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QoE: A market perspective analysis

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Title:

QoE: A market perspective analysis

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Abstract

With the development of mobile networks, customer needs and behaviours have changed. Mobile communications means so much more than simple voice communication; there is now mobile Internet with web surfing, videophone, streaming media, and micro blogging. The objective of network optimization has gradually shifted from enhancing network performance to improve quality of experience (QoE). Therefore, assessing and optimizing QoE is the trend for optimizing future mobile networks.

Today, users want reliable access for their content, wherever they go in the network. To deliver the best possible experience to mobile broadband subscribers, operators need new ways to assess performance that will enable them to build and manage their networks in the most efficient way. The new paradigmatic eco system (user-interface-network-content) requires novel and disruptive end-to-end considerations in order to enable and sustain the next generation of services and user experience. Thus, the extraordinary adoption of mobile connectivity by end users, and the need for optimized bandwidth management network resource, on the one hand, and the growing interest for good quality content delivery/consumption, is boosting the creation of new network solutions.

We consider that by taking advantage of the capacity to support multimedia platforms and applications of mobile devices (e.g. smartphones, tablets, etc.) is possible to incorporate and provide awareness to the wireless infrastructures in the context of cross-layer systems to manage the resource allocation according to expected QoE levels. In this thesis, we address the question on how to implement QoE-aware mobile networks and evaluate different schedulers oriented to take advantage of the proposed architecture. With this study, we provide insights into the broader question of whether future mobile infrastructures can be deployed considering QoE besides the classical QoS considerations. In that sense, QoE-aware architecture takes advantage of the current features of mobile terminals and applications to provide awareness of the content processing and user's QoE to the wireless networks. The proposed solutions are believed to have a significant impact on the development of future mobile networks.

Key words:

Quality of Service (QoS), Quality of Experience (QoE), mobile networks.

1. Introduction

Recent years have witnessed a huge growth in the network traffic, mainly generated by the increasing number of wireless devices that are accessing mobile networks worldwide. Improvements in mobile devices, on hardware (embedded sensors, memory, power consumption, touchscreen, better ergonomic design, etc.), in software (more numerous and more sophisticated applications due to the release of iPhone and Android platforms) and in transmission (higher data transmission rates achieved with 3G and 4G technologies), have contributed towards having higher mobile penetration. When device capabilities are combined with faster, higher bandwidth and more intelligent networks, it leads to wide adoption of advanced multimedia applications that contribute to increase mobile traffic (Cisco 2012). According to (Ericsson 2014), mobile data traffic is expected to grow at a compound annual growth rate (CAGR) of around 45\% (2013-2019). This will result in an increase of around 10 times by the end of 2019, with video representing the largest and fastest growing mobile data traffic segment. In that sense, mobile video will generate much of the mobile traffic growth through 2018 (at a CAGR of 69\% between 2013 and 2018), indicating the highest growth rate of any mobile application (Cisco 2012).

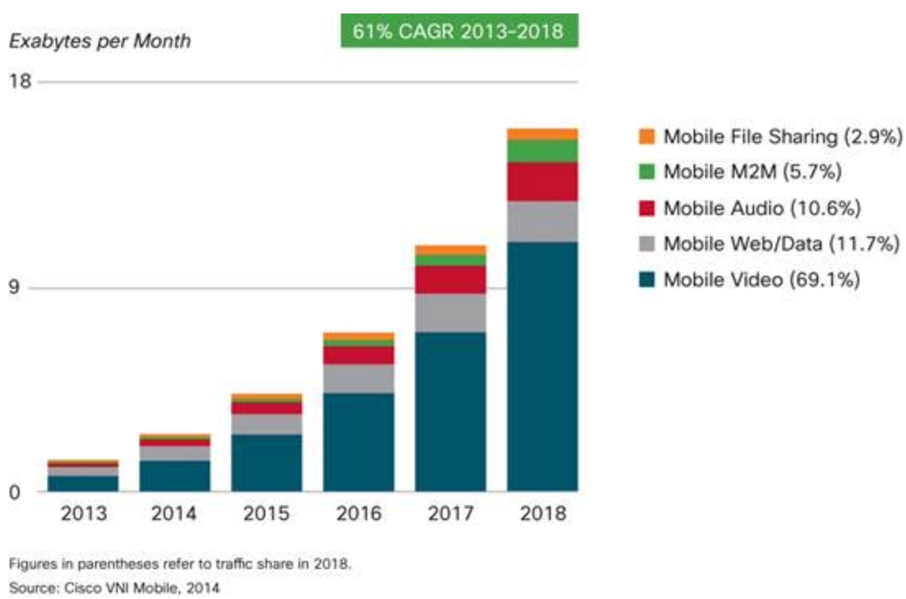

Figure 1. Global Mobile traffic distribution, 2013 - 2018. (Source: Cisco Visual Networking Index Mobile, 2014)

