Cost Oriented Adaptive Multimedia Delivery

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Abstract—**Mobile Internet and mobile services which make use of mobile data are increasingly popular. However, the cost of content delivery, in particular multimedia type content over cellular networks is a still high and poses challenge for some of the users who are not necessarily willing or cannot afford to pay too much for it. The problem is further on aggravated when video content is used, as this type of content is heavier and can lead to higher bills. In this context, this paper presents a novel Cost Oriented adaptive MultimEdia DeliverY (COMEDY) mechanism that considers the user willingness to pay for a certain video quality and user's mobile device characteristics in order to deliver adaptive multimedia content over wireless connection. The aim of the mechanism is to reduce the cost of multimedia delivery for users that are not willing to pay that much. The mechanism has been evaluated both through objective and subjective studies. The evaluation shows that the proposed mechanism provides a reduction in the price paid for accessing multimedia content, and the user's perceived quality is not negatively affected.**

Index Terms—**Adaptive multimedia, cost of multimedia delivery, mobile devices, mobile data billing plans.**

I. Introduction

MOBILE phone usage is increasing both in the developing and the developed world [1], and mobile network coverage is supposed to be ubiquitous by 2015 [2]. This has contributed to the expansion of mobile-based services. However, when mobile users access the Internet over cellular networks one problem they face is the high cost of data transmission [3, 4]. Moreover, mobile network operators that previously offered flat rate plans are backing up, and capping their mobile data billing plans [5-7].

Capped billing plans offer to the users a limited amount of data, as opposed to unlimited billing plans. The consequences of exceeding data consumption vary from paying more for the exceeding data, paying for a new bundle, or having the bandwidth limited. These types of billing plans are commonly used for mobile Internet access, and sometimes for home Internet connections [8].

Despite their popularity, few research studies have covered mobile data billing plans from the mobile Internet users' perspective. Research has been focused mostly on these billing plans as means of managing network congestion and the technical aspects involved [8].

However, this pricing model is likely to continue to persist as: Internet Service Providers (ISPs) argue that as it provides a consistent service [9] the mobile data traffic increases dramatically [10, 11] and not even the deployment of high speed networks such as Long Term Evolution (LTE) will make uncapped plans sustainable [11].

Among the studies that have focused on how mobile data billing plans affect Internet usage one can count [8, 12-16]. [8, 12-14] addressed the effects that different billing plans have on the mobile user's behaviour. All these studies report that the mobile user changes its behaviour according to the Internet billing plan used. Moreover, most of them report difficulties from the user perspective to estimate how much they consumed [8, 12, 14].

[15] explores how the cost of delivery influences people's choices when they have to consider a trade-off between multimedia quality and cost, when mobile data is capped. The study shows that people are willing to accept a lower multimedia quality when they are aware that they have to pay more for a high quality. However, some participants were willing to pay for the quality even when the price is quite high. [16] shows that the difference in the attitude of people when choosing a certain multimedia quality over the price to be paid can be explained by people's attitude towards risk. A method that classifies people either in willing to pay for the multimedia quality (risk averse) or not (risk seekers) based on their age, gender and attitude towards risk was also proposed [16].

However, to the best of our knowledge, there is a lack of studies proposing solutions for the people who are not willing to pay that much for data transmission. This problem is further on aggravated when multimedia content is used, as it has a bigger size compared to the other types of content (e.g. text), which could lead to an increase in delivery cost. In this context, there is a need for a mechanism that addresses the needs of mobile users who cannot afford, or are not willing to pay high cost when multimedia content is involved. Our research addresses this problem by proposing a Cost Oriented Adaptive MultimEdia DeliverY (COMEDY) mechanism that aims to reduce the cost of multimedia content delivery for the users who are not willing to pay that much. Multimedia is understood in the context of this paper as video in combination with audio and possibly text. A user classification method, presented in [16], is used to design the user centric cost oriented multimedia delivery mechanism that provides a slightly reduced multimedia quality for the people who are not

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willing to pay high cost for the multimedia content.

The rest of this paper is organised as follows: Section II presents related work on adaptive multimedia and methods used to assess multimedia quality. Section III introduces the existing methods used for evaluating the multimedia quality. Section IV presents the proposed adaptive multimedia mechanism. Section V discusses the study methodology and set up. Section VI presents the results of the objective multimedia quality assessment, using two well-known metrics PSNR and SSIM; the savings obtained in terms of monetary cost, and the subjective assessment of the multimedia quality. Section VII presents discussions while Section VIII the conclusions.

II. Adaptive Multimedia for Mobile Devices

Multimedia adaptation here refers to changing multimedia parameters, such as bit rate, frame rate, resolution and/or colour depth. The adaptation of the multimedia content has been performed for different purposes, such as adapting the content to the mobile device characteristics [17], optimising the delivery bandwidth [18] or increasing the battery life [19].

Mobile Cinema [17] is an application that adapts high-resolution multimedia content for mobile devices by considering the screen resolution, the bit rate 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 losses in the semantic information when the video is cropped [17].

Quality-Oriented Adaptive Scheme (QOAS) [79] adapts the multimedia content by using Moving Picture Quality Motion (MPQM) to estimate user perceived quality [18]. The proposed mechanism is compared with other non-adaptive solutions and shows that by using it a, higher number of simultaneous clients can connect to a Wi-Fi network.

[19] proposes a system that adapts the multimedia clips based on their importance with the aim of improving the battery lifetime. They have shown positive results when testing the system through simulations.

Unlike the previously presented approaches our aim is to adapt the multimedia quality based on the willingness of people to pay for it, and the device characteristics (resolution).

A. Multimedia Adaptation Techniques

There are different ways of adapting multimedia content: entirely - focusing on the entire multimedia clip; or partially - focusing on specific areas from the multimedia clip (ROI - "regions of interest") identified as important for the users. Multimedia adaptation is based on the fact that people prefer reduced bit rates to packet losses [20].

By adapting the multimedia content entirely, a more uniform adaptation is possible. Different adaptive solutions have been proposed with different aims. [21] changes the bit rate and the frame rate of multimedia clips with the aim of reducing the bandwidth necessary for the transmission of multimedia. 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. [22] addresses the battery power problem on mobile devices, when the multimedia content is presented on heterogeneous 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.

[23] shows that in a multimedia clip, specific regions can be identified, on which the users are more interested in. Based on this approach, different adaptation schemes have been proposed [24, 25]. These schemes aim to reduce the quality for regions that are of little or no interest for the user and to increase the quality on the "region of interest" (ROI). The idea is based on the human visual system that has different sensitivity to different visual areas [26]. Adaptation based on ROI can deliver better-perceived quality, especially for mobile users, where the resources are quite limited [25]. However, these solutions might not be suitable in all contexts such as low bit rate multimedia with high movement [25], or multimedia with less than 15 frames per second [27].

