. A division in age groups similar to the one in Purcell et al. (2007) was used: 18 – 23, 24- 30, and over 30. However, since the subjects were up to 90 years old, the over 30 category included 60 years, which might not be relevant if considered as a whole. Therefore, the last category (over 30) was divided into three other sub-categories 31-50, 51-70, and 71-90. The vertical axis represents the peoples' age. The colour corresponding to a risk aversion is represented in the legend. The three risk values with the highest percentage are labelled in each figure indicating the percentage of people that were classified under that risk value.

5.1.1.2.1 Female Gender

For example, the risk distribution for 18-23 years old presented in Figure 5-4 (females) indicates that the highest number (22.84%) of females of age 21, were identified as having risk values equal to 5. 16.67% of the females of age 21 are identified having a risk value of 6 and 13.58% are identified having a risk value of 4. It can be noticed that for women with ages of 18-23, generally a risk value of 5 is the most common, with the exception of 19 years old for whom a risk value of 7 is mostly reported (Figure 5-4).

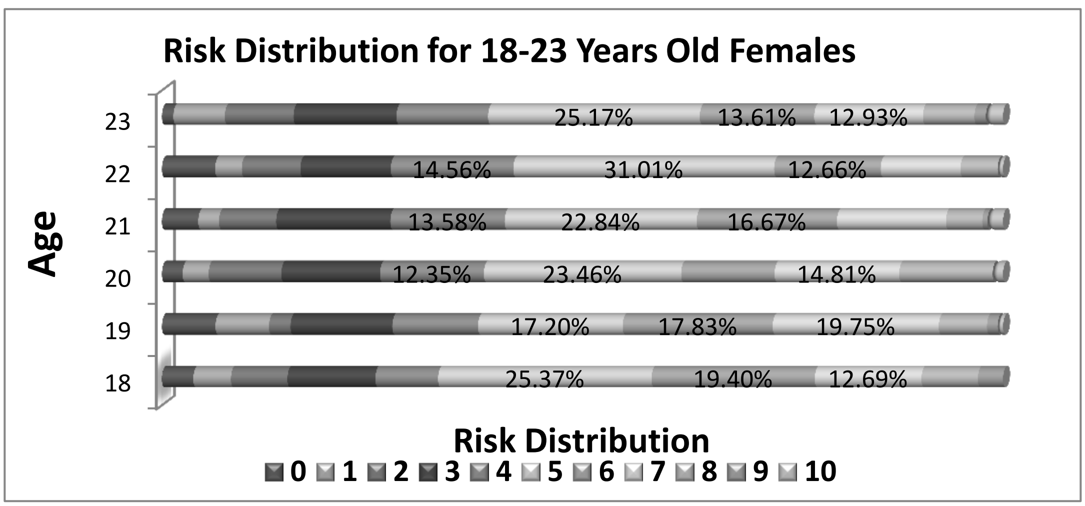

Figure 5-4 Risk Distribution for 18-23 Years Old Females

For 24 to 33 years old females, the most common risk value continues to be 5 (Figure 5-5 & Figure 5-6). However, for 30 years old females there are two common values 3 and 5 (Figure 5-5).

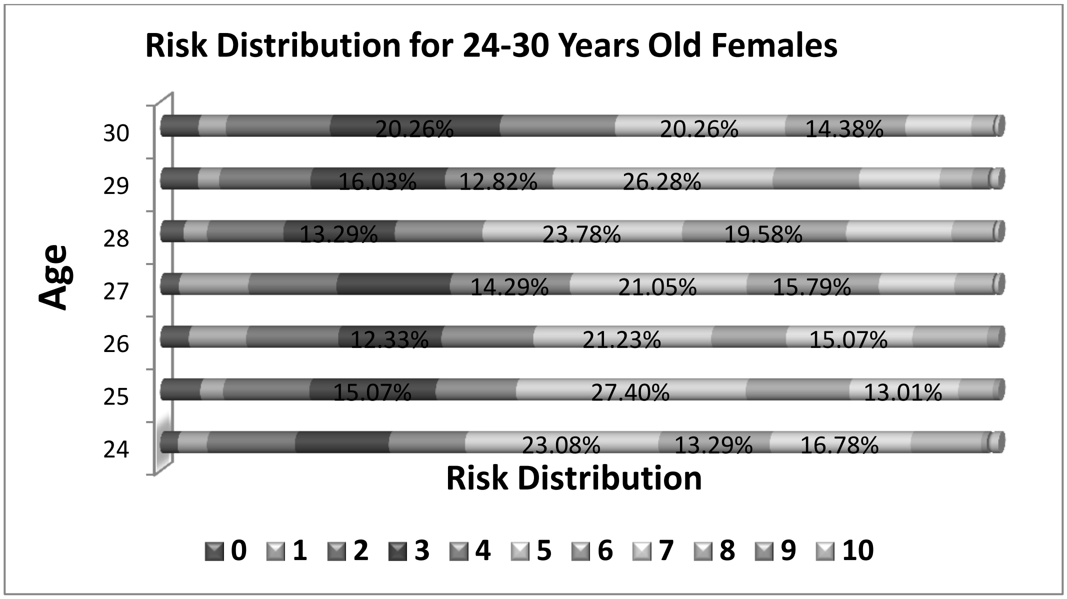

Figure 5-5 Risk Distribution for 24-30 Years Old Females

For females from 31 to 50 years old there are variations across the ages (Figure 5-6). At 34, the most common risk value switches from 5 (for 33 years old persons) to 3, and it switches back to 5 for 35 years old persons. It changes back to 3 for 38 and 39 year old persons, and afterwards it remains 5 until the age of 46, when the most common risk value is 2. Then, until the age of 51 the risk value remains unchanged to 5. For 32 year old persons, there are two risk values which are most used, 3 and 5.

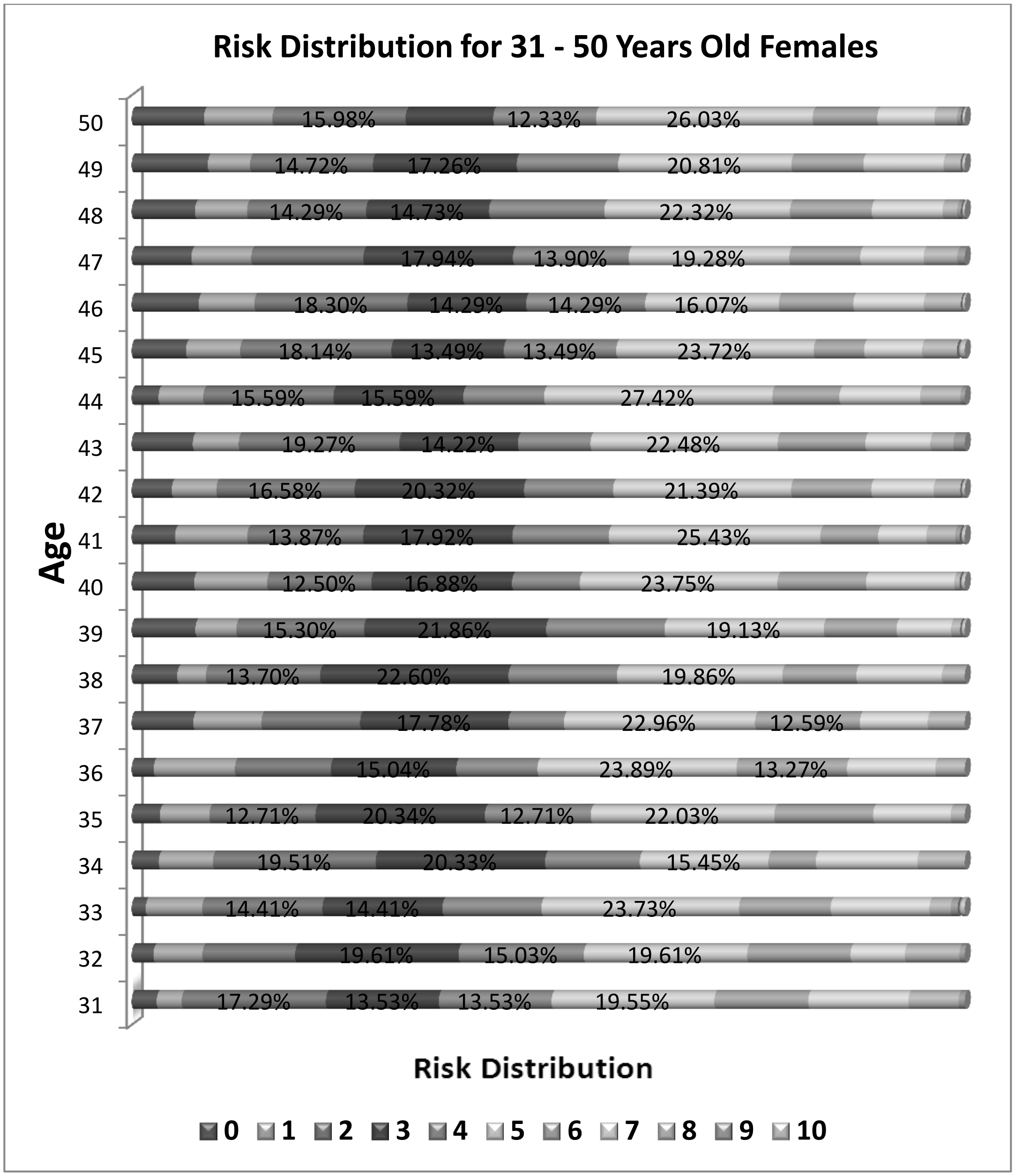

Figure 5-6 Risk Distribution for 31- 50 Years Old Females

After 50 years old the most common selected risk value has again variations (Figure 5-7 & Figure 5-8). The value of 5 is the most common for 51-53, 55, 58, 63, 64 and 66-69 year old persons. For 52 and 66 year old the risk value 3 and 5 are the most common ones. For 54, 56-57, 59, 62, 66, and 70 years old the most common risk value is 3. It decreases to 2 for 59-62, and 65 years old.

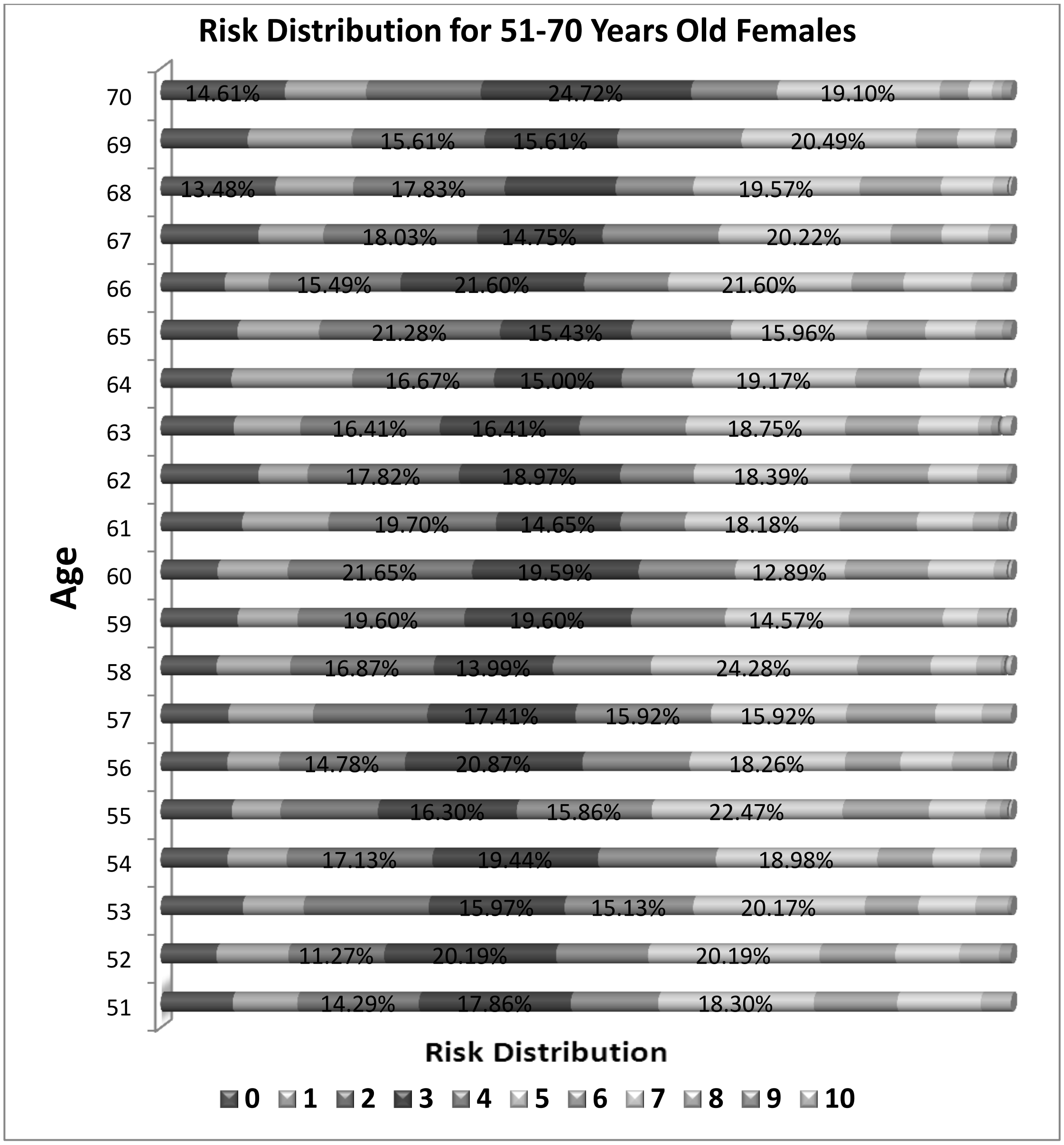

Figure 5-7 Risk Distribution for 51-70 Years Old Females

From 71 to 90 years old more subjects were classified in a lower risk aversion category (Figure 5-8), than for 51 to 70 years old. Only for 71, 74 and 77 years old the most common value is 5. For 72-73, 75, 79, 83 and 90 years old the most common value is 2. For 90 years old, the 3 risk value is selected by the same number of subjects as the ones that selected 2. A value of 1 is commonly selected by the 81, 85 and 86 years old. For females of 76, 78, 80, 82, 84, and 87-89 years old the most common risk value is 0.

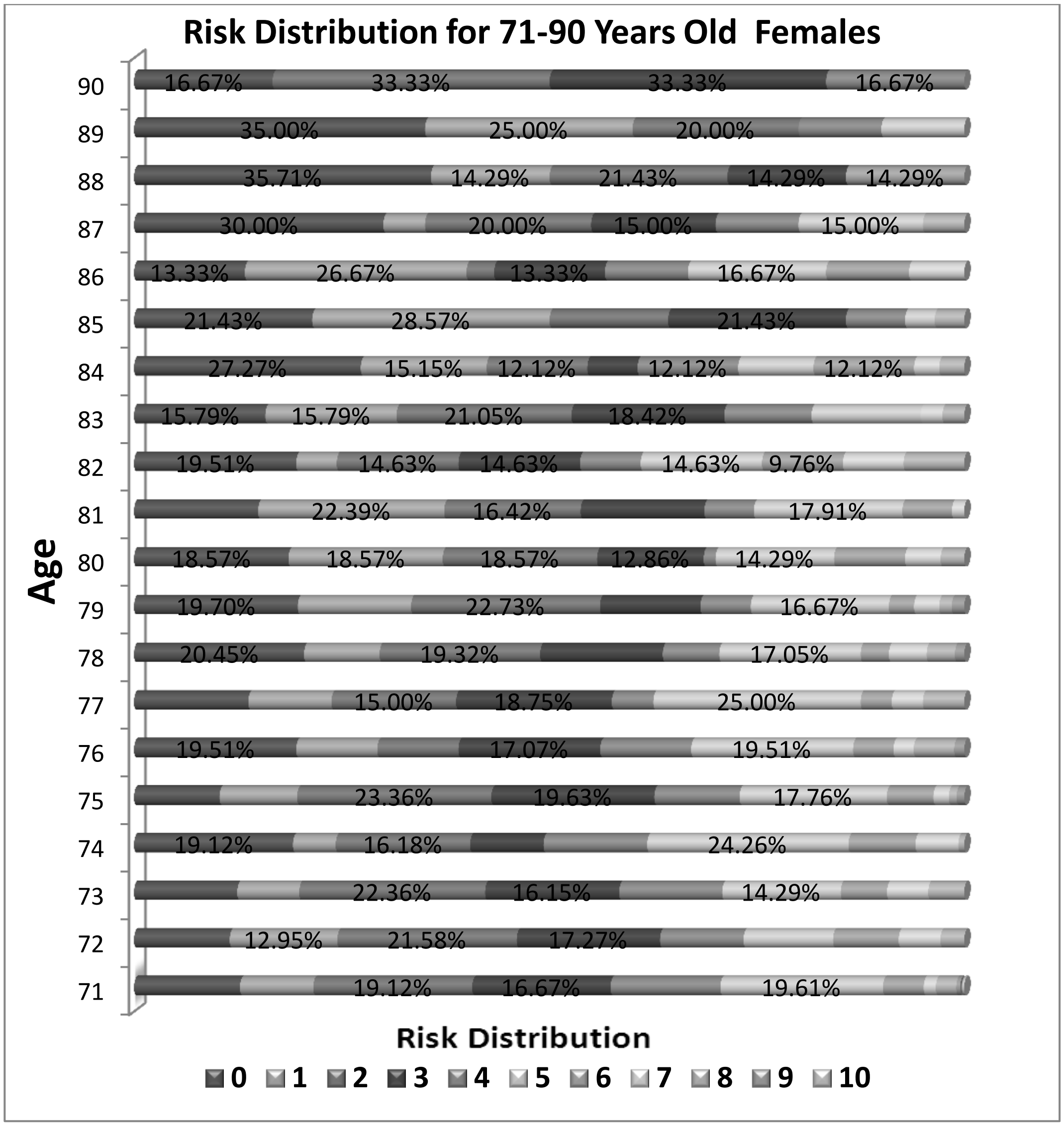

Figure 5-8 Risk Distribution for 71-90 Years Old Females

5.1.1.2.2 Male Gender

Figure 5-9 presents the risk distribution for 18 to 23 years old males. The most common risk value is 5. Except for 19 year old males, the most selected risk value is similar with the ones for females. For 19 year old males the most common risk value is 7.

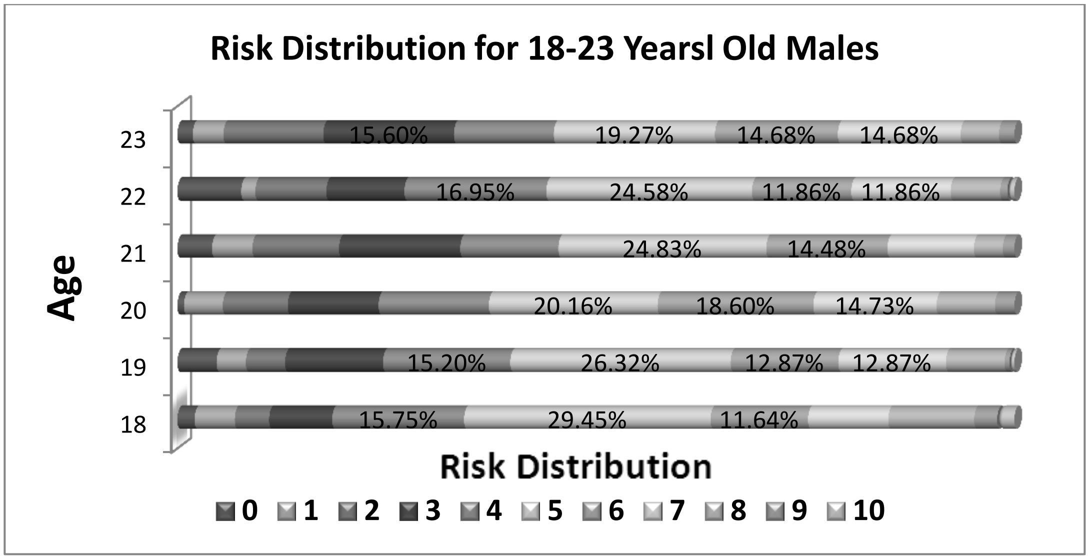

Figure 5-9 Risk Distribution for 18-23 Years Old Males

For 24, 25 and 27-29 years old males the most common risk value is 5. The risk decreases for 26 years old to 4 and for 30 years old to 3. The difference between males and females can be seen for the 26 years old category when males have the most common risk value 4 and females 5.

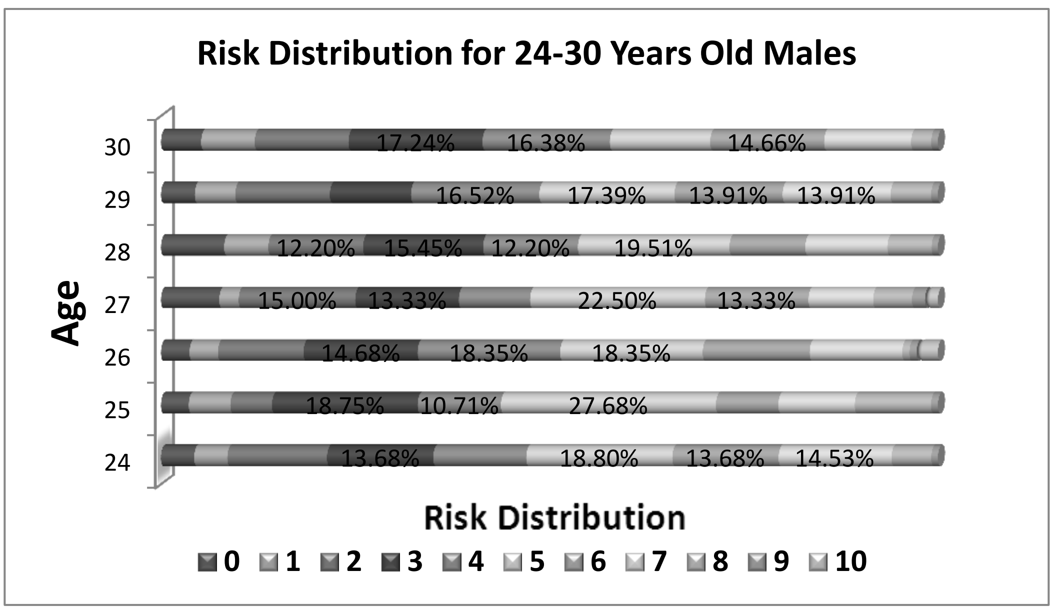

Figure 5-10 Risk Distribution for 24-30 Years Old Males

For 31-50 years old males, the most common risk value is 5, with the exception of the 40 years old where the risk value decreases to 3. This differs for females where the risk value with the greatest percentage varies along the age range.

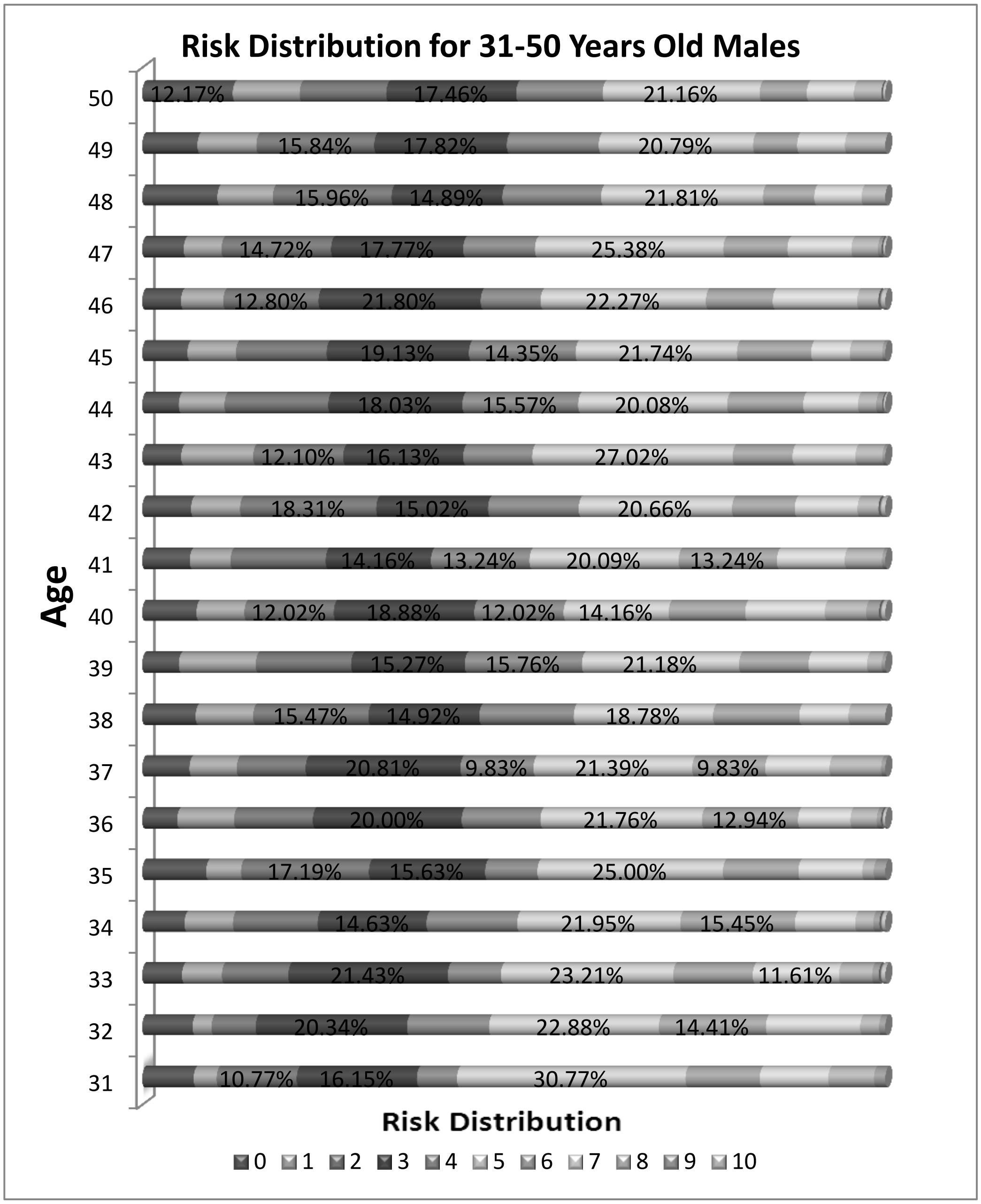

Figure 5-11 Risk Distribution for 31-50 Years Old Males

Figure 5-12 presents how the risk values differ across ages for males between 51 to 70 years old. For 51, 61, 68 and 70 years old the most common risk value is 3. 5 is the most common risk value for 52-54, 56, 58-60, 63, and 66 year olds. The most selected risk value decreases to 2 for 55, 64-65, and 67 years old males, and to 0 for 57, 62, and 69 years old. For 51-70 age groups, the most common risk value for men is in most of the cases lower than for females. The most common value for females is 2, while for men it decreases as low as 0.