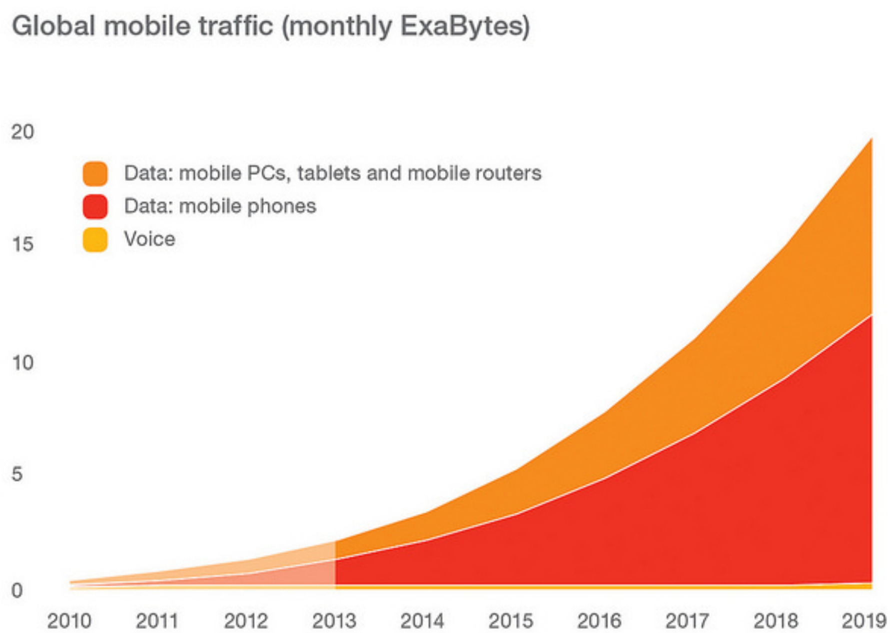

Figure 2. Growth in mobile data traffic between 2013. (Source: Ericsson Mobility Report, 2013)

While in 1G and 2G networks mobile traffic was mainly voice, with 3G and 4G networks development traffic is now dominated by video and data owing to applications like video streaming, Facebook, Twitter and mobile browsing. This has not only increased the amount of mobile broadband traffic transported by the carrier networks, but also transformed its composition. We have moved from a world where providing quality speech was the major concern to one where we must incorporate techniques to manage diverse traffic characteristics of the growing range of multimedia applications and services. At the same time, the demand for enhanced user's experience with differentiated service levels also extends. This trend continues to growth as the variety and number of applications and services increases, and the subscriber base grows.

In this scenario, mobile network infrastructures face a challenge represented by the traffic explosion and more demanding user's expectations. The common approach to answer this situation has been the capacity expansion and the implementation of quality of service (QoS) techniques. Solutions to the capacity issue and the growing traffic are focused in three key elements: spectrum, technology, i.e., spectral efficiency, and topology, i.e., network architecture. A consequence of this approach usually implies an increase both in capital expenditure (CAPEX) and operational expenditure (OPEX). However, the revenues generated by traffic increase are limited, just a few percent of average revenue per user (ARPU), and thus not compensating for declining voice revenues, creating a so called "revenue gap" (Markendahl 2009).

The new paradigmatic eco system (user-interface-network-content) requires novel and disruptive end-to-end considerations in order to enable and sustain the next generation of services and user experience. Thus, the extraordinary adoption of mobile connectivity by end users, and the need for optimized bandwidth management network resource, on the one hand, and the growing interest for good quality content delivery/consumption, requires the creation of new network solutions. To deliver the best possible experience to mobile broadband subscribers, operators need new ways to assess performance that will enable them to build and manage their networks in the most efficient way.

