On the Incorporation of Quality of Experience (QoE) in Mobile Networks

A technical, regulatory and business analysis

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Abstract

Mobile operators face a scenario characterised by new challenges such as growing data consumption, a slowdown in subscriber growth and reduced revenues due to the success of OTT providers. To remain competitive, mobile operators must offer affordable services and think on strategies to retain current customers.

Quality of Experience (QoE) is a well-established methodology for measuring and understanding the overall level of customer satisfaction with a service services and has been presented as a way to improve telecommunication services. Even though QoE can be used to solve problems such as customer loyalty and optimisation of network resources in mobile networks, there is a great lack of knowledge on how mobile operators can take advantage of QoE and its potential benefits.

This thesis explores the incorporation of QoE in mobile networks to improve their service offering from a technical, regulatory and business perspective. The technical level focuses on the definition of the mechanism to integrate QoE in the operation of mobile networks. The second part of this study has been focused on the regulatory framework on Net Neutrality. Finally, the third part of this thesis focuses on the identification of potential business scenarios and models based on the incorporation of QoE in mobile networks.

An important conclusion is that due to the nature of the challenges faced by the mobile industry, a QoE analysis cannot be limited to a technical discussion. A technical solution can be the first step to the first step to overcoming industry challenges. However, it is important that a technical decision comes along with an informed analysis of the regulatory conditions and the business implications of the proposed solution. On the other hand, mobile operators require new methods that integrate technical, market and business considerations to improve their service offer. A method analysed in this dissertation is a Customer Experience Management (CEM) platform. Given the technical, regulatory and business factors covered in this thesis, a CEM platform can be used by mobile operators to make a better use of QoE in their business operation.

Keywords: Quality of Experience (QoE), Mobile Networks, Net Neutrality, Business Analysis.

Sammanfattning

Mobiloperatörer möter ett scenario som kännetecknas av en ökande trend inom dataförbrukning, tecken på en avmattning i abonnenttillväxten, en en minskning av de traditionella intäkter på grund av framgången med OTT leverantörer. Dessutom, mobila användare har gott om alternativ för att ändra tjänsteleverantören. I det här fallet måste mobiloperatörer förbli konkurrenskraftiga baseras både på pris och deras abonnenter tillfredsställelse. Kvalitet Erfarenhets (QoE) införlivande i mobilnät kan vara ett av alternativen för att möta vissa mobilbranschen utmaningar som omfattar tekniska, kommersiella och marknadsnivå.

QoE möjliggör en bredare och mer övergripande förståelse av användarnas erfarenheter med utförandet av applikationer, tjänster och nätverk, samtidigt som kompletterar traditionella techno-centric begrepp som Quality of Service (QoS). Händelse om användningen av QoE data har föreslagits som ett sätt att lösa problem som optimering av nätverksresurser och kundomsättning upplevs av mobiloperatörer, finns det fortfarande en lucka på hur man utnyttjar QoE och dess potentiella fördelar i ramen för mobilnät. Således är den övergripande inriktningen av denna avhandling på att analysera hur mobiloperatörer kan integrera QoE feedback för att förbättra sin serviceerbjudande. Men på grund av arten av de utmaningar som den mobila industrin står inför, denna analys kan inte begränsas till en teknisk nivå diskussion. även hitta en teknisk lösning skulle kunna vara det första steget för att övervinna utmaningarna på marknaden, är det viktigt att ett tekniskt beslut kommer tillsammans med en välgrundad analys av de regulatoriska förutsättningarna för att genomförandet och affärs konsekvenserna av den föreslagna lösningen. Så kan en skådespelare intresserad av genomförandet av det föreslagna i denna avhandling mekanism har fler verktyg för ett välgrundat beslut fattandet.

På teknisk nivå, fokuserar denna uppsats på identifiering av teknisk mekanism för att införliva QoE i mobilnätet. Sedan vår analys kretsar kring identifieringen av regelverket om nätneutralitet och dess potentiella inverkan på genomförandet av den föreslagna mekanismen för införliva QoE i mobilnät. Slutligen, och letar efter en helhetssyn på QoE frågan, erbjuder vi en analys av konsekvenserna av att införliva QoE för hela mobilnät ekosystemet och intressenterna längs hela värdenätverket.

Keywords: Kvalitet Erfarenhets (QoE), Mobilnät, nätneutralitet, affärsanalys.

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Luis Guillermo Martinez Ballesteros
Stockholm, February 3, 2017

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List of Acronyms

ICT	Information Communication Technology
MNO	Mobile Network Operator
NN	Net Neutrality
OTT	Over The Top
QoE	Quality of Experience
QoS	Quality of Service

Part I

Thesis Overview

Chapter 1

Introduction

1.1 Background

1.1.1 Mobile Network Trends and Challenges

The mobile communications market is growing as more people around the world gain access to new technology. According to the GSM Association (GSMA) [1], this growth is reflected in the more than 7.6 billion mobile connections and operator revenues of more than US$1 trillion. This phenomenon has been accompanied by a growth in network traffic. Cisco [2] estimates that mobile data traffic will grow 53 percent from 2015 to 2020, reaching 30.6 exabytes (EB) per month by 2020.

Even though the growing trend in both number of connections and data traffic may represent a positive landscape for mobile operators, the industry, including the GSMA [1] and operators such as Vodafone [3], have foreseen a slowdown in the number of new subscriptions, coupled with a more competitive scenario within a challenging macro-economic scenario in most of the developing markets. GSMA [1] estimates that the number of subscriptions will show annual average growth rate of just under 2% for the period between 2015 and 2020.

On the other hand, there have been signs from operators losing out on revenues to over-the-top (OTT) players like WhatsApp or Skype, or suffering reductions in revenues such as Vodafone (ranging from 0.4% to 3% in the last year) in markets like the UK, Spain and Germany [3]. Informa Telecoms [4] forecasts mobile operators will see a decline in the SMS revenues (from US$120 billion in 2013 to US$96.7 billion in 2018) caused by the popularity of OTT messaging applications. Regarding the voice market, according to Ovum in its report 'Consumer OTT VoIP Outlook: 2013-18' [5], the use of OTT VoIP will reach 1.7 trillion minutes in 2018. For mobile operators, this indicates US$63 billion in lost revenue by 2018.

The revenue reduction is accompanied by an explosive increase in data traffic generated by the growing popularity of OTT services, especially video. According to Cisco [2], mobile video traffic will reach 23.0 EB per month by 2020. GSMA [1] estimates that during the last five year, mobile operators have invested more than

US$880 billion in CAPEX to increase capacity and deploy mobile infrastructure. A combination of decreasing revenues and slowing subscriber growth limit the return on the invested capital on network infrastructure.

Even though many mobile operators are attempting to diversify their revenue streams, ensuring that new services deliver healthy margins remains challenging. The mobile industry is highly competitive with a large number of providers in both fixed line and mobile segments. At the same time, OTT players are also expanding the scope of their offerings, increasing the number of actors competing for the same customer base. With the expected slowing subscriber growth, customer retention will become more important, and customer initiatives will target churning customers (i.e., lost customers) rather than new ones, a view that is shared by Ericsson in the report 'Capitalizing on Customer Experience' [6] and by Ovum in the 'Telecoms, Media and Entertainment Outlook 2015' report [7]. Ericsson [6] reported that almost 40% of customer churn can be attributed to perceived low levels of quality of experience from service providers. The study revealed that subscribers are '*concerned about network service performance and they also want a better experience across their entire service life cycle*' [6]. Meanwhile, a report prepared by Wireless Data Service (WDS) (a Xerox company) [8] in 2012 shows that for a mobile operator with 1.5 million net additions (new subscribers minus lost (churned) customers) in a year and an average revenue per user (ARPU) of US$39 and a 3.5% quarterly churn rate, '*decreasing that churn by 50 base points to 3% would deliver an additional US$40m of revenue and US$22m profit in just 36 months*' [8]. In that sense, mobile operators need to look at new and innovative ways to drive long-term loyalty and stem immediate churn.

Mobile operators have considered different solutions and approaches to address the challenges in the market. Before the pressure of growing data traffic demand, mobile operators had to invest in additional radio spectrum, spectrum sharing, and deployment of small cells to enhance the network capacity. At the same time, in order to increase revenues and remain competitive, mobile operators have started to explore new business models, expanding their portfolio to services beyond the pure connectivity approach (i.e., cloud services, data management, Internet of Things). According to GSMA in the report 'Mobile operators: the digital transformation opportunity' [9], the key determinant of operator revenues will be the ability to capture value beyond the provision of connectivity and the extent to which the operators are able to develop new business models to gain a share of value in the digital ecosystem areas showing the strongest growth.

For Ericsson [6], WDS [8], and EY [10], mobile operators must look at the so called customer experience factors and find points of contention in order reduce customer churn, stand out among the competitors and maximise their customer share. Both Ericsson and WPS agree on customer experience being a key driver for mobile operators' differentiation within the marketplace. According to WDS [8] and EY [10], the customer experience factors that mobile operators must pay special attention to include both technical (e.g., network performance, coverage, device quality) and business parameters (e.g., customer care, retail experience, pricing).