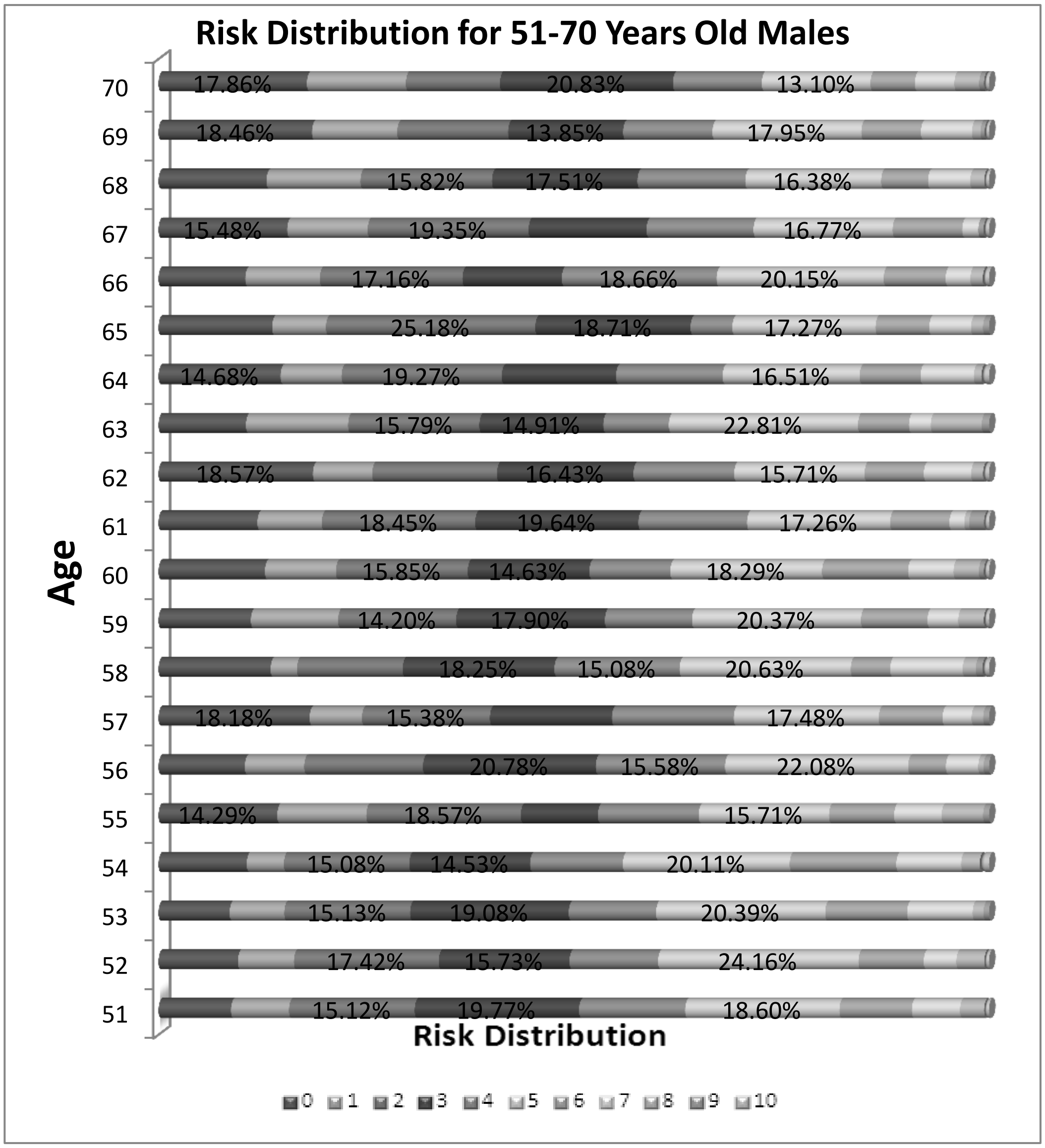

Figure 5-12 Risk Distribution for 51-70 Years Old Males

Figure 5-13 presents the percentage risk values for male subjects with the age between 71 and 90 years old. Only 80 years old have as the most common risk value 5. The value is 3 for 72, 74 and 82 years old subjects, and 2 for 73, 76-77, 79, and 82 years' old subjects. For the rest of the ages, the most common risk value is 0. The most common risk values for females for the 71-90 age group decreased as well compared with the previous age group, but there are not so many low values as for men.

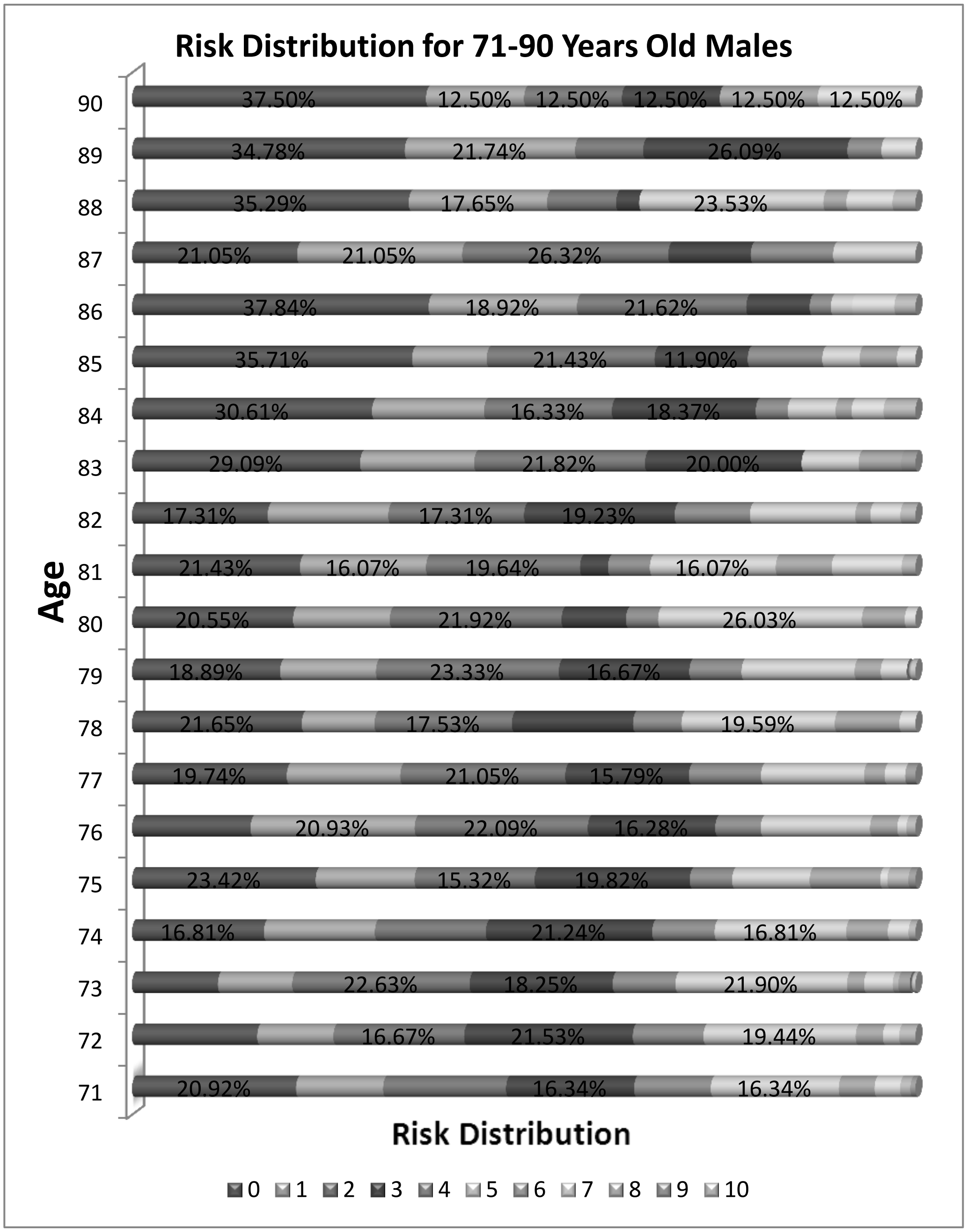

Figure 5-13 Risk Distribution for 71-90 Years Old Males

5.1.1.2.3 Males vs. Females

It can be noticed that the risk values vary across the ages (with the eldest being more risk averse) as well based on gender. 5 is a common risk value for persons up to 55 years old. However, it decreases rapidly after 80; 0 is the most common risk value. There are also differences across gender. For the females, risk values change more in the 31-50 age group than for men, while for men it decreases more for 50 year olds. These findings are in concordance with the previous research done in the area (Ding et al., 2010; Dohmen & Falk, 2011; Karhunen & Ledyaeva, 2010; Niederle & Vesterlund, 2007).

5.1.1.3 Person's General Risk Aversion

When the user first logs-in into the system s/he is classified as being either a risk averse or a risk seeker, by combining the answer to the general risk question, $RV_{GeneralRiskQuestion}$, with his/her probability of having a certain risk value (on the 0-10 scale) based on her/his gender and age, $RV_{AgeGender}$. This value is called RV_{Stable} and it is computed as in Equation 1. Since $RV_{GeneralRiskQuestion}$ and $RV_{AgeGender}$ have the same importance they were assigned equal weights. Based on this result, and similar to what was proposed in Dohmen et al. (2011), a user who will have a RV_{Stable} value less than or equal with 5 will be considered as being risk averse and a user with a value greater than 5 as a risk seeker.

Equation 1 Persons' General Risk Attitude

$$RV_{Stable} = w_1 * \mathrm{RV}_{GeneralRiskQuestion} + w_2 * RV_{AgeGender}$$

where,

$$w_1 + w_2 = 1$$

$RV_{AgeGender}$ (Risk Value based on Age and Gender) for a person is computed as the sum of probabilities of having a certain risk value *i* for a certain gender and certain age ($RiskProbability_i$), multiplied by the risk value *i* $RiskValue_i$, where *i* can have a value from 0 up to 10, as the risk values scale from the general risk question.

Equation 2 Risk Attitude based on Gender and Age

$$\mathrm{RV}_{AgeGender} = \sum_{i=0}^{10} RiskValue_i * ProbabilityRiskValue_i$$

For example, for a 24 year old female, the percentage of subjects that have assigned a particular risk value is presented in Table 5-2. The first row represents the 0 to 10 risk value range, and the second column the percentage of 24 years old females that were assigned for each risk value. To the $RV_{AgeGender}$ computation, $RiskValue_i$ represents a particular risk value as presented in the first row of the Table 5-2, and *ProbabilityRisk Value*$_\mathrm{i}$ represents the percentage of people being assigned the , $RiskValue_i$. Therefore:

$$RV_{24Female} = 0*0.021 + 1*0.0035 + 2*0.1049 + 3*0.1109 + 4*0.0909 + 5*0.2308 + 6*0.1329 + 7*0.1678 + 8*0.0839 + 9 * 0.007 + 10*0.014$$

$$RV_{24Female} = 4.94$$

The computed value is less than 5, so a 24 years old female will be classified as risk averse.

Table 5-2 Percentages of 24 Years Old Females for each Risk Values based on SOEP (SOEP, v26) Data

RV	0	1	2	3	4	5	6	7	8	9	10
%	2.10	3.50	10.49	11.19	9.09	23.08	13.29	16.78	8.39	0.70	1.40

An exemplification for computing RV_{Stable} is presented next. Considering the value for a female of 24 years old, $RV_{24Female}$ is 4.94. If the person selects at the general risk question a value of 6 ($RV_{GeneralRiskQuestion}$) at the general risk question, the RV_{Stable} will be computed as in Equation 1:

$$RV_{Stable} = 0.5 * 4.94 + 0.5* 6$$

$$RV_{Stable} = 5.47$$

This value is greater than 5, therefore the person is a risk seeker.

The RV_{Stable} value may change when the user's age changes and therefore his/her age/gender based risk attitude might be affected, which leads to a change in the $RV_{AgeGender}$ value.

5.1.2 Real – Time User's Risk Assessment

Although it is considered that a stable attitude towards risk exists, it has been shown that it can vary across different contexts (Dohmen et al., 2011). Different factors that affect it are considered implicitly by this study: whether the user is or not in roaming, and changes in the billing plans. Also, the user could explicitly change the value of the risk attitude.

5.1.2.1 User Updated Risk

The user can update his/her profile by changing the risk value. This model was opted because the user attitude can change due to different circumstances, and due to the fact that the user prefers models for which they have control over (Ahn et al., 2007). When the user changes his profile, the selected risk attitude, $RV_{Updated}$, will be considered for the duration of the session, unless the user specifies otherwise.

5.1.2.2 User Billing Plan Usage

For bundle based billing, the personal consumption is monitored and tried to be maintained under the bundle size. First, when the user requests a new video, an estimation of the remaining data quantity from the bundle is computed as in Equation 3, where *DataQuota* represents how much data the bundle had initially, when it was bought; *TimeLimitInterval* the time interval for which the bundle is available, *CurrInterval* is the time interval for which the video is requested (for example, if the bundle has an availability of 30 days, *CurrInterval* will be the number of the day in which the multimedia has been requested counting from the day in which the data is activated), and *DataCons* is the data consumed so far from the bundle.

Equation 3 Estimated Remaining Bundle Data

$$EstimatedRemainingData = \frac{DataQuota}{TimeLimitInterval} * CurrInterval - DataCons$$

For example, if the person acquires a 500MB bundle for 30 days, by the third day s/he already consumed 100MB, the value computed in Equation 3 is -50, which means that the person exceeded its allowed quantity by 50MB.

$$EstimatedRemainingData = \frac{500}{30} * 3 - 100$$

$$EstimatedRemainingData = -50$$

If the *EstimatedRemainingData* is negative, the estimated risk value is computed as in the Equation 4. A slow decrease in the user risk attitude was considered desirable, such that when the user exceeds the quantity for the first time s/he is not penalised as much, but continuing to exceed the quantity its risk attitude would be slowly decreasing. A slow modification of the values from the user model is recommended when the initial value is a reasonable approximation (Rich, 1979), which is the case here. This has also been applied in networking (RFC: 793, 1981), to avoid spikes in the network traffic smooth modifications of the previous values that have to be obtained. This is done by considering the new value having a weight from 10% to 20%, while the old one the remaining value. In this case, a 10% decrease from the previous RV was opted for the decrease of the risk value was used when the learner is exceeding the quantity at national level and 20% for roaming, as the prices for roaming are typically higher.

Equation 4 Risk Value Updated based on the Billing Plan Usage

$$RV_{Billing} = \mathrm{RV} - \mathrm{RV} * 10\%$$

, where RV is the last risk value saved in the user profile.

This risk value became the new risk value, until the user request again data, when this value is recomputed. If the *EstimatedRemainingData* is not negative, the risk value is switched to the latest value before $RV_{Billing}$ was computed, unless other changes took place (e.g. the user change the risk value). In this case it switches to the latest value in which only changes to the billing plan were applied.

5.1.2.3 User Roaming

For using Internet while roaming, depending on the MNO (Mobile Network Operator), different numbers of roaming zones can exist. Based on these roaming zones, the price can vary (section 4.3). Depending on the zone the user is travelling in, the risk level is decreased by a constant which is 20% of the previous risk value (Equation 5).

Equation 5 Risk Value Change Based on Roaming Zones

$$RV_{Roaming} = \mathrm{RV} - \mathrm{RV} * 20\%$$

, where RV is the last risk value saved in the user profile. A higher percentage was chosen to decreased from, since the prices in roaming are usually higher than national prices.

This risk value is considered for the duration of the session, unless other factors change it.

5.1.2.4 Multiple Factors Affecting Risk Value at the Same Time

If multiple factors (user, billing plan, and/or roaming) affect the risk value at the same time, risk value, $RV_{RealTime}$, is computed as an average of the values of the factors: $RV_{Updated}$, $RV_{Billing}$, and/or $RV_{Roaming}$ (see Equation 6). If just two factors affect the risk value, the average will be done based on those two factors, and this will be the value available for the session or until other changes occur. There is only one exception from this rule, when the user changes the risk value, and does not explicitly accept other factors to be taken into account. In this case the user input will overwrite any previous changes.

Equation 6 Real Time Formula

$$RV_{RealtTime} = Avg(RV_{Updated}, RV_{Billing}, RV_{Roaming})$$

5.1.2.5 User Profile Update

The user profile updates the risk value RV, every time when $RV_{RealTime}$, $RV_{Updated}$, $RV_{Billing}$, and/or $RV_{Updated}$ change, based on the Equation 7. For simplification, only $RV_{RealTime}$ is presented in the equation, but it can be any of the previous values to trigger this change. The weight values, w'_1 and $w'_{2,}$ are in this case 0.1 is 0.9. These values were taken in order to ensure a slow modification of RV over time, such that a certain change which might be triggered by an occasional change of context for the user, will not affect the whole value very quickly. A slow modification of the values is recommended when the initial value is a reasonable approximation (Rich, 1979), which is in our case. This approach and the weight values were considered based on the TCP/IP model (RFC: 793, 1981). This approach is used with the aim to ensure that there are no sudden spikes in the traffic. The computed value will be used for the next user multimedia session as:

Equation 7 Risk Attitude Changes

$$RV_1 = \mathrm{RV}_{Stable}$$

$$RV_j = w'_1 * \mathrm{RV}_{RealTime} + w'_2 * \frac{RV_{j-1} + RV_{Stable}}{2}$$

where,

$$w'_1 + w'_2 = 1$$

For example if the person had RV_{j-1} of 4.94 and an $\mathrm{RV}_{\mathrm{Stable}}$ of 5. If, $\mathrm{RV}_{\mathrm{RealTime}}$ is 6, then RV_{j} for the duration of the session would be computed based on Equation 7, as following:

$$RV_{11} = 0.1 * 6 + 0.9 * \frac{4.94 + 5}{2}$$

$$RV_{11} = 5.073$$

5.1.3 Summary

The user attitude towards risk varies across different contexts, based on age and gender or certain changes in the user context. This chapter presented how the user attitude towards risk can be computed by taking into account the user age, gender and the user answer to the general risk question. It also shows how variations in risk values can be computed based on the changes in age, user preferences, quantity of data the user consumes (for bundle based billing using), and/or whether s/he is in roaming or not.

5.2 MULTIMEDIA BITRATE RECOMMENDATIONS

5.2.1 Introduction

This section presents a multimedia mechanism which aims to deliver personalized multimedia content based on the user's attitude towards risk (Section 5.1.1). There are several factors that are tackled in this research such as: resolution, bitrate, and bandwidth over which multimedia content is delivered. These are selected as they have a direct or indirect effect on the size of the multimedia content, and hence its size. A lower bitrate value implies lower size. However, a multimedia with a higher resolution needs a higher bitrate. If the device has a smaller resolution there is no point in delivering multimedia content at that resolution as the device will scale it down anyway. By delivering the content directly to the resolution the device has the bitrate can be lowered, hence the size and therefore the cost. The available bandwidth influences how much information can be delivered over the network. To prevent the loss of data in multimedia streaming the network bandwidth should be higher or equal with the multimedia bitrate. Therefore adapting the bitrate values of the multimedia content to the network over which the content is to be delivered, can reduce the cost of delivery.

5.2.2 Resolution

Mobile phones support various resolutions, with bigger or smaller variations among them. The resolutions are classified in four groups based on the first four classes of resolutions, from the five classes described in Media (2011): 240p, 360p, 480p, 720p, and 1080p. This notation is used to describe the progressive lines of resolution of vertical resolution, where p stands for progressive, and the number in front is the number of lines of vertical resolution. Basically, a 240p video will have 240 progressive lines of vertical resolution; a 360p video will have 360 lines of vertical resolution and so forth. In a progressive scan, the lines are drawn one by one from top to bottom. In contrast to progressive scan, when using interlacing, the odd lines are drawn, followed by the even lines. This is mostly used in classical television.

Since mobile phones do not have resolutions higher than 720p that correspond to a resolution of 720 x 1080 (960 x 640 is so far the biggest smartphone resolution, present in the iPhone 4), the first four classes were selected for this research. The rest of the resolutions which do not match exactly the corresponding resolution (Table 5-3, column 2) are grouped around these four resolutions (see Section 3.2.1.1). The reason for doing so is in the high number of devices' resolution, and in the inherent difficulty to manage so many resolutions during the adaptation process (Media, 2011). The first column of Table 5-3 is the name of the class, the second one contains the resolution associated with that class, and the third column has examples of smartphones resolutions included in the class by the previous classification. Further on, the fourth column is the resolution at which the multimedia is actually kept. This was chosen by looking at the most common resolutions in the years 2009 and 2010 that are contained within that class. Following this logic:

- For a device classified in the 720p resolution, it will have associated a multimedia clip with a resolution of 640 x 960, since so far, it is the biggest mobile phone resolution that fits into this class.

- A device classified in the 480p category will have a resolution of 480 x 800, since it is the most used resolution among the feature phones and smartphones which fit the 480p category (75%), and the most used smartphone resolution accounting for 27.38% of all the smartphones, during the period 2009-2010.
- A device classified in the 360p category will have a multimedia with the resolution 320 x 480, since this resolution counts for 67% of the feature phones and smartphones which fit this class, and 16.67% of the total smartphones. It is also the third most used resolution among the smartphones in 2009-2010.
- A device classified in the 240p category will be kept with a resolution of 240 x 320, since 84% of the feature phones and smartphone resolutions that fit into this class have this resolution. Moreover, 25.89% of the smartphones have this resolution. This is also the third most used smartphone resolution between the years 2009 -2010.

Table 5-3 Mobile Phones Resolutions Classes

Video class	Resolution	Example resolutions included	Used resolution
720p	1020 x 720	640 x 960	640 x 960
480p	800 x 480	480 x 800 480 x 854	480 x 800
360p	640 x 360	360 x 640 320 x 480 360 x 480 320 x 320	320 x 480
240p	320 x 240	240 x 320	240 x 320

5.2.3 Bitrate

Selecting a suitable bitrate for a multimedia clip is a complicated problem as it depends on the video content, its resolution, the role of the clip, and the network it will be delivered on. Since a recommendation that will fit all requirements of this research (for taking into account all the smartphones' resolutions, and the suitability for various wireless networks), has not been found, different recommendations have been analysed in order to recommend the interval that the bitrate should have, and how it should be changed under different network constraints. The recommendations I took into account are from: *Mobile Learning Standard* (Mobile Learning Standard, 2010), *wowza* (Wowza Media Systems, 2011; Media, 2011), *Apple Technical Note TN 2224 – Best Practices for Creating and Deploying HTTP Live Streaming Media for the iPhone and iPad* (Technical Note TN224, 2010), and *Adobe* (Au, 2010).