In this paper we do not intend to provide a definitive or exhaustive answer to the question about how to deploy a QoE-aware network solution in the future mobile networks infrastructure and its impact in the market, as such answer can only be achieved by making numerous assumptions about future developments that are beyond of the scope of this study. In order to establish a solid understanding the problem and provide a convincing analysis, we limited our focus to propose what would be the architecture and measure the potential of the proposed mechanisms to impact the user QoE.

2. Quality of Service (QoS) and Quality of Experience (QoE)

The technical ITU definition of QoS is the "Totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service", in which "service" is a set of functions offered to a user by an service provider. QoS is therefore a measure of the performance of a set of functions observable indicators at the user interface of the service which known as Key performance indicators.

QoS implementation enables network operators to isolate traffic into flows based on attributes, such as traffic type (voice, video or control) or application needs (throughput, latency and/or jitter), and then to transport each flow accordingly. The major challenges when considering QoS in mobile networks are varying rate channel characteristics, bandwidth allocation, fault tolerance levels and handoff support among heterogeneous wireless networks. However, this focus does not consider all the content delivered features or the use of information regarding the content processing, provided by terminals. Things get even more complicated when data and voice services have to be supported.

From mobile operator's perspectives, the interpretations of QoE go hand-in-hand with the assumption that by optimizing the QoS, the end user's QoE will also increase, but is this really the case? QoE is the definition of overall acceptability of service, as perceived subjectively by the end-user which normally hard to be quantified. To provide the "best experience" to highly mobile user equipments (UEs) and communicating machine devices, robust and reliable connectivity solutions are needed as well as the ability to efficiently manage the mobility. Moreover, associated regulations and policy framework need to be developed to set clear definitions to what mean by minimum QoS and QoE as can been seen on the activities of the European Regulatory Body (BEREC).

The concept of QoS continues to be important in the service provider environment, but a new concept called quality of experience (QoE) is rapidly gaining mindshare. The QoE concept differs from QoS in that it considers much more than the performance of the network. QoE is concerned with the overall experience consumers have when accessing and using provided services. Thus, it is important for mobile operators and content providers to incorporate a high degree of intelligence to transport different types of traffic in a way that provides a satisfactory and competitive end-user experience, while also maximizing revenue per user. As the mobile operators deploy more and more infrastructure, comprehensive QoE capabilities will be needed to support next-generation services and applications. This makes QoE a new fundamental component of the mobile networks framework for satisfactory delivery of applications and services with effective end-to-end management of network resources.

With the development of mobile networks, customer needs and behaviours have changed. Mobile communications means so much more than simple voice communication; there is now mobile Internet with web surfing, videophone, streaming media, and microblogging. Traditional KPIs are no longer adequate for measuring the quality of mobile services. The objective of network optimization has gradually shifted from enhancing network performance to improving QoE. Therefore, assessing and optimizing QoE is the trend for improving future mobile networks. The lack of multidisciplinary work enhancing the development of more complete models to link user experience and resource allocation is still evident. Up to now, most of the communication network deployments have been done taking into account economic and technical considerations with the user's satisfaction regarding content provided through these infrastructures will be reached only by having better technology and higher bandwidth.

In that sense, it is also important to consider what is happening during the content processing at user's side in order to get a better picture of the traffic management. Mobile networks can utilize this information to impact in a positive way the use of limited resources inside the infrastructure. By taking advantage of the capacity to support multimedia platforms and applications of mobile devices (e.g. smartphones, tablets, etc.) it is possible to incorporate and provide awareness to the wireless infrastructures in the context of cross-layer systems to manage the resource allocation according to expected QoE levels. From a user's perspective, this QoE-awareness will represent the probability that the network delivers sufficient performance to run a particular application/service at an acceptable quality level. From the network side, the use of this concept would ensure a high probability that the most widely used application/services will deliver exactly what the user expects, improving the utilization of the network infrastructure resources.

The main challenge that operators face nowadays is to find a solution to manage the traffic growth while meeting the users' expectations in a cost effective manner. A common approach to reach the goal of high quality information delivery has been the implementation of resource management schemes and scheduling algorithms to optimize resource allocation and traffic distribution as function of network parameters (Yin 2000) (Piamrat 2009) (Thakolsri 2009) (Aristomenopoulos 2010) (Shehada 2011) (Chuah 2012) (Dutta 2012). By maximizing performance through infrastructure improvements mostly oriented to increase QoS, network providers want to meet the growing end-user demand for more quality and faster connectivity on the move.