As there is no consensus on which multimedia content adaptation technique is the best, the proposed mechanism, COMEDY, adapts the entire multimedia clip.

B. Location of the Adaptive Mechanism

Multimedia adaptation can take place: at the server, at an intermediary proxy, or at client.

Server side adaptation is performed at the delivery server that has already access to the content. The main advantage of this approach is that the content is transmitted already fitting the client or delivery channel requirements. This requires fewer resources at the client, which is highly important when it comes to devices with limited resource power and battery energy (e.g. mobile devices). Most important less bandwidth is needed for the content delivery to the client device (for example, a clip to be sent to a mobile device adapted to a format most suitable both to the device and access network). There are also other advantages in the sense that the content provider controls the content in terms of copyright. Drawbacks of this approach include increased traffic and processing at the that the server especially if adaptation is performed individually for each stream, solution less scalable to large number of clients. Among the research studies that follow this approach are: [28], [29] and [80].

Client side: In this case the adaptation is done at 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 (mostly in terms processor capabilities). There is a need as well that the users to install 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 [30] and [31].

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. 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 have used this approach are: [32] and [33].

C. Timing Multimedia Adaptation

Taking into account the moment when 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 use.

Offline Adaptation (Static Mode): Offline adaptation is performed before the content is sent to the client. After the adaptation is applied, the content is stored for future use. Offline adaptation can be performed 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, and the impossibility to serve live video [34, 35].

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, one can count: 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. [36] and [37] are example of studies that have used online multimedia adaptation.

The COMEDY mechanism presented in this paper can be performed at any place; however, care has to be taken as whether this could add an extra monetary cost from the user perspective.

III. Multimedia Quality Evaluation

In order to show the benefits of different adaptation solutions, various metrics for assessing multimedia quality have been proposed. These metrics can be either objective or subjective.

A. Objective Video Quality Evaluation

Objective metrics are used to estimate the video quality, as the user would perceive it 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 [38], VQM - Video Quality Metric [39], SSIM - Structural Similarity Index [40], MS-SSIM - MultiScale-Structural SIMilarity index [41], MOVIE - MOtion-based Video Integrity Evaluation [42], etc.

Among these, PSNR has a low computational complexity. It has been shown to obtain more accurate results compared to the more complex models (e.g. VQM) [43], however it is sometimes criticised for correlating poorly with perceived video quality [44]. 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 the quality.

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

MS-SSIM is one of the extensions of the SSIM [45]. It improves the SSIM by allowing variations in resolution and viewing conditions.

MOVIE model is based on the neuroscience studies. It aims to capture the characteristics of the human brain for the analysis of the video quality.

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

Although some metrics are more suitable in certain conditions than others [45], to the best of our knowledge there is not a general accepted metric that is accurate well enough to estimate the perceived user quality. However, PSNR and SSIM have their values mapped onto 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, PSNR and SSIM will be used for the objective video quality evaluation. This is because they provide easier comparison to the subjective evaluation results.

The MOS scale is used to subjectively assess the perceived video quality. The 5-point MOS scale and the PSNR and SSIM mapping are presented in Table I. 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,

TABLE I
PSNR and SSIM Mapping to MOS [46]

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

a PSNR from 33 (including 33) up to 45 (excluding 45), will correspond to a MOS value of 4 (good perceived video quality). The third column presents the SSIM intervals and its correspondent on the MOS scale. For example, SSIM values between 0.95 (including) and 0.99, correspond to a MOS value of 4.

B. *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, especially in the assessment of low bit rate video codecs [47]. 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 [47], and ITU-R BT-500 [48]. 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 follows, provides recommendations regarding the experimental design, viewers, instructions, analysis of results, etc.

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 subject videos in pair, one of the sequences being the reference and the other one the sequence under evaluation. On the PC, the sequences are presented in pairs with different systems under test.

IV. COMEDY: COST ORIENTED ADAPTIVE MULTIMEDIA DELIVERY

The proposed adaptive multimedia mechanism takes into account the user willingness to pay for the delivery of multimedia on a mobile device [16]. The aim of the mechanism is to deliver a lower quality multimedia content to the people who cannot afford or are not willing to pay high cost for the multimedia delivery while for those who are willing to pay, a high quality is provided. In order to do so, the multimedia bit rate and the resolution have been affected. The main questions to be addressed is how one selects the bit rate such that the quality is high for the people who are willing to pay and lower, but acceptable for the ones who are not willing, as there seems in the literature to be no consensus on how to select it.

To address this, the diversity of mobile phones a user can have was taken into account. There are several factors that are tackled in this research such as the resolution and the bit rate of the multimedia to be delivered. These are selected as they have a direct or indirect effect on the size of the multimedia content, and hence its delivery cost. A lower bit rate value implies lower multimedia clip size. However, a multimedia with high resolution requires a high bit rate. If the device has a smaller resolution than the multimedia clip there is no point in delivering a high resolution multimedia as the device will scale it down anyway. By delivering the content directly to the resolution the device has the bit rate can be lowered, hence the size and therefore the delivery cost.

Next, a summary of mobile phones analysis we have performed is presented. The period 2008 up to 18 December 2011 was considered. The aim of this analysis is to determine what resolutions are currently used on the mobile phones market.

A. *Mobile Phones Analysis*

Three main categories can be distinguished among mobile phones:

- *Basic phones*
- *Feature phones* (*cellular phones*)
- *Smartphones*.

Basic phones are mobile phones that allow users to place calls and have a basic functionality. Due to the fact that these phones do not usually allow for multimedia access, we decided that they would be left out of our analysis.

Feature phones (also called *cellular phones*) are mobile phones that allow users to place calls. They have enhanced functionalities compared to a basic phone, such as: Internet access; the capability of playing multimedia, and support for Java applications.

Smartphones are mobile phones that apart from allowing users to make a call, they can also provide high functionality, run an Operating System (OS) and support multitask applications. Smartphones have high capabilities, support for multimedia, Internet access, and multiple network capabilities. The smartphones provide the best combination between portability and functionality.

For the purpose of this research, feature phones and smartphones were considered in our analysis as they support multimedia.

Worldwide feature phones and smartphones published on the GSM arena website [49] were considered from 1 January 2008 up to 18 December 2011. A total of 1115 feature phones were found listed on the website, among which 29% were announced in 2008, 29% were announced in 2009, 30% in 2010, and 12% in 2011. The lower number of feature phones from 2011 is due to the fact that mobile phones producers are more focused towards smartphones now.

A total of 685 smartphones models were analysed. Among these, 90 (13%) of them were announced in 2008, 128 (19%) were announced in 2009, 210 (31%) were announced in 2010 and 257 (37%) announced in 2011. One can notice an increase in the number of smartphones through the years. An analysis for 2011, and the predominant resolutions for the rest of the years is presented next.