The *Mobile Learning Standard* (Mobile Learning Standard, 2010) is part of the Australian Flexible Learning Framework (Australian Flexible Learning Framework, 2011). The framework is a national Australian strategy cofounded by the Australian Government. It contains various resources useful for e-learning, among them different standards. The *Mobile Learning Standard* is a standard that contains recommendations regarding what resolution and bitrate can be used for an educational multimedia clip. The standard recommends that for videos with a resolution from 176x 144 up to 640 x 480 the video bitrate should be within 140 kbps and 300 kbps. For higher resolutions there are no bitrate recommendations. Their recommendations do not consider the network type.

wowza (Wowza Media Systems, 2011; Media, 2011) is a media streaming software company. Their media server delivers live and on demand video to various media platforms such as: Android, Blackberry, Apple IOS, etc. (Wowza Media Systems, 2011). The media server has been selected as the number one choice for media streaming by the Streaming Media Magazine, for three years in a row (Wowza Media Systems, 2011). They recommend bitrate ranges for five different resolutions (Media, 2011). However, they do not take into account the network over which the media is delivered, some of the bitrates being too high for current cellular networks. The multi-bitrate example of videos used in adaptation is:

- 2 – 3 Mbps for 1080p
- 1.5 -1.8 Mbps for 720p
- 600 – 1000 kbps for 480p
- 350 – 550 kbps for 360p
- 150 -250 kbps for 240p

Apple Technical Note TN 2224 – Best Practices for Creating and Deploying HTTP Live Streaming Media for the iPhone and iPad (Technical Note TN224, 2010)- is an Internet Draft that is one of the first stages in order to became an Internet Engineering Task Force Informational Standard(Informational Internet Draft, 2010). The document has various recommendations based on whether the network is cellular or WiFi, the video aspect ratio, resolutions, etc. (see Figure 5-14). However, this recommendation does not cover all the resolutions, nor it makes a distinction between various types of cellular networks, whose performances differ.

Figure 5-14 presents a table with the recommendations from Apple. The table is divided into three parts based on the type of device: iPhone & iPod touch, iPad and iPad only. Two profiles are presented for the iPad one with Baseline and one in which all the recommendations are done for the Main profile, but with exactly the same recommended resolutions. The Baseline profile is designed mostly for videoconferencing and mobile applications and the Main profile is used mostly for television broadcast. The table is further on divided based on the image aspect ratio. The aspect ratio is defined as the width of the picture to the height. Two aspect ratios, 4:3 and 16:9 are considered. The first column of the table indicates the considered wireless network for which the multimedia characteristics are recommended, where CELL stands for cellular network (e.g. UMTS). The second column shows the multimedia resolution which differs based on the aspect ratio. The video frame rate is indicated in the third column and the bitrate in the forth. Further on, the forth column presents the audio bitrate, and the next column the sample rate. The eight column presents the video key frames and the last one the profile for which the recommendation is restricted.

For HTTP Streaming Delivery								
iPhone/iPod touch								
16:9 Aspect Ratio								
	Dimensions	**Frame Rate ***	**Total Bit Rate**	**Video Bit Rate**	**Audio Bit Rate**	**Audio Sample Rate**	**Keyframe**	**Restrict Profile to:**
CELL	480x320	na	64**	na	40	22.05	na	na
CELL	400x224	10	150	110	40	22.05	30	Baseline, 3.0
CELL	400x224	12 to 15	240	200	40	22.05	45	Baseline, 3.0
WIFI	400x224	29.97	440	400	40	22.05	90	Baseline, 3.0
WIFI	400x224	29.97	640	600	40	22.05	90	Baseline, 3.0
4:3 Aspect Ratio								
	Dimensions	**Frame Rate ***	**Total Bit Rate**	**Video Bit Rate**	**Audio Bit Rate**	**Audio Sample Rate**	**Keyframe**	**Restrict Profile to:**
CELL	480x320	na	64**	na	40	22.05	na	na
CELL	400x300	10	150	110	40	22.05	30	Baseline, 3.0
CELL	400x300	12 to 15	240	200	40	22.05	45	Baseline, 3.0
WIFI	400x300	29.97	440	400	40	22.05	90	Baseline, 3.0
WIFI	400x300	29.97	640	600	40	22.05	90	Baseline, 3.0
iPad								
16:9 Aspect Ratio								
	Dimensions	**Frame Rate ***	**Total Bit Rate**	**Video Bit Rate**	**Audio Bit Rate**	**Audio Sample Rate**	**Keyframe**	**Restrict Profile to:**
CELL	480x320	na	64**	na	40	22.05	na	na
CELL	400x224	10	150	110	40	22.05	30	Baseline, 3.0
CELL	400x224	12 to 15	240	200	40	22.05	45	Baseline, 3.0
CELL	400x224	29.97	440	400	40	22.05	90	Baseline, 3.0
WIFI	640x360	29.97	640	600	40	22.05	90	Baseline, 3.0
WIFI	640x360	29.97	840	800	40	22.05	90	Main, 3.1
WIFI	640x360	29.97	1240	1200	40	22.05	90	Main, 3.1
4:3 Aspect Ratio								
	Dimensions	**Frame Rate ***	**Total Bit Rate**	**Video Bit Rate**	**Audio Bit Rate**	**Audio Sample Rate**	**Keyframe**	**Restrict Profile to:**
CELL	480x320	na	64**	na	40	22.05	na	na
CELL	400x300	10	150	110	40	22.05	30	Baseline, 3.0
CELL	400x300	12 to 15	240	200	40	22.05	45	Baseline, 3.0
CELL	400x300	29.97	440	400	40	22.05	90	Baseline, 3.0
WIFI	640x480	29.97	640	600	40	22.05	90	Baseline, 3.0
WIFI	640x480	29.97	840	800	40	22.05	90	Main, 3.1
WIFI	640x480	29.97	1240	1200	40	22.05	90	Main, 3.1
iPad Only								
16:9 Aspect Ratio								
	Dimensions	**Frame Rate ***	**Total Bit Rate**	**Video Bit Rate**	**Audio Bit Rate**	**Audio Sample Rate**	**Keyframe**	**Restrict Profile to:**
CELL	480x320	na	64**	na	40	22.05	na	na
CELL	400x224	10	150	110	40	22.05	30	Main, 3.1
CELL	400x224	12 to 15	240	200	40	22.05	45	Main, 3.1
CELL	400x224	29.97	440	400	40	22.05	90	Main, 3.1
WIFI	640x360	29.97	640	600	40	22.05	90	Main, 3.1
WIFI	640x360	29.97	840	800	40	22.05	90	Main, 3.1
WIFI	640x360	29.97	1240	1200	40	22.05	90	Main, 3.1
4:3 Aspect Ratio								
	Dimensions	**Frame Rate ***	**Total Bit Rate**	**Video Bit Rate**	**Audio Bit Rate**	**Audio Sample Rate**	**Keyframe**	**Restrict Profile to:**
CELL	480x320	na	64**	na	40	22.05	na	na
CELL	400x300	10	150	110	40	22.05	30	Main, 3.1
CELL	400x300	12 to 15	240	200	40	22.05	45	Main, 3.1
CELL	400x300	29.97	440	400	40	22.05	90	Main, 3.1
WIFI	640x480	29.97	640	600	40	22.05	90	Main, 3.1
WIFI	640x480	29.97	840	800	40	22.05	90	Main, 3.1
WIFI	640x480	29.97	1240	1200	40	22.05	90	Main, 3.1

*** Frame Rate: Assumes current frame rate is 29.97. For other frame rates see below:**

For	For 150k Use	For 240k Use	For All Else Use
30	10	12 to 15	30
60	10	12 to 15	30
29.97	10	12 to 15	29.97
59.94	10	12 to 15	29.97
24	8	10 to 12	24
23.98	8	10 to 12	23.98
25	8	10 to 12	25
50	8	10 to 12	25

**** The 64 Kbps data rate is required if you deliver over the cell network. While called "audio only", this can include still frames or very low frame rate video. We recommend still frames, which must be 480x320 on both iPhone and iPad.**

Figure 5-14 Recommended Encoding Settings for HTTP Live Streaming Media (Technical Note TN224, 2010)

Adobe (Au, 2010) recommends video bitrates, for delivery on mobile devices, depending on the type of network (Wi-Fi, 3G and 2.5 G) but they do not have recommendations for all resolutions or for 3.5G data rates which are becoming more and more popular. The bitrates they proposed for different resolutions are presented in Figure 5-15.

Preferred format	Video: H.264, Constrained Baseline profile at 24 fps[1] Audio: AAC-LC, 44.1 kHz, stereo			
Alternate format	Video: On2 VP6, Simple profile or Sorenson Spark at 24 fps[1] Audio: MP3, 44.1 kHz, stereo			
	WiFi – H.264	**WiFi – On2/Sorenson**	**3G – All**	**2.5G – All**
Bit rate (combined)	500 kbps	350 kbps	350 kbps	100 kbps
Resolution	HVGA (480 x 320)	HVGA (480 x 320)	HVGA (480 x 320)	QVGA (320 x 240)
Audio bit rate	Up to 160 kbps	Up to 128 kbps	Up to 64 kbps	Up to 32 kbps

1. For true source frame rate greater than 24, downsample by an even factor such as 2, e.g. 30 to 15, to maintain optimal performance.

Figure 5-15 Adobe Mobile Video Encoding Guidelines (Au, 2010)

5.2.4 Bandwidth

Different networks support different bandwidth and this influences how much information can be delivered over the network. To prevent the loss of data in a multimedia streaming the network bandwidth should be higher or equal with the multimedia bitrate. The medium bandwidth supported by different wireless network types is presented next:

- 3G network – 384 kbps medium coverage for pedestrian use by IMT 2000 (ITU-T, 2000) as cited by (Jeff, 2008)
- 3.5G network – HSDPA: 1200 kbps for mobile user (Derksen et al., 2006)
- Wi-Fi network – 5 Mbps (Raghavendra & Belding, 2010)

5.2.5 Multimedia Adaptation Mechanism

Cost of delivery over cellular networks is still expensive. The user attitude towards risk can predict his/her economic behaviour. Below, a mechanism that adapts the multimedia content such as risk adverse persons get the lower price version and the risk seekers the better quality version is presented. The fact that risk averse users are less willing to pay in risky situations is well documented in different previous studies (Brachinger et al., 1997; Weber, 1999). Moreover, Markowitz (1959) has modelled the people willingness to pay as a function of risk. Since risk attitude has been used in various studies, it is relatively easy to assess it, and a stable attitude towards has been shown to exist across different domains (Dohman et al., 2011). It was decided to use it for the adaptation mechanism, as opposed to the willingness to pay. The mechanism is applied every time the user requests a multimedia clip.

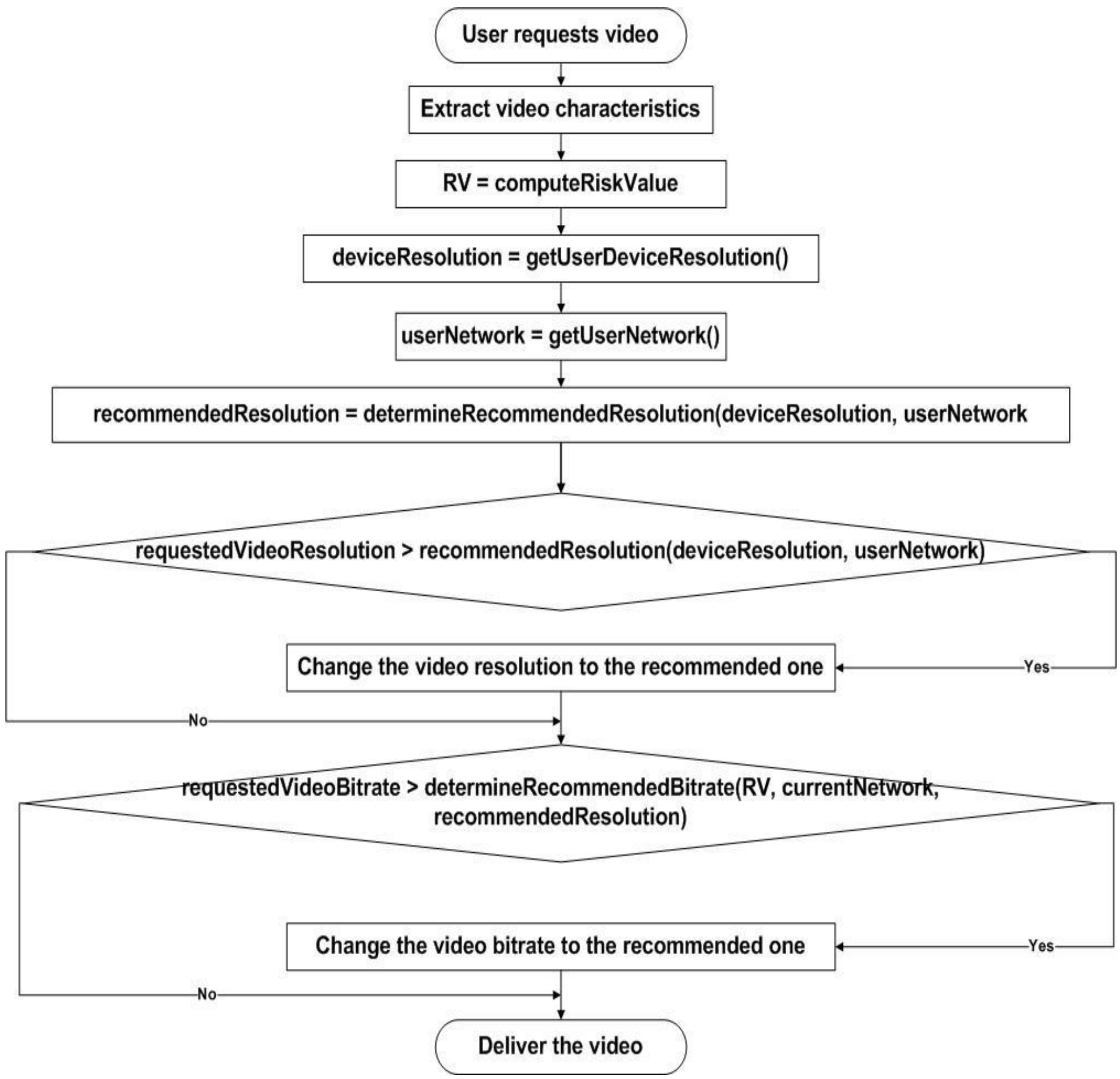

Figure 5-16 Multimedia Adaptation Mechanism

A division of the user profiles in two classes of risk was presented in section 5.1. In order to adapt the multimedia content for the two classes of users, two multimedia bitrate values have to be proposed, one for the risk averse users (a lower threshold) and one for the risk seekers (an upper threshold). Although a more granular classification could have been done by considering the 11 points scale on which the risk is computed no research has currently been done to characterise the users based on each point of the scale, therefore I will focus on the two categories, currently used.

The proposed adaptive mechanism take into account three factors: the learner (by considering her risk attitude), the learner device (by taking into account its resolution), and the network on which the multimedia is delivered (e.g. Wi-Fi, 3G etc). The networks were considered in this analysis due to the difference in performance among the different types of technologies that exist. Table 5-4, Table 5-5, and Table 5-6 present the proposed multimedia bitrate values to be used by the adaptive mechanism when delivering multimedia over Wi-Fi, 3.5G and 3G network. Table 5-4 presents the proposed multimedia bitrate values when delivering content over Wi-Fi networks. The first column indicates the resolution class, the second column the resolution to be used for a multimedia (see section 5.2.2 for a discussion on how the resolutions were proposed). The third and the forth columns show the recommended bitrate threshold based on the risk attitude. The last column presents the documentation based on which the bitrate threshold was recommended. An explanation on how the bitrate values were selected based on resolution classes is presented below:

- 720p: proposed bitrate thresholds follows the suggestions from *wowza* (Wowza Media Systems, 2011)
- 480p: proposed bitrate thresholds follows the suggestions from *wowza* (Wowza Media Systems, 2011) as well as some of the resolutions recommended by the *Apple* (Technical Note TN224, 2010) that fit into this category and have similar bitrates (e.g. 640 x 480 has recommended 640kbps or 840kbps)
- 360p: the risk adverse user's threshold was taken as a combination among the value recommended by the *Mobile Learning Standard* (Australian Flexible Learning Framework, 2011) and *Apple (Technical Note TN224, 2010)*. The first one recommends that 140 kbps be the bitrate for the video with resolution between 176x 144 and 640 x 480, while the second one recommends 150 kbps for multimedia with resolutions of 400 x 224 or 400 x 300. Since 140 kbps is the bitrate only for the video at which the audio bitrate is added, 150 kbps was taken as a lower threshold. The risk seeker threshold was taken from *wowza* (Wowza Media Systems, 2011).

- 240p: the risk averse threshold (risk averse users) was taken as previously described for the previous group. This matches also with the *wowza* (Wowza Media Systems, 2011) exemplification. The risk seekers threshold (risk seekers users) is taken from the *wowza* (Wowza Media Systems, 2011) recommendations.

Table 5-4 Wi-Fi Multimedia Bitrate Recommendation

Class Resolution	**Recommended Resolution**	**Bitrate Threshold (video + audio)**		**Source**
		Risk aversion	***Risk seeker***	
720p	640 x 960	1.5 MB	1.8 MB	*wowza* (Wowza Media Systems, 2011)
480p	480 x 800	0.6 MB	1 MB	*wowza* (Wowza Media Systems, 2011), *Apple* (Technical Note TN224, 2010)
360p	320 x 480	150 kbps	550 kbps	*wowza* (Wowza Media Systems, 2011), *Apple* (Technical Note TN224, 2010), *Mobile Learning Standard* (Australian Flexible Learning Framework, 2011)
240p	240 x 320	150 kbps	250 kbps	*wowza* (Wowza Media Systems, 2011), *Mobile Learning Standard* (Australian Flexible Learning Framework, 2011)

Table 5-5 presents the changes required due to the lower performance of 3.5G network. Because the 720p class requires a higher bitrate, this category will use the bitrate thresholds for the 480p class. The idea to deliver at a lower resolution rather than diminishing the bitrate under the recommended bitrate is not new and is currently used also among others by the Microsoft IIS Smooth Streaming (IIS Smooth Streaming Technical Overview, 2009).

Table 5-5 3.5G Multimedia Bitrate Recommendation

Class Resolutions	**Recommended Resolution**	**Bitrate Thresholds (video + audio)**		**Source**
		Risk aversion	***Risk seekers***	
720p	*Use the bitrate and resolution from 480p*			
480p	480 x 800	0.6 MB	1 MB	*wowza* (Wowza Media Systems, 2011), *Apple* (Technical Note TN224, 2010)
360p	320 x 480	150 kbps	550 kbps	*wowza* (Wowza Media Systems, 2011), *Apple* (Technical Note TN224, 2010), *Mobile Learning Standard* (Australian Flexible Learning Framework, 2011)
240p	240 x 320	150 kbps	250 kbps	*wowza* (Wowza Media Systems, 2011), *Mobile Learning Standard* (Australian Flexible Learning Framework, 2011)

For 3G networks (Table 5-6), changes are performed to the 720p and 480p classes. The first two, 720p and 480p will use the 360p resolution, for the same reason as in the previous case. The 360p class has a higher threshold in order for it to be under the bandwidth of the network (the higher threshold was not selected to be 384 kbps as the network requires, as there can be variations in the bitrate of the video at different moments in the video, when the video is encoded with the average bitrate)

For the aim of our adaptation algorithm, these recommendations will be used to adapt the multimedia content based on the device resolution, the delivery network and the user economic attitude. The users who are classified as not willing to pay will get multimedia with the bitrate from the lower threshold, while the users who are aiming for quality will get the higher threshold bitrate.

Table 5-6 3G Multimedia Bitrate Recommendations

Class Resolution	**Recommended Resolution**	**Bitrate Threshold (video + audio)**		**Source**
		Risk aversion	***Risk seekers***	
720p	*640 x 960*	*Use the resolution from 360p*		
480p	480 x 800			
360p	320 x 480	150 kbps	350 kbps	
240p	240 x 320	150 kbps	250 kbps	wowza (Wowza Media Systems, 2011), Mobile Learning Standard (Australian Flexible Learning Framework, 2011)

5.2.6 Summary

This chapter presented a classification of mobile devices in four classes based on their resolutions. For each class a recommended resolution was proposed. The grouping was done such as the quality of the multimedia clip will not be affected. It also presented how bandwidth differs among different types of networks, imposing further limitations to the multimedia clip delivered over this type of network. It ends by presenting recommendations for different multimedia clips taking into account the class to which they belong, and the network over which they will be delivered.

5.3 CONCLUSIONS

The user attitude towards risk has been shown to predict the user economic behaviour. The aim of this thesis is to deliver lower cost multimedia content (with a low quality) for the people who are not willing to pay high prices for it, and good quality for those who are willing to pay for it. A mechanism that adapts the multimedia content is proposed which takes into account the resolution, bitrate and bandwidth over which the multimedia content is to be delivered.

6 EVALUATION

The research presented in this thesis has proposed a methodology that determines user (learner) attitude towards risk and predicts consumer behaviour based on gender, age, and a general risk question. It also considers in real time various factors that may change user attitude towards risk in certain context. Once the user's risk attitude was determined a multimedia based content adaptation mechanism was proposed with the aim of reducing cost of downloading the content on mobile devices through a wireless network. The adaptive multimedia mechanism involves reducing the quality of the clip to a level acceptable to the user. Quality as perceived by the learner is very important for the learning process, since poor multimedia quality may affect the information assimilation process.

This chapter presents the results of the evaluation of the proposed adaptive multimedia mechanism using both objective and subjective assessment. The objective evaluation has assessed the perceived video quality (using two well-known objective metrics: PSNR and SSIM), and the savings obtained when using the proposed adaptive mechanism. The savings were assessed using various mobile data billing plans used on the market. The selected billing plans are the most representative among the ones presented in section 4. Based on the billing plan a person may have to pay a different price when accessing the multimedia clip.

The subjective assessment was performed as an experimental study that has tested and validated the proposed adaptive multimedia-based content delivery mechanism in the m-learning context (see section 6.4). The study set-up was performed following the recommendations from the (ITU-T P.910, 2008). Since the study assesses the quality of the multimedia clips, various techniques for assessing multimedia quality are presented. A discussion on their advantages and disadvantages is also presented. Another aspect the experimental study has investigated is the learning achievements, in terms of correct answers to various questions regarding the educational content presented in the video clip. Since only the video quality was affected, educational questions concerned just the information presented through this medium. The aim of the test was to investigate if the proposed adaptation mechanism affects the learning achievements. The study also assessed the subjects' preferences towards the multimedia quality in different scenarios, involving various mobile data billing plans used on the market.

The chapter is structured as follows: First, the methodology used is presented. Section 6.2 presents the evaluation set-up. The results of the objective evaluation are presented next and the results of the subjective evaluation are presented in Section 6.4. Section 6.5 presents a discussion of the results. The last chapter draws the conclusions of this study.

6.1 METHODOLOGY

The aim of this research is to test and validate the proposed user's risk attitude-based multimedia adaptive mechanism categories presented in section 5.2.5. There are three main factors that were assessed: how the perceived multimedia quality was affected, if the learning achievements were affected, and cost savings that were obtained.

This section presents an overview on how the multimedia quality, learning achievements and savings cost of delivery where assessed.

6.1.1 Multimedia Quality Evaluation

Various metrics for assessing multimedia quality have been proposed. These metrics can be either objective or subjective.

6.1.1.1 Objective Video Quality Evaluation

Objective metrics are used to estimate the video quality as it would be perceived by the user by using mathematical models. They differ through their computational complexity and the factors they take into account to estimate the quality. Objective metrics include: PSNR-Peak Signal to Noise Ratio (Osberger et al., 1998), VQM - Video Quality Metric (Pinson & Wolf, 2004), and SSIM - Structural Similarity Index (Wu et al., 2004).

Among these, PSNR is the most used, due to the low computational complexity. PSNR has been shown obtained accurate results as the more complex models (e.g. VQM) (VQEG, 2000), however it is sometimes criticised for correlating poorly with perceived video quality (Gorley & Holliman, 2008). The PSNR is based on the comparison of two sequences of signals: the original video and the distorted one. The higher the result obtained by the PSNR formula, the better is the quality.

SSIM aims at being more consistent with the human eye than the PSNR is. It compares the similarity between two images. As in the PSNR case, the higher the score obtained with SSIM, the better the quality is considered.

VQM measures the effect of different video impairments on perceived quality. In the VQM case, the lower the score obtained with this metric, the better the multimedia clip perceived quality is.

There is not a general accepted metric, among the three of them, that is accurate well enough to estimate the perceived user quality. However, PSNR and SSIM have their values mapped into the MOS (Mean Option Score) scale, used for subjective video quality evaluation. Since the aim of this research is to analyse the multimedia quality both objective and subjective, these two metrics will be used for the objective video quality evaluation. This is because they provide easier comparison to the subjective evaluation.

The MOS scale is used to subjectively assess the perceived video quality. The 5-point MOS scale and the PSNR and SSIM mapping is presented in Figure 6-1. The first column indicates the MOS values, where 5 rates excellent quality and 1 bad quality. The second column presents the PSNR value intervals that correspond to a given MOS value. For example, PSNR values of 33(including) up to 45, will correspond to a MOS value of 4 (good perceived video quality). The third column presents the SSIM interval and its correspondent on the MOS scale. For example, SSIM values between 0.95 (including) and 0.99, corresponds to a MOS value of 4.