Solutions have been gradually evolved from a perspective mainly centred on the evaluation of network based constraints (e.g. signal-to-noise ratio (SNR) or instant data rates) deprived of knowledge about the transferred content (Yin 2000), to a perspective where inherent characteristics of the content are considered to improve network performance. In this regard, solutions oriented to improve video transmission are a clear example. Although proposed solutions offer a path towards the solution of the traffic growth and the demanding user expectation issue, this approach does not consider the type of content delivered by the network or the use of information provided by terminals to manage the resource allocation. Thus, our aim is to propose a mechanism to incorporate QoE-awareness to the mobile networks. Considering the potential scale of the implementation of a QoE-aware infrastructure, we concentrate our effort on proposing a QoE-aware mobile network architecture. This is highlighted in Figure 3.

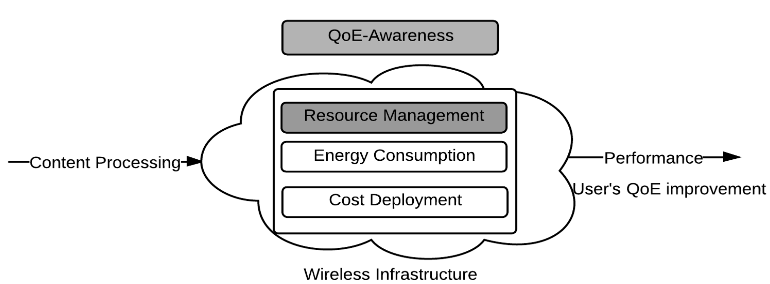

Figure 3. Framework of study.

3. Current mobile networks infrastructure

Current mobile broadband networks must support multiple applications of voice, video, and data on a single IP-based infrastructure. Mobile operators are therefore looking to offer differentiated mobile service packages. One approach is to distinguish between the traffic from different applications, offering a range of QoS standards as appropriate. This technique is designed to ensure application quality, allow operators to offer differentiated services to users and manage network congestion. In that sense, the 3rd Generation Partnership Project (3GPP) has developed a QoS, charging and policy control framework oriented to UMTS/LTE to make an efficient partitioning of the available wireless network resources (ETSI 2012).

The 3GPP's goal is to define an access-agnostic policy control framework, with the objective of standardizing QoS and policy mechanisms that enable operators to provide service and subscriber differentiation. 3GPP standards explain how to build transmission paths between the user equipment (UE) and the external packet data network (PDN) with well-defined QoS. To this end, the 3GPP has defined an extensive "bearer model" to implement QoS (ETSI 2012). Bearer separation is a solution foreseen by 3GPP, where different applications are carried over different radio bearers.

A bearer is a traffic separation element that enables differentiated treatment of traffic based on its QoS requirements, and provides a logical path between the mobile terminal or UE and a gateway. Each bearer is associated with a set of QoS parameters that describe the properties of the transport channel, including bit rates, packet delay, packet loss, bit error rate, and scheduling policy in the radio base station.

According to (Mojtahed 2013) the functions that the network elements need to implement for achieving end-to-end QoS in 3GPP networks are:

- QoS identification and marking. IP packets belonging to a particular traffic flow are identified and marked through the classification of each packet. This is necessary for coordinating QoS provisions end-to-end throughout the network. Common methods of identifying flows include access control lists and policy-based routing using routing tables. Marking ensures the flow characteristics are carried through portions of, or if necessary, the entire network.

- Policing. The policing function is needed to ensure that a flow does not exceed the agreed-upon bitrate. The policing mechanisms also guarantee a minimum share of service to all types of traffic characterized by average/sustained throughput, peak throughput, etc.

- Traffic management and shaping. The traffic management function ensures that bandwidth is available whenever needed to pass mission-critical traffic. It manages the overall bandwidth so that the negotiated bandwidth requirements for different services are all satisfied. For example, it ensures a guaranteed bandwidth for VoIP and control traffic, or a minimum bandwidth for file transfers.

- Administration of QoS policy and management: These functions are realized via provisioning and accounting algorithms in the operations, administration and management domain.
- Queuing and scheduling. The scheduling function ensures that important traffic is not dropped in the event of heavy oversubscription. Because IP traffic is usually carried over an Ethernet core in LTE networks, the DiffServ protocol feature of Ethernet is used to provide QoS. The DiffServ standard provides for up to six queues, and the IP traffic is mapped to one of the DiffServ classes. DiffServ class can also be determined by the differentiated services code point (DSCP) field in the IP layer in the tunnel header. Scheduling is based on algorithms like strict priority without starvation avoidance, weighted round robin (WRR), weighted fair queuing (WFQ) and deficit weighted round robin (DWRR), or smoothed deficit weighted round robin (SDWRR).