Therefore, solutions for customer churn go beyond network improvements. They need to look at the customer experience and offer a holistic response, including business and market considerations, to the end user. In the words of TeliaSonera's Chief Commercial Officer (CCO), Hélene Barnekow at the Mobile World Congress 2015 [11], '*While technology innovation is playing its role in the changing face of the industry, the real driver of the transformation is the customer. The industry landscape is changing very quickly, and I actually try to frame that change from two angles, one is from the customers' point of view because it's not that technology is driving customers, customers are driving us*'. This indicates that the telecom market is adopting a new approach: a user/customer-centric paradigm.

1.1.2 Quality of Experience and the User-Centric Paradigm

Authors such as Liotou et al. [12], Lin et al. [13] or Bangerter et al. [14] and companies like Ericsson [15] and Huawei [16] agree on the idea that 5G communications should adopt a user-centric service provisioning approach to deliver 'always sufficient' throughput and low latency. For Monserrat et al. [17], with this approach, operators may operate the network in a proactive way based on the knowledge of users' experience. Meanwhile, Liotou et al. [12] affirm this new approach will transform the current paradigm centred on Quality of Service (QoS) to one based on Quality of Experience (QoE).

Traditionally, the telecommunications industry has relied on QoS as the principal descriptor of the overall performance of their network services, as stated by different authors such as Reis et al. [18] and Thakolsri et al. [19]. For Varela et al. [20], QoS has been defined from a system perspective subordinating the user's response entirely to the influence of the telecommunication system. Even though the 'network-centric' approach for QoS has allowed mobile operators to deploy their network infrastructure and guarantee acceptable service levels, the correlation between network performance and good user experience is not direct, as stated by Thakolsri et al. [21] and Cuadra et al. [22]. This is because QoS deals only with technical aspects, ignoring the other elements impacting users' perception.

Meanwhile, the goal of QoE is to interpret and understand end-to-end quality including human users' point of view. According to the Qualinet project, QoE can be defined as '*the degree of delight or annoyance of the user of an application or service. It results from the fulfillment of his or her expectations with respect to the utility and/or enjoyment of the application or service in the light of the user's personality and current state*' [23]. This definition remarks that QoE in communications services is influenced by content, network, device, application, user expectations, and context of use. This view is shared by Stankiewicz et al. [24] who point out the various dimensions of QoE (technical and non-technical) and remark on the effect that factors such as user expectation, experience with similar services and pricing policies have on users' QoE. According to Hoßfeld [20], a practical application of QoE has to consider the entire QoE ecosystem, including all the stakeholders involved in the service provision, and the identification of business implications. For

Liotou [20], acquiring QoE and controlling a network in a QoE-centric way must address questions such as (1) How can QoE be measured, monitored and controlled in telecommunication networks? Such a QoE management framework is essential before any operator-specific business decisions are made. (2) What kinds of business opportunities are created for the operator and other stakeholders assuming that QoE can be managed? New QoE-based business models need to be designed, carefully considering Network Neutrality issues. (3) What is the new (more active) role of the end user in such a QoE-aware/QoEcentric network (e.g., users may provide feedback about their preferences, priorities and experience)? Moreover, how can the end user be convinced to 'buy' QoE? Potential strategies of the network operator may include 'personalising' each end user and providing QoE accordingly, or building more aggregated user-profiles, acknowledging the fact that the 'average user' does not exist. (4) What are the stakeholder incentives? (5) What (novel) solutions are needed for coordination and information exchange among actors involved in the service delivery chain in order to provide channels for effective QoE control/improvement?

Technical solutions can lead to new business models, but the path from technology development/implementation towards the final user requires the identification of both the business scenarios and the required changes in the operator business and market structure. This also requires identifying the regulatory framework. When thinking about the incorporation of QoE, there are several examples where delivering a service with proper quality might require deals between the service and network providers involved, which could lead to neutrality issues, as mentioned by Varela and Skorin-Kapov [20]. Therefore, conducting a study on the use of QoE and the subsequent implementation of a user-centric approach in mobile networks should be framed in the context of the regulatory policy and the ongoing Net Neutrality debate.

This thesis considers that the incorporation of QoE in mobile infrastructure offers important ways to overcome the mobile market challenges, and its contribution attempts to cover QoE from a holistic perspective with technical, business and market levels. At a technical level, this thesis focuses on the identification of the technical mechanisms to incorporate QoE in the mobile network. At a market level, our analysis centres on the identification of the regulatory framework on Net Neutrality and its potential effect on the implementation of a mechanism to incorporate QoE in mobile networks. Finally, and looking for a holistic approach on the QoE issue, we offer a business analysis of the implications of incorporating QoE in mobile networks operation.

1.2 Research Motivation and Research Questions

As discussed before, mobile operators face a scenario characterised by an increasing trend in data consumption, signs of a slowdown in subscriber growth, and a reduction in the traditional revenues due to the success of OTT providers. In addition,

mobile users have plenty of options to change service provider. In this scenario, mobile operators must remain competitive based both on price and their subscribers' satisfaction (Ericsson [6], Vodafone [3], and EY [10]).

According to De Moor et al. [20], there are three potential benefits that derive from incorporating QoE in the networks operation: *(a) to increase the loyalty curve of the customers and to decrease customer churn, (b) to drive business operations and Customer Experience Management solutions, and (c) to cut costs by exploiting the non-linear QoS-QoE relationship.* On the other hand, Nesse et al. [25] claim that an operator optimising the network for QoE differentiated services will improve the profit for the operators between 10 to 15%. Wahlmueller et al. [26] demonstrated the economic desirability for network operators to apply QoE-based price differentiation. Thus, QoE incorporation in mobile networks might be one of the alternatives to address some the mobile industry challenges covering technical, business and market levels.

QoE enables a holistic understanding of the users' experience regarding the performance of applications, services, and networks, complementing traditional technocentric concepts such as QoS. As discussed above, the use of QoE data has been proposed as a way to solve problems such as the optimisation of network resources and the customer churn experienced by mobile operators. However, there is still a gap on how to make use of QoE and its potential benefits in the context of mobile networks. Technical research on QoE needs to be complemented with the analysis of the regulatory scenario and the business implications of using QoE as basis of the mobile networks operation. Thus, the overall focus of this thesis is on:

- *Analysing how mobile operators can incorporate QoE feedback to improve their service offer considering technical, regulatory and business implications*

Although finding a technology solution might be the first step to overcoming market challenges, it is important that a technical decision comes along with an informed analysis of the regulatory conditions for that implementation and the business implications of the proposed solution. Therefore, we consider that to analyse the incorporation of QoE in mobile infrastructure, it is necessary to complement the description of the technical solution with regulatory and business analyses. Thus, an actor interested in the implementation of the mechanism proposed in this dissertation can have more tools for an informed decision-making process. The approach followed in this thesis is illustrated in Figure 1.1.

Even though substantial work has been done on the technical area, the traditional approach on mobile network operation has been to assume a positive QoE by guaranteeing high QoS. This approach does not take into account the actual experience as perceived by subscribers, and can lead to inaccuracies or false conclusions on the customers' experience, the users' perception and the mechanisms to improve it. It also leads to breakdowns between MNO marketing and network operation teams over how well the MNO is or is not meeting subscribers' expectations. Mapping network, application or even service events to a user response is not easy with

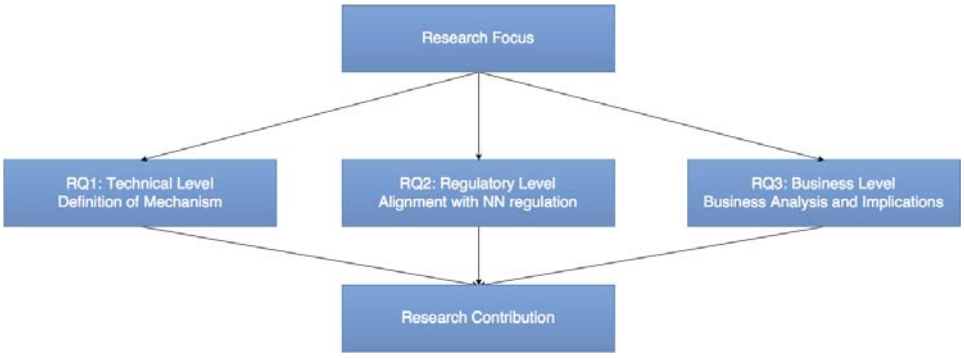


Figure 1.1: Approach followed in the thesis.

the conventional QoS measurement solutions and it does not provide views of QoE from the perspective of a mobile subscriber. In order to identify mechanisms to incorporate QoE data within the operation of mobile networks, this thesis aims at answering the following research question:

- *RQ1. How can QoE feedback be incorporated in the technical operation of mobile network infrastructure?*

We propose a mechanism and the architecture that would facilitate the incorporation of QoE in the mobile networks. The solution is evaluated through empirical testing, statistical analysis and simulation. The potential benefits of the considered approach at the energy level are presented. Chapter 3 offers more details on the answer to RQ1. Incorporation of QoE feedback in mobile networks would require mechanisms to capture/collect QoE-related information and the implementation of resource management strategies that make use of the captured data with a business goal. Therefore, it is important to consider how the regulatory framework can affect the incorporation of QoE in mobile networks and the implementation of the required technical mechanisms.