Below, the results of the mobile phones resolution analysis for the year 2011 are presented. Fig. 1 shows the feature phone resolutions released in 2011 (up to 18th of December). The 240 x 320 resolution is popular among feature phones, accounting for 57% of feature phones. The second most popular is 128 x

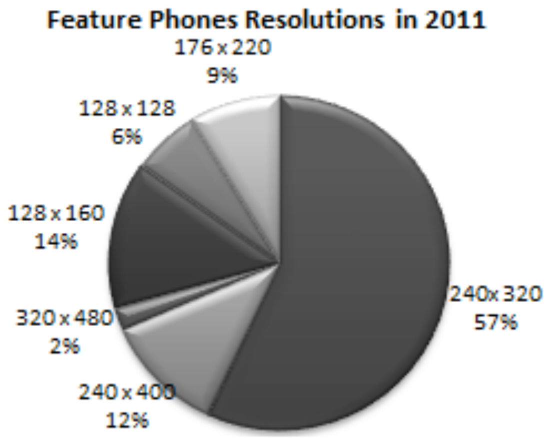

Fig. 1. Resolutions for Feature Phones Announced in 2011

160 accounting for 14% of feature phones and the third most used is 240 x 400 accounting for 12% of feature phones.

An analysis for previous years was performed as well, and through all the years, the resolution of 240 x 320 was predominant too.

Fig. 2 presents the smartphones resolutions released in 2011. The most used resolution is 480 x 800 accounting for 35%. The second most used resolution is 320 x 480 that counts for 25% of the smartphones, and the third most used is 240 x 320, accounting for 14%.

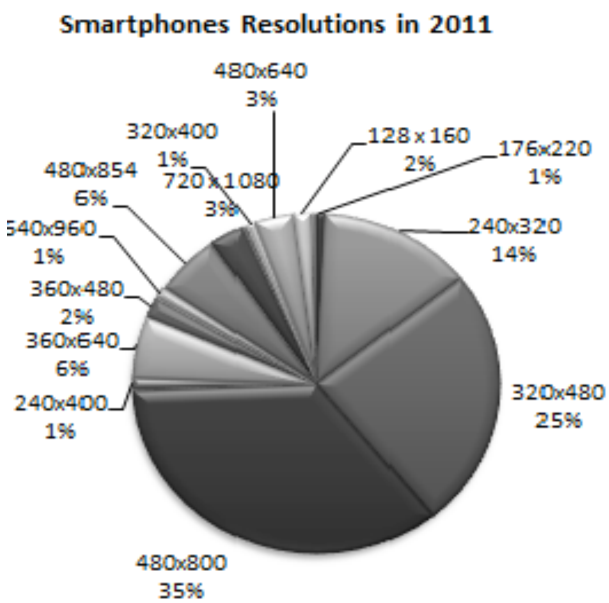

Fig. 2. Resolutions for Smartphones Announced in 2011

In 2008 and 2009, the predominant resolution for smartphones has been 240 x 320 same as for feature phones, accounting for 66% and 34% of smartphones respectively. 480 x 800 became the predominant resolution accounting for 31% of smartphones in 2010, and it remains predominant. One can notice an increase in the number of high definition resolutions in smartphones, starting with 2011.

B. Multimedia Resolution Clustering and Bit Rate

As it can be seen from the previous analysis and not only a variety of resolutions exist among mobile phones. There are also various standards regarding resolutions [50, 51], each of them including just certain resolutions. This makes difficult to group devices in certain categories. Hence, with the aim of providing a better view of the capabilities of mobile phones in terms of resolution we propose to classify the resolutions in five classes as presented in Table III, by adapting the resolution classification found in [52]. Another reason for doing so is the high number of device resolutions found and in the inherent difficulty to manage so many resolutions during an adaptation process [52]. Wowza [53] is a company specialised in multimedia streaming to different platforms. Their server has been selected as the best media server for three years in a row starting with 2008 [53]. They have proposed in [52] a classification of resolutions for multimedia adaptation as presented in Table II. The second column of the table presents the resolution corresponding to the class presented in the first column.

TABLE II
MOBILE DEVICES RESOLUTIONS

Shorthand/Class	Resolution
1080p	1920 x 1080
720p	1080 x 720
480p	800 x 480
360p	640 x 360
240p	320 x 240

TABLE III
PROPOSED MOBILE PHONES RESOLUTION CLASSIFICATION

Shorthand/Class	Resolutions
1080p	800 x 1280
720p	720 x 1080; 640 x 960
480p	480 x 640; 480 x 800; 480 x 854
360p	360 x 640; 360 x 480; 320 x 480; 320 x 320
240p	240 x 400; 240 x 320; 176 x 220; 128 x 160; 120 x 160; 128 x 128; 96 x 128

Among the resolution classes presented in Table II, the 1080p resolution class is not yet present on the mobile phone market. However, since resolutions bigger than 720p are already present with mobile devices (e.g. Samsung Galaxy Note has a resolution of 800 x 1280), and probably even higher resolutions will be supported in the future, the 1080p resolution class was included in the proposed classification (see Table III). Unfortunately, taking into account only the resolutions from Table II would not solve the problem, since there are many other resolutions. Therefore, the proposed classification, groups all mobile phone resolutions that were found in our analysis around the proposed classification. This is done by adding resolutions that do not exist in the Table II; in the class immediately higher in terms of resolution size. The proposed classification ensures a better preview of the resolutions present on the market.

Based on our analysis Table IV presents the division of smartphones in the proposed resolution classes, across all years. Smartphones have suffered major changes in terms of

TABLE IV
CLASSIFICATION OF SMARTPHONES RESOLUTION

Shorthand	2008	2009	2010	2011
240p	70%	43%	29%	18%
360p	5%	24%	23%	34%
480p	25%	27%	41%	44%
720p	-	-	-	4%

the supported resolutions, across the years, whereas a feature phone, even though the resolutions have been increasing overall there has not been such a steep change in resolutions. The dominant class of resolution for the last four years for feature phones is 240p.

Determining a suitable bit rate for a multimedia clip is a complicated problem as it depends on the video content, its resolution, the role of the clip, and the type of network it will be delivered on. Since a recommendation that will fit all requirements of this research (suitable for a variety of mobile phones resolutions and for various wireless networks), has not been found, different recommendations have been analysed such as Mobile Learning Standard [54], wowza [52], Apple Technical Note TN 2224 – Best Practices for Creating and Deploying HTTP Live Streaming Media for the iPhone and iPad [55], and Adobe [56].