If we look at these required functions, it is clear they are dominated by techno-centric interpretations of QoE. This goes hand-in-hand with the assumption that by optimizing the QoS, the end user's QoE will also increase. However, this is not always the case: Even with excellent QoS, QoE can be really poor \cite{DeMoor2010a}. QoE is usually measured in terms of technical metrics (QoS), ignoring the fact that the ultimate goal should not be to deliver applications with the most advanced features, but to deliver content that will ensure a good user experience. This gap is usually caused by a lack of insight in the totality of dimensions of a customer's experience and here is where HCI can offer the tools to complete the development of a structured QoE system of assessment and implementation where users are really involved.

4. QoE-aware mobile architechture

One of the goals for mobile operators today is to enable the best experience for as many users as possible, given the available content, apps and devices (Ericsson 2014) (Citrix 2013) (De Pessemier 2013). In addition to monitoring network performance, operators must increasingly be aware of the usage of both devices and content/apps in their networks. They then need to measure how fast the demands on the network are increasing but also what the user’s perception is regarding the content delivered by the network infrastructure in order to build this knowledge into their network investment.

Traditionally, QoE has been evaluated through subjective tests carried out on the users in order to assess their satisfaction degree with a MOS value. This method cannot be used for making decisions (including resource allocation ones) to improve the QoE on the move. A possible solution to evaluate the QoE and the content processing status instantaneously is to integrate reporting tools in the mobile terminal, providing QoE-awareness to the wireless infrastructure. In this regard, QoE-awareness might represent a way to optimize wireless communication based on a model of the mobile service requirements for wireless communication in the context of a desired QoE. In order to incorporate this capacity in the context of a mobile infrastructure, we propose an architecture that can be used to implement a QoE-aware resource management for delivery of multimedia content. The key idea of the QoE-aware architecture is to collect information about content processing and buffer status in the mobile terminal at a central entity, the QoE-aware communication engine. It is able to evaluate information sent by mobile terminals and make resource allocation decisions considering the impact of the interruptions in the QoE perceived by mobile users. This architecture was introduced in paper (Ballesteros, 2012).

Towards QoE-aware mobile infrastructures, one important element is the definition of the network architecture that will allow the incorporation of QoE-awareness concept within the wireless infrastructure. We present an architecture proposal that takes advantage of the current features of mobile terminals and applications to provide awareness to the wireless networks about the content processing and user's QoE.

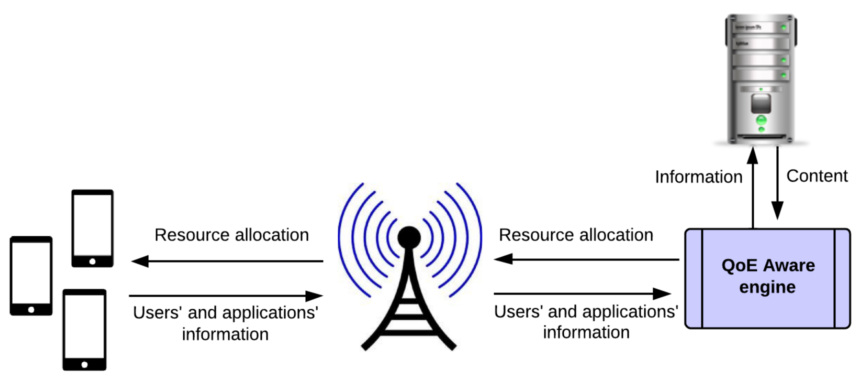

Figure 4. QoE-aware proposed architecture.

Figure 4 shows the different components of the proposed architecture. This is, first of all, the QoE-aware communication engine that receives information from the application and the mobile terminal. It is additionally connected to the devices in the network that actually enforce resourcemanagement decisions (radio interface/content servers). When notified by an application monitor about a critical state of an application (a potential interruption), the QoE-aware communication engine evaluates information provided by terminal and decides about the resource allocation. This means that based on the information on application, it determines how close to experience an interruption a user is, and allocate resources in a way that can avoid a situation that impacts negatively the end user's QoE.