Current regulatory discussion is focused on Net Neutrality principles and the rules to guarantee that no content or application will be favoured or blocked based on commercial goals. This scenario prompts the following research question:

- *RQ2. How can the incorporation of QoE best be aligned with Net Neutrality regulation?*

The answer to this question is presented in Chapter 4. It includes an identification of the main elements guiding the current discussion on Net Neutrality in the US and EU market because of their impact and relevance in the telecom market. The answer to this question also includes an analysis of the alternatives that mobile

operators have to incorporate QoE in the mobile network operation. Answering this question also provides elements to structure the business analysis.

QoE incorporation might impact the structure of the mobile ecosystem, impact the relationship among its different actors and modify the value configuration opening the door to new business alternatives. Analysis of these implications considers both the technical mechanism to incorporate QoE in mobile networks and the regulatory elements on Net Neutrality identified in the answer to RQ2. It is thus crucial to identify:

- *RQ3. How can QoE feedback impact mobile operators' service provision at the business level?*

Chapter 5 offers responses to this question and establishes a link between the technical and regulatory areas. We identify and describe the alternatives the mobile networks ecosystem might face when incorporating QoE feedback. Proposed scenarios consider the role that regulation on Net Neutrality might have on the mobile network ecosystem. Value network configuration is used to describe how value creation is affected under the different scenarios and provide insights on potential business ideas with QoE feedback incorporation.

1.3 Previous Work

In this section, we review previous work relevant to the 'high-level' problem and the research questions that drive the entire thesis project.

1.3.1 QoE and the Future of Mobile Network Infrastructure

As mentioned by Varela [20], even though QoE can have the potential to overcome some of the mobile industry challenges, most of the work in this field has been in the technical area, especially covering QoE modelling, estimation or measurement. Studies developed by authors such as Sacchi et al. [27], Zhang et al. in [28] and De Pessemier et al. [29] are representative of this type of work.

On QoE modelling, authors such as Fiedler et al. [30], or Mok et al. [31, 32], Hsu et al. [33] have focused on developing models that can predict user's QoE based on the analysis of QoS parameters (i.e., delay, throughput). Hoßfeld et al. [34] extended the scope of QoE analysis by including parameters of performance applications, specifically video stalling, in the models. *Even though these studies explore QoS/QoE relation, they do not address the mechanisms to incorporate QoE data in mobile infrastructure.*

Considerable efforts have been focused on QoE-based management of network resources. Research work by Essaili et al. [35] and Ramamurthi et al. [36] has explored the use of video QoE as input for the resource management strategies. These principles are integrated with different QoE-architecture proposals by authors such as Foster et al. [37], Ameigeiras et al. [38], Thakolsri et al. [21] and Gómez

et al. [39]. However, these architectures focus on video services without taking into account other types of traffic. *Proposed architectures do not offer details on the use of tools for monitoring application performance and finding correlations that can be used to tune the service offer in a mobile network. In this thesis we extend the discussion on the incorporation of QoE in mobile networks to the business and regulatory levels, highlighting the importance of a holistic approach in the adoption of technical solutions.*

1.3.2 Regulatory Implications on the Integration of QoE Feedback in Mobile Networks

Regulatory implications on the use of QoE in mobile networks have not been directly approached by the current literature. Instead, the analysis has been focused on the implications of Net Neutrality on the implementation of QoS management mechanisms, as pointed out by authors such as Nurski [40], Cooper [41] and Krämer and Wieworra [42], *leaving the implications of using QoE data in the network management almost unaddressed.*

The key aspect the Net Neutrality literature has focused on the incentives to discriminate traffic, and the economic impact of traffic prioritization. Legal research, carried out by authors such as Wu [43] and Frischmann and Schewick [44], has stated network operators implementing traffic discrimination would be against the best effort principle and the original design of Internet. Meanwhile, Weisman [45] and Yoo [46] found that traffic discrimination might contribute to create new type of services adapted to the user demands. However, most of these previous studies only address the discussion within a fixed network scenario. In addition, *the role of QoE incorporation and its use in potential service differentiation in mobile networks services is not mentioned.* In this thesis, we study the regulatory framework on Net Neutrality, and analyse its impact on the incorporation of QoE feedback in mobile networks.

1.3.3 Business Analysis of the Incorporation of QoE Feedback in Mobile Networks

Even though studies such as De Moor et al. [20], Perkis et al. [47] or Aznar et al. [48] state that QoE is linked to potential for increased revenues and reduced customer churn, *the research on QoE in the business domain has been rather scarce.* For De Moor et al. [20] research on QoE should push the transition from the QoE assessment to the generation of business opportunities assuming that QoE can be managed. In that sense, efforts by Aznar et al. and Perkis et al. reinforce this idea. Aznar et al. [48] explored the integration of QoE within the value chain of mobile business actors as a mechanism to increase their revenues. Meanwhile, Perkis et al. [47] developed an analysis of the mobile ecosystem actors and their relationship with QoE. However, *these studies have mainly focused on a generic business analysis that does not consider the implications of a technical solution to incorporate*

QoE in the value network configuration. In addition, *the business considerations of these studies do not include regulatory elements in the analysis of QoE.* This thesis takes a technical mechanism to incorporate QoE in mobile networks and gives insights into its impact on mobile operators' business model. Hence, our research is one of a few addressing the QoE area from a business perspective. We have investigated the implications that the incorporation of QoE would bring to the mobile network ecosystem at the business level. The business analysis is supported by the construction of future scenarios for the QoE incorporation according to regulatory considerations, and the value network configuration analysis, which makes the identification of changes possible in the value creation when QoE is used in mobile networks. This analysis can be used for mobile operators and other actors to forecast and plan the required actions to implement new services and business models based on the use of QoE data.

1.4 Summary of Contributions

The contributions to the three main areas of this thesis are outlined in this section. It is also important to underline that apart from addressing the research questions, another important contribution of this thesis lies in the development of a methodology integrating technical, regulatory and business levels and the relationships among them to analyse the incorporation of QoE in mobile networks. Figure 1.2 illustrates the approach followed in this thesis, linking contributions, chapters and publications.

1.4.1 QoE and the Future of Mobile Network Infrastructure

We provide insights on how mobile operators can use app information in the operation of their networks and incorporate QoE in mobile networks. Based on this principle, we introduce a QoE-based architecture and show how mobile networks can use app information in the resource allocation decisions and generate improvements in the end users' QoE. We also present a methodology that can be used to find correlations between network performance and app choice and usage patterns. The proposed architecture will eventually facilitate the incorporation of QoE in mobile networks and the development of new business models based on the personalisation/customisation of services. Another contribution is showing that it is possible to save energy in the smartphone while maintaining the users' QoE by leveraging QoE models.

Contributions at the technical level are discussed in detail in Chapter 3.

1.4.2 Regulatory Implications on the Integration of QoE Feedback in Mobile Networks

We present a regulatory analysis of the impact of Net Neutrality rules on the incorporation of QoE in mobile networks. Regulatory studies on the QoE area have

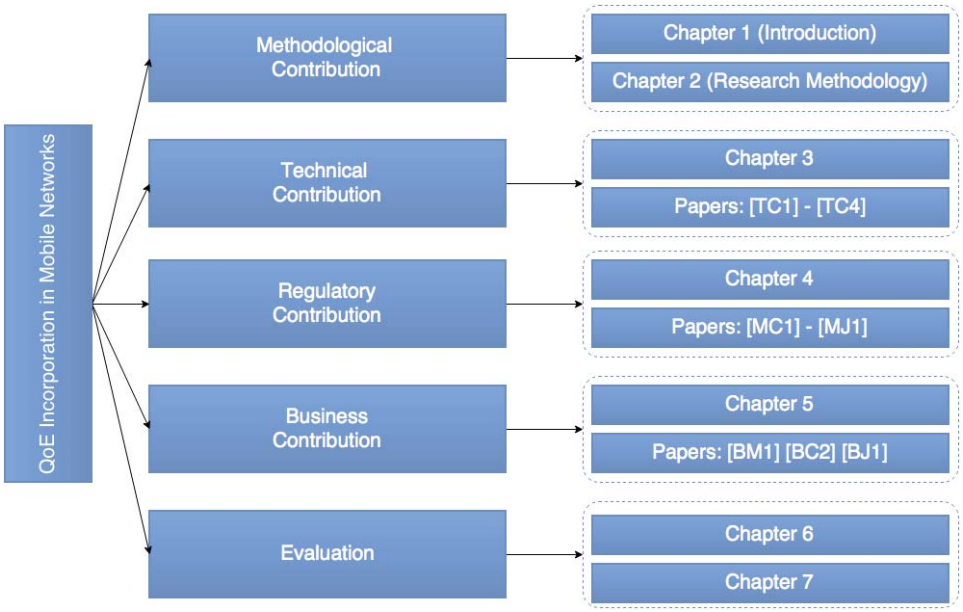


Figure 1.2: Contributions map.

been almost unaddressed, therefore one contribution is positioning a new research area. The regulatory analysis presented in this thesis shows the alternatives that mobile actors have to incorporate QoE in their networks and business models within the current regulatory framework on Net Neutrality, specifically in the US and EU markets. Contributions at the regulatory level are discussed in detail in Chapter 4.