C. Adaptation Mecanism

The cost of multimedia content delivery over cellular networks is still high, and users have concerns and problems estimating how much data they use [8, 12]. However, as some people want to reduce their cost of delivery trading it off for example for video quality, while others prefer to pay for it and get premium quality [15]. It has been shown that the people willingness to pay for multimedia quality can be modelled [16, 57], so it can be used by an automatic adaptation algorithm as long some data about the users can be obtained – this can be done by asking the users to answer a short questionnaire.

A division of the user profiles in two classes of risk averse and risk seekers was presented in [16]. The division is done based on the person age, gender and self-assessment of the risk attitude. Based on this information a risk value for each person is computed. The risk value can vary between 0 and 10. If the user risk value is greater than 5 the person is considered risk seeker, otherwise s/he is risk averse.

In order to adapt the multimedia content for the two classes of users, two multimedia bit rate values have to be determined, one for risk adverse users (a lower threshold) and one for risk seekers (an upper threshold). Although a more granular classification could have been performed by considering the 11 points scale on which the risk is computed, no research has currently been done to characterise users based on each point of the scale. Therefore we will focus on the two categories, currently used.

Table V presents the proposed multimedia bit rates thresholds for the two categories of users and for every class of device resolution. The first column indicates the resolution

TABLE V
MULTIMEDIA BIT RATE RECOMMENDATION

Shorthand	Recommended Resolution	Bit rate threshold risk averse	Bit rate threshold risk seeker	Source
240p	240 x 320	150 kbps	250 kbps	[54]
360p	360 x 640	0.6 MB	550 kbps	[52, 54, 55]
480p	480 x 800	0.6 MB	1 MB	[52, 55]
720p	720 x 1080	1.5 MB	1.8 MB	[52]
1080p	800 x 1280	2 MB	3 MB	[52]

class, the second column the resolution to be used for multimedia. The third and the forth columns show the recommended bit rate threshold based on the risk attitude. The last column presents the documentation based on which the bit rate threshold was recommended.

An explanation on how the bit rate thresholds were selected for each resolution class is presented below:

- 1080p: the proposed bit rate thresholds follow the suggestions from wowza [52].
- 720p: the proposed bit rate thresholds follow the suggestions from wowza [52].
- 480p: the proposed bit rate thresholds follow the suggestions from wowza [52] as well as some values recommended by Apple [55] that fit for this class and have similar bit rates (e.g. for 640 x 480 was recommended 640kbps or 840kbps)
- 360p: the risk adverse user's threshold was proposed as a combination of the values recommended by the Mobile Learning Standard [54] and Apple [55]. The first one recommends a bit rate of 140 kbps for a video clip with resolutions 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 bit rate only for the video at which the audio bit rate is added, 150 kbps was taken as a lower threshold. The bit rate threshold for risk seeker was proposed based on wowza [52].
- 240p: the bit rate threshold for risk averse users was selected using the same principle as for 360p class. This matches also with the wowza [52] exemplification. The risk seekers threshold (risk seeking users) was selected based on the wowza [52] recommendations.

The proposed adaptive mechanism – COMEDY - (see Fig. 3) takes into account: the user (by considering her/his risk attitude hence her/his willingness to pay), and the user mobile device (by taking into account device resolution). First the mechanism classifies the user on one of the two categories by computing its risk value, *RV* [16], and retrieves the user device resolution (*deviceResolution*). The recommended resolution (*recommendedResolution*) is computed based on the recommendations proposed in Table III (to determine the resolution class) and Table V (based on the resolution class to determine the resolution for the multimedia clip that is delivered). The bit rate at which multimedia clip is to be

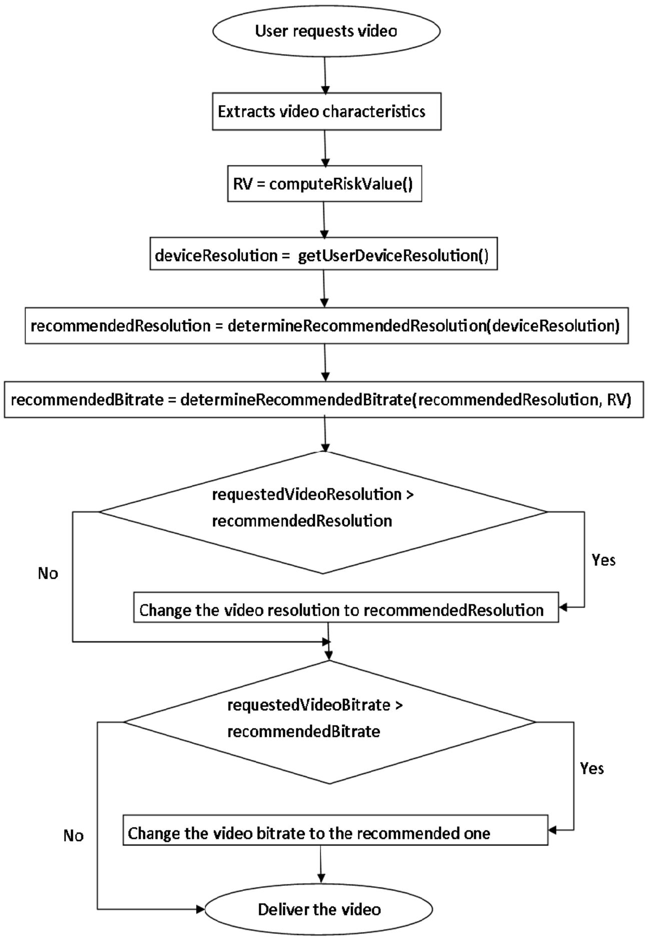

Fig. 3. COMEDY - Cost Oriented adaptive MultimEdia DeliverY-Mechanism

delivered (*recommendedBitrate*) is determined based on the recommended resolution class and computed risk value based on the values proposed in Table V. A multimedia clip with the *recommendedResolution* and *recommendedBitrate* is either transcoded at the time, if the version of the multimedia clip with these requirements is not present, or just retrieved and delivered to the person, if that version exists.

V. Experimental Study Methodology and Set Up

The proposed adaptive multimedia mechanism (COMEDY) was evaluated using both objective and subjective assessments. The objective assessment has measured the perceived video quality (using two well-known objective metrics: PSNR and SSIM), and the savings (both monetary and in terms of delivery time) obtained when using the proposed adaptive mechanism. The savings were assessed as case studies for different mobile data billing plans currently used on the market.

The subjective assessment was performed as an experimental study that has tested and validated the proposed mechanism. The aim of the subjective test was to determine whether the user perceived quality was negatively affected for the risk adverse users. The study set-up was performed following the recommendations from the ITU-T P.910 [47].