Another key component is the application monitor that is running on the client. It sends the content processing and buffer status to the QoE-aware communication engine. The task of the monitor is to keep track of the status of the applications that are subject to the resource management decisions. The status of an application is a collection of key performance indicators that the customer will directly perceive as quality parameters. These key performance indicators are specific for each application and describe whether the current performance offered by the network leads or not to QoE degradation. Evaluating these key performance indicators, the architecture is able to indirectly consider the QoE of applications within the resource management and avoid degradations. Key performance indicators (KPIs) for video streaming services are the bandwidth or the buffered playtime in the client. When the buffered playtime is low and the bandwidth is below the video rate, a period of stalling will probably occur if no measures are taken.

Two approaches are introduced in this chapter to address the challenge to develop a QoE-aware resource management in a mobile infrastructure: Fully integrated within the operator network (FION) and over the top (OTT). FION proposes a system where the base station (BS) is aware about both the content processing and the buffer status in the mobile terminal and uses this information to make resource allocation decisions. For OTT approach, it is the content server who allocates resources after evaluating the content processing and the buffer status in the mobile terminal.

4.1. FION approach

In this approach the QoE-aware communication engine capability is placed in the BS. Thus, the BS is aware about both the content processing and the buffer status in the mobile terminal making resource allocation decisions at each time slot by evaluating information provided by application monitors. Content provider server is agnostic about the content status in the terminal. Figure 5 shows the scenario considered in this study.

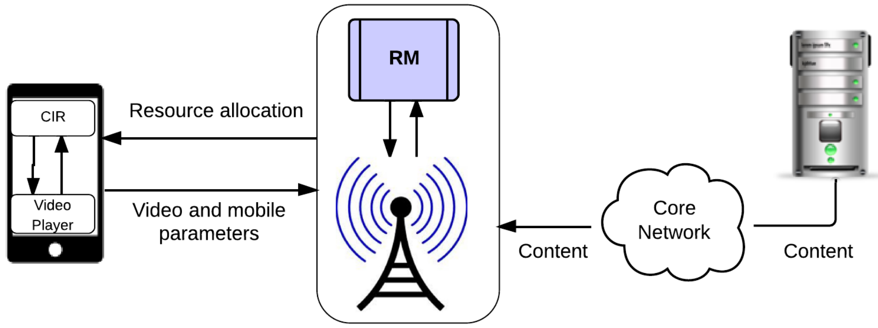

Figure 5. FION architecture.

In the proposed infrastructure we can identify two entities, fully integrated within the operator network. These entities are:

- An entity dedicated to the resource allocation based on the information received from terminals about current status of interruptions.
- An entity dedicated to report the information about the current status of the playback from the mobile device to the wireless infrastructure.

The first entity or resource manager (RM) plays the role of the QoE-aware communication engine proposed in our architecture. It is centrally located in the BS and collects the reports provided by the user's terminals. It takes care of profiling user requests, as well as keeping track of the terminals and content's processing current status. A proper dynamic linkage between the RM and the BS is recommended with the aim of achieving a dynamic control of the resource allocation based on user perception.

Second entity or application monitor is a client application in the mobile terminal (MT), called client information reporter (CIR). CIR reports to the RM information regarding the current buffer status at the terminal, the player data rate consumption, and the remaining bits to download. The CIRs are software applications with collecting and sensing functionalities installed in the mobile terminals. The application monitor will require the establishment of a radio bearer between the terminal and the BS in order to send the QoE/buffer-based associated information.

To facilitate this, the terminal has to initiate an attach procedure when the user's application starts. Once the attach procedure succeeds, an initial context is established for the MT in the BS controller, and a default bearer is established between the terminal and the core network. Once the MT and the CIR have connectivity, the terminal can start sending information to the infrastructure. Reported information will be passed to the BS. Once the gathered data is passed to the RM, this selects the more appropriate moment for allocating resources and delivering content to individual users by applying a scheduling policy.

4.2. OTT approach

In this approach, it is the content provider who is aware about the content processing in the mobile terminal. The QoE-aware engine is placed in the content server and helps the provider to allocate resources according to the content processing status. BS and radio access network (RAN) are not aware about what happens in each terminal. Figure 6 shows the OTT architecture.