1.4.3 Business Analysis of the Incorporation of QoE Feedback in Mobile Networks

We identify the key trends and uncertainties regarding the development of mobile networks and the incorporation of QoE in their operation. Based on the trends and uncertainties, we find the possible scenarios that the mobile industry will face incorporating and exploiting QoE. The main idea behind the scenarios is to offer a neutral perspective of the business implications of incorporating QoE while also considering the regulatory conditions.

Stakeholders interested in incorporating QoE in their operation may exploit the results of the scenario analysis to plan actions for the future. Based on the different value networks presented in this work and the considered scenarios, the business relationships can be identified that will happen in case QoE is incorporated in the mobile network operation in the context of the proposed future scenarios. Chapter 5 presents the contributions of this dissertation at business level.

1.4.4 Overview of Publications and Authors' Contributions

This thesis is based on peer-reviewed publications and submitted papers. The papers cover the technical, market and business areas proposed for this study.

Technical level publications

Contributions in the technical domain include:

- **[TC1]** *L. Martinez, M. Örblom, J. Markendahl and K. Tollmar, "Effects of network performance on smartphone user behavior," in 5th ISCA/DEGA Workshop on Perceptual Quality of Systems, 2016, (PQS 2016)*
- **[TC2]** *L.G.M. Ballesteros, P. Lungaro and Z. Segall, "Impact of semantic-aware radio resource management schemes on video streaming service," in 8th IEEE International Conference on Wireless and Mobile Computing, Networking and Communications, 2012, (WiMob 2012).*
- **[TC3]** *L.G.M. Ballesteros, C. Cavdar, P. Lungaro and Z. Segall, "Towards a Semantic-aware radio resource management," in The Third International Conference on Mobile Services, Resources, and Users, (MOBILITY 2013), Lisbon, Portugal, November, 2013.*
- **[TC4]** *L.Martinez, S. Ickin, K. Tollmar, M. Fiedler and J. Markendahl, "Energy saving approaches for video streaming on smartphone based on QoE modeling" in 13th Annual IEEE Consumer Communications & Networking Conference, 2016, (CCNC 2016).*

The main purpose of paper [TC1] was to provide insight into how network performance affects app usage. Luis Martinez acted as the main author, formulated the research problem and developed the analysis framework. Örblom and Martinez gathered and analysed the information obtained during the different experiments and user tests.

The main contribution of paper [TC2] is the mobile architecture proposal that enables mobile operators to implement QoE-aware resource management in the access network. Paper [TC3] presents an extension of the results obtained in [TC2]. The focus of the system is on multimedia content delivery and includes a set of scheduling strategies oriented to reduce video stalling by evaluating application level information. Defining the architecture is the result of Luis Martinez's work, and discussions with Pietro Lungaro and Zary Segall at an early stage of this research. Simulations and analysis of the results were developed by Martinez.

Paper [TC4] proposes QoE models that are obtained in realistic scenarios on the smartphone. The obtained models identify the maximum threshold value for an acceptable MOS. This paper also provides energy-saving approaches for smartphones by leveraging the proposed QoE models. The author of this thesis, Luis Martinez, designed the test scenario and acted as the main author. Selim Ickin contributed

with insights on the QoE model and conducted the energy measurements. Martinez and Ickin carried out interviews and user tests. Markus Fiedler, Konrad Tollmar and Jan Markendahl contributed with ideas and suggestions on the experiments and the analysis of the results.

Regulatory level publications

Contributions in the regulatory domain include:

- **[MC1]***L.Martinez, O. Alvarez, and J. Markendahl, "Net Neutrality principles and its impact on Quality of Experience based Service Differentiation in Mobile Networks," ITSLA Conference, Los Angeles, USA, November, 2015.*
- **[MJ1]** *L.Martinez, O. Alvarez, and K Tollmar and J. Markendahl, "Impact of Net Neutrality principles on Quality of Experience based services: Business and Market Analysis", submitted to Telecommunications Policy (Dec 2016).*

[MC1] and [MJ1] present the analysis of the implications of Net Neutrality in a specific business scenario based on QoE and service customisation. The author of this thesis together with Oscar Alvarez developed the analysis of QoE challenges regarding the Net Neutrality Principles and the study on regulatory views from different countries. The results and conclusions of this study have been shared and discussed with Fredrik Blömstrom at PTS, who also provided insights on the regulatory structure in Europe and USA. Analysis of market implications and regulatory issues associated with the service provision considering users' QoE was done by Luis Martinez based on discussions with different Telco actors.

Business level publications

Contributions in the business domain include:

- **[BM1]** *L.Martinez, P-J. Nesse, and J. Markendahl, "QoE-based service differentiation: Business models analysis for the mobile market," in the 26st European Regional ITS Conference, San Lorenzo de El Escorial, Spain, June, 2015*
- **[BC2]** *L.Martinez, O. Alvarez, and J. Markendahl, "Quality of Experience (QoE)-based service differentiation in the smart cities context: An Initial Business Analysis," in the 1st IEEE Smart Cities Conference, Guadalajara, Mexico, 2015.*
- **[BJ1]** *L.Martinez, P-J. Nesse, K. Tollmar and J. Markendahl, "QoE-based service differentiation in the mobile market: Business models analysis," Submitted to International Journal of Information Technology and Management (Dec 2016).*

In paper [BM1], we present the initial insights on the business model analysis considering a scenario centred on the use of QoE feedback. In this paper, the architecture presented in papers [TC2] and [TC3] is integrated within the business analysis. The author of the thesis conducted the research, collected the initial data and acted as the lead author. Per-Jonny Nesse and Oscar Alvarez made major contributions for the business models and identification of business roles. Tollmar and Markendahl offered input in the scenarios discussion. [BJ1] is planned as an extension of the analysis developed in [BM1]. In both cases, the analysis is supported by discussions with telco actors involved in the research projects 'QoE: An analysis from a Techno Economic Perspective' and 'QoE and Net Neutrality' funded by KTH.

The analysis of the impact of QoE differentiation in smart cities presented in [BC2] highlights the importance of considering users' QoE in the deployment of ICT solutions. A contribution of this work is to start the discussion on the implications of QoE on smart cities deployment. The integration of these two concepts has not been well studied so far, but paper [BC2] brings new elements to the discussion. Luis Martinez conducted the interviews, analysis and mapping of actors' relations, and business models. Discussion on Smart Cities and the implications of QoE were led by Luis Martinez and considered comments and ideas from Oscar Alvarez. The author of this thesis described the business environment and the developed the analysis of the implications.

1.5 Thesis Outline

To provide answers to the formulated research questions, the thesis is divided into three parts. The first part includes this introductory chapter and Chapter 2 about the research approach and methodology. Chapter 3 includes the results and analysis on the technical elements to be considered when incorporating QoE feedback into mobile networks. This includes the description of the technical mechanism to incorporate QoE in the mobile networks. We present an evaluation of the proposed mechanism and the benefits from the incorporation of QoE at the energy level.

Chapter 4 presents the analysis of the market level implications. This comprises an evaluation of the impact of Net Neutrality principles on the incorporation of user's feedback in mobile networks.

The business level analysis, including a description of the QoE ecosystem, the scenarios faced by mobile networks actors with the incorporation of QoE, and the analysis of the value network configuration in each one of the scenarios is presented in Chapter 5. The last part of this thesis consists of the discussion and conclusions.

The business level analysis, including a description of the QoE ecosystem, the scenarios faced by mobile networks actors with the incorporation of QoE, and the analysis of the value network configuration in each one of the scenarios is presented in the Chapter 5. The last part of this thesis consists of chapters with the discussion and conclusions.

Chapter 2

Research Approach and Methodology

This chapter provides an overview of the overall research approach and the methodology followed in this thesis. The methodology has been devised to address the 'high-level' problem formulation and the research questions described in Chapter 1.

2.1 Methodological Framework

As discussed in Chapter 1, analysing the incorporation of QoE in mobile networks needs to be addressed from an interdisciplinary focus. This type of focus entails a research method that aligns with the different disciplines involved in this research work (i.e., technical, regulatory and business).