MOS	PSNR	SSIM
5 (excellent)	≥ 45	> 0.99
4 (good)	≥ 33 & < 45	≥ 0.95 & < 0.99
3 (fair)	≥ 27.4 & < 33	≥ 0.88 & < 0.95
2 (poor)	≥ 18.7 & < 27.4	≥ 0.5 & < 0.88
1 (bad)	< 18.7	< 0.5

Figure 6-1 PSNR and SSIM Mapping to MOS (Zinner et al., 2010)

The objective assessment of the video quality is faster and easier to be done and can be automatic. However, the subjective quality tests are considered to be the best method in assessing the multimedia quality (Webster et al., 1993).

6.1.1.2 Subjective Video Quality Evaluation

Subjective methods involve people assessing the quality of the multimedia clip. The perceived video quality is usually measured on the MOS scale. The MOS scale has values between 1 and 5, but a scale from 1 to 10 is also possible to be used, especially in the assessment of low bitrate video codecs (ITU-T P.910, 2008). Different standards for assessing user perceived quality have also been proposed by the International Telecommunication Union - Telecommunication Standardisation Sector (ITU-T), such as, ITU-T P.910 (ITU-T P.910, 2008), ITU-R BT-500 (ITU-R, 2002). Among these, ITU-T P.910 is used for multimedia clip transmissions that have both video and sound. ITU-R BT-500 is used for assessing the video quality of television pictures.

ITU-T P.910, the standard that this research will follow, provides recommendations regarding the experimental design, viewers, instructions, analysis of results, etc. According to the recommendation, the number of subjects involved in the test should be between 4 and 40, with at least 15 being the recommended value. It is also recommended that subjects do not work in the area of quality evaluation.

There are several different methods for assessing multimedia quality: Absolute Category Rating (ACR), Absolute Category Rating with Hidden Reference (ACR-HR), Degradation Category Rating (DCR), and Pair Comparison (PC) method. In ACR the subjects are asked to rate the multimedia clips one by one. ACR-HR differs from ACR by including a hidden reference in the test sequence. DCR presents the subjects videos in pair, one of the sequences being the reference and the other one the sequence under evaluation. In PC the sequences are presented in pairs with different systems under test. This research will use ACR since for this study having repeating sequences will affect the learning achievement.

6.1.2 Learning Achievement Assessment

Learning achievement is defined as the quantity of knowledge the learner has accumulated. Learner assessment can be *formative*, *summative* or *criterion referenced* (Allen et al., 2007). The *formative assessment* is defined as evaluating the student knowledge, capabilities, etc. without passing a formal grade. The *summative assessment* is defined as the evaluation in which the learner is graded, at a certain point in time. The *criterion referenced assessment* is defined as evaluating the learner against a set of benchmarks.

A *summative assessment* allows easier comparison of subjects' performance and provides reliable data (Shute & Zapata-Rivera, 2010); therefore this method is suitable to be used in an experimental study, where the aim is to assess/compare students' performance. The *summative assessment* can be performed as a course grade, pre/post test scores, and standardised scores. In general, the tests can contain the following types of test items:

- *True-False*: when the learner is asked to confirm or infirm the given statement. This type of tests is easy to administrate and can be quickly answered and evaluated. However they can have a guessing chance of 50%, which makes them unreliable.
- *Forced-Choice*: when the learner has to select one answer across multiple alternatives provided (usually 3 to 5). They are also easy to manage, can test simple or more complex concepts and they are also easy to answer and evaluate.
- *Multiple-Choice*: when the learner can select none/one or more answers across the multiple alternatives provided. This kind of tests are considered the most difficult to answer compared to *True-False*, and *Force-Choice*, but they are more difficult to assess. They can also be answered relatively quickly.
- *Essay*: when the learner is asked to answer the given question freely. They are considered the most suitable when assessing complex and higher level thinking skills. They have the advantages of being easy to construct and do not permit guessing. They are also more difficult to evaluate, and thus are subject to the evaluator impression.
- *Gap-Filling*: the learner is asked to fill the gaps in a statement with one or more words. They are mostly suitable when recalling information is necessary. It is more difficult to guess the answer, as it is in the *True-False*, *Forced-Choice* or *Multiple-Choice*, but they

are more difficult to evaluate, unless there is a single possible way to answer it. However, they are easier to evaluate and not so subjective, as the essay type questions.

Each of these presented forms of evaluation has its advantages and disadvantages. For experimental study the most used form of assessment is a pre/post-test, where students' knowledge is evaluated before the educational content is introduced and a post-test to analyse the effect on the results. Pre/post-test may include combinations of various types of test items.

6.1.3 Delivery Cost Savings Assessment

The savings achieved in term of content delivery cost are assessed through objective metrics. The objective assessment consists of computing the savings for risk averse users when using different billing plans.

An analysis of the existing mobile data billing plan has been done for the European market, and presented in section 4. Based on this analysis one can notice that the most common billing type is bundle based billing, that is either capped and people have to pay more when they exceed a certain quantity or it is bandwidth limited. A sample of the most representative plans has been selected in order to assess the savings when delivering multimedia content over mobile networks.

A subjective assessment of the users' preferences for multimedia quality when multiple billing plans are involved was also performed by using scenarios, in which the subjects are asked to select their option based on a given scenario.

6.1.4 Research Instruments

6.1.4.1 Video Sequences

The evaluation of the proposed user risk attitude based adaptive multimedia mechanism is performed in the area of m-learning. Therefore various multimedia clips presenting educational content are used.

Two researchers have tried to classify the multimedia type educational content Fadde (Fadde, 2008) and Moldovan (Moldovan, 2010).

In (Fadde, 2008), the author describes the format of video learning objects, dividing them in four categories:

1. *Mini-Lecture format*: characterised by the presence of one or more teachers speaking into a webcam.
2. *Interview format*: similar to the interviews presented on television, where one or more participants answer question(s).
3. *Demonstration format*: the video is characterised by showing something rather than telling something
4. *Scenario format*: characterised by filming people in real setting scenarios.

In (Moldovan, 2010), eight types of educational content have been proposed:

1. *Screencast*: the clip consists of video sequences in which the computer screen is recorded.
2. *Slideshow*: defined as "a sequence of images accompanied by audio narration" (Moldovan, 2010).
3. *Animation*: defined as "computer generated animations" (Moldovan, 2010).
4. *Games & Virtual World Recording:* defined as a multimedia clip presenting "computer generated learning environments, such as educational games, 3D virtual learning environments" (Moldovan, 2010).
5. *Interview:* described as a multimedia clip in which the interviewer and the interviewed are presented or only one of them.
6. *Presentation:* defined as a multimedia clip in which the lecturer and the accompanying slides or blackboard are presented.
7. *Lab Demo:* described as a multimedia clip in which a person shows how to do certain practical things.
8. *Documentary:* characterised as having a "higher number of content types that may occur across the different scenes comprising the clip" (Moldovan, 2010).

It can be noticed that the first category is actually a subset of the second one, and some of the video categories being shared among the two authors. For the test performed in this research, multimedia clips belonging to the categories defined by Moldovan (2010) are used.

6.1.4.2 Mobile Devices

An analysis and classification of mobile devices present on the market during the period 2008 - 2011[117] has been done in section 3. The section also presented an analysis in terms of their: resolution, screen size, access to cellular networks and supported video formats for the feature phones and smartphones. Smartphones have the best multimedia capability and most of them have access to 3G and 3G transitional networks, which makes them suitable for multimedia content delivery (Ullrich et al., 2010). It has been shown that the most used resolution for the period 2009-2010, for this kind of devices is 480 x 800. This resolution, according to the mobile devices found so far for 2011[117] seems to be the most popular as well. Moreover this resolution is common to other mobile devices such as notebooks. The second most used resolution in 2009-2010, was 240 x 320, a resolution that is very popular among feature phones (44%) covering most of the feature phones released (see section 1.3). These two resolutions cover the majority of the smartphones (53%) and feature phones (46%) released on the market (49% in total during 2009-2010). Therefore two mobile devices having this resolution were selected for this study.

It was decided that both devices to be smartphones, due to the fact that these devices would soon be dominant on the market (Ho, 2009) . Concerning the OS, Android smartphones were selected due to the fact that they have the most common OS on the market (IDC, 2011; comScore, 2011). Concerning the manufacturer, Samsung and Google were selected, since Samsung is the most used manufacturers by the overall mobile subscriptions, and Google has the most smartphones subscribers (comScore Mobile Subscribers, 2011).

6.2 SET UP

This section presents the set up for the objective and subjective video assessment. Multimedia clips used in the objective and subjective video assessment, how they have been selected and based on what criteria. The selection of the multimedia clips is presented first. They are used both for objective and subjective studies. Then the section will present the set-up which is used just in the subjective video assessment.

6.2.1 Subjects

82 subjects took part in this study on volunteer basis. Two of these did not provide their age and had to be eliminated leaving 80 subjects. Furthermore, four more people have to be eliminated in order to comply with the ITU-T P.910 recommendations (ITU-T P.910, 2008). According to the ITU P.910, the subjects “should not be directly involved in picture quality evaluation as part of their work and should not be experienced assessors”. The four people eliminated declared that they work in the area of subjective quality evaluation.

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[117] Up to 14 June 2011

As a result, the data collected from 76 subjects was used for the analysis. The subjects were either students (37) or professionals (39).

The subjects’ division based on gender is presented in Figure 6-2. Most of the subjects were males, accounting for 74% of the total subjects.

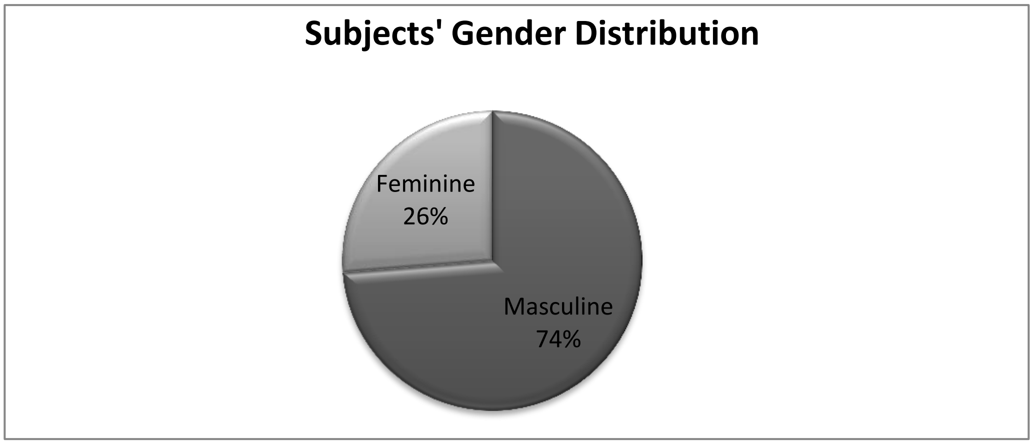

Figure 6-2 Subjects' Gender Distribution

The subjects’ age is quite spread. Their ages varied from 19 to 57 years old, with most of the subjects (37%) being younger than 30 years (Figure 6-3 & Figure 6-4).

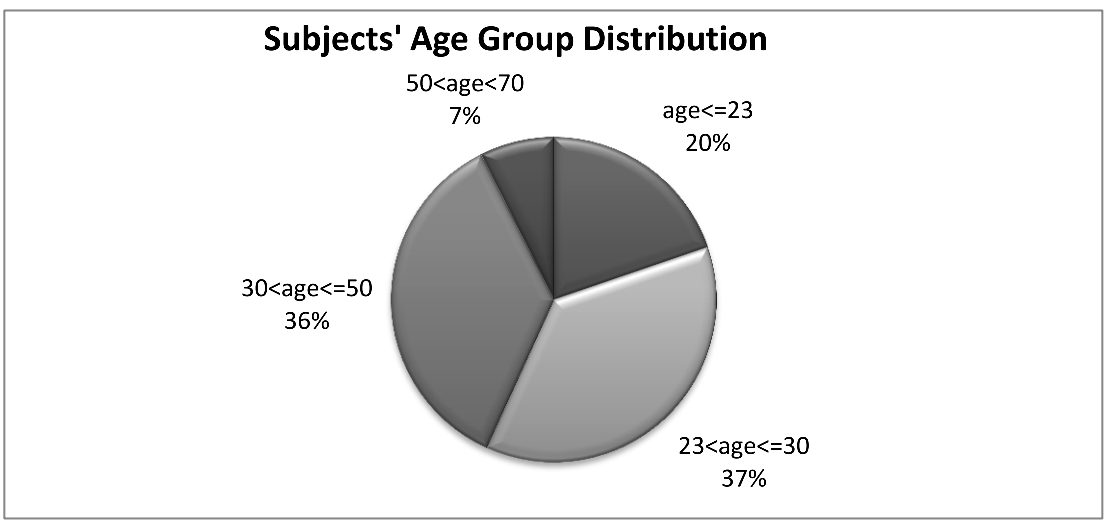

Figure 6-3 Subjects' Age Group Distribution

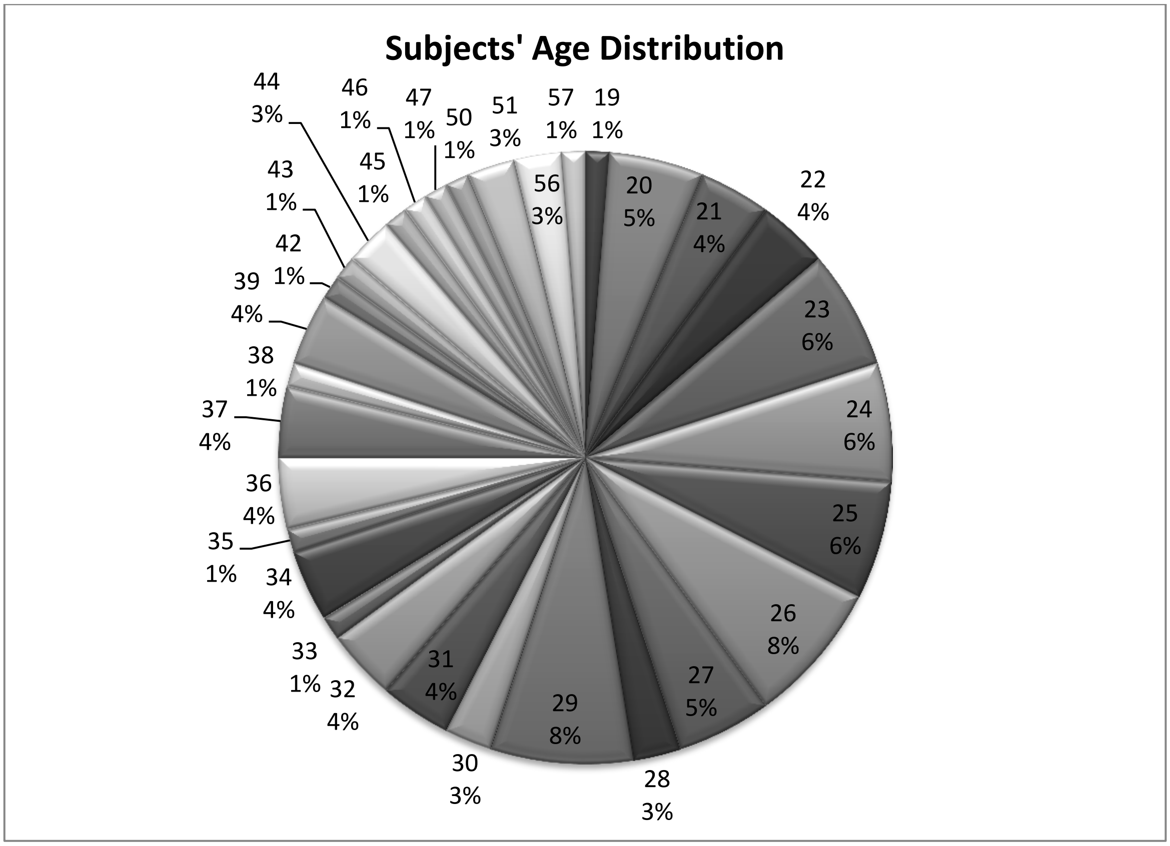

Figure 6-4 Subjects' Age Distribution

6.2.2 Mobile Devices

The two smartphones selected for the study were Google Nexus and Samsung Europa, based on the fact that their resolutions cover most of the smartphones between 2009-2010 (see section 6.1.4.2). Their characteristics are presented in Table 6-1. The first column is the device name, the second its resolution, the third column presents the screen size, the fourth the video capabilities, the fifth column the networks to which they have access to, and the last two columns the internal memory and CPU. As it can be seen both devices have access to high bandwidth mobile networks, making them suitable for multimedia delivery.

Table 6-1 Mobile Devices Characteristics

Device	**Resolution**	**Screen Size**	**Video Capabilities**	**Mobile Networks**	**Internal Memory**	**CPU**
Google Nexus	480 x 800	3.7''	MP4/H.263/H.264	2G, 2G transitional, 3G, 3G transitional, Wi-Fi	512MB	1GHz
Samsung Galaxy	240 x 320	2.8''	MP4/H.264/H.263	2G, 2G transitional, 3G, 3G transitional, Wi-Fi	170MB	600MHz

6.2.3 Multimedia Sequences

Multimedia Sequence Selection Criteria

Multimedia clip sequences used in both objective and subjective test were selected to match the categories from Fadde (2008) and Moldovan (2010). Since Moldovan (2010) classification takes into account more characteristics of the multimedia clips, it was chosen as the preferred guideline based on which multimedia clips were selected. This research has merged the *Animation* and *Games & virtual world recordings* categories. The reason for doing so, is that the cartoons (from which the *Games & virtual world recordings* is) are defined as animations. Also, both categories are defined as being computer generated, one as computer generated animation, and the other one as a computer generated cartoon that can be one and the same thing. Therefore seven categories of multimedia education content were considered and thus seven multimedia clips matching each category were selected.

The multimedia educational clips that were used during assessment were downloaded from the iTunes U[niversity] (iTunesU). iTunes U[niversity] is a distribution system having over 350 000 lectures from more than 800 universities (iTunesU). About half of these universities have their courses available to the public (iTunesU). Moreover, iTunes U[niversity] is the most popular online educational catalogue (Zibreg, 2010). The supported multimedia content type is MPEG-4 with H.264 compression, having the extensions .mov, .mp4, or m4a (ITunesU Administration Guide, 2010), a multimedia format that makes it accessible also from non-Apple products.

In order to post content on iTunes U[niversity] institutions have to be declared eligible which involves passing through an application that involves a great deal of logistics (iTunesU; iTunesU Eligibility; Strickland, 2007). One of the conditions for having content publicly available is that the institution needs to have at least 150 files and the content be added afterwards on a regular basis (Wicks, 2010).

Description of the Multimedia Clips

A description of the multimedia clips is presented next:

- **Clip 1**: *Harmonizing Content, Channels and Platforms to Create Competitive Advantages*, published by Duke University, The Fuqua School of Business
- **Clip 2**: *Moodle Induction Video*, published by City University London- Learning Development Centre
- **Clip 3**: *Beverly and Dereck Joubert*, published by The American Academy of Achievements
- **Clip 4**: *Science and Cooking: A Dialogue*, published by Harvard University, Harvard School of Engineering and Applied Sciences
- **Clip 5**: *Curtis Sittenfeld*, published by University of Iowa, The Iowa Writers Workshop
- **Clip 6**: *An Introduction to the Marine Ecology Research Centre*, published by Southern Cross University, Marine Ecology Research Centre
- **Clip 7**: *Year on Earth*, published by Cassiopeia Project, Space

Next, the sequences are described in more details:

Clip 1*: Harmonizing Content, Channels and Platforms to Create Competitive Advantages*

The multimedia clip explained Turner's television network and his partners' business plan. The first test sequence extracted from the multimedia clip, presents statistics regarding the user spending for the media segment over several years. The second test sequence details the distribution partners that Turner has on emerging markets and their business strategies regarding the TV market (Figure 6-5). Both the selected sequences have slides on the video, with the voice of the presenter explaining the slides. The extracted multimedia clips belong to the *Slideshow* category.

Figure 6-5 Harmonizing Content, Channels and Platforms to Create Competitive Advantages

Clip 2: *Moodle Induction Video*

The multimedia clip explains to the students how to use Moodle (Figure 6-6). The first extracted sequence explains the components of the Moodle application, and shows an explanation on what students see once they are logged in. The second extracted sequence explains students how they can display or hide their course content. Both sequences consist of screen recordings of the Moodle system and a voice explaining. Different parts of the system are zoomed in or zoomed out during the presentation. The extracted sequences belong to the *Screencast* category.

Figure 6-6 Moodle Induction Video

Clip 3: *Beverly and Dereck Joubert*

The clip *Beverly and Dereck Joubert (*Figure 6-7*)* presents Beverly and Dereck Joubert speaking about their environmental activities. They use slides for their presentation. The first extracted sequence discusses about suprapopulation and its consequences. The second sequence discusses about the extinction of species and their decline, focusing on Africa. Both sequences consist of the presenters and the slides in their background. The extracted clips belong to the *Presentation* category.

Figure 6-7 Beverly and Dereck Joubert

Clip 4: *Science and Cooking: A Dialogue*

The *Science and Cooking: A Dialogue* clip (Figure 6-8) makes an overview of the *Science and Cooking* course organised at Harvard University, School of Engineering and Applied Science. The clip presents as well some applications of science for cooking purposes. The first selected sequence, presents what spherification is, while the second sequence explains how a sphere can be created by using Calcium. These sequences belong to the *Lab Demo* category.

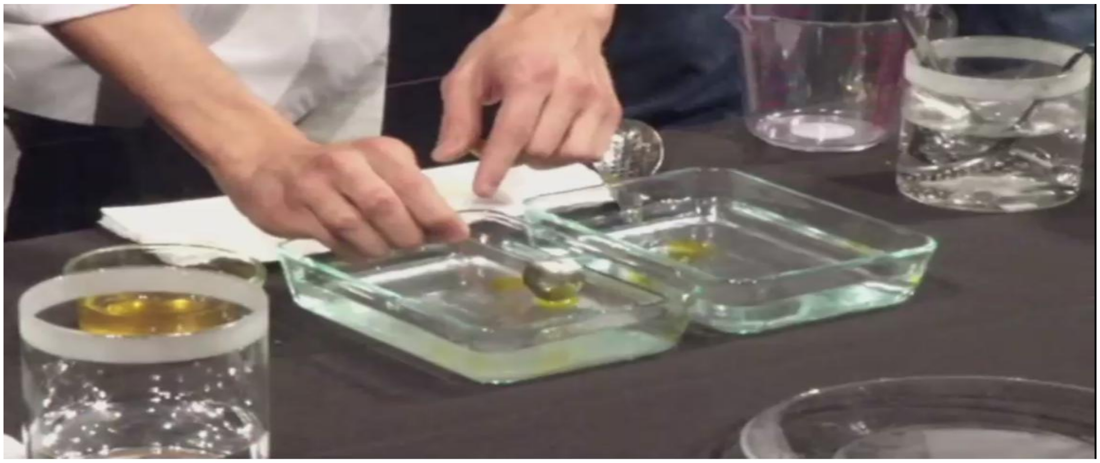

Figure 6-8 Science and Cooking: A Dialogue

Clip 5: *Curtis Sittenfeld*

The *Curtis Sittenfeld* clip (Figure 6-9) is a multimedia clip from a series of interviews at the Iowa Writers Workshops. This clip presents the interview with Curtis Sittenfeld, regarding her book, *American Wife*. In the first extracted sequence the interviewer introduces the book. The second sequence discusses how fiction and reality are embedded in the novel. Both sequences belong to the *Interview* category.

Figure 6-9 Curtis Sittenfeld

Clip 6: *An Introduction to the Marine Ecology Research Centre*

The *An Introduction to the Marine Ecology Research Centre* (Figure 6-10) presents the Marine Ecology Research Centre. The first extracted sequence presents the marine ecology research arenas. The second sequence documents the National Marine Science Centre. Both the extracted sequences belong to the documentary category.

Figure 6-10 An Introduction to the Marine Ecology Research Centre

Clip 7: *Year on Earth*

This clip presents how a year on Earth is formed (Figure 6-11). The first selected sequence shows how a year on Earth is formed based on the Earth's movements around the Sun. The second sequence show how Earth's orbit moves relatively to the Sun. Both the extracted sequences belong to the Animation category.