A. Multimedia Content

Seven multimedia clips were used both for the subjective and objective assessments such that they would cover a large variety of multimedia content:

1) *Slideshow*: the multimedia clip is a slideshow with low dynamicity. The level of details is quite high, and a lot of text is presented.
2) *Screencast*: the multimedia clip has many transitions between images, such as zoom in and zooms out; fading in and fading out; there are also text and details. The dynamicity is medium - low.
3) *Presentation*: the multimedia clip consists of two persons speaking using slides for their presentation. The slides change during speaking while the speakers' dynamicity is quite low.
4) *Lab Demo*: the multimedia clip is a cooking scene, having multiple persons showing the stages of the cooking and the ingredients. The scene varies some having high level of details while others less.
5) *Interview*: the multimedia clip consists of a static background and two persons speaking. The dynamicity is low.
6) *Documentary*: the multimedia clip shows different aspects of the marine ecology research. The scene content varies, with different aspects presented in different scenes.
7) *Animation*: the multimedia clip consists of a cartoon, where the level of dynamicity is low.

Since the downloaded multimedia clips used for testing were too long for evaluation purposes, approximately 30 seconds long self-contained multimedia sequences were extracted. Thus, the evaluation duration was kept short and the multimedia clip presents information that may be understood independently from the rest of the clip..

Another multimedia clip, *Introductory Trailer to Chandra*, was used for a case study assessment of the gains (both monetary and delivery time) when using the proposed adaptive multimedia mechanism. The clip consists of a variety of scenes having both low and high level of dynamicity. The clip was kept at his original length of 1 minute and 44 seconds, as it was considered that the original length would better represent a multimedia clip seen by the user in real-life.

All the multimedia clips that were used during the evaluations were downloaded from the iTunes U [58]. The encoding of the multimedia clips is MEPG-4 ACV/H.264. The clips have high resolutions so that a clip could be transcoded at different resolutions as required by the algorithm. Their bit rate was high too.

B. Mobile Devices

An analysis and classification of mobile phones present on the market during the period 2008 -2011 (up to 18 December 2011) has been done in Section IV A-B. 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 [59]. Our analysis has shown that 480x800 is the most used resolution for smartphones in the last two years. The second most used resolution across smartphones and feature phones during the last years was 240x320, a resolution that is at the moment very popular among feature phones. Based on our study, these two resolutions cover the majority of smartphones and feature phones present on the market in the last two years. Therefore, mobile devices with these resolutions 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 [60]. Concerning the Operating System (OS), Android smartphones were selected due to the fact that they have the most common OS on the market [61, 62]. Regarding the manufacturer, Samsung and Google were selected, since Samsung is the most used manufacturer by overall mobile subscriptions, and Google has the most smartphones subscribers [63].

TABLE VI
MOBILE DEVICES CHARACTERISTICS

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

Therefore the two smartphones selected for the study were Google Nexus and Samsung Europa, based on the above-mentioned criteria. Their characteristics are presented in Table VI. The first row has the device name, the second its resolution, the third column presents the screen size, the fourth the video capabilities, the fifth row the networks to which they have access to, and the last two rows 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.

C. Subjects

76 subjects took part in this study on a volunteer basis. The subjects were either students (37) or professionals (39). Most of the subjects were males, accounting for 74% of the total subjects. The subjects’ age is quite spread. Their ages varied from 19 to 57 years old, 37% being younger than 30 years.

The subjects’ risk attitude was assessed as described in [16]. The risk attitude formula uses the participants’ age and gender, and the general risk question in order to compute the risk aversion of an individual. The general risk question is a method of assessing the user risk attitude by asking the user to assess his/her risk attitude on a 0 to 10 scale [16]. 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 subjects were divided in two risk attitude 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. 36% of the subjects were risk averse and 64% risk seekers. This high number of risk seeking subjects can be explained by the fact that many of the subjects have a high level of education (e.g. PhD students or postdoctoral researchers), and this category is known to have a positive attitude towards risk [64, 65].

D. Billing Plans

To compute the savings obtained in terms of cost of delivery it was necessary to investigate what type of billing plans are on the market. The following plans were found

1. Bundle billing. The user pays for a specific amount of data in advance. That 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 has to pay a different price for the exceeding quantity;
   - to buy a new bundle at the same or different price;
   - the bandwidth is limited.
2. Time based billing. The user pays for the time s/he spends using the Internet.
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. This type of billing plan was used starting with packet switched networks such as 2.5G and 3G [12].
4. Flat rate. The user has unlimited Internet access. Usually a monthly fee is involved, but Internet access it could be unlimited for a shorter period of time such as a session.
5. Free Internet access. This is the most desirable case for the user, when s/he does not pay for the data.

In order to decide which billing plans to be used for our testing we looked at what are the most common billing plan in Europe. Five European countries were selected: Ireland, Germany, France, UK, and Italy. Except for Ireland, the last four were selected due to the fact that they have the biggest

TABLE VII
MOBILE PHONE SUBSCRIPTIONS BY COUNTRY

Country	Population	Mobile Phone Subscriptions as Percentage of the Population [66]
Ireland	4 100 000	106.63%
Germany	82 600 000	127.42%
France	60 000 000	95.35%
UK	59 700 000	130.17%
Italy	57 800 000	146.08%

number of people in Europe, high penetration rate of mobile subscriptions (see Table VII), 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. Therefore, whenever possible in the study we took a billing plan from Ireland, as being more representative for the people living here. However, if a different plan type was to be found representative for the study it had to be added regardless of the country.

The billing plans offered by non-virtual mobile operators were 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. This analysis did not consider different offers that mobile operators may have when buying a certain mobile (e.g. when you buy a BlackBerry you can get a different mobile data offer than when buying one other type of mobile phone), or offers for a limited period of time (e.g. free Internet for one month when switching to the given mobile operator).

Both pre-paid (pay as you go) and contract based (billed paid, post-paid) plans were analysed. A pre-paid billing plan also called pay as you go is a billing plan in which the customer pays in advance for the provided service. Figure 4 presents the breakdown of the billing plans offered for pay as you go customers we found. We can notice that capped billing plan is predominant. Although many of the billing plans that are advertised to consumers are flat based, we found just 4% who did not really have any limitations in terms of the amount of data.

A contract based billing plan (also named as bill paid billing plan or post-paid billing plan) is a plan in which the user pays for the services after s/he has used them. Fig 5 presents breakdown of the billing plans for the contract-based customers. We can notice that capped billing plan is predominant on the market.