Incorporation of QoE in mobile networks implies the use of QoE feedback in the operation of the network. Thus, it requires devising the mechanism/architecture to integrate QoE and make use of it in the mobile network operation. Then, the devised solution need to be analysed in the context of a regulatory framework to determine the level of alignment between the technical solution and the regulation and identify alternatives so the solution can be implemented. Finally, this thesis analyses the business implications of implementing the solution to incorporate QoE in mobile networks, considering both the regulatory conditions and the business alternatives brought about by the technical solution. Therefore, the nature of the problem explored in this thesis makes it necessary to follow a research methodology that allows for creating a technical innovation oriented to solve a problem in a practical setting and to carry out the analysis and evaluation of the regulatory and business implications of the technical solution.

Thus, the methodology followed in this thesis resembles a design science process as described by Simon [49],Hevner et al. [50], and Peffers et al. [51]. Comparing different design science frameworks proposed by authors such as Nunamaker et al. [52],

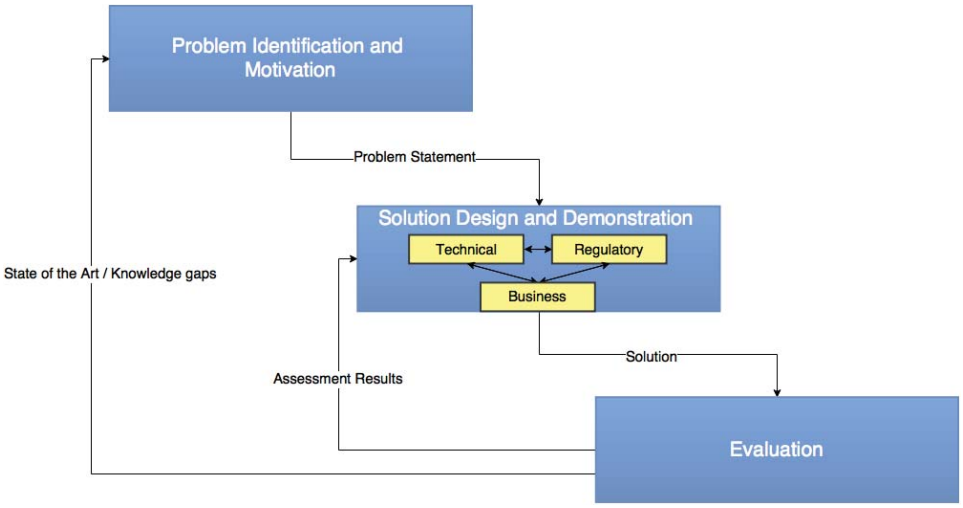


Figure 2.1: Methodological Framework.

Vaishnavi and Kuechler [53], Peffers et al. [51], the design-science process is structured in three phases: 'problem definition', 'solution design' and 'evaluation'. These phases are connected throughout the research process and divided into steps that contribute to devise the artefact. However, none of the aforementioned frameworks explicitly take into account business and regulatory considerations in the design and evaluation of the technical solution. In that sense, we include the business and regulatory steps of the methodological framework in this dissertation. Figure 2.1 shows the fundamental structure of the methodology used in this thesis. More specifically, this methodology comprises the following stages:

1. Problem definition.

2. Solution design and demonstration.

3. Evaluation.

2.2 Use of the Methodological Framework

This section presents the operasionalisation of the methodological framework. Figure 2.2 illustrates the structure of this dissertation and the connections between the framework, the chapters and the proposed research questions.

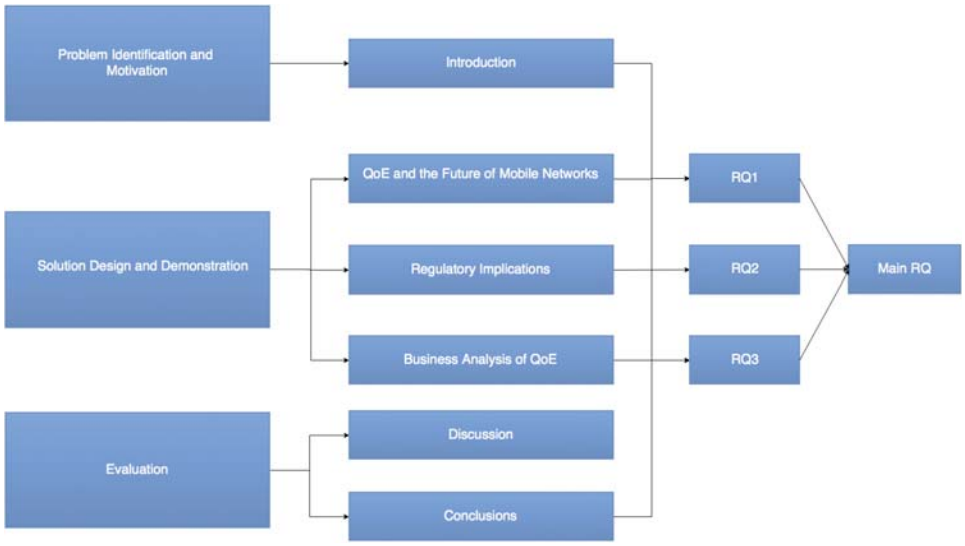


Figure 2.2: Operationalisation of the Methodological Framework.

2.2.1 Problem Identification and Motivation

The result of the first step of the research process is the identification of the problem, ensuring that it has or might have relevance once solved. It includes the definition of the research questions that may arise from technical challenges, the opportunities offered by new technology, a business problem, the interest on increasing the efficiency of a business process or the regulatory conditions for the implementation of a technical development.

Problem identification entailed exploring the challenges faced by the mobile networks industry. Literature survey, discussions and interviews with different stakeholders in the mobile networks industry contributed to the identification of challenges at technical, business and regulatory levels. In this context, we realise that solutions for the industry problems must not only address the technical side, but need to be evaluated in a broader context, understanding the implication at business and regulatory levels of technical developments. Through an extensive literature survey, QoE has been seen as one of the alternatives to address mobile industry challenges at technical and business levels, but most of the research results have focused only on the technical level without exploring the business implications of using QoE in a mobile infrastructure. Additionally, the mechanisms for using QoE in mobile networks were rarely described in the literature. All available studies at the time of writing this thesis lack an analysis on how the incorporation of QoE can be operationalised and how the industry structure will be impacted by this technical development.

Discussion with mobile business actors about the technical incorporation of QoE

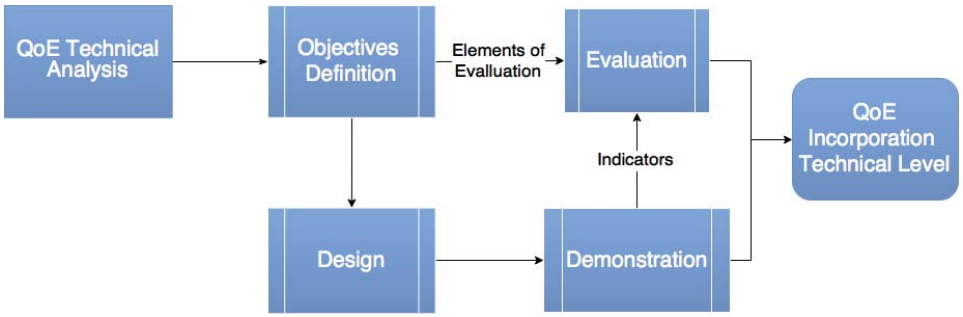


Figure 2.3: Technical Analysis Steps.

and its use with business purposes led to the need for analysing the impact of the regulatory framework, and the ongoing discussion on Net Neutrality rules, in the implementation of QoE incorporation in a real context. The problem identification and motivation step is supported by different activities such as literature review, interviews with experts, case analysis, and group discussions. The problem description and motivation are included in Chapter 1 of this thesis.

2.2.2 Solution Design and Demonstration

This is the stage where the development of conceptual solutions takes place. At the same time, this stage offers the elements to answer the research questions of this thesis. Taking the problem statement and working objectives obtained in the previous phase as the basis for the research development, the artefact/mechanism to incorporate QoE in mobile networks is designed as well as the demonstration tools necessary to evaluate the proposed solution within regulatory and business contexts. According to Hevner et al. [50], the '*demonstration of the use of the artefact to solve one or more instances of the problem involves its use in experimentation, simulation, case study, proof, or other appropriate activity*'. In this dissertation, analysis and demonstration of the QoE incorporation in mobile networks covers the technical, regulatory and business levels. Chapters 3, 4, and 5 of this dissertation detail the results of the solution design and demonstration stage. Next, a description of the three (steps) levels considered in this framework stage is presented.

2.2.2.1 Technical Level Analysis

The process followed in this step of the research framework to offer a technical-level answer to the RQ1: *How can QoE feedback be incorporated in the technical operation of mobile network infrastructure?* is developed in Chapter 3 and presented in Figure 2.3.