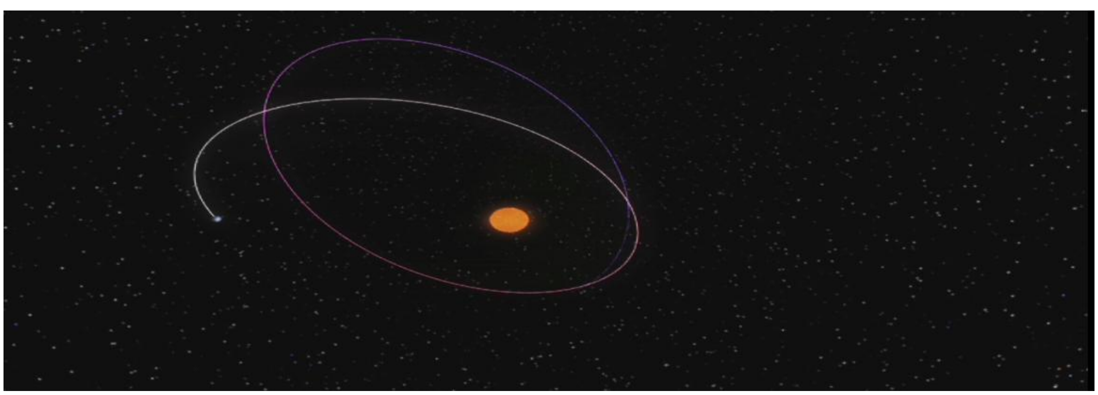

Figure 6-11 Year on Earth

Multimedia Properties

Table 6-2 presents the characteristics of the multimedia clips presented above from which the sequences were extracted. The first column has the multimedia clip name, the second column the encoding format at which they were downloaded, the third column clip resolution, and the forth column the length of the clip. As it can be seen, the selected sequences were taken at high resolution, with the aim to be able to extract multimedia clips of suitable resolution for the test.

Table 6-2 Mobile Clips Characteristics

Multimedia Clip	Encoding	Resolution	Length
Harmonizing Content, Channels and Platforms to Create Competitive Advantages	MEPG-4 ACV/H.264	720 x 960	53 minutes, 32 seconds
Moodle Induction Video	MEPG-4 ACV/H.264	720 x 1280	8 minutes, 30 seconds
Beverly and Dereck Joubert	MEPG-4 ACV/H.264	720 x 1280	10 minutes, 56 seconds
Science and Cooking: A Dialogue	MEPG-4 ACV/H.264	540 x 960	2 hours, 6 minutes, 7seconds
Curtis Sittenfeld	MEPG-4 ACV/H.264	720 x 1280	21 minutes, 40 seconds
An Introduction to the Marine Ecology Research Centre	MEPG-4 ACV/H.264	720 x 1280	1 minute, 44 seconds
Year on Earth	MEPG-4 ACV/H.264	540 x 960	9 minutes, 27 seconds

Table 6-3 presents the categories to which the multimedia clips belong to. The second column of Table 6-3 described which category the extracted clips matched from the ones described in (Fadde, 2008). The third column shows which of the categories presented in Moldovan (2010) the multimedia clip matches. The forth column indicates which category the original clip was placed in iTunes U[niversity]. As it can be seen, the clips are selected to match a broad area of educational content, and the categories presented in Moldovan (2010) and Fadde (2008). From here on the categories defined in Moldovan (2010) are used to identify the clips, in order to simplify writing the whole name.

Table 6-3 Multimedia Clip Categories

Multimedia Clip	**Clip format as given in (Fadde, 2008)**	**Clip category as given in** (Moldovan, 2010)	**Clip category as given on iTunes U[niversity]**
Harmonizing Content, Channels and Platforms to Create Competitive Advantages	Mini-lecture	Slideshow	Business
Moodle Induction Video	Demonstration	Screencast	Learning Resources
Beverly and Dereck Joubert	Mini-lecture	Presentation	Environmental
Science and Cooking: A Dialogue	Demonstration	Lab Demo	Science
Curtis Sittenfeld	Interview	Interview	Unknown
An Introduction to the Marine Ecology Research Centre	Scenario	Documentary	Ecology
Year on Earth	Scenario	Animation	Astronomy

All the educational clips have been downloaded at very high quality even though a lower quality version was available. This decision was justified by the fact that different versions with various bitrate values and resolutions of the same clip were needed therefore it was easier to get a higher quality clip and reduce the resolution.

The selected multimedia clips have been adapted following the indication provided by the adaptive multimedia mechanism presented in the section 5.2.5. Two multimedia sequences (around 30s) were extracted from each multimedia clip. The reason for choosing 30s was that it is a suitable length for delivering multimedia to mobile devices (Trifonova & Ronchetti, 2003), and also for keeping the length of the test short. The clips were cut such that they match the categories presented in Table 6-3, they are approximately 30s long, they represent a standalone educational content, and the educational question that contained information presented just in the multimedia clip image/video and not in the sound could be formulated.

The first sequence was used for the first device and the second one for the second device. The test sequences resolution and bitrate values have been modified to match 240p (240 x 320) and 480p (480 x 800) classes. The two devices used for the test (see section 6.2.2) are chosen to have resolutions from the 240p class (Samsung Galaxy) and 480p class (Google Nexus). The resolution is reduced because higher resolution implies larger content size, which could imply higher cost for delivery. There is no sense to deliver higher resolution multimedia if the device will display it anyway at a lower resolution. Two types of wireless networks were considered for the study. Therefore the multimedia quality clip bitrate values were reduced to match the proposed multimedia recommendation algorithm for Wi-Fi and 3.5G networks. There are several reasons why the bitrate adaptation is performed on the multimedia clips. One of them is that the lower the bitrate is, the smaller the size of the multimedia clip is, which can have consequences on the price paid for the content delivery. Also the bitrate is considered to be "critical for the final perceptual outcome" (Khan et al., 2010). Another reason is that he high bitrate values for multimedia are not suitable for cellular networks due to their limited bandwidth, and therefore lost may occur affecting the user perceived quality.

Multimedia Clip Used for the Scenario based Assessment

A scenario based assessment was used to determine subjects' preferences depending on the content when cost and multimedia clips of different quality are involved. For this scenario a different multimedia clip was used. The clip *Introductory Trailer to Chandra* was taken from the iTunes U[niversity] page of Harvard University. This clip (Figure 6-12) does an introduction on the importance of telescopes for knowing more about the universe. It also introduces Chandra, the most powerful telescope ever made in 1999.

Figure 6-12 Sequence Selected for the Scenarios

The selected multimedia clip had a resolution of 540 x 960, a bitrate value of 3654kbps, and the encoding format is MEPG-4 ACV/H.264. This clip was encoded at different quality levels. For the aim of the study, five different quality levels were chosen. The quality levels follow all the possible multimedia quality levels of the adaptive multimedia mechanism, a device with a resolution from the 480p class, can have (based on the recommendations from section 5.2.5).

The scenario was done for the 480p class because it is the most used resolution class, among smartphones in 2009-2010, and continues to be in 2011[118] (see section 3.2.3.1.1). However, since the 480p class uses resolutions from the 360p class, when the bandwidth is low, one can say that this class was covered as well. Table 6-4 presents different encoding settings that were used for the scenario based study. The first column shows the resolution, the second the bit rate the multimedia clip was encoded, and last column presents the size of the clip for a given bitrate and resolution.

[118] Up to 14 June 2011

Table 6-4 Multimedia Clip Encoding for the Scenarios

Multimedia Clip Resolution	Multimedia Clip Bitrate (kbps)	Multimedia Clip Size (MB)
480 x 800	1000	14
480 x 800	600	9.15
320 x 480	550	8.46
320 x 480	350	5.99
320 x 480	150	3.65

6.2.4 Risk Attitude

Subjects' risk attitude was assessed by using Equation 1 presented in section 5.1. That formula uses the general risk question, the age and the gender, in order to compute the risk aversion of an individual. The subjects were asked at the beginning to provide their age, and gender and to answer the general risk question. Based on this data, the formula was used to divide subjects into two classes risk averse and risk seekers. The result of the formula was interpreted as follows: the subjects who get a value lower or equal to 5, are considered risk averse, and the ones over 5 are considered risk seekers.

A stereotypical approach was considered because the methodology allows an easy division of people in two groups: risk averse and risk seekers. An overlay approach would have been more suitable when an adaptation based on the learning outcome would have been performed. A Bayesian network approach would have been more suitable when the probabilities for all the factors taken into account would have been known which it is not the case here as the probabilities are known only for the part of the formula involving the age and the gender.

Figure 6-13 presents the subjects' risk attitudes. 36% of the subjects were risk averse and 64% risk seekers. This high number of risk seekers subjects can be explained by the fact that many of the subjects have a high level of education (e.g. postdoctoral researchers), and this category is known to have a positive attitude towards risk (Rosen et al., 2003; Donkers et al., 2001).

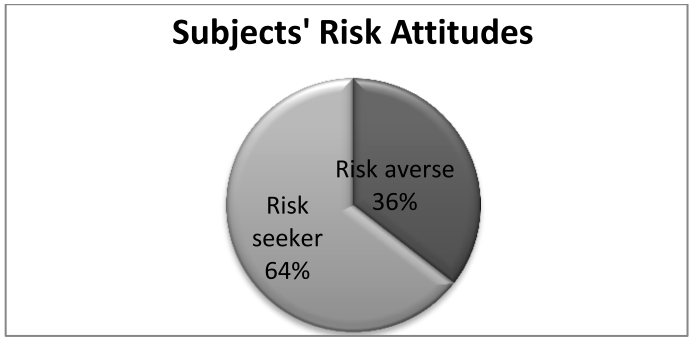

Figure 6-13 Subjects' Risk Attitude

The division based on risk attitude was used in experimental study to create two groups: risk averse and risk seekers. Based on the group multimedia content of different quality is provided to the subjects. Risk averse subjects are provided with the multimedia clips of lower bitrate than the clips released to the risk seekers. The risk adverse group has 27 subjects and the risk seeking group 49 subjects.

6.2.5 Procedure

The subjects were first asked to fill a questionnaire with the demographic data and to answer the general risk question. Based on this data they were divided into one of the two groups. The subjects were also asked to do a pre-test, in order to evaluate their knowledge level on different areas covered by the multimedia clips. The results of the pre-test are used to assess learning achievements.

Afterwards, a written description of the experiment was given to the subjects. As recommended by the ITU-T P.910 (ITU-T P.910, 2008), the subjects were explained the assessment procedure and the scale of assessment.

A training session was also done before starting the actual experiment in order to avoid biases due to misunderstanding. The results of this session were not taken into account in the analysis. The training session is also one of the recommendations from ITU-T P.910 (ITU-T P.910, 2008). Up to this point, the tasks were the same for the subjects regardless of their group. From this point on, the division in the groups accounted for the multimedia version they received: risk averse subjects got the low quality version and risk seekers got the high quality version.

Among the methods available for assessing the multimedia quality, Absolute Category Ranking (ACR) was chosen. This method was considered the most suitable since it does not imply viewing two sequences in parallel, or having a reference among the clips. If the subjects can see both the reference and the adapted version either in parallel or at different point in times. The learning achievements would have been affected. It is hard to assess if the subjects accumulated knowledge by seeing the reference or the adapted version.

The subjects saw the first sequence of the multimedia clips on the Samsung Galaxy Europa smartphone, and after that the second sequence of the multimedia clips on the Google Nexus. After seeing each clip they have to rate the multimedia clip quality, on the 5 point MOS scale, and to answer the question related to the video. A between subjects design was chosen in order not to affect the assessment of the learning outcomes. The sequences were distributed for all the subjects in the same order.

After the subjects finalised the experiment with the second device, they were asked to watch a multimedia clip, encoded at five different quality levels (the multimedia clips used for the scenario based assessment). This task was independent of their division in groups. Afterwards five scenarios were given and the subjects were asked to state their preference for one of the five multimedia qualities in different scenarios.

6.2.6 Data Analysis

Parametric or non-parametric procedures can be used to analyse the data. The parametric analysis works under the assumptions that the sample data has a normal distribution and variances are equal among different groups. Non-parametric analysis does not make these assumptions. However, non-parametric tests are criticised in losing precision and power (Hodges & Lehmann, 1956), and giving a false sense of security; Zimmerman (2000) showing that in fact they can be affected by the variances in groups. Considering these the parametric analyses was used in this research.

Student t-test may be used for analysing whether the differences between two groups are significant. An adaptation of the Student t-test, Welch’s t test (Welch, 1947), can be used when the assumption of equal variances cannot necessarily be made. The Welch’s t-test works also well with samples of unequal sizes, as those involved in this research are. Therefore, Welch’s t test has been considered the most suitable for this study. A confidence interval of 95% was adopted.

The dependent variables included in this research are the MOS score and the learner achievement. The independent variables are the subjects' risk attitudes, multimedia clips classification (e.g. slideshow, cartoon, etc.), and multimedia clips categories (clips encoded at different quality levels). The data was analysed using *R*, released 1.12.1 (R Project, n.d.).

A between subject design was selected. As opposed to the within subject design in which the subject participated both in the treatment and control group, in an between subject design the subjects cannot be part of both groups. This constraint has to be included due to learning outcome assessment. If the same clip with different quality will be used for a single subject it would have been hard to know from what clip the subject actually learnt.

6.3 OBJECTIVE ASSESSMENT

This section aims to assess objectively the multimedia quality and the savings obtained for risk averse users when using a certain billing plans. Video quality is assessed by using two well-known metrics: PSNR and SSIM, and the results of the two metrics are mapped onto MOS scale. The savings are computed by using different scenarios, in which representative billing plans from the section 4 are used.

6.3.1 Video Quality Analysis

Objective multimedia quality analysis is done using two well-known assessment metrics: PSNR, which is the most, used one in video quality assessment due to its low complexity, and SSIM. These metrics were chosen because research has been performed to map their results on the MOS scale making them comparable with subjective assessment results.

I use these two metrics in order to assess how much the video quality has been degraded for the people getting the lower quality. The obtained values are presented in Table 6-5 (for 240p class), Table 6-6 (for 360p class), and Table 6-7 (for 480p class). The first column presents the multimedia clip type. For each clip the PSNR value is given in the second column. The third column has the converted value from PSNR to MOS based on Figure 6-1. The fourth column presents the SSIM value and the last one the equivalent of the SSIM value on the MOS scale.

For 240p class, it can be noticed that for most of the videos, both techniques of assessing video quality, score for the lower bitrate version a MOS of 4 (Good). The only exception being for the *Documentary* clip where SSIM metric resulted in a value of 3 (Fair) on the MOS scale. This could be explained by the fact that *Documentary* clip was more dynamic, with different scenes, which require higher quality.

Table 6-5 PSNR & SSIM Value for 240p Multimedia Class

Multimedia Category	PSNR (dB)	PSNR_MOS	SSIM	SSIM_MOS
Slideshow	39.51	4	0.98	4
Screencast	39.69	4	0.98	4
Presentation	41.05	4	0.98	4
Lab Demo	37.14	4	0.97	4
Interview	40.94	4	0.98	4
Documentation	33.82	4	0.95	3
Animation	42.42	4	0.97	4

For 360p class, the lower quality multimedia clips got MOS values between 5 (Excellent), and 3 (Fair). The *Slideshow* sequence got with all metrics 5 on a MOS scale. *Presentation*, *Lab Demo*, and *Interview* got all 4 with both metrics, and the Animation with the PSNR. The rest of clips got a MOS value of 3.

For 480p class, the lower quality clips, got as well MOS values between 5 and 3. *Slideshow* sequence got again, with all metrics 5 on a MOS scale. For the rest of the multimedia clips, except the one from the *Documentary* category, MOS values of 4 were obtained. The *Documentary* clip got a MOS value of 3.

Table 6-6 PSNR & SSIM Value for 360p Multimedia Class

Multimedia Category	PSNR (dB)	PSNR_MOS	SSIM	SSIM_MOS
Slideshow	46.15	5	0.99	5
Screencast	31.52	3	0.94	3
Presentation	38.61	4	0.96	4
Lab Demo	35.65	4	0.95	4
Interview	37.80	4	0.95	4
Documentary	29.47	3	0.85	3
Animation	38.10	4	0.94	3

Table 6-7 PSNR & SSIM Value for 480p Multimedia Class

Multimedia Category	PSNR (dB)	PSNR_MOS	SSIM	SSIM_MOS
Slideshow	49.00	5	0.99	5
Screencast	37.45	4	0.98	4
Presentation	42.56	4	0.97	4
Lab Demo	42.25	4	0.97	4
Interview	43.32	4	0.98	4
Documentary	34.71	3	0.94	3
Animation	40.10	4	0.97	4

It can be noticed that for neither of the classes the MOS values is under 3 (Fair quality). In conclusion, it can be noted, that based on the objective metrics, the MOS score for the multimedia clips is at least at a fair quality, mostly having a good quality. A good quality is considered satisfactory for all users (Telchemy, 2011).

6.3.2 Content Delivery Cost Savings Assessment

In order to analyse the savings the billing plans that are the most used ones were selected for this study. It can be noticed from the analysis done in section 4, that the bundle based billing plans are by far the most common form of billing for mobile data. Two kinds of bundle based billing plans can be distinguished:

- The user pays for the exceeding quantity
- The bandwidth is limited when exceeding the quantity

Therefore, billing plans pertaining to each of these categories were selected. Two billing plans from the first category were selected, due to the difference in price to be paid for the exceeding quantity in the two cases. The following billing plans are considered:

1. Vodafone Ireland daily data billing plan, in which for 50MB one pays €0.99, and for the exceeding quantity €1/MB
2. O2 Ireland monthly data billing plan, in which one gets 500MB of data, and for the exceeding quantity he pays 2c/MB
3. T-Mobile Germany, in which after consuming 300MB for the monthly bundle the traffic is limited to 64kbps download

For each of the following billing plans two case studies were considered: one in which the user is still in the bundle quantity, and the other one in which s/he exceeds the bundle. For exemplification I used the multimedia clip from the scenario based assessment.

The multimedia clip, *Introductory Trailer to Chandra*, was used. The clip is 1 minute and 44 seconds long. Educational content designed for mobile devices should be in "bite size" (Bradley et al., 2009; Traxler, 2007) and should not be longer than a few minutes (Trifonova & Ronchetti, 2003; Bradley et al., 2009), starting from 30 seconds (Trifonova & Ronchetti, 2003). Based on the aforementioned reasons, *Introductory Trailer to Chandra* was considered a suitable multimedia clip to be used in our study.

Four version of the multimedia clip have been created using *XMedia Recorde*: two versions for the 240p class and two versions for the 480p class. For the 240p class, for risk averse learners the bitrate is of 150kbps and for the risk seekers 250kbps (see section 5.2). For the 480p class, for risk averse learners the bitrate is of 600kbps and for the risk seekers 1000kbps (see section 5.2).

Table 6-8, Table 6-9, and Table 6-10 present the results of assessing savings by using the proposed mechanism. All the tables address both the classes 240p (rows three and four of the table) and 480p (last two rows of the table). The savings are presented in terms of monetary cost for the case in which the learner exceeds the bundle quantity. For the case in which the learner has still data in the bundle (having all the bundle data remaining is considered here), the savings are assessed in terms of the remaining data in the bundle. The first column of each of these tables present the clip version, there are two for each of the classes, one version for the risk averse and one for the risk seeking learners. The second column presents the size of the multimedia clip. The third and the fourth column address the case in which the learner has data in the bundle. The third column presents the remaining data from the bundle (considering that no data has been previously consumed in the bundle), after receiving the multimedia clip over the wireless network. The forth column presents the percentage of savings obtained in the bundle data for risk averse as compared to risk seekers.

For Table 6-8, and Table 6-9, the fourth column presents the price to be paid if the multimedia clip would have been billed as exceeding the quantity from the bundle. The last column presents the savings in percentage for the risk averse learners.

In Table 6-8 it can be seen the results for the first scenario. It can be noticed that in terms of monetary cost, savings around 30% are obtained for the risk averse people, when they exceed the bundle quantity, that means €1.20 less for the first class and €4.85 less for the second class. When the subjects still have data in the bundle available, risk averse people save with 2.4% more data quantity for the bundle (1.2MB), for the 240p class and 9.7% (4.85MB) for the 480p class.

Table 6-8 Savings for the First Billing Plan

Clip Version	Size (MB)	All bundle data available		Exceeding bundle quantity	
		Remaining data	**Savings (remaining data)**	**Price (€)**	**Savings (monetary)**
240p class					
Chandra: risk averse (150kbps)	2.90	47.10	2.4%	2.90	29.27%
Chandra: risk seeker (250kbps)	4.10	45.90	-	4.10	-
480p class					
Chandra: risk averse (600kbps)	9.15	40.85	9.7%	9.15	34.64%
Chandra: risk seeker (1000kbps)	14	36		14	-

The savings for the second scenario are presented in Table 6-9. Savings around 30%, (when the learner exceeds the quantity) are obtained also for the risk averse learners. The savings for the remaining data are lower in percentage, since a bigger quantity is present in the bundle. In terms of data saved, they are equal as for the previous case: 1.2MB for the risk averse learners from the 240p class and 4.85MB for the risk averse learners from the 480p class.

Table 6-9 Savings for the Second Billing Plan

Clip Version	Size (MB)	All bundle data available		Exceeding bundle quantity	
		Remaining data	**Savings (remaining data)**	**Price (€)**	**Savings (monetary)**
240p class					
Chandra: risk averse (150kbps)	2.90	497.10	0.24%	0.058	29.27%
Chandra: risk seeker (250kbps)	4.10	495.9	-	0.082	-
480p class					
Chandra: risk averse (600kbps)	9.15	490.85	0.97%	0.183	34.64%
Chandra: risk seeker (1000kbps)	14	486		0.28	-

Table 6-10 presents the savings for the third scenario. The last two columns present the download time necessary to get the multimedia clip, and the percentage by which the download is faster for the risk averse learners. The bandwidth for this billing plan is limited to 64kbps, which leads to downloading times of 46 seconds in the 240p class for the risk averse and 1 minute and 6 seconds for risk seeking learners. This means that the download time for the risk averse is approximately with 30.30% faster than for the risk seekers. For the 480p class, the download time is approximately of 2 minutes 26 seconds for the risk averse and 3 minutes and 44 seconds for the risk seeking learner. This means that the risk averse learners get the multimedia clip approximately

34.64% faster. Even though the aim of this research was not to reduce the delivery time this is also one of the advantages of using this type of adaptation.

Table 6-10 Savings for the Third Billing Plan

Clip Version	**Size (MB)**	**All bundle data available**		**Exceeding bundle quantity**	
		Remaining data	**Savings (remaining data)**	**Download time**	**Percentage faster**
240p class					
Chandra: risk averse (150kbps)	2.90	297.10	0.41%	46s	30.30%
Chandra: risk seeker (250kbps)	4.10	295.9	-	1min 6s	-
480p class					
Chandra: risk averse (600kbps)	9.15	290.85	1.70%	2min 26s	34.64%
Chandra: risk seeker (1000kbps)	14	286		3min 44s	-

In conclusion savings of approximately 30% in terms of monetary cost are obtained for the risk averse users, when they pay outside the bundle. Savings are obtained as well, in terms of the remaining quantity of data in the bundle. Benefits of this adaptation when the bandwidth is limited can be seen when streaming the multimedia clip. The adapted multimedia clip version when streamed has better chances of not being affected by interruptions, due to the low bandwidth. These interruptions are disruptive because they affect the concentration (Csikszentmihalyi, 1991).

6.4 SUBJECTIVE ASSESSMENT

The aim of the subjective study is to investigate whether the proposed multimedia mechanism has affected:

- the perceived multimedia quality for the risk averse and risk seekers subjects
- the learning achievements for the risk averse and risk seekers subjects are affected
- the subjects preferences change depending on the context when cost/billing plans and multimedia clips of different quality are involved (scenario assessment).

The user's perceived multimedia quality was assessed on the 5 point MOS - Mean Option Score scale. Learning achievements were measured based on the number of correct answers to the questions given in the study. The questions were a combination of various test terms types. Changes in subject preferences are measured using scenarios that involved different billing plans, present on the mobile data market.

6.4.1 Subjects Preferences Survey

Subjects were asked to rate their familiarity with subjective quality evaluation. After the elimination of the subjects who work on subjective quality evaluation, most of the subjects (53) reported not being familiar with subjective quality evaluation, and 23 reported that they are familiar with the area (Figure 6-14).

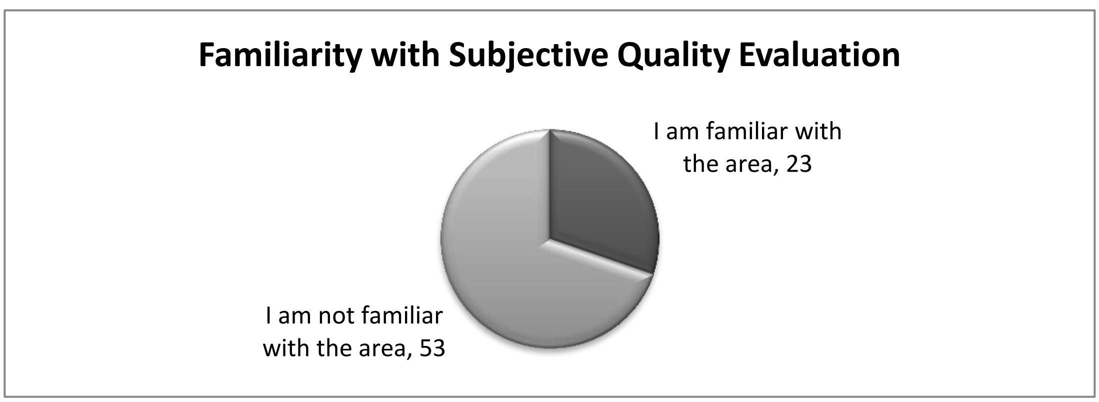

Figure 6-14 Subjects' Familiarity with Subjective Quality Evaluation

The subjects were asked to report which is their preferred educational content type for learning when using mobile devices. They had to choose from the following options available: text, text and images, audio, and multimedia. Multiple choices were allowed. Most of the people, 46.05%

selected multimedia as their preferred content. 36.84% preferred text and images, 25 % preferred audio and 19.74% text (Figure 6-15).