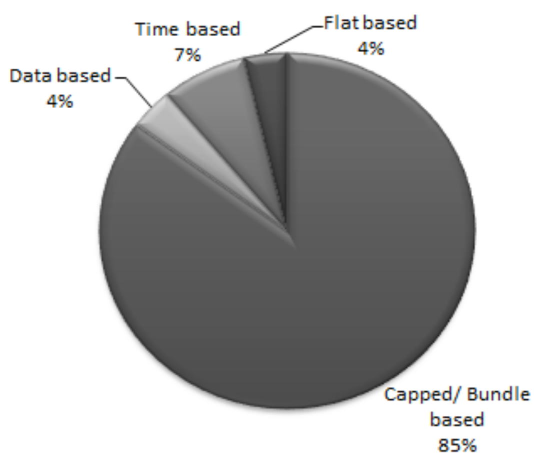

Fig. 4. Pre-paid type billing plans breakdown

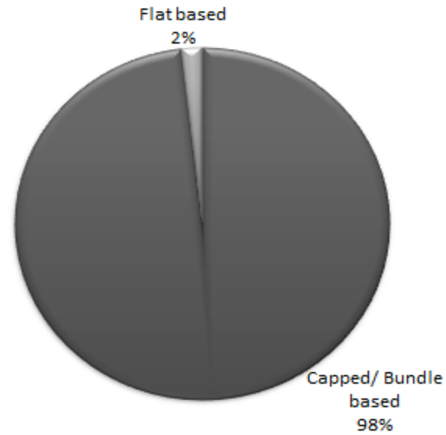

Fig. 5. Contract based billing plans breakdown

Considering that for both the pre-paid and contract based billing plans, capped/bundle billing plan is by far the predominant one it was selected for our case studies. The bundle billing plans used were selected to cover a variety of prices, and different consequences that would happen when the limit is exceed, such as paying extra or having the bandwidth limited.

For maintaining the clarity of the results, and not repeating ourselves, the representative billing plans selected for the evaluation in terms of user gains (both monetary and in terms of delivery time) are presented in Section VI.

E. Procedure

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

The subjects were first asked to fill in a questionnaire with demographic data and to answer the general risk question. Based on this data they were divided into one of the two groups. Afterwards, a written description of the experiment was given to the subjects. As recommended by the ITU-T P.910 [47], the subjects were explained the assessment procedure and the scale of assessment.

A training session, as recommended by ITU-T P.910 [47], was also run before starting the actual experiment in order to avoid biases due to misunderstanding. The results of the training session were not taken into account in the analysis. 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. The two quality versions were generated based on the proposed COMEDY mechanism.

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 clips in parallel, or having a reference among the clips. This method was selected, as being the most appropriate of what people would see when watching a multimedia clip on their mobile device.

F. Data Analysis

Parametric or non-parametric procedures can be used to analyse the data. The parametric analysis works under the assumption 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 [67], and giving a false sense of security; Zimmerman [68] has shown that in fact they can be affected by the variances in groups. Considering these the parametric analyses was used in this research.

The 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 [69], 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 (CI) of 95% was adopted.

The dependent variables included in this research are the MOS score. The independent variables are the subjects' risk attitudes, multimedia clips classification (e.g. slideshow, cartoon, etc.), and multimedia clip categories (clips encoded at different quality levels). The data was analysed using R, released 1.12.1 [70].

VI. Results and Discussions

The proposed adaptive multimedia mechanism (COMEDY) was assessed using both objective and subjective assessments. The objective evaluation has assessed the perceived video quality (using two well-known objective metrics: PSNR and SSIM), and the savings (both monetary and in terms of delivery time) obtained when using the proposed mechanism. The savings were assessed using different mobile data billing plans used on the market.

The subjective assessment was performed as an experimental study that assesses video perceived quality on the MOS scale according to ITU-T P.910 [47] recommendations.

A. Objective Assessment

This section presents the results of the tests that assessed objectively the multimedia quality and the savings obtained for risk averse users when using certain billing plans. The video quality was assessed using two well-known metrics: PSNR and SSIM, and the results of the two metrics were mapped onto the MOS scale. The savings are computed by using different scenarios, in which representative capped/bundle based billing plans from Section V - D are used.

Video Quality

To assess the multimedia quality, the multimedia sequences downloaded and presented in Section V – A were encoded so that they match the resolution and bit rate as recommended by the COMMEDY mechanism. Table V from Section IV – C presents in details what resolution and bit rate corresponds to each multimedia clip based on the resolution class and user risk attitude. The clips were transcoded using XMedia Recode [71]. The same clips were used for subjective evaluation, and the clips were approximate 30 seconds long.

Objective multimedia quality analysis is done using well-known assessment metrics: PSNR 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.

These two metrics were used with the aim to assess how much the video quality has been degraded for the people getting the lower quality. The obtained values are presented in Table VIII (for 240p class), Table IX (for 360p class), and Table X (for 480p class). Due to the low number of mobile phones having high definition video, the analysis for 7 has not been performed. 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 Table I. The fourth column presents the SSIM value and the last one the equivalent of the SSIM value on the MOS scale.

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

TABLE VIII
PSNR & SSIM Values for 240p (240 x 320) 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
Documentary	33.82	4	0.95	3
Animation	42.42	4	0.97	4

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

For the 480p class, majority of the clips got values between 5 and 4 with the exception of *Documentary* which got 3.

TABLE IX
PSNR & SSIM VALUES FOR 360P (360 X 640) 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 X
PSNR & SSIM VALUE FOR 480P (480 X 800) 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

We can notice that for neither of the classes the MOS value is under 3 (Fair quality), and the majority of the values are 4 or 5. In conclusion, one can note that based on the objective metrics the MOS score for the multimedia clips is at least of a fair quality, mostly having a good quality. A good quality is considered satisfactory for all users [72].

Content Delivery Savings

In order to analyse the savings for the users who got the lower quality, three billing plans were selected. It can be noticed from the analysis done in Section V - D, that the bundle based billing plan type is by far the most common form of billing for mobile data. Two types 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:

Plan A: The Vodafone Ireland daily data billing plan, where for 50MB one pays €0.99, and for the exceeding quantity €1/MB.

Plan B: The O2 Ireland monthly data billing plan, where one gets 500MB of data, and for the exceeding quantity s/he pays 2c/MB.

Plan C: The T-Mobile Germany monthly data billing plan, where 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.

The multimedia clip, *Introductory Trailer to Chandra* was used for this assessment. The clip is 1 minute and 44 seconds long and has not been cut at all, so it is a typical clip a person might download from iTunes and watch it. It is also not too long so that it will not create high cost or the people would avoid downloading it.

Four versions of the multimedia clip have been created using XMedia Recorde: two versions for the 240p resolution class and two versions for the 480p resolution class. For the 240p class, one version has a bit rate of a 150kbps for risk averse users and 250kbps for the risk seekers. For the 480p class, the bit rate is of 600kbps for risk averse users and 1000kbps for the risk seekers. These are values presented in Table IV, Section IV – C, based on the COMEDY mechanism.