The first step in the technical analysis was to infer the objectives of the solution identified based on the problem identification stage. This process was implemented via a systematic review of the literature on technical developments on QoE and related research work.

This was followed by the design of the artefact or the mechanism to incorporate QoE in mobile networks. A software-based monitoring tool able to capture relevant applications/network level performance indicators and report them to the mobile infrastructure was used. The next step was the implementation of the concept which is followed by the demonstration of the mechanism.

Demonstration of the monitoring tool and it use in the mobile networks concept were done through empirical testing complemented with statistical analysis. To do this, we used Ericsson Apps (EA), an app engine for Android smartphones developed and provided by Ericsson as part of the research project 'QoE: an analysis from a techno-economic perspective'. EA collects all kinds of app usage data, such as app name, category, session duration and data consumption from all apps that are used in the foreground; EA also collects a broad range of client-side network data, such as network type (EDGE, UMTS, HSPA, HSDPA, HSPAP, and LTE), uplink and downlink throughput, dropped packages, duration of timeouts and signal strength.

By applying statistical analysis to the data captured with EA (from approximately 1500 users), we demonstrated that by using monitoring tools installed in the mobile terminal it is possible to find correlations between network performance and the users' patterns of usage and choice of application, which can later be used by mobile networks to trigger network management actions. Then, the use of information provided by a monitoring tool to activate a resource management decision was demonstrated and evaluated through extensive simulation of a mobile network in a video streaming scenario. Simulation evaluated the impact of different resource schedulers fed with data on the applications' performance. Performance indicators for the system operation included frequency and length of video interruptions. The scenario considered in the simulation is shown in Figure 2.4.

Next, the technical analysis included the evaluation of the obtained results and the identification of impacts and benefits of the proposed QoE incorporation. Besides the statistical analysis of the user tests and the evaluation of the simulation results, this thesis extends the identification of benefits and impacts to the energy savings obtained by using application performance data and building-in QoE models in mobile networks. To do this, an in-the-wild user study was conducted for collecting user opinion scores for video streaming on smartphone and obtaining QoE-based models to leverage them in energy savings. Combining the two parts provides implications for solutions minimising the energy consumption by leveraging the QoE proposed models.

The final step was the presentation of technical conclusions and the discussion of the obtained results. Analysis and discussion were complemented with the feedback obtained through group discussions and semi-structured interviews with representatives of the mobile industry. In these interviews, we identified relevant elements

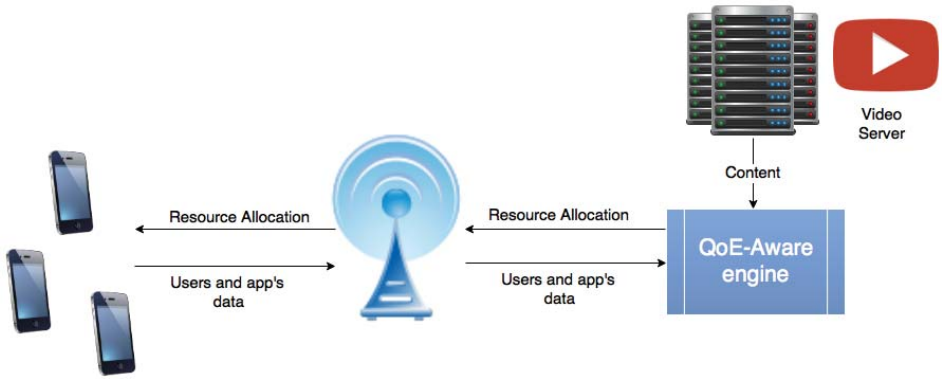


Figure 2.4: Proposed Solution.

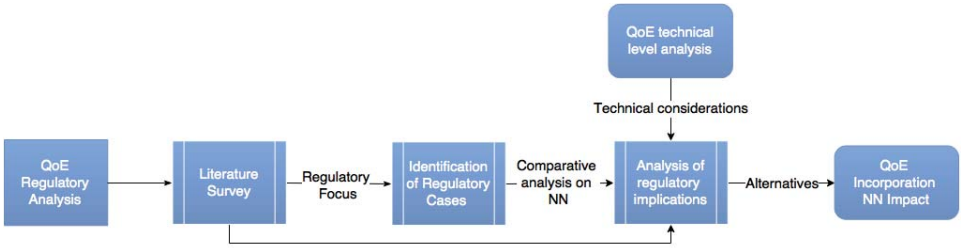


Figure 2.5: Regulatory Analysis Steps.

when incorporating QoE in mobile networks and the challenges mobile business actors face in order to achieve the use of QoE in their technical/business operation.

After the interviews and a literature review, the need for having a common view on QoE and Customer Experience arose. Therefore, the incorporation of QoE not only implies the deployment of a technical infrastructure but the definition of a framework that integrates the business and technical levels.

2.2.2.2 Regulatory Analysis

By developing the regulatory analysis, this thesis aims at answering RQ2: *How can the incorporation of QoE best be aligned with Net Neutrality regulation?* Figure 2.5 presents the methodology followed in the regulatory analysis and the result are presented in Chapter 4. Below is a description of the steps developed in the regulatory analysis.

Business analysis started with the definition of the goals of this step based on the elements provided by the problem identification stage, the regulatory analysis input and the characteristics of the devised technical solution.

The first step was the definition of the goals for the regulatory activity considering both the problem statement and the characteristics of the technical solution, developed in Chapter 2, to incorporate QoE in mobile networks. Through a literature review and discussion with experts in the area of study, it was possible to identify the regulation relevant for the subject of study. The identification activity led to the Net Neutrality regulation.

Once the focus of the regulatory analysis was defined, the next step was the identification of the main elements guiding the regulatory discussion. The goal centred on the analysis of the regulatory aspects affecting the development/implementation of the technical solution. This goal was achieved through an extensive literature review covering the historical development of the discussion on Net Neutrality from its origin to the present day. The result was the identification of the Net Neutrality principles guiding the discussion today.

With the identification of the key discussion points, it is important to identify cases of implementation of the regulatory framework. The goal was to identify scenarios of regulatory implementation that would help interpret the scope of the regulation, identify special considerations in the implementation of the regulation and extract lessons from the regulatory approach that add to the discussion on possible deployment scenarios of the technical solution. In order to review the regulatory scenario on Net Neutrality and identify relevant implementation scenarios, we chose a qualitative comparative approach. The comparative method is a research strategy that allows for the analysis of a small number of cases and the discovery of empirical relationships among variables (Lijphart [54]). Regulatory analysis compares the United States (US) and the European Union (EU) views on Net Neutrality establishing similarities and differences in their approaches. US and EU cases are considered because of their relevance and the impact of their decisions on other regulatory frameworks worldwide.

Next, the research should focus on the implications of the regulation if the artefact were to be implemented on a larger scale. Alternatives and considerations of the impact of the regulation on the technical solution need to be described providing elements that can support an implementation decision.

Based on the elements identified in the Net Neutrality regulation, we analysed the implications of the regulatory framework on the QoE incorporation in mobile networks. To do this, we combined the analysis of existing literature on QoE-based architectures and frameworks, like the one considered for the technical chapter of this dissertation, and the insights provided by representatives from the mobile industry. We conducted a half-day workshop and subsequent interviews with representatives from the mobile industry. Finally, we compared the requirements for QoE incorporation with the elements identified in the Net Neutrality regulation and provide alternatives to incorporate QoE in mobile networks within the context of current Net Neutrality regulation.

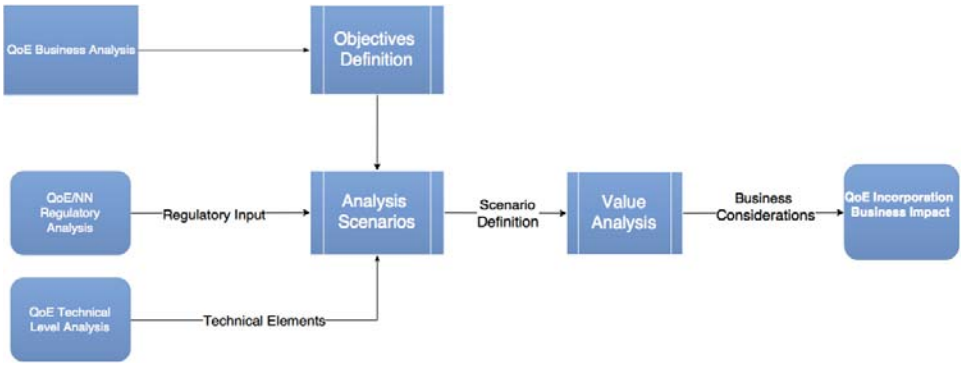


Figure 2.6: Business Analysis steps.

2.2.2.3 Business Analysis

This step of the research framework aims at answering RQ3: *How can QoE feedback impact mobile operators' service provision at the business level?* Figure 2.6 presents the methodology followed in the business analysis and Chapter 5 presents the results.