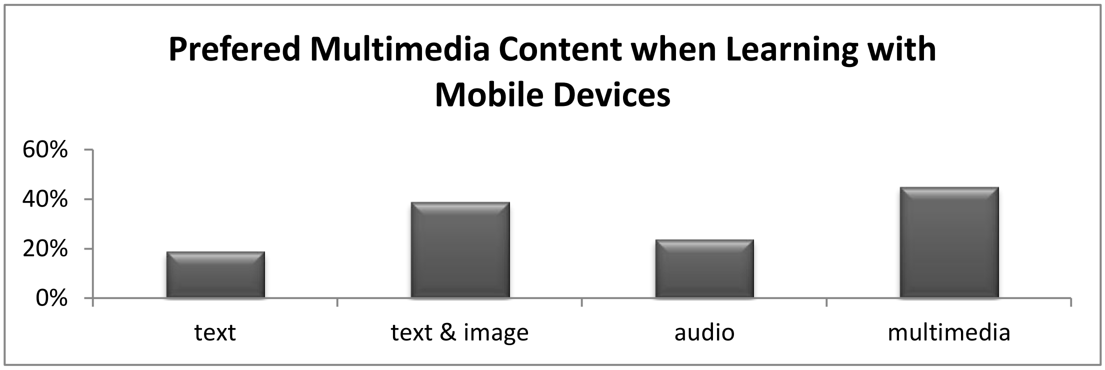

Figure 6-15 Preferred Multimedia Content Type when Learning on Mobile Devices

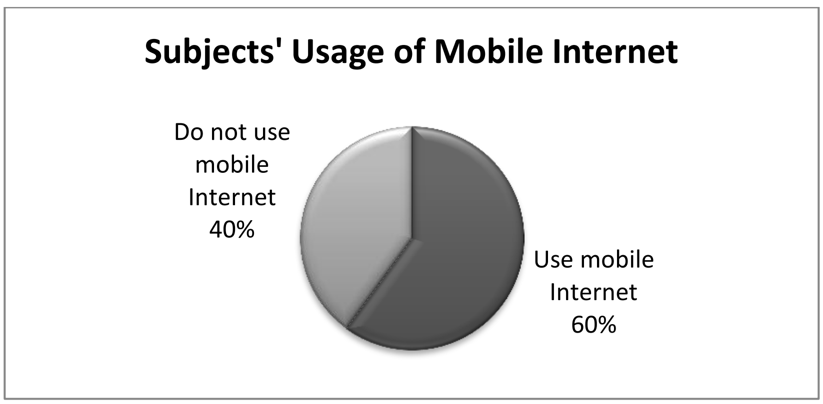

Figure 6-16 Subjects' Usage of Mobile Internet

60% of the subjects reported using mobile Internet (Figure 6-16). The people that answered that they do not use it were asked to provide a reason. Table 6-11 represents the reasons as reported by the subjects. The first column shows the reasons for not accessing mobile Internet and the second column, the percentage of subjects who provided an answer from the ones answering the question. Most of them reported cost and the preference of usage of other means for accessing Internet.

Table 6-11 Reasons for not Using Mobile Internet

Reason for not using mobile Internet	**Percentage**
Cost	27%
Use other means to access Internet (e.g. use a desktop computer)	27%
Not interested	20%
Incompatible cell phone	18%
Difficulty in accessing it	8%

Figure 6-17 presents how many subjects use the mobile Internet for watching multimedia clips. 70% of the subjects reported that they use the mobile Internet to watch multimedia clips, as opposed to 30% who do not.

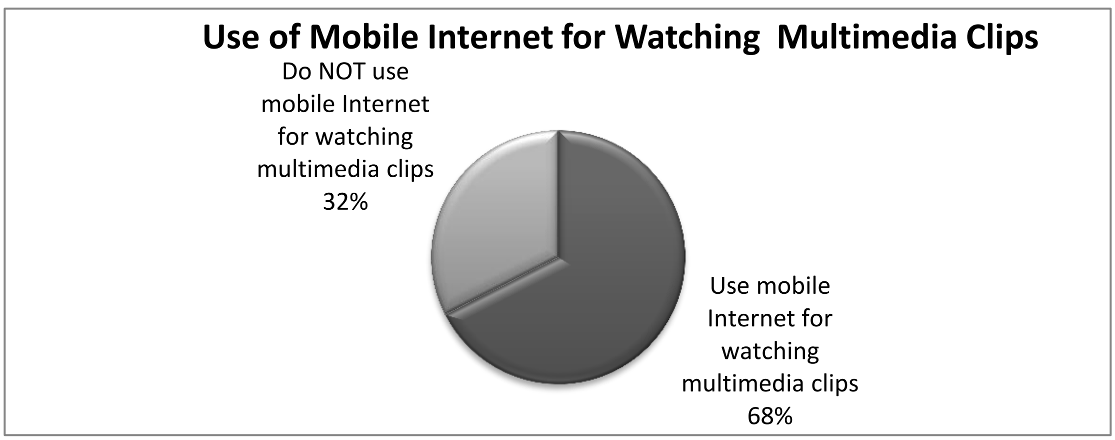

Figure 6-17 Subjects' Usage of Mobile Internet for Watching Multimedia Clips

Another question from the survey questionnaire has assessed if people estimates how much they spend on mobile Internet. Among the people who use the mobile Internet, 62% reported to find it difficult to estimate how much they spend when using the mobile Internet (Figure 6-18). This is in concordance with previous studies who reported difficulties in people estimating how much they have to pay for mobile Internet (Roto et al., 2006).

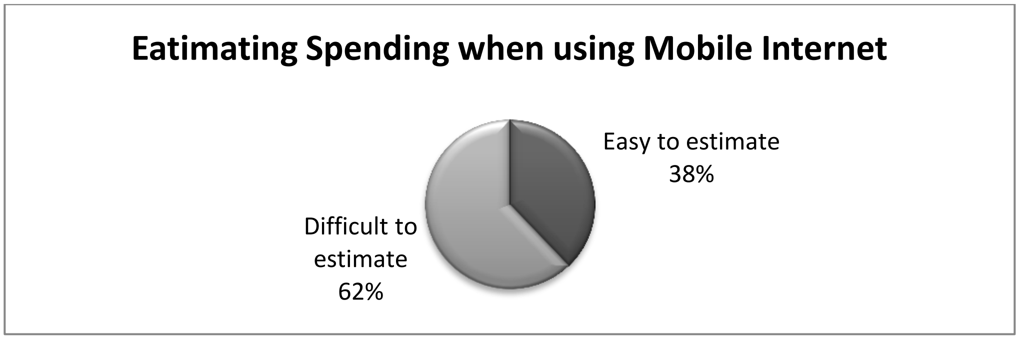

Figure 6-18 Users in Estimation on Spending when Using Mobile Internet

6.4.2 Pre-Test Analysis

The pre-test consists of a combination of Force-*Choice* and *True-False* questions. There are five *Force-Choice* questions and two *True-False* questions, which is in line with the recommendations for an evaluation test, which should not exceed 25 items (Preece, 2000). Each of the seven questions assessed learner knowledge on the information presented in one of the seven sequences. The role of the pre-test is to assess whether the user could have known the answers for the post-test question before seeing the educational content.

Figure 6-19 presents the percentage of people who answered correct the questions based on the risk category they are in, and the multimedia type they have seen. It can be seen that the subjects' had previous knowledge only on the content presented in the *Animation* clip, and much less knowledge regarding the content presented in the other clips.

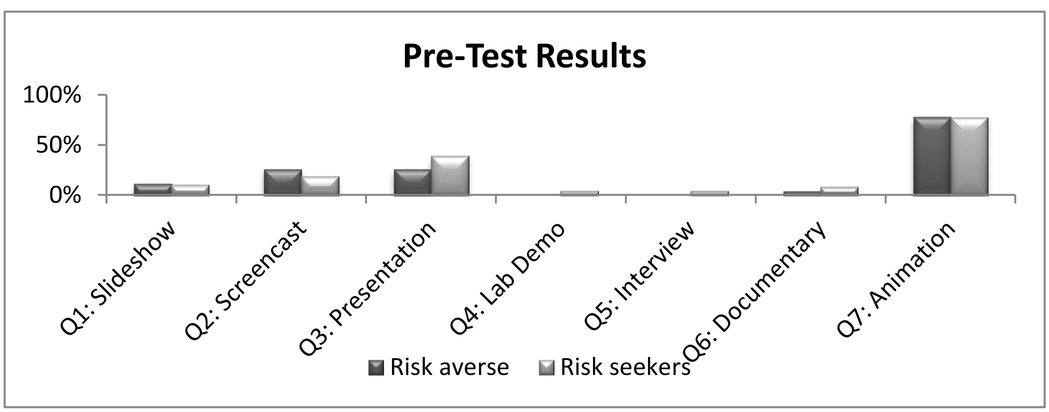

Figure 6-19 Pre-Test Results

In order to determine if the risk averse and risk seekers groups have the same pre-knowledge, in any of the domains of the clips presented, a Welch t test was performed. Welch's t test is an adaptation of the Student t-test for samples that have possibly unequal variances. Since the material presented in each clip, came from different areas, it was decided that the test should be performed for each clip.

The Welch t test was done with a 95% confidence interval on *Slideshow* (t = 0.1201, p-value = 0.9049, CI=0.95), *Screencast* (t = 0.7373, p-value = 0.4645, CI=0.95), *Presentation* (t = -1.1571, p-value = 0.2520, CI=0.95), *Lab Demo* (t = -1.4292, p-value = 0.1594, CI=0.95), *Interview* (t = -1.4292, p-value = 0.1594, CI=0.95), *Documentary* (t = -0.8234, p-value = 0.4131, CI=0.95), and *Animation* (t = 0.2213, p-value = 0.8257, CI=0.95) and it did not show a significant difference between the two groups. Since the two groups do not vary significantly in their knowledge, only the post-test results will be used further on in the analysis.

6.4.3 Assessment for the Galaxy Europa (240p class device)

6.4.3.1 User Perceived Quality Assessment

Figure 6-20 presents the average MOS scores obtained for each of the multimedia clip. It can be noticed that on average there is no significant difference between the MOS scores of the two qualities. *Documentary* is the only clip to have an average MOS value under 3(Fair), the average for risk averse being 2.89 and for risk seekers 2.78. This could be explained by the quantity of details and text presented in the slides that might make them difficult to read at such low resolutions.

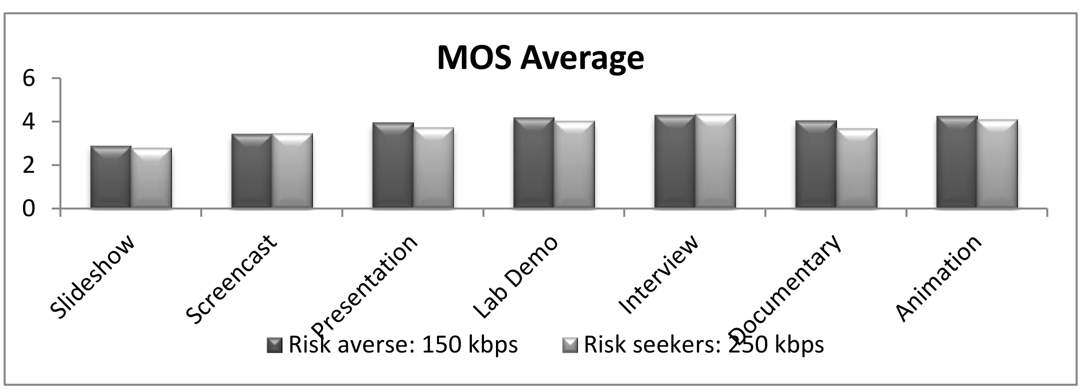

Figure 6-20 MOS Average for 240p Class

In order to see whether there is a significant difference between the two groups, a Welch t test was performed on the results for each clip type: *Slideshow*(t = 0.4285, p-value = 0.6702, CI=0.95), *Screencast* (t = -0.1005, p-value = 0.9204, CI=0.95), *Presentation* (t = 1.1562, p-value = 0.2520, CI=0.95), *Lab Demo* (t = 0.9041, p-value = 0.3697, CI=0.95), *Interview* (t = -0.4032, p-value = 0.6884, CI=0.95), *Documentary* (t = 1.6624, p-value = 0.1030, CI=0.95), and *Animation* (t = 0.8824, p-value = 0.3811, CI=0.95) not showing a significant difference between the two groups in any of the multimedia categories.

6.4.3.2 Learning Outcome Analysis Assessment

Figure 6-21 shows the percentage of subjects who answered correctly based on the multimedia category and the groups they are in. For *Interview* and *Documentary* all the subjects answered the questions correctly regardless of the group they were in. There are also 100% questions answered correctly at the low quality of *Screencast* and *Presentation*. However, where there is a difference in the percentage answered correctly between the two groups, the difference is low. The lower number of correct responses was for *Slideshow* but they are low in both groups.

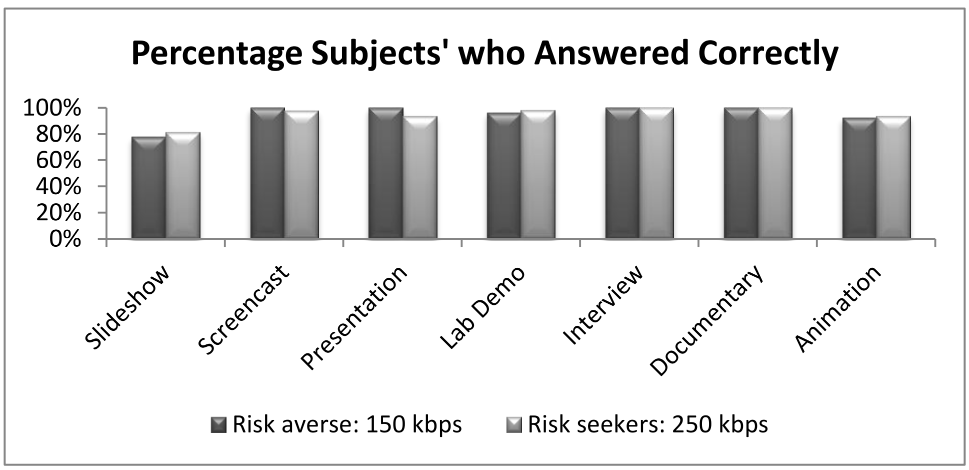

Figure 6-21 Percentage Subjects' who Answered Correctly

The Welch t test with a 95% confidence interval was performed for each multimedia clip. Any of the groups: *Slideshow* (t = -0.39, p-value = 0.6982, CI=0.95), *Screencast* (t = 1, p-value = 0.3223, CI=0.95), *Presentation* (t = 1.7693, p-value = 0.0832, CI=0.95), *Lab Demo* (t = -0.3932, p-value = 0.6961, CI=0.95), and *Animation* (t = -0.2075, p-value = 0.8365, CI=0.95), did not show significant differences. The Welch t test was not performed for *Interview* and *Documentary* since all the subjects answered correctly all the questions regarding these two multimedia clips.

6.4.4 Assessment for the Google Nexus (480p class device)

6.4.4.1 User Perceived Quality Assessment

Figure 6-22 presents the MOS average values for each clip when displayed on the second device. The increase in the average MOS values is noticeable for the second device when compared with the first device, which could be explained by the fact that people formed their opinions based on the capabilities of the medium (Telchemy, 2011).

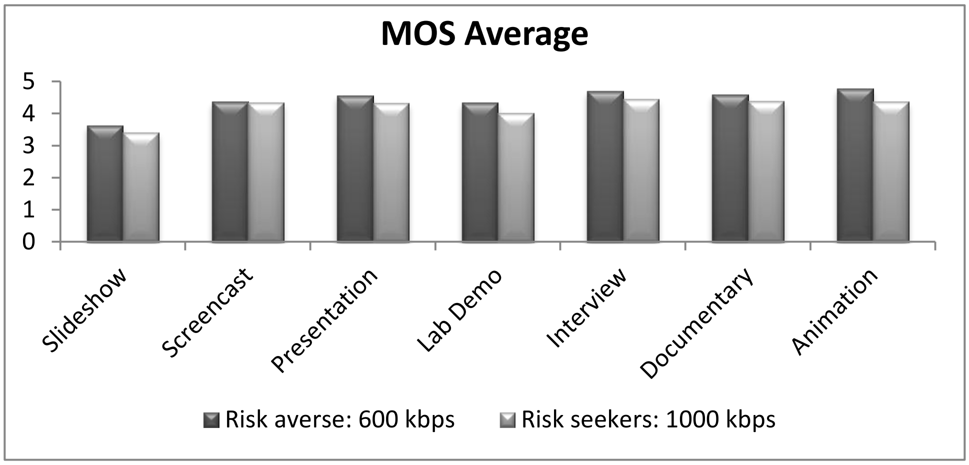

Figure 6-22 MOS Average for 480p Class

Lower MOS values were obtained again for the *Slideshow* multimedia category. However, in this case, they were over 3 (Fair). For the rest of the categories, all MOS values are over 4 (Good). Once again no significant differences in the average MOS values was noticed for the two groups.

In order to see whether there are significant differences between the two groups' scores on the multimedia clips, Welch t test with 95% confidence interval was performed. The results of the test for *Slideshow* (t = 0.8751, p-value = 0.3853, CI=0.95), *Screencast* (t = 0.1279, p-value = 0.8987, CI=0.95), *Presentation* (t = 1.0048, p-value = 0.3191, CI=0.95), *Lab Demo* (t = 1.5284, p-value = 0.1314, CI=0.95), *Interview* (t = 1.7651, p-value = 0.0817, CI=0.95), and *Documentary* (t = 1.2148, p-value = 0.2288, CI=0.95) show no significant difference between the two group. However, Welch t test on *Animation* (t = 2.8429, p-value = 0.005782, CI=0.95) shows that there is a significant difference in the two groups. It can be noticed from Figure 6-22 that risk averse subjects got on average a higher quality score. It can then be assumed that this adaptation did not degrade the perceived quality.

6.4.4.2 Learning Outcome Analysis Assessment

Figure 6-23 presents the percentage of subjects who answered correctly the question. Except for the *Interview*, the subjects got results over 80% or in the case of *Documentary*, they all answered correctly the questions, regardless of the group they were in.

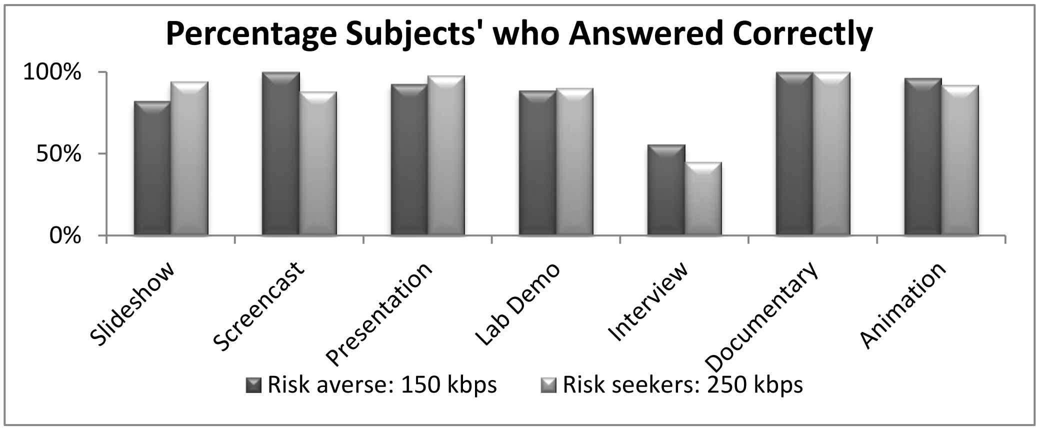

Figure 6-23 Percentage Subjects' who Answered Correctly for 480p Class

Similar to the 240p category, a Welch t test with a 95% confidence interval was performed on each of the results of the multimedia clips. The only exception was the *Documentary* category, for which, the subjects answered all the questions correctly regardless of the category. For *Slideshow* (t=-1.4815, p-value = 0.1469, CI=0.95), *Presentation* (t = -0.971, p-value = 0.3383, CI=0.95), *Lab Demo* (t = -0.1201, p-value = 0.9049, CI=0.95), *Interview* (t = 0.8805, p-value = 0.3825, CI=0.95), and *Animation* (t = 0.8234, p-value = 0.4131, CI=0.95), the test did not show significant differences between the two groups. For multimedia clip from the *Screencast* category, the Welch t test shows that the differences between the groups are statistically significant (t = 2.588, p-value = 0.01274, CI=0.95). It can be noticed from Figure 6-23 that the risk adverse group answered better to this test.

6.4.5 Billing Plan Scenarios Analysis

Five scenarios were designed to investigate how the subjects' preferences towards the quality of the multimedia content change when monetary cost is involved. Five different multimedia versions of the *Introductory Trailer to Chandra* were created for two different resolutions (480 x 800 and 320 x 480) and 5 different bitrates (600kbps and 1000kbps for a resolution of 480 x 800 and 550kbps, 350kbps and 150kbps for a resolution for 320 x 480) (Table 6-12). These resolutions and bitrate values were selected to cover all the possibilities of combinations of resolution and bitrate values suggested by the proposed adaptive mechanism for a device with a resolution of 480 x 800, that may be connected to three types of wireless networks Wi-Fi, 3.5G and 3G(see section 5.2). The 480 x 800 resolution type device was selected because this resolution is the most common one present on smartphones released in the period 2009-2010 (see section 3.2.3.1.1).

Table 6-12 Multimedia Version

Versions as seen by the subjects	Resolution	Bitrate
Chandra_v1	480 x 800	600kbps
Chandra_v2	480 x 800	1000kbps
Chandra_v3	320 x 480	550kbps
Chandra_v4	320 x 480	150kbps
Chandra_v5	320 x 480	350kbps

6.4.5.1 Scenario 1 Analysis

In the first scenario the subjects were asked to report which is their preferred multimedia quality among the five versions of a multimedia clip presented. If they prefer any version they have the option to choose *Any* of them, but they could not select more than one as preferred. The subjects were not provided with any information regarding the multimedia content resolution or bitrate. The five versions differs based on the resolution and bitrate (see Table 6-12).

Figure 6-24 presents the results for this scenario. Most of the people (41%) preferred the high resolution 480 x 800 clip, with the highest bitrate 1000kbps. 18% preferred the video with the same resolution but lower bitrate (600kbps), 13% the 320 x 480 multimedia clip with 550kbps, which is the same percentage of people who preferred any of the multimedia clips. 8% preferred 320 x 480 version of the multimedia with the bitrate of 350kbps and the remaining 7% the lowest version of 320 x 480. The relatively big number of people who preferred any or lower versions of the multimedia clip can be explained by the fact that people can be happy with a “good enough” (Masie, 2011) video.

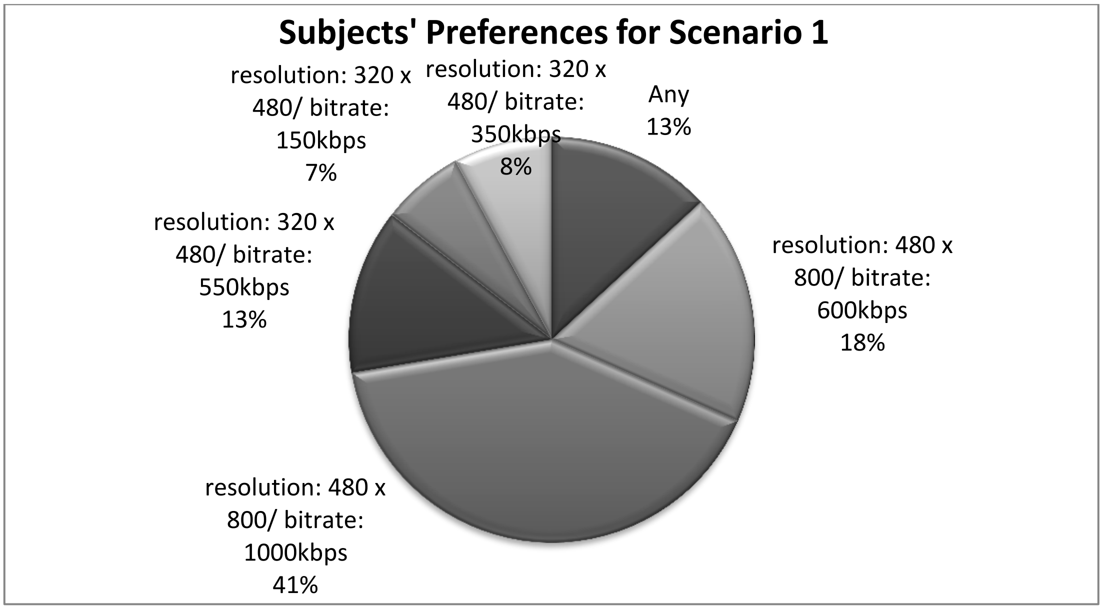

Figure 6-24 Subjects' Preferences for the Quality of Multimedia for Scenario 1

6.4.5.2 Scenario 2 Analysis

In the second scenario (Figure 6-25) the subjects were asked to assume that they have a billing plan that allows them to use unlimited data. They were moreover told the size of the multimedia files. Afterwards they were asked again to choose again one of the five modified versions of the multimedia clip. In this case 57% preferred the highest quality version (the multimedia file with the resolution of 480 x 800 and bitrate of 1000kbps). The same percentage of people as in the previous scenario, 18%, preferred the version with the resolution of 480 x 800 and bitrate of 600kbps. The number of people preferring the version with the resolution of 320 x 480 and bitrate 350kbps increases from 8% to 11%. The rest of the people preferred the remaining version or all of them decreased. Nevertheless, there were still an important number of people preferring lower quality versions.