Table XI, Table XII, and Table XIII present the results of assessing savings by using the proposed mechanism, COMEDY. All the tables address both the classes 240p and 480p. The savings are presented in terms of monetary cost for the case when the user exceeds the bundle quantity. For the case in which the user still has data in the bundle (having all the data bundle left is also considered here), the savings are assessed in terms of the data left in the bundle. The first column of each of these tables presents the user type: risk averse or risk seeking users. The second column presents the size of the multimedia clip. The third column presents the recommended multimedia bit rate corresponding to the resolution class and user type. The fourth column presents the resolution class. The fifth and the sixth columns address the case in which the user has data in the bundle. The fifth column presents the remaining data from the bundle, after receiving the multimedia clip over the wireless network. The sixth column presents the percentage of savings obtained in the bundle data for risk averse as compared to risk seekers, as a lower quality and a smaller clip was transmitted for risk averse users.

For Table XI, and Table XII, the seventh 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 users.

Table XI shows can see the results for the plan A. We can notice that in terms of monetary cost, savings around 30% are obtained for the risk averse people. When one exceeds the bundle quantity it is charged €1.20 less for the first class and €4.85 less for the second class. For the case in which the subjects still have data in their bundle available, risk averse people save 2.4% more data quantity for the bundle (1.2MB), for the 240p class and 9.7% (4.85MB) for the 480p class.

The savings for the plan B are presented in Table XII. Savings around 30%, (when the user exceeds the quantity) are obtained also for risk averse users. 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 users from the 240p class and 4.85MB for the risk averse users from the 480p class.

TABLE XI
SAVINGS FOR THE BILLING PLAN A

User Type	Multimedia Clip Size (MB)	Multimedia bit rate (kbps)	Resolution Class	In Bundle: Remaining Data (MB)	In Bundle: Percentage of Data Saved	Exceeds Bundle: Price (€)	Exceeds the Bundle: Quantity Savings (monetary)
Risk averse	2.90	150	240p	47.10	2.4%	2.90	29.27%
Risk seeker	4.10	250	240p	45.90	-	4.10	-
Risk averse	9.15	600	480p	40.85	9.7%	9.15	34.64%
Risk seeker	14	1000	480p	36	-	14	-

TABLE XII
SAVINGS FOR THE BILLING PLAN B

User Tyoe	Multimedia Clip Size (MB)	Multimedia bit rate (kbps)	Resolution Class	In Bundle: Remaining Data (MB)	In Bundle: Percentage of Data Saved	Exceeds Bundle: Price (€)	Exceeds the Bundle: Quantity Savings (monetary)
Risk averse	2.90	150	240p	407.10	0.24%	0.058	29.27%
Risk seeker	4.10	250	240p	495.90	-	0.082	-
Risk averse	9.15	600	480p	490.85	0.97%	0.183	34.64%
Risk seeker	14	1000	480p	486	-	0.28	-

TABLE XIII
SAVINGS FOR THE BILLING PLAN C

User Type	Multimedia Clip Size (MB)	Multimedia bit rate (kbps)	Resolution Class	In Bundle: Remaining Data (MB)	In Bundle: Percentage of Data Saved	In Bundle: Download Time	In Bundle: Download Percentage Faster
Risk averse	2.90	150	240p	297.10	0.41%	46s	30.30%
Risk seeker	4.10	250	240p	295.9	-	1 min. 6s	-
Risk averse	9.15	600	480p	290.85	1.70%	2 min 26s	34.64%
Risk seeker	14	1000	480p	286	-	3 min 44s	-

Table XIII presents the savings for the plan C. The last two columns present the download time necessary to get the multimedia clip, and the percentage by which the download is shorted for the risk averse users. The bandwidth for this billing plan is limited to 64kbps, which leads to downloading times of 46 seconds for the 240p class for the risk averse and 1 minute and 6 seconds for risk seeking users. This means that the download time for the risk averse is approximately with 30.30% shorter 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 user. This means that the risk averse users 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.

In conclusion, savings of approximately 30% in terms of monetary cost are obtained for the risk averse users, when they have to 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 also 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.

B. *Subjective Assessment*

The aim of the subjective study is to investigate whether the proposed adaptive multimedia mechanism (COMEDY) has affected the perceived multimedia quality for the risk averse and risk seekers subjects, and whether the differences between the risk averse and risk-seeking subjects are considerable. 76 subjects took part in the study. The user's perceived multimedia quality was assessed on the 5 point MOS - Mean Option Score scale.

Google Nexus and Samsung Europe with resolutions that belong to the classes 240p (240 x 320) and 480p (480 x 800) respectively, were used. These two resolutions categories cover most of the mobile phones we analysed (more details in Section IV B).

Video Quality for 240p resolution class (Samsung Galaxy Europe Mobile Phone)

Fig. 6 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 for the two video qualities delivered for risk averse and risk seekers. Slideshow is the only clip to have an average MOS value under 3(Fair), the average for risk averse being 2.89 and for

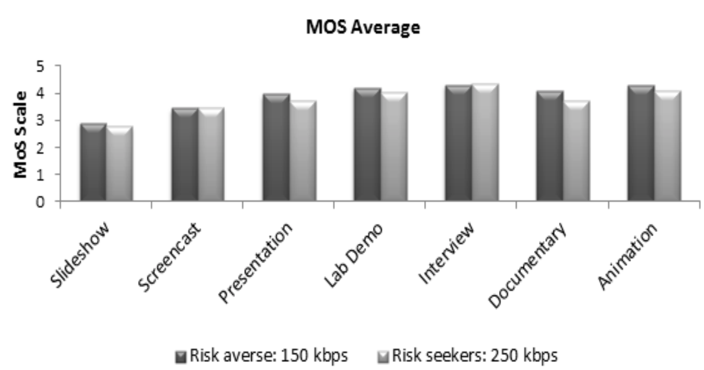

Fig. 6. MOS Average for 240p Resolution Class

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.

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 clips:. Table XIV presents the t and p value obtained as a result of this Welsh t-test. One can notice that there is no significant difference between the two groups in terms of the perceived multimedia quality, regardless of the multimedia clip used. This suggests that the risk averse users do not perceived the multimedia clip given as a different quality than the risk seekers group.

TABLE XIV
WELCH T TEST RESULTS PERFORMED ON THE MOS VALUES THE RISK AVERSE AND RISK SEEKERS REPORTED

Multimedia Clip Category	t value	p value	CI
Slideshow	0.4285	0.6702	0.95
Screencast	-0.1005	0.9204	0.95
Presentation	1.1562	0.2520	0.95
Lab Demo	0.9041	0.3697	0.95
Interview	-0.4032	0.6884	0.95
Documentary	1.6624	0.1030	0.95
Animation	0.8824	0.3811	0.95

Video Quality for 480p resolution class (Samsung Galaxy Europe Mobile Phone)

Fig. 7 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 [72]. Lower MOS values were obtained again for the *Slideshow* multimedia category. However, in this case, the values were over 3 (Fair). For the rest of the clips, all MOS values are over 4 (Good). Once again, no significant difference in the average MOS values was noticed for the two groups.