Business analysis started with the definition of the goals of this step based on the elements provided by the problem identification stage, the regulatory analysis input and the characteristics of the devised technical solution. For this dissertation, the goal of the business analysis was to identify the implications of implementing the devised artefact from a business perspective. This process was carried out via a systematic review of the literature on business analysis and related research work. In addition, discussion and exchange of ideas with mobile business players provided information to structure the business analysis. Definition of goals was followed by the definition of analysis scenarios, including the identification of the actors, the relations between actors (technical, business) and the variables to be considered in the scenario construction. For this thesis, the definition of the scenarios requires the identification of the mobile ecosystem and its main actors as well as the definition of the key trends and uncertainties affecting the incorporation of QoE in mobile networks.

Identification of ecosystem actors was achieved through an extensive literature survey including white papers, academic journals and news articles. Later, this information was contrasted and discussed with representatives of the ecosystem's stakeholders during a workshop conducted in Kista on February 2016. The workshop was part of the seed project 'QoE and Net Neutrality' and involved key actors in the telecom industry: mobile operators, network equipment vendors, regulatory authorities and representatives of telecom services' users. The discussion on the ecosystem identification revolved around the current market structure, the role played by each actor and the implications of the incorporation of QoE feedback in

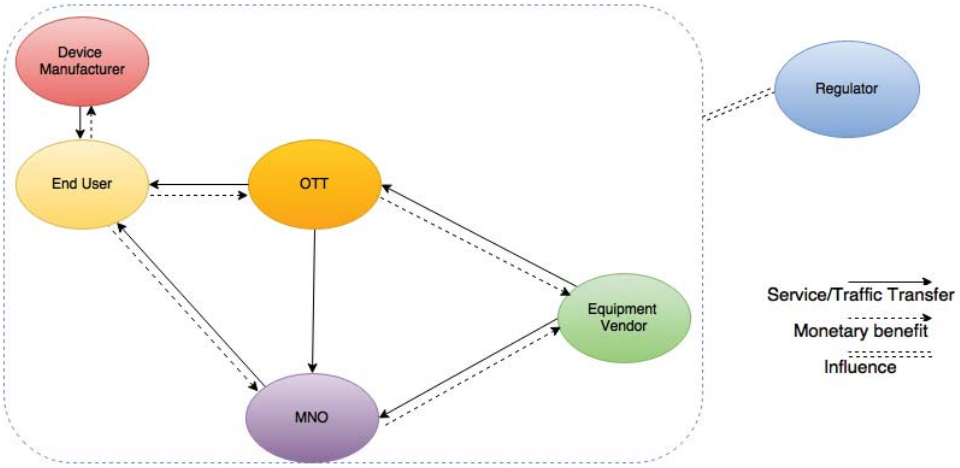


Figure 2.7: Mobile Networks Ecosystem.

the mobile industry. Even though no content provider representative participated in the workshop, the network equipment vendors and the mobile operators shared their knowledge on the content provider's role. This information was complemented with some references on mobile network ecosystems and the mobile industry structure (Kilkki [55], Peppard and Rylander [56], Zhang et al. [57] and Funk [58]).

The stakeholders considered in this ecosystem are presented in Figure 2.7. The different value exchanges in the ecosystem are denoted with different line styles and arrows: solid line for traffic/content transfer, dashed line for monetary exchange, and double dashed line to denote influence. A description of the value network's stakeholders is presented in Table 2.1. The core stakeholders, including users, are the focal actors considered in the analysis for the incorporation of QoE feedback in mobile networks. Core members are those highly involved in the service provision.

The next step in defining the analysis scenarios was capturing a range of possibilities for the implementation of the technical solution and determining what is possible. Scenario planning method proposed by Schoemaker and Mavaddat [59] is the tool proposed for this purpose. Scenario construction is based on the identification of trends and uncertainties at technical, business and regulatory levels regarding the incorporation of QoE in mobile networks. Literature review and discussion/interviews with experts and stakeholders can be used to obtain the key uncertainties and trends. The key uncertainties and trends are compared to achieve a final scenario matrix.

Later, the obtained scenarios were analysed in more detail through a value network analysis. The goal of the analysis was to identify how the incorporation of QoE in mobile networks might affect the value creation process, and change the relation between stakeholders. This analysis also provided insights on the business alternatives based on the QoE incorporation under different regulatory conditions.

Table 2.1: Mobile Network's Ecosystem Actors.

System	Actors	Description
Core Member	Mobile Network provider	Provide portfolio of Internet connectivity services
	Over-the-top player	Provider of content and application (CAP) based services
	Market and users	Consume CAP services using the infrastructure provided by MNO
Broader member	Equipment vendor	Provides physical and software-based infrastructure required to operate and manage the network
	Device manufacturers	Provide the mobile devices to end users
	Regulator	Designs policy and administrates the legislation. Net neutrality principles surveillance

Value network configuration analysis was based on literature review and elements identified in the discussions/interviews with the participants in the research project 'QoE and Net Neutrality.' Structure of the value networks was also shared and discussed with some stakeholders in the mobile market to address realistic concerns. We developed a value network analysis based on the methodology proposed by Peppard and Rylander [56], and adopted the value network configuration approach presented by Casey et al. [60] to represent the different relations between actors.

The final step was the presentation of technical conclusions and the discussion of the obtained results. Analysis and discussion were complemented with feedback obtained through group discussions and semi-structured interviews with representatives of the mobile industry. In these interviews, we identified relevant elements to incorporate QoE in mobile networks and the challenges mobile business actors face in order to achieve the use of QoE in their technical/business operation.

2.2.3 Evaluation

The evaluation step entails observing how well the proposed design supports a solution for the problem. At the same time, it offers an analysis of the business and regulatory implications affecting the incorporation of QoE in mobile networks and the solutions to address the potential implications at technical, business and regulatory levels. According to Hevner et al. [50], '*Evaluation is to be achieved by means of a case study showing applicability in practice, by arranging a broad expert survey and by laboratory experiments or simulations*'.

For this study, evaluation was performed through empirical testing of the monitoring tool and its application, simulations, the presentation of the obtained results in workshops with representatives of the mobile network ecosystem and different conferences, and the researcher's own reflections in Chapters 3 to 7.

Table 2.2: Companies interviewed about QoE challenges and Customer Experience Management

Company	Position or Unit
Ericsson	Customer Experience Area
Telia	Customer Experience Area
Tele2	Customer Experience Managemet
Telenor	Business Unit

2.3 Data Collection and Analysis

Different quantitative and qualitative information was collected in this study. This section presents the data collection process, especially considering the technical, business and regulatory analysis steps.

2.3.1 Primary data

For the technical domain, we collected the primary data from different sources. For the test demonstrating the use of the monitoring tool, we gathered app consumption data provided by the smartphone app EA. Data collection was executed during the first semester of 2015, and covered roughly 1500 users in different countries (most of them in Sweden). For the analysis of the impact of QoE on energy consumption levels, data was collected in a number of tests with real users (roughly 60). Data included both users' answers to the survey and energy consumption measurements of the mobile phone.

In order to identify the current approach on QoE applied in the mobile industry, we conducted a set of interviews with representative actors in the industry. Interviews revolved around the challenges and requirements for the QoE incorporation in mobile networks operation. Each interview lasted approximately one hour. We recorded the interviews and transcribed them. The summary of interviews is presented in Table 2.3.

For the regulatory analysis, we used semi-structured interviews and workshops. In the first semester of 2016, we conducted interviews with top representatives of different telecom actors, the Swedish regulator and experts on Net Neutrality. The discussion themes included the following:

- View on Net Neutrality regulation.
- Implications of Net Neutrality for the mobile business.
- Quality of Experience and Net Neutrality relation.

Each interview lasted approximately one hour. We recorded the interviews and transcribed them. The summary of interviews is presented in Table 2.3. Workshops

Table 2.3: Companies interviewed about Net Neutrality and QoE

Company	Position or Unit
Ericsson	Business Development
Telia	Regulatory Unit
Tele2	Product Managemet
Telenor	Business Unit
Edgeware	Chief Technology Officer
Telemanagement	Consultant
PTS	Net Neutrality area
Strand Consultant	Consultant

on Net Neutrality were organised during the first semester of 2016 (3 workshops) as part of the seed project 'QoE and Net Neutrality'.

In the business level analysis, we collected primary data using different approaches: semi-structured interviews and workshops. In the first semester of 2016, we conducted a number of interviews with top and middle-level managers of different telecom actors. The discussion themes included the following:

- Role of their organisation in the communications ecosystem.
- Understanding of Quality of Experience role in the communications ecosystem.
- Potential of QoE as differentiator factor.
- Customer Experience management systems and the incorporation of QoE feedback.

Each interview lasted approximately one hour. We recorded the interviews and transcribed them. The summary of interviews is presented in Table 2.4.