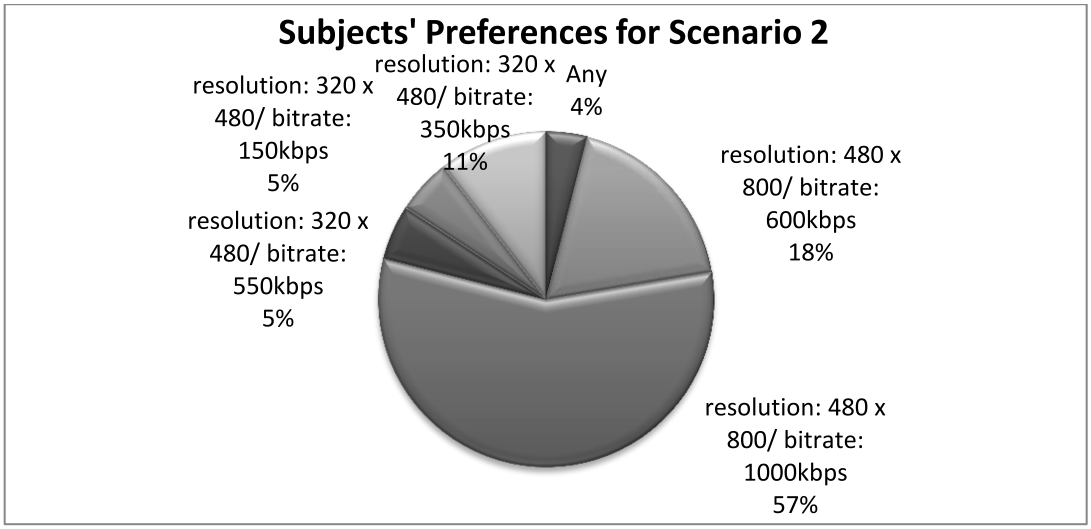

Figure 6-25Subjects' Preferences for the Quality of Multimedia for Scenario 2

6.4.5.3 Scenario 3 Analysis

The third scenario consists of two parts. First, users are asked to assume that they have a daily billing plan in which for €0.99 per fay they get 50MB data included. If the bundle is exceeded they have to pay €1/MB. They are told that they did not exceed the bundle data and they can see any of the five versions of the multimedia clip without exceeding the bundle quantity. Thus they are asked to select which version would they prefer to see in this case.

Figure 6-26 presents the subjects' preferences towards the multimedia versions for scenario three. Most of the subjects still prefer to get the highest quality version (26%), however a much lower number than the ones from Scenario 1 and Scenario 2. The lowest quality version (the multimedia clip with 320 x 480 resolution and 150kbps) is preferred by now a higher number of people (21%). 20% preferred the version with the resolution of 320 x 480 and 350 kbps. The version with the resolution of 480 x 800 and bitrate of 600kbps is preferred by 14% of the subjects, while the one with 320 x 480 resolution and 550kbps by 13% of the subjects. 5% of the subjects prefer any of the versions. It can be noticed that in this case the extreme versions are mostly preferred. A preference towards the lower versions may be due to the fact that people prefer to save the remaining data quantity from the bundle.

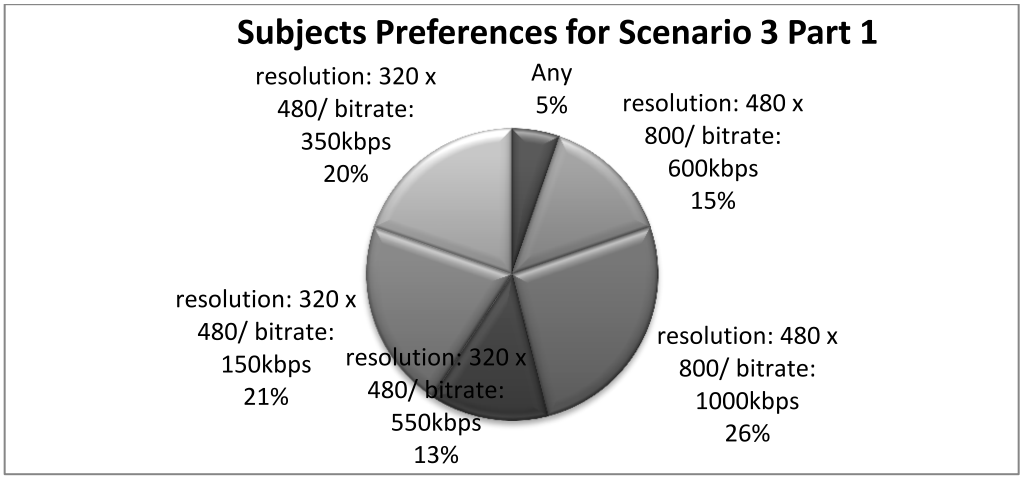

Figure 6-26 Subjects' Preferences for Scenario Three Part 1

The second part of Scenario 2 question asked the subjects how their preferences would change in the situation when they exceeded the bundle quantity and they would be charged at €1/MB. The price to be paid for each version was provided to the users (Table 6-13). However, the subjects were not provided with details on the resolution (second column) and the bitrate (third column) of each version of the multimedia clip.

Table 6-13 Price to be Paid for Each Multimedia Version for Scenario 3

Versions as seen by the subjects	Resolution	Bitrate	Price
Chandra_v1	480 x 800	600kbps	€9.15
Chandra_v2	480 x 800	1000kbps	€14
Chandra_v3	320 x 480	550kbps	€8.46
Chandra_v4	320 x 480	150kbps	€3.65
Chandra_v5	320 x 480	350kbps	€5.99

Figure 6-27 shows the subjects preferences for the second part of this scenario. In this case most of the subjects (33%) preferred the lowest quality version. The second lowest quality version was preferred by 18% of the subjects, while the versions with 480 x 800 resolution and 600kbps bitrate, and 320 x 480 resolution and 550 kbps bitrate were preferred by 17% of the subjects. Just 12% preferred in this case the highest quality version. 3% still preferred any of the versions. It can be noticed that when higher cost is involved most of the subjects would prefer to pay a low price, making a compromise between money and quality.

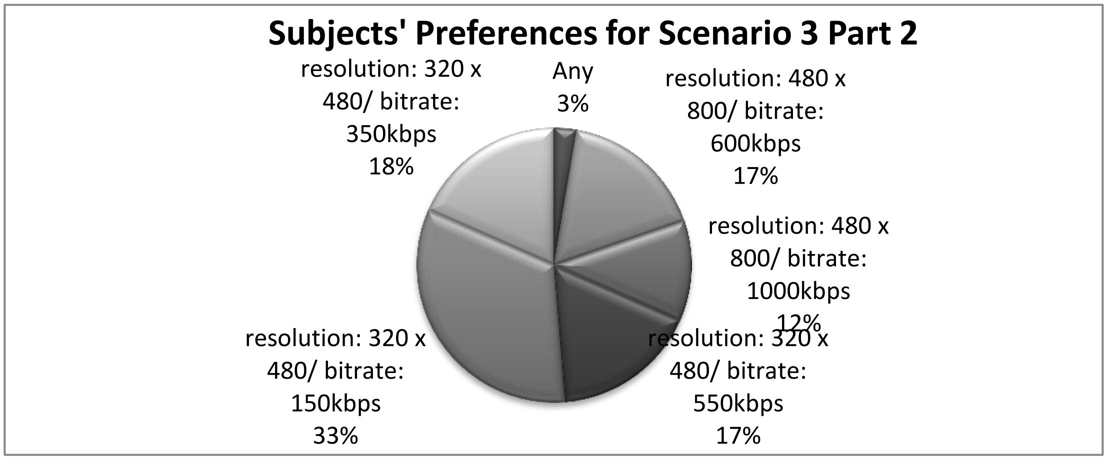

Figure 6-27 Subjects' Preferences for Scenario Three Part 2

6.4.5.4 Scenario 4 Analysis

The fourth scenario was divided in three parts. First, the subjects were told that they have a contract based billing plan, which gives them 500MB per month. In case they exceed the quantity they will pay 2c/MB. As in the previous scenarios they were asked what version they will choose if they would have enough data in the bundle to download/stream any of the versions without having to pay extra.

Figure 6-28 presents the subjects' preferences in this case. As in the previous scenario most of them preferred the highest version (38%). The second most preferred (20%) being the second highest version. The lowest version was preferred by 16% of the subjects and the rest of the remaining version by 12%. Only 3% preferred any of the versions.

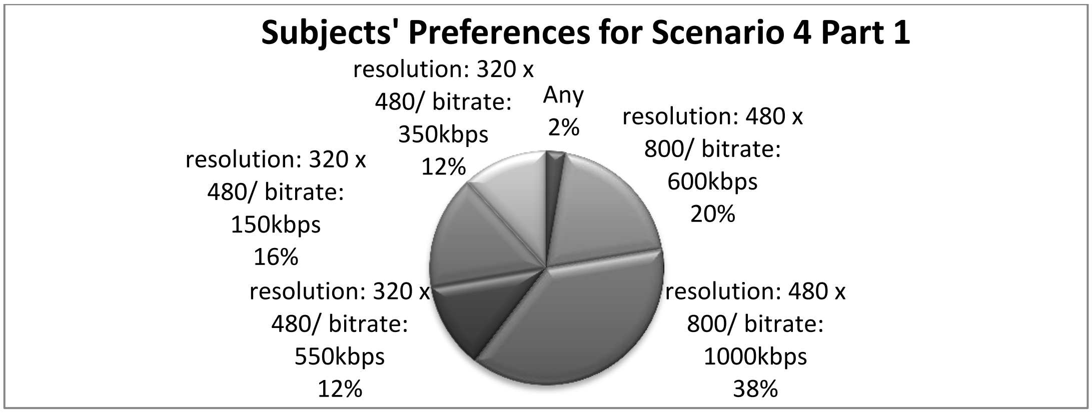

Figure 6-28 Subjects' Preferences for Scenario 4 Part 1

In the second part of the scenario 4 the subjects were told that they reached the limit of their bundle and they have to pay extra for accessing the multimedia clip. The cost involved is presented in Table 6-14. This time a much lower cost is involved as compared to Scenario 3.

Table 6-14 Prices to be Paid for each Multimedia Version Prices for Scenario 4 Part 2

Versions as seen by the subjects	Resolution	Bitrate	Price
Chandra_v1	480 x 800	600kbps	€0.18
Chandra_v2	480 x 800	1000kbps	€0.48
Chandra_v3	320 x 480	550kbps	€0.08
Chandra_v4	320 x 480	150kbps	€0.03
Chandra_v5	320 x 480	350kbps	€0.05

The subjects were asked again to state their preferences (Figure 6-29). Even though the cost was much lower, the distribution of people preferring a certain quality of multimedia content is exactly identical to the one from Scenario 3 part two, with most of the people going for the lower quality version (33%). This might suggest that the price does not make such a big difference, however, further research needs to be done to confirm or infirm this.

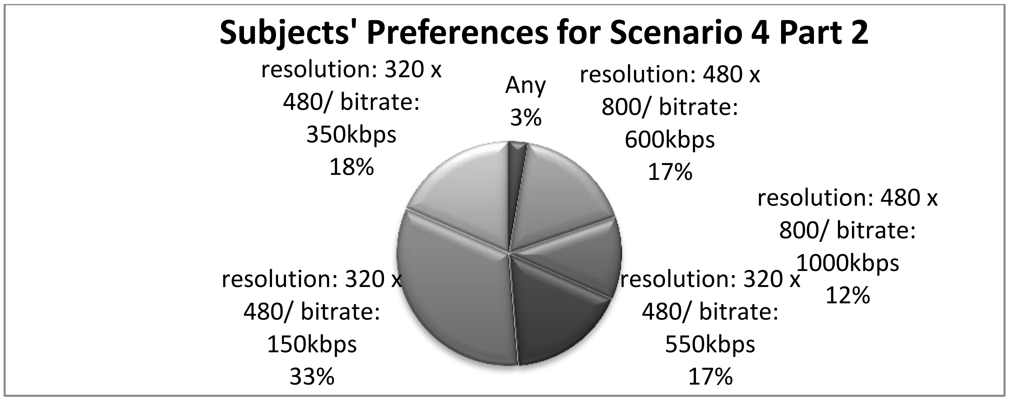

Figure 6-29 Subjects' Preferences for Scenario 4 Part 2

In the third part of the scenario the users are asked how their preferences would change if they would have to pay for 15 clips of the similar size with a given version. The cost involved for the 15 clips was provided to the users (Table 6-15). As in the previous case no information about the resolution and bitrate was provided.

Table 6-15 Price to be Paid for 15 Clips of a Certain Version from Scenario Part 3

Versions as seen by the subjects	Resolution	Bitrate	Price
Chandra_v1	480 x 800	600kbps	€5.49
Chandra_v2	480 x 800	1000kbps	€8.40
Chandra_v3	320 x 480	550kbps	€5.07
Chandra_v4	320 x 480	150kbps	€2.19
Chandra_v5	320 x 480	350kbps	€3.59

The subject' preferences are presented in Figure 6-30. In contrast to the previous results, 46% prefer any of the versions imperceptive of price, 18% the lowest version, 12% the 550 kbps and 600kbps, 9% the highest version and 3% the 350kbps version.

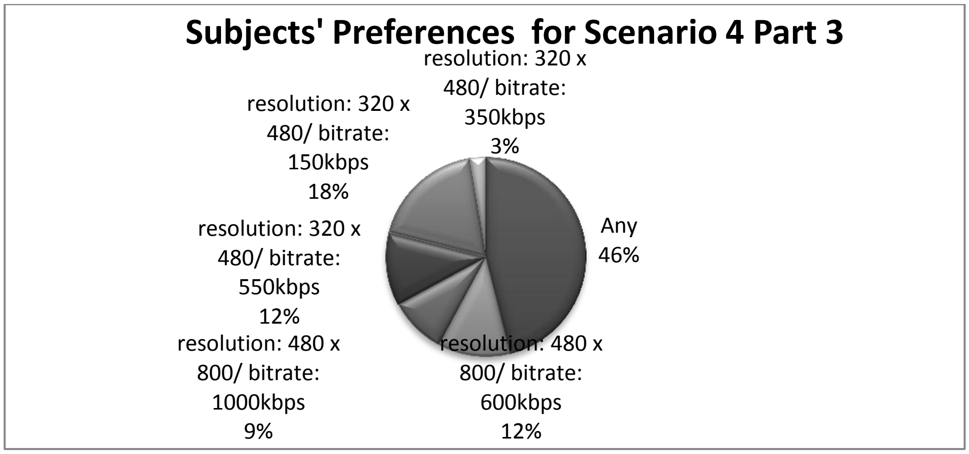

Figure 6-30 Subjects' Preferences for Scenario 4 Part 3

6.4.5.5 Scenario 5 Analysis

The subjects were given a data billing plan, in which after the quantity is exceeded, their bandwidth would be limited to 64kbps. This would lead to the streaming/downloading times as presented in Table 6-16. The multimedia clip presented was 1 minute and 44 seconds long.

Table 6-16 Streaming Time Multimedia Version

Versions as seen by the subjects	Resolution	Bitrate	Time
Chandra_v1	480 x 800	600kbps	2 minutes and 23 seconds
Chandra_v2	480 x 800	1000kbps	3 minutes and 39 seconds
Chandra_v3	320 x 480	550kbps	2 minutes and 12 seconds
Chandra_v4	320 x 480	150kbps	57 seconds
Chandra_v5	320 x 480	350kbps	1 minutes and 34 seconds

The subjects were asked to say which version they would prefer in this case. Figure 6-31 presents their preferences. Most people (37%) preferred the 350 kbps version, and 33% preferred the lowest version, probably because people prefer in general to have fast access to information and the question did not clearly specify whether they still have enough data or they are/will exceed it. The highest quality version was preferred by 13% of the subjects, the second highest by 11% and the 550 kbps version by 5%. Just 1% of the subjects did not have any preference regarding the versions.

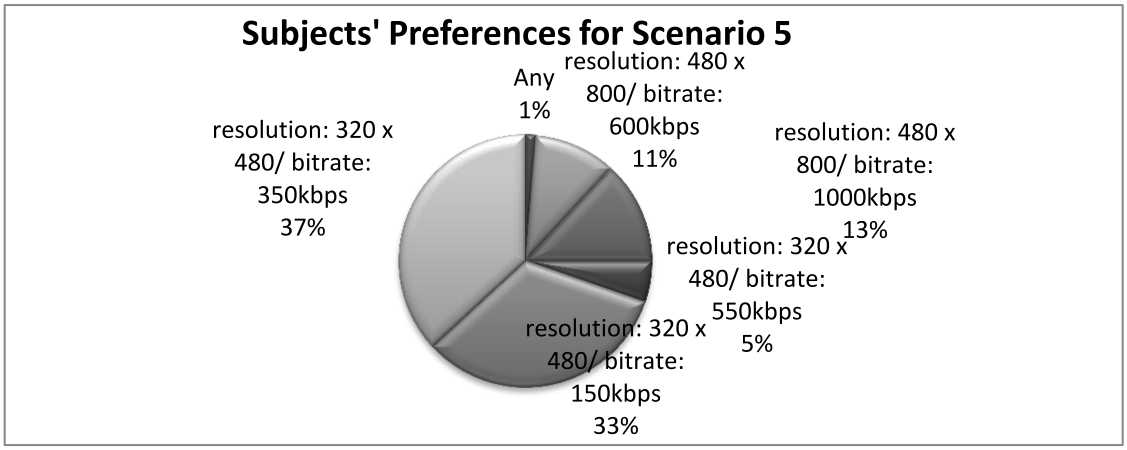

Figure 6-31 Subjects' Preferences for Scenario 5

6.4.5.6 Scenario based Risk Assessment

This part shows how the subjects' preferences towards multimedia quality change in Scenario 3 Part 1 and Scenario 4 Part 1, as compared with Scenario 2, where subjects attitude towards risk are taken into account (Figure 6-32). In Scenario 2 (see section 6.4.5.2) the subjects were given information about the multimedia clips size, and were asked to select a preferred quality, considering that their plan did not impose any restrictions on how much data they can use. This scenario was preferred for comparison, since subjects were aware of the quality of the different multimedia clips.

In Scenario 3 Part 1 (see section 6.4.5.3) and Scenario 4 Part 1 (see section 6.4.5.4) the subjects were given two bundle based billing plans. In where the subjects exceeded the quantity of data included in the bundle they have to pay extra. The plans differ in terms of the amount of data the user has to pay.

Figure 6-32 presents the percentage of subjects who prefer a lower quality for Scenario 3 Part and Scenario 4 Part 1, among the ones who preferred the best available quality in Scenario 2. For Scenario 3 Part 1, 68.18% of the risk averse subjects preferred a lower quality, and only 38.10% of the subjects from among the risk seekers preferred the lower quality videos. For Scenario 4 Part 1, 50% of the risk averse preferred a lower quality as opposed to 14.29% of the risk seekers. These findings confirm that most of the time, the division in risk categories, can show the preference for multimedia quality when the cost is involved. However, this depends on the external factors. As it can be seen when the subjects were given a lower price to be paid for the exceeding quantity (Scenario 4 Part 1), slightly less subjects preferred a low quality. This suggests the necessity of letting users change their profile.

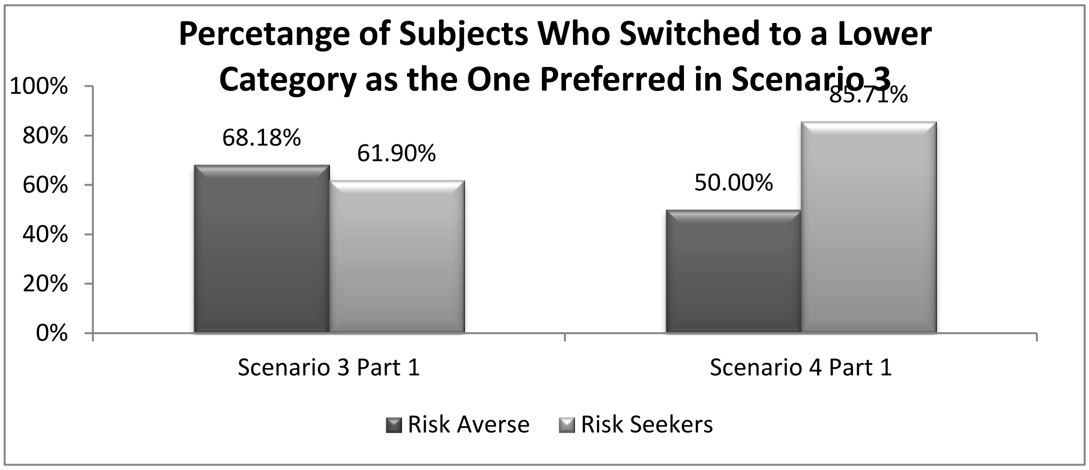

Figure 6-32 Percentage of Subjects Who Switched to a Lower Multimedia Quality as the One Preferred in Scenario 3

6.5 DISCUSSION

This chapter presents the results of assessing how the perceived multimedia quality and knowledge acquisition are affected when the adaptation mechanism proposed in section 5.2 is used for determining the resolution and bitrate values for a multimedia clip to be streamed on a particular device, over a given cellular network. It also assesses what savings can be obtained by using the proposed mechanism in conjunction with data bundle billing plan.

The results of the **objective studies** show that the multimedia quality for the risk averse group, as assessed using PSNR and SSIM metrics, has the lowest value of 3, which is fair multimedia quality. The **subjective study** shows slightly low values on average. Only for the *Slideshow* type clip for the 240p device class category, the average MOS was 2.89, probably due to the difficulty to read the text from the slides presented with the clip on a low resolution (240 x 320). Other than that all the MOS values were, predominantly over 4. The results show that there was no significant statistical difference between the two groups of people (risk averse and risk seekers) in the case of

240p device class, and two most of the 480p category, except for the *Animation*. In the case of the *Animation* type clip, the results of the Welch's t test show that there is a significant difference, however, for that clip MOS as assessed by the subjects was higher in the risk averse category. This is in concordance with previous research with has shown that video quality can be degraded without affecting he user perception (Ghinea & Thomas, 1998). Therefore it can be concluded that the result of this adaptation does not negatively affect the perceived multimedia quality. An explanation for the relatively lower scores for the 240p class, compared to the 480p class can lie in the fact that the people form their opinion based on the capabilities of the medium (Telchemy, 2011), the example being given is of a video clip seen on a high definition TV, which may receive a MOS score of 4.5, while the same clip on a mobile device might receive a MOS score of 3.1.

Learning achievements have been measured on correct answers to the questions related to the educational content presented in the video clip. The results of the post-test show improvements compared to the pre-test results. Questions related to the Documentary clip were answered correctly by all the subjects regardless the group and video class. For the 240p class all subjects also answered correctly for the Interview clip, regardless the group they were in. For the remaining group Welch's t test was performed to see if there is a significant difference among the two groups. The test show significant differences only for the Animation clip. It can be noted that in this case, the risk averse group answered better. Therefore it can be conclude that the result of this adaptation does not negatively affect the knowledge acquisition from the video clip.

An analysis performed on a sample of the billing plans from section 4 shows that **savings** of around 30% can be obtained by using the proposed mechanism, when the user exceeds the bundle quantity. If the user still uses the bundle data, savings in terms of the remaining bundle quantity have been observed.

Validity of the proposed user model was addressed in Section 6.4.5.6. The section shows that the risk attitude can predict willingness to pay in most of the cases.

Overall, this study has provided evidence of benefits in terms of monetary cost, when the proposed resolution and bitrate based multimedia adaptation is performed. The adaptation does not affect the subjects' perceived quality or their capacity of learning from the video clip. This research can have impact on designing multimedia based educational courses for mobile learning, when the cost of delivery is a problem.

6.6 SUMMARY

Overall, when people seem to have to pay extra for the multimedia quality or to wait in order to get it, subjects seem to prefer mostly the lower quality versions. However, the higher quality versions were also preferred. It can be deduced, due to the difference in preference from the results for the first and second scenario that not all the people seem to realise what the best quality is. Some people seem to still prefer the lower quality versions. This could be due to unperceived differences.