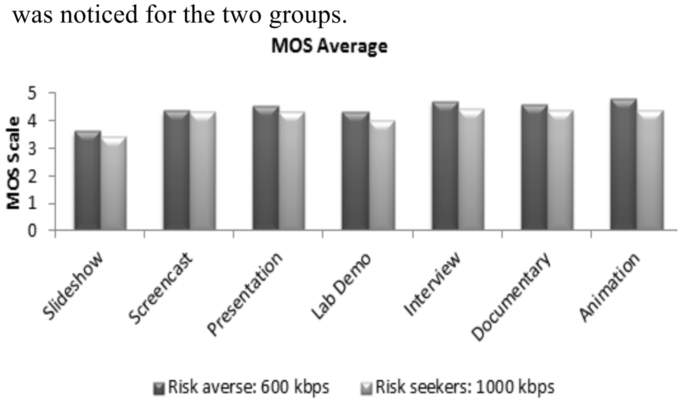

Fig. 7. MOS Average for 480p Resolution Class

In order to see whether there are significant differences between the two groups' scores for the multimedia clips, Welch t test with 95% confidence interval was performed. The results of the test are presented in Table XV. It can be noticed that for *Slideshow*, *Screencast*, *Presentation, Lab Demo*, *Interview*, and *Documentary* show no significant difference between the two groups. However, the Welch t test on Animation shows that there is a significant difference for the two groups. It can be noticed from Fig. 7 that risk averse subjects got on average a higher quality score. It can then be assumed that the proposed adaptation did not affect the perceived quality.

TABLE XV
WELCH T TEST RESULTS PERFORMED ON THE MOS VALUES THE RISK AVERSE AND RISK SEEKERS REPORTED

Multimedia Clip Category	t value	p value	CI
Slideshow	0.8751	0.3853	0.95
Screencast	0.1279	0.8987	0.95
Presentation	1.0048	0.3191	0.95
Lab Demo	1.5284	0.1314	0.95
Interview	1.7651	0.0817	0.95
Documentary	1.2148	0.2288	0.95
Animation	2.8429	0.0057	0.95

VII. DISCUSSIONS

Overall, this study has provided evidence of benefits in terms of monetary cost, when the proposed multimedia adaptation is performed. The adaptation does not negatively affect the subjects' perceived quality.

For end-users, the outcome of this research could be beneficial, as they can obtain personalised multimedia 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.

From the providers' point of view, proving personalised content may lead to more satisfied users. It could also reduce the bandwidth consumption and the traffic on the server or proxy. Adapting content to the user mobile phone characteristics 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 phone 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 paper 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.

Regarding the possible avenues that would further explore the research presented in this paper, the proposed adaptation mechanism, COMEDY, may be expanded by considering other parameters such as user preference for multimedia content, user context, to better model both user's preferences and technical constraints imposed by the user device or the delivery infrastructure. Thus a more fine-grained mechanism that classifies users in different categories will be provided. Moreover, other user characteristics could be considered such as preference towards multimedia content or quality.

Concerning the user device, different hardware (battery life) and/or software components (such as OS, multimedia player supported) could affect the perceived quality or the information assimilation from the video clip [72].

From the Internet infrastructure perspective, the available bandwidth can have a considerable effect on the perceived quality, and it has been shown that a controlled decrease in the multimedia quality could provide a better perceived quality than delivering the multimedia clip as it is on a network with poor performance [73]. Therefore, the adaptation mechanism would provide a better user experience if these factors are taken into account.

Previous work in the field has been shown that by reducing the video clip bit rate values, it is possible to save the battery lifetime [74]. This aspect of the COMEDY mechanism would have to be further researched, and independent off the cost savings, the mechanism could potentially improve the battery life for the risk averse users. A possible extension the COMEDY mechanism may consider how battery lifetime affects the multimedia quality choices under the cost constraints.

Moreover, it would be interesting to determine how the mechanism would behave on vehicular networks, where the data storage cost [75] is important. When COMEDY is used as an adaptation mechanism for risk averse users a lower size multimedia clip is delivered and this may lead to reducing the data storage cost. Moreover, COMEDY could be incorporated and used in a network selection mechanism, similar to the cost-function based network-selection proposed in [76]. In this mechanism, if multiple networks are accessible to the user, traffic load and strength are considered as criteria for network selection. The mechanism could be improved by taking into account the cost of delivery and the user risk attitude. If there is a cost of delivery over the specific network, COMEDY, may be performed.

VIII. Conclusions And Discussion

The cost of delivery of multimedia content over mobile networks is still high, and there are people who would prefer not to pay that much as a trade-off for quality. This paper presents COMEDY, a mechanism that adapts the multimedia quality so that the people who are not willing to pay high price for a high quality multimedia content would receive a lower quality (and a lower price) than the ones who are willing to pay for the high multimedia quality. The COMEDY mechanism takes into account the user risk aversion and the resolution of the devices people use. The type of resolutions available on mobile phones have been assessed by analysing 1800 mobile phones announced from 2008 up to 2011 (18 December 2011).

The COMEDY mechanism has been assessed both through objective and subjective studies. The objective studies assessed the multimedia quality and billing plans. The multimedia quality has been assessed using two well-known metrics PSNR and SSIM. The savings obtained were computed by taking into account three representative billing plans savings. The results of the objective studies show that the multimedia quality for the risk averse group, as assessed using PSNR and SSIM metrics, has values of 4 and 5 on the MOS scale for majority of the clips used in our tests, when resolution from 240p, 360p and 480p classes are used.

The subjective study looked at the perceived multimedia quality. The subjective study shows slightly lower on average values. Only for the Slideshow 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 in 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 the 240p device class, and for most of the 480p category, except for the Animation. In the case of the Animation clip, the results of the Welch's t test show that there is a significant difference, however, for that clip, the MOS as assessed by the subjects was higher for the risk averse category. This is in concordance with previous research that has shown that the video quality can be degraded without negatively affecting the user perception [57, 77].

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 make their opinion based on the capabilities of the medium [78], 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.

An analysis performed on a sample of billing plans shows that savings of around 30% can be obtained by using the proposed COMEDY 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.

Overall, this study has provided evidence of benefits in terms of monetary cost, when the proposed multimedia adaptation is performed. The adaptation does not negatively affect the subjects' perceived quality.

For end users, the outcome of this research could be beneficial, as they can obtain personalised multimedia 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.

From the providers' point of view, proving personalised content may lead to more satisfied users. It could also reduce the bandwidth consumption and the traffic on the server or proxy. Adapting content to the user mobile phone characteristics 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 phone 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 paper 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.

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