Finally, we organised a number of workshops on business models and value networks as part of the seed projects 'QoE: An Analysis from a Techno-economic' and 'QoE and Net Neutrality'. Workshops were organised in 2015 (5 workshops) and first semester of 2016 (3 workshops).

2.3.2 Secondary data

We used secondary data to build the simulation system used in the QoE architecture performance evaluation. The main sources were research papers and technical reports.

In the regulatory analysis we used secondary data to understand the Net Neutrality regulation in US and Europe. The main sources were FCC and BEREC reports related to the regulation on Net Neutrality.

Table 2.4: Companies interviewed about Business Implications of QoE

Company	Position or Unit
Ericsson	Research
Ericsson	Business Development
Telia	Business Unit
Tele2	Product Managemet
Tele2	Customer Experience
Telenor	Research
Telenor	Business Unit
Edgeware	Chief Technology Officer
Telemanagement	Consultant

Finally, in the business level analysis, we used secondary data to understand the current situation in the market and to describe the potential development of industry. Secondary data sources included press releases, reports, and other documents related to the mobile industry.

2.3.3 Data Analysis

As mentioned above, we considered different approaches for the analysis of the collected data. In order to answer RQ1, we used statistical/quantitative analysis. Multi case study analysis was combined with quantitative analysis to answer RQ2. Scenario planning and value network configuration analysis were used to answer RQ3. Application of the data analysis at each level is described in Chapters 3 to 5. These chapters also include a literature/background review, the obtained results, and conclusions.

Chapter 3

QoE and the Future of Mobile Network Infrastructures

In this chapter we discuss RQ1: *How can QoE feedback be incorporated in the technical operation of mobile network infrastructure?*. To do this, we focus on analyzing how mobile networks can use apps' information as mechanisms to find correlations between network performance and apps' usage patterns. Then, we present a how this principle can be used as mechanism to incorporate QoE in mobile networks. This is shown in a QoE-aware architecture proposal, where application level data is used to make resource allocation decisions. We also present an analysis of some of the potential benefits of using QoE models. Finally, we discuss on the incorporation of QoE in mobile networks by using Customer Experience Management (CEM) systems and propose and architecture framework to carry out this incorporation.

3.1 QoE Management and Integration with Mobile Networks

Different authors have focused their attention on studying QoE from a technical perspective. The majority of the research work on QoE is related to its assessment, as reflected in works by Jelassi et al. [61], Serral [62], Lin and Jay [63] and Chikkerur et al. [64]. In general, the goal of this research work has been focused on evaluating how the user perceives and evaluates a service considering the impact of QoS parameters. During the last decade, research on QoE has extended its focus to devising alternatives for using QoE in the management of network resources and defining QoE frameworks that make possible the deployment of QoE-based network infrastructures.

One of the first attempts to integrate QoE in the network operation is presented by Gallo et al. [65]. The authors proposed a QoE ontology as an attempt to relate application and network QoS aspects with the user perception on the service. Their experimental work showed that by mapping QoS and QoE the network can decide

the QoS mechanism that is better according to the user needs. Within the paper, Gallo et al. also affirm that QoS-QoE mapping allow the network operator to perform monitoring and detection of service level agreement (SLA) violations. Another benefit of QoS-QoE mapping is the possibility to offer better resource management by adapting QoS levels. Even though this paper defines some of the principles and goals of QoE management systems, the results are not supported by a technical implementation.

A QoE-based management framework to control QoS parameters is presented by Agboma and Liotta [66]. Authors introduce how to capture user's QoE and they developed QoE models for different types of mobile multimedia services. Their study identified how different QoS parameters might influence the end-user perception. Even though the authors focused on the definition of predictive models to maximise end user quality, they did not consider the use of these models to optimise the usage of network resources. On the other hand, the way to capture user's QoE relied on subjective tests and not in an online-based process.

In a study developed by Kim et al. [67], the authors proposed a framework oriented to guarantee QoS/QoE in mobile IPTV. The framework used information on available resources, terminal capability and user's profile details to make resource allocation decisions (redistribute the available resources) according to a desired QoE level. Obtained results showed the validity of using terminal information and users' profiles to improve network resource management. However, the authors did not give details on the incorporation of this framework in the operation of mobile networks.

With the name of QoE-aware real-time multimedia management or (QoE2M), Mu et al. proposed [68] a framework that combines video assessment and QoS-QoE mapping to manage content delivery. QoE2M was able to detect congestion periods and adapt the applications according to both the network conditions and the user's terminal features. Even though the high level description of the framework is well detailed, the implementation of the framework or its use in the context of a mobile network is not discussed by the authors.

An attempt to integrate QoE-management in the context of mobile networks is presented by Fajardo et al. [69]. Authors proposed a QoE-management system for Voice over IP (VoIP) in 3G Networks. Fajardo et al. identified the causes of content degradation in different segments of the network infrastructure and described the impact of degradation in the end user's QoE. Based on this analysis, the authors presented a lightweight implementation of the framework. Implementation showed that VoIP configuration can be adapted according to the availability of network resources. However, the implementation only considered the end-to-end delay to calculate the QoE degradation. Application level information was not considered in the resource allocation decisions. In addition, further implementation aspects or the incorporation of the proposed system in a mobile network were not discussed.

Continuing with the application of QoE management in the operation of multimedia applications, Vakili and Gregoire [70] proposed a QoE framework for video conferencing. First, the authors used subjective test to measure the quality per-

ceived by end users. Then, the authors identified the relation between user's QoE and parameters such as frame rate and video quantization. Based on the results, authors showed that video parameters can be adjusted looking at the available bandwidth and expected user's QoE. As a result, Vakili and Gregoire proposed a mechanism that decides the frame rate and the video quantization according to the bandwidth and the expected user's QoE. Although this study shows that QoE-based resource management decisions can consider the application performance, the paper did not mention alternatives to incorporate the proposed framework in the operation of mobile networks. In addition, the adjustment of the network resources was based on a stand-alone process where the application information is not gathered in real-time.

On the other hand, Gómez et al. [39] proposed a QoE-driven architecture for resource control in long-term evolution (LTE) networks. Even though the paper focused on the integration of the proposed architecture with LTE infrastructure, it relied on deep packet inspection (DPI) to capture relevant information on the applications used by the end-user. In addition, Gómez et al. did not mention the role that OTT players can have in the architecture.

Meanwhile, Kim et al. [71] provided design considerations for the incorporation of QoE feedback in mobile infrastructures. In their work, Kim et al. showed that end users can be actively involved in the process of measuring QoE and provide instantaneous feedback whenever a service disruption/dissatisfaction occurs. This information combined with network parameters and application information can be used to detect location of faults and the reason behind QoE disturbances. However, the authors did not implement a technical solution based on their design considerations.

On the other hand, Zhang and Ansari [72] affirmed that incorporation of QoE into Next Generation Infrastructures (NGN) needs to consider both the network and the application layers. The authors described a general end-to-end QoE assurance system able to degrade QoE when the network resources were not sufficient. Similar to Kim et al. [71], Zhang and Ansari refered to the challenges of the QoE incorporation but they did not defined any mechanism to interactively capture information from the user's terminal.

Finally, Menkovski [73] introduced a QoE management framework for an IPTV service. The author remarked on the importance of deploying probes to collect Quality Performance Indicators (QPI) that can be used by the service provider to define and execute resource management strategies. However, the solution proposed by the author limits its approach to a fixed network environment without considering the implications of probing/monitoring systems used in the mobile networks context.

Described works coincide in the importance of incorporating QoE in the operation of network infrastructures. The authors have proposed different alternatives and design considerations to achieve this goal. However, the incorporation of QoE in mobile networks needs more discussion, especially with regard to the definition of the mechanism to incorporate QoE feedback and make use of this feedback in both

the technical and business operation of mobile infrastructures. In that sense, our research proposes a technical mechanism to incorporate QoE feedback in mobile networks, discusses the potential benefits of this incorporation, including energy saving considerations, and proposes a solution that make possible the use of the gathered information in the operation of mobile networks at the technical and business levels.

3.2 Smartphone Monitoring-based Method for End-User Data Collection

As mentioned by Menkovski [73], the use of QoE in the network operation requires collecting information that can be used by the service provider to define and execute resource management strategies. Besides monitoring the traditional network, it is important to combine network data with information from the user's side in order to have more elements to deploy QoE-aware infrastructures, as stated by Kim et al. [71] and Zhang and Ansari [72]. Traditionally, monitoring and assessment of QoS/QoE in mobile networks rely on analytics and reporting indoor testing, drive testing, and network diagnostics. Even though these methods offer important and relevant data at the network level, they do not provide metrics on application performance or the real user's experience, as stated by Akamai [77] and by Paolini [74].

We propose an alternative based on monitoring tools at the application level. In this case, users can download a monitoring application on their terminal. This application is able to report performance indicators both on the app and network level to a database for later analysis. Different from traditional crowd-source approaches, like the one proposed by Hoßfeld et al. [34], where users run tests and later send reports, we