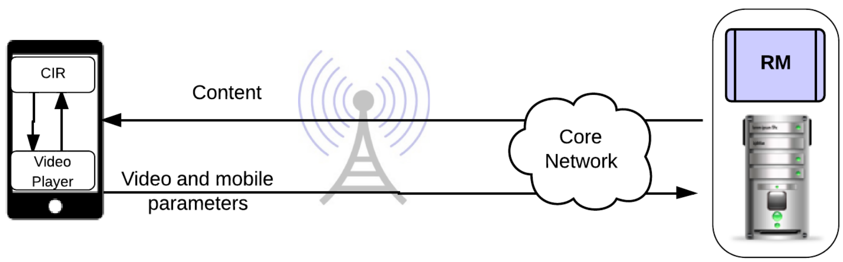

Figure 6. OTT architecture.

In the proposed infrastructure we can identify two entities working for the content provider and leaving the ISP responsible only for transporting IP packets. These entities are:

- An entity dedicated to the resource allocation based on the information received from terminals about current status of interruptions.
- An entity dedicated to report the information about the current status of the playback from the mobile device to the wireless infrastructure.

The first entity or resource manager (RM) plays the role of the QoE-aware communication engine proposed in our architecture. It is centrally located in the content provider infrastructure and collects the reports provided by the user's terminals. It takes care of profiling user requests, as well as keeping track of the terminals and content's processing current status.

Second entity or application monitor is a client application in the mobile terminal (MT), called client information reporter (CIR). CIR reports to the RM information regarding the current buffer status at the terminal, the player data rate consumption, and the remaining bits to download. The CIRs are software applications with collecting and sensing functionalities installed in the mobile terminals. Once the MT and the CIR have connectivity, the terminal can start sending information to the content provider. The gathered data is passed to the RM, this will make decisions about bandwidth selects the more appropriate moment for allocating resources and delivering content to individual users by applying a scheduling policy.

Form the two proposed architectures we can envision user's QoE can be improved by incorporating a more user-centric approach in the resource allocation. In our case, an initial step towards this goal is represented by a mobile network capable of identifying users' expectations and using this information to dynamically adjust network parameters according to a QoE model while the content is being processed in the user terminal.

5. Conclusions and future work.

With the development of mobile networks, customer needs and behaviours have changed. Mobile communications means so much more than simple voice communication; there is now mobile Internet with web surfing, videophone, streaming media, and microblogging. Traditional KPIs are no longer adequate for measuring the quality of mobile services. The objective of network optimization has gradually shifted from enhancing network performance to improving QoE. Therefore, assessing and optimizing QoE is the trend for improving future mobile networks. The lack of multidisciplinary work enhancing the development of more complete models to link user experience and resource allocation is still evident. Up to now, most of the communication network deployments have been done taking into account economic and technical considerations with the user's satisfaction regarding content provided through these infrastructures will be reached only by having better technology and higher bandwidth.

We claim that an alternative way to improve the QoE is having networks capable of identifying users expectations and using this information to dynamically allocate resources adjusted to a semantic model of the mobile service requirements while the content is being processed in the user terminal. And it is here that a better understanding of user's perceptions might contribute to the creation of network infrastructures with better performance based on the evaluation of predefined QoE model. Even though we consider the adjustment of network parameters based on QoE evaluation, it is necessary to develop new studies where the application of concepts such as UX and HCI can feed systems like we propose with more accurate description of what users want.

One alternative is considering a FION approach, which implies a modification in the resource management scheme implemented at the base station. The other option is entirely relying on an OTT approach, where the content provider manages the resource allocation.

A few issues that have not been addressed in this dissertation deserve further attention, such as the study of the potential privacy issues of implementing QoE-aware solution in future mobile infrastructures. It is necessary to consider more complex network scenarios (closer to real deployed infrastructures) to evaluate the level of impact of the results in this study.

Considering the growing importance of QoE in the mobile telecommunications market, it would be key to analyse the importance of QoE considering different actors (operators, regulators, content providers) from a market perspective, since QoE might be seen as competitive/differentiation factor in the provision of telecommunication services.

The relationship between QoE and energy consumption at the mobile terminal and the BS might be a future extension of the current work. The impact of interruptions on the online time, and the relation between interruptions and QoE seems to show that it is possible to obtain energy savings in the wireless infrastructure. The quantification and modelling of this relationship will be an interesting next step of this research.

Finally, we envisage interesting further research areas such as the definition of a model to allocate resource based on the expected QoE incorporating HCI elements in the definition of more effective RRM in energy consumption that simultaneously improves users' QoE.

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