7 CONCLUSIONS AND FUTURE WORK

7.1 CONCLUSIONS

Monetary cost of data delivery over wireless networks is still high, compared with a transmission over wired networks. Moreover uncapped billing plans are not norm (Telecoms Pricing, 2010; Goldman, 2011), and this could lead to a higher price to be paid by the learners when accessing multimedia type content.

In mobile learning area cost of content delivery is considered to be one of the most important problems, hindering its widespread adoption (Dyson et al., 2009). Moreover, not all people are affected in the same way, and the delivery cost may be an issue just in certain circumstances (e.g. the delivery content might be very important and the learner is willing to pay more than for something that is not as important for him/her; if the phone bill is paid by somebody else (e.g. company), the cost might not be such a big issue as it would be if the learner pays for it).

At the same time, multimedia content is the preferred form to deliver educational content to mobile devices (Macdonald & Chiu, 2011; Gregson & Jordaan, 2009). However, its characteristics make a considerable bigger size for the information, than other types of content (e.g. text). Since most of the Internet billing plans for wireless networks are capped, this may lead to an increase in the cost of content delivery over these of networks.

This addresses the problem of balancing the desire for multimedia based content access via wireless networks (Wi-Fi, and cellular networks) with the cost of content delivery in the context of user willingness to pay during learning. This thesis proposes an adaptive mechanism which reduces the delivery cost for the learners who are not willing to pay high price by decreasing the quality of the delivered multimedia content and provides high quality multimedia for learners who are willing to pay, or have access to free Internet connectivity. In order to assess the learner willingness to pay, research done in the consumer behaviour area was taken into account. In this space, the consumer attitude towards risk can predict the economic behaviour of the person (Dohmen et al., 2011).

The contributions of this research are:

1. Performs an analysis of the feature phones and smartphones that exits on the market during the period 2008-2011[119].
2. Performs an analysis of the mobile data billing plans that exists in five European countries: Ireland, Germany, United Kingdom, France, and Italy.
3. A new adaptive mechanism that takes into account the learner risk attitude, learner device characteristics (resolution), and wireless network type over which the multimedia content is delivered.
4. Models the learner risk attitude, by taking into account differences between gender and age, changes in the learner location, data usage history and learner own assessment of its risk attitudes.

1. **Analysis of the feature phones and smartphones**: In order to determine the characteristics of mobile devices that exist on the market, an analysis of the feature phones and smartphones released between 2008 and 2011[119] was carried out in terms of resolution, screen size, supported multimedia (video) format and wireless network access. The data from 2009-2010 was aggregated, since it was the most recent data at the moment when the study was performed. The results have shown that for feature phones, the most used resolution is 240 x 320 and for smartphones 480 x 840. Screens between 2'' up to 2.2'' are the most common for feature phones, while big screens, over 4'' are common for

[119] Up to 14 June 2011

smartphones. MP4 is the most common multimedia format on both devices. Both feature phones and smartphones have access to 2G and 2G transitional networks. However, smartphones offer better capabilities in terms of 3G and 3G transitional networks, as well as Wi-Fi. All smartphones have Bluetooth but only 81.87% of the feature phones support it.

2. **Analysis of the mobile data billing plans**: An analysis of the billing plans present on the European market for mobile Internet has been performed. Five countries were analysed: Ireland, Germany, UK, France, and Italy. Except for Ireland, which was selected due to the fact that the subjective test involved Irish people, or people living in Ireland, the rest of the four countries were selected due to their big population and high penetration rate of mobile phone subscriptions, among the countries in Europe. The results have shown that unlimited billing plans are not common, and that billing plans are mostly limited. Exceeding the bundle data leads to either paying extra or getting Internet connectivity throttled. The most common billing plan is bundle data for using mobile Internet at the national level. In roaming context, both bundle based billing and data based billing are present. No unlimited billing plan is available for roaming.
3. **Adaptive Mechanism:** Based on previous mobile devices classification and the analysis of feature phones and smartphones that exist on the market, the mobile devices have been grouped in four categories bases on their resolution. A review of proposed bitrate values to be used when streaming multimedia has been also presented. Based on these recommendations, bitrate value intervals that take into account both the resolution and the bandwidth of the mobile networks has been proposed.

This research proposed an adaptive mechanism that adjusts the educational content delivery cost by taking into account the learner willingness to pay for multimedia content, the learner device features, and the wireless network over which the multimedia content is delivered. In order to do so, this research bridges the following areas: consumer behaviour, multimedia adaptation, and multimedia usage in education.

The proposed mechanism adapts the multimedia content based on the type of used wireless network for multimedia content delivery, since delivering high bitrate multimedia over a low bandwidth network could lead to loss in multimedia content, which is more frustrating than a controlled adapted content (Verscheure et al., 1998). Adapting the content to the learner device was necessary due to the diversity of mobile devices resolutions and differences that exists among them (from 240 x 320 to 960 x 720) for smartphones released during 2009-2011[119]). The proposed bitrate values intervals were used by the adaptive mechanism that takes into account the learner attitude towards risk in order to suggest multimedia adaptation. The lower thresholds were used for risk adverse users and the upper thresholds for the risk seeking users.

4. **Learner risk attitude:** The risk attitude was modelled taking into account the learner answer to the *general risk question*, and changes that can occur due to age and gender, or in different learning context. Learners risk attitude based on their gender and age was modelled based on the analysis of a very large (over 22 000) samples. Changes were modelled taking into account the learner feedback, but also changes in where the learner is (in the same country where the subscription has been acquired or in roaming), and his/her billing plan and data consuming history.

The adaptation mechanism proposed in this research caters for multimedia content, differentiating from the other proposed solutions on mobile learning. The benefits of the adaptation mechanism were investigated both through objective and subjective. Next, the conclusions drawn from these assessments were presented.

Objective Evaluation

The objective evaluation addressed the multimedia quality and the savings (in terms of monetary cost and/or amount of data) obtained for risk averse persons, the proposed adaptive mechanism is used. The multimedia quality was assessed using two well-known objective metrics: PSNR and SSIM. The results of these metrics were mapped on the MOS scale which is used to measure the user perceptive quality. The evaluation results, with any of the two metrics showed that the degraded version does not get a score under 3 (Fair on the MOS scale), and this was obtained only for few multimedia clips, mostly for those with high dynamicity. For the rest of the test sequences a score of either 4 (Good on the MOS scale) or 5 (Excellent on the MOS scale) was obtained. This shows that the lower bitrate multimedia clip perceived quality is not drastically affected during the adaptation process.

Another aspect of the objective evaluation was to assess what savings were obtained when using the proposed mechanism, since this was the aim of the adaptation. The results of the case studies have shown that when the learner has to pay extra for the multimedia content (e.g. having a data billing plan, or paying for data outside the bundle), savings around 30% are obtained, for the risk averse learners. Savings in terms of the remaining data, when the learner has limited data were also obtained for risks averse. The savings depend on the bundle size. Other benefits observed, are in the time of delivery of the multimedia content, especially when the bandwidth is throttled. The risk averse multimedia file deliver faster, and this is particularly important in the case in which the bandwidth is limited, as the time for waiting for a clip to download can he quite high. In the case of streaming, this would avoid, or diminish the interruptions during the multimedia streaming.

Subjective Evaluation

The subjective evaluation addressed the perceived user quality, the learning outcome, and the learner preferences. The study was done on two devices that belong of two of the proposed classes of resolutions. This was motivated by the fact that the two selected resolution classes cover the majority of feature phones and smartphones existent on the market. The classes are 480p (which is the most used for smartphones) and 240p (which is the most used for feature phones and the second most used for smartphones). Subjects were divided in two groups based on the computed attitude towards risk. The risk adverse subjects got low quality video and the risk seekers the high quality version.

The subjective test that assessed multimedia quality has shown that regardless of the device resolution class, there is either no statistical difference among the subject groups in perceived multimedia quality or when a significant statistical difference exists it is the risk seekers subjects' group that perceived a better quality. The clips shown on the small device (240p) got on average a lower perceived quality than the clips presented on the higher resolution device (480p).

Learning outcome was assessed by asking subjects to answer a question on the information presented in each multimedia clip. The question was related to the information presented only in the video component but not in the audio one. The results of the test have shown no statistical difference in the results obtained for the risk averse and risk seekers group regardless of the category they were in. Even though the pre-test have shown that for the most of multimedia clips, few subjects knew the answer, the post-test have shown that the majority of the subjects answered correctly all of the questions related to the content presented.

I assessed through different case scenarios how the subjects' preferences towards the multimedia content change when they have to pay for accessing the multimedia content. The most representative billing plans were selected based on the analysis done on the European billing plans. The study confirmed that subjects preference change, with more subjects preferring lower quality versions when they have to pay extra for the multimedia content. However, there were still a large number of people preferring high quality content regardless of the price they have to pay. For example, for Scenario 3 Part 2: 17% of the subjects preferred the multimedia clip with a resolution of 480 x 800 and a bitrate value of 1000kbps; 12% of the subjects preferred the multimedia clip with a resolution of 480 x 800 and a bitrate value of 600kbps; 17% of the subjects preferred the multimedia clip with a resolution of 320 x 480 and a bitrate value of 550kbps; 18% of the subjects preferred the multimedia clip with a resolution of 320 x 480 and a bitrate value of 350kbps; 33% of the subjects preferred the multimedia clip with a resolution of 320 x 480 and a bitrate value of 150kbps; 3% of the subjects preferred any of the previous versions.

7.2 LIMITATIONS

There are several limitations of this study concerning the user's risk aversion model, the adaptation mechanism and the experimental study design. Concerning the user model, the validation was done just for two case studies.

The adaptation mechanism considers a limited number of factors that could have effect on the perceived user quality, focusing on those who mostly affect the size of the multimedia and hence the monetary cost of delivery. There are other factors that could affect the user satisfaction such as the user preference for the multimedia content, the way s/he perceives multimedia quality, the delay, jitter etc.

When the subjects' preferences were assessed they were asked about their preferred multimedia content. One of the options they could pick was multimedia. They were however, not given a definition of what multimedia means. That may lead to problems identifying to what type of multimedia content the subjects were referring to. However, this question does not affect the assessment of the proposed adaptation mechanism, as it was independent from the study.

For the experimental study an between subjects design was chosen, which was a constraint that had to be included due to the assessment of learning outcomes (if multiple clips were used for assessment by a single person, it would have been hard to know from which clip the subject learned). Moreover, the test sequences were not randomised between subjects and this may have an effect on the subjects' assessment. Also, a limited number of characteristics of the mobile phones capabilities were considered and analised.

7.3 FUTURE WORK

Several research directions can be further on pursued based on this research.

First, it can be noticed that not all the multimedia clips for the 240p class obtained a high score. It could be further explored what kind of multimedia files are suitable for small screen devices, and whether other forms of adaptation could lead to improvements in the perceived quality.

Second, a better granularity when achieving adaptation can be obtained, by further on exploring the 0 to 10 risk aversion scale, and introducing multiple multimedia file versions. The effect of this adaptation on the learner experience as well as the effects on the system performance can be further on explored.

Third, an optimisation of the adaptation algorithm can be performed such that a better prediction on changes in user preference can be achieved. This might be done using a machine learning algorithm. The same thing can be applied on the multimedia adaptation to provide a more personalised adaptation and perceived user quality.

Fourth, a better adaptation of the multimedia content could be research such that spatial and temporal parameters of the multimedia clip (such as dynamicity), to be taken into account. This could lead to better user perceived quality and lower price for delivery.

Fifth, to investigate what effect this adaptation mechanism has on the device battery consumption, since this adaptation could improve the battery since if less quantity is received, less wireless card is used and hence less battery power.

Sixth, to investigate the effect of the proposed adaptation mechanism on mobile multimedia systems which are not necessarily focused on educational content, such as entertainment systems.

Seventh, to explore the effects of proposed multimedia adaptation on different networks. Further on, this analysis could continue with exploring the different network performance parameters such as delay and jitter which have big chances to appear when the bandwidth is throttled by the network operator. Loss is another parameter that has been shown to affect the perceived user quality. It could be investigated what the effects it has on the perceived quality of the delivered multimedia version.

7.4 RECOMMANDATIONS

There are several implications of this research. Although this thesis addresses mostly the learners in particular (and users in general), content providers and mobile network operators could benefit as well from the results of this research.

To the **learners**, the outcome of this research could be beneficial, as they can obtain personsalised educational content based on their needs: the risk averse will get multimedia content that involves low delivery cost and the risk seekers higher quality than the one provided to the risk averse. This may potentially be beneficial for any users in general; however, further testing has to be done on how the proposed adaptation affects other types of content, such as the high dynamic one, that is potentially more affected by lowering the quality.

From the **providers** point of view, proving personalised educational content may lead to more satisfied learners/users. It could also reduce the bandwidth consumption and the traffic to the server or proxy. Adapting content to the learner/user mobile phone characteristics and wireless network, could improve the quality of the delivered content. When multimedia content is delivered at higher quality than the network permits loss, delay and jitter could appear, affecting the perceived quality. Moreover, the analysis performed on the mobile phones characteristics can help them decide what devices to target, especially when an adaptation to every single device is not feasible.

Mobile network operators can also benefit from the research presented in this thesis as well. As the bandwidth is limited and the congestion is still a big problem in wireless networks, this research can help in reducing the bandwidth consumption, hence diminishing the congestion problem. It can also lead to happier customers as they would have personalised content based on their needs, and less congestion to deal with.

APPENDIX

SUBJECTIVE TEST MATERIAL

Welcome Message

Welcome to the perceptual testing session organised by National College of Ireland.

Test Objectives

The aim of this research is to reduce the cost of delivery to smartphones for multimedia educational content. These tests will evaluate new strategies that support low cost delivery of educational multimedia.

Disclaimer

Please fill in the personal information page. The data will be used for demographic statistics.

Demographic Data

Gender:

Male	Female

Age:

<20	20 to 30	30 to 50	>50

Occupation:

Do you use glasses or contact lenses?

Yes	No

How familiar are you with subjective video quality evaluation?

I work in the area	I am familiar	I am not familiar

Risk Assessment

How do you see yourself?

Are you generally a person who is fully prepared to take risks or do you try to avoid taking risks?

Please tick a box on the scale, where the 0 value means: “risk averse” and the value of 10 means “fully prepared to take risk”.

0	1	2	3	4	5	6	7	8	9	10
☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Mobile Phone Usage

What is your preferred media type for learning on mobile devices?

Text	
Text+ Images	
Audio	
Multimedia	

How many mobile subscriptions do you currently have?

1	2	3	>3

Do you own a smartphone?

Yes	No

Who pays your mobile phone bills?

You	
Your company	
Parents/relatives	
Other (please specify)	

Do you access the Internet from the mobile phone?

Yes	No

If your answer was negative to the previous question, what is the reason for not using it?

What kind of mobile data billing plan do you have?

Do you use mobile Internet to watch multimedia clips?

Yes	No

Do you find it easy to estimate how much you spend when using Internet on your mobile phone?

Yes	No

<u>Preliminary Test</u>

Select one answer for the following question:

What distribution partners does Turner have on emerging TV markets?

a. Sony
b. Amazon
c. Vodafone
d. Starbucks
e. I do not know

What types of blocks can be added on the Moodle web page?

a. Videos
b. Calendar
c. Pictures
d. Songs
e. I do not know

Name one endangered species that lives in Rwanda?

a. Sloth Bear
b. Giant Panda
c. Mountain Gorilla
d. Meerkat
e. I do not know

Have you seen the interview with Curtis Sittenfeld, about her book “American Wife” at the Iowa Writers’ Workshop?

a. Yes
b. No

Have you seen the interview documentary related to the Marine Research from Southern Cross University, Australia?

a. Yes
b. No

Do you know what spherification is?

a. A delivery process of shaping solid substances into a sphere
b. A delivery process of shaping liquids into a sphere
c. A delivery process of shaping gases into a sphere
d. A delivery process of shaping water into a sphere
e. I do not know

What is the shape of the path on which the Earth orbits around the Sun?

a. Circular
b. Oval
c. Rectangular
d. Triangular
e. I do not know

<u>Directions</u>

There are 14 multimedia clips, and 1 extra used as an example in this section. You will be asked to answer the following questions for each sequence shown:

Please rate the perceived quality of the multimedia clip from 1 (the worst quality) to 5 (the best) on the subjective scale presented below (ITU-T R P.911).

Afterwards, please answer the question related to the information presented in the multimedia clip?

The test will take less than 30 minutes. You are allowed to see the videos just once.

Quality scale for subjective testing (ITU-T R P.911)

Rating	Quality	Impairment
5	Excellent	Imperceptible
4	Good	Perceptible, not annoying
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

Exemplification of the Test

Please rate the perceived quality of the multimedia clip:

5. Excellent	4. Good	3. Fair	2. Poor	1. Bad

Select one answer for the following question:

What planet is shown in the video clip?

a. Earth
b. Mars
c. Saturn
d. Jupiter

Small Device (Samsung Galaxy Europa)

Clip 1 - Harmonizing:

Please rate the perceived quality of the multimedia clip:

5. Excellent	4. Good	3. Fair	2. Poor	1. Bad

Select one answer for the following question:

What label is shown on the x axes?

a. Years
b. Hours
c. Kilograms
d. Days

Clip 2 - Moodle:

Please rate the perceived quality of the multimedia clip:

5. Excellent	4. Good	3. Fair	2. Poor	1. Bad

Select one answer for the following question:

What is shown on the left side column of the Moodle web page?

a. A calendar
b. Emails
c. Pictures
d. Videos

Clip 3 - Joubert:

Please rate the perceived quality of the multimedia clip:

5. Excellent	4. Good	3. Fair	2. Poor	1. Bad

Select one answer for the following question:

How many presenters are in the video?

a. 0
b. 1
c. 2
d. More than 2

Clip 4- Science*:*

Please rate the perceived quality of the multimedia clip:

5. Excellent	4. Good	3. Fair	2. Poor	1. Bad

Select one answer for the following question:

What is the colour of the submerged liquid?

a. Yellowish
b. Blue like
c. Reddish
d. Black

Clip 5- Sittenfeld:

Please rate the perceived quality of the multimedia clip:

5. Excellent	4. Good	3. Fair	2. Poor	1. Bad

Select one answer for the following question:

What people are in the room?

a. A female
b. Two females
c. A male and a female
d. Three females

Clip 6- Marine:

Please rate the perceived quality of the multimedia clip:

5. Excellent	4. Good	3. Fair	2. Poor	1. Bad

Select one answer for the following question:

Where is the speaker staying?

a. In a laboratory
b. On the beach
c. In a bedroom
d. In a kitchen

Clip 7- Earth:

Please rate the perceived quality of the multimedia clip:

5. Excellent	4. Good	3. Fair	2. Poor	1. Bad

Select one answer for the following question:

What is the shape of the path that the Earth travels around the Sun?

a. Circular
b. Oval
c. Rectangular
d. Triangular

Bigger Device (Google Nexus)

Clip 1 - Harmonizing:

Please rate the perceived quality of the multimedia clip:

5. Excellent	4. Good	3. Fair	2. Poor	1. Bad

Select one answer for the following question:

Select the name of the TV distribution partners:

a. Sony
b. Amazon
c. Vodafone
d. Starbucks

Clip 2- Moodle:

Please rate the perceived quality of the multimedia clip:

5. Excellent	4. Good	3. Fair	2. Poor	1. Bad

Select one answer for the following question:

What is shown on the right hand side column in the blocks section of the Moodle web page?

a. My Courses
b. My Emails
c. My Pictures
d. My Videos

Clip 3 - Joubert:

Please rate the perceived quality of the multimedia clip:

5. Excellent	4. Good	3. Fair	2. Poor	1. Bad

Select one answer for the following question:

What is shown on the TV monitor that exists in the background of the speakers?

a. A snake
b. A bear
c. A fox
d. A gorilla

Clip 4 - Science*:*

Please rate the perceived quality of the multimedia clip:

5. Excellent	4. Good	3. Fair	2. Poor	1. Bad

Select one answer for the following question:

Where does he place the yellowish ball in the experiment after he takes it from the rectangular glass bowl?

a. On a plate
b. On a pan
c. On a pot
d. On a tray

Clip 5- Sittenfeld:

Please rate the perceived quality of the multimedia clip:

5. Excellent	4. Good	3. Fair	2. Poor	1. Bad

Select one answer for the following question:

What room accessories are in the room behind the speakers?

a. A paper bin
b. A bookend
c. A fan
d. A lamp

Clip 6 - Marine:

Please rate the perceived quality of the multimedia clip:

5. Excellent	4. Good	3. Fair	2. Poor	1. Bad

Select one answer for the following question:

The second person is taking a sample of

a. Liquid
b. Soil
c. Gas
d. Blood

Clip 7- Earth:

Please rate the perceived quality of the multimedia clip:

5. Excellent	4. Good	3. Fair	2. Poor	1. Bad

Select one answer for the following question:

How many planets spin around the Sun in the video?

a. 0
b. 1
c. 2
d. 3

Scenarios

Please watch the following multimedia clips:

a. Chndra_v1
b. Chndra_v2
c. Chndra_v3
d. Chndra_v4
e. Chndra_v5

You are allowed to watch them as much time as you like. These clip versions remain the same until the end of the test.

Scenario1:

Which version of the clip do you prefer?

a. Chndra_v1
b. Chndra_v2
c. Chndra_v3
d. Chndra_v4
e. Chndra_v5
f. Any of them

Scenario2:

Suppose that you have a 24 month contract that will give you for £25 (€28.58)/month a quantity of 5000 texts, 2000 minutes, and unlimited data. You want to watch the multimedia clip Chandra. You have to pick among the following five versions of the clip:

a. Chndra_v1: 9.15MB
b. Chndra_v2: 14MB
c. Chndra_v3: 8.46MB
d. Chndra_v4: 3.65MB
e. Chndra_v5: 5.99MB

Which version of the clip would you prefer?

a. Chndra_v1
b. Chndra_v2
c. Chndra_v3
d. Chndra_v4
e. Chndra_v5
f. Any of them

Scenario 3 Part 1:

Suppose now you have a daily data billing plan that for €0.99/day will get you 50MB. The data has to be consumed within the given day. If you exceed the data in the bundle, you have to pay €1/MB for the exceeding quantity.

Considering that you still have enough data in the bundle to see any of the previous five videos, which version would you prefer in this case?

a. Chndra_v1
b. Chndra_v2
c. Chndra_v3
d. Chndra_v4
e. Chndra_v5
f. Any of them

Scenario 3 Part 2:

Considering that the data in the bundle is exceeded and you have to pay €1/MB:

a. Chndra_v1: €9.15
b. Chndra_v2: €14
c. Chndra_v3: €8.46
d. Chndra_v4: €3.65
e. Chndra_v5: €5.99

Which one would you prefer now?

a. Chndra_v1
b. Chndra_v2
c. Chndra_v3
d. Chndra_v4
e. Chndra_v5
f. Any of them

Scenario 4 Part 1:

Suppose you have a contract based billing plan. Among the services included (e.g. 150 minutes, 100 texts), you have also 500MB/month of data. If you exceed this quantity you will pay 2c/MB. Considering that you still have enough data in the bundle to see any of the previous videos,

Which version would you prefer in this case?

a. Chndra_v1
b. Chndra_v2
c. Chndra_v3
d. Chndra_v4
e. Chndra_v5
f. Any of them

Scenario 4 Part 2:

Considering that the data in the bundle is exceeded and you have to pay 2c/MB, which will give you approximately these prices:

a. Chndra_v1: 18c
b. Chndra_v2: 48c
c. Chndra_v3: 8c
d. Chndra_v4: 3c
e. Chndra_v5: 5c

Which one would you prefer now?

a. Chndra_v1
b. Chndra_v2
c. Chndra_v3
d. Chndra_v4
e. Chndra_v5
f. Any of them

Scenario 4 Part 3:

How about if you would have to see 15 clips of similar size (since this clip is 1 minute 44 seconds, 15 clips will be approximately 26 minutes of a multimedia clip). This will give you the following prices for the whole 15 clips:

a. Chndra_v1: €5.49
b. Chndra_v2: €8.40
c. Chndra_v3: €5.07
d. Chndra_v4: €2.19
e. Chndra_v5: €3.59

Which one would you prefer now?

a. Chndra_v1
b. Chndra_v2
c. Chndra_v3
d. Chndra_v4
e. Chndra_v5
f. Any of them

Scenario 5 Part 1:

Suppose now that you have a monthly data billing plan that for €10/month will get you 7.2GB. But after consuming 300MB your bandwidth is limited to 64kbits. With 64kbps it will take to download approximately:

a. Chndra_v1: 2 minutes and 23 seconds
b. Chndra_v2: 3 minutes and 39 seconds
c. Chndra_v3: 2 min and 12 seconds
d. Chndra_v4: 57 seconds
e. Chndra_v5: 1 minute and 34 seconds

Which one would you prefer now?

a. Chndra_v1
b. Chndra_v2
c. Chndra_v3
d. Chndra_v4
e. Chndra_v5
f. Any of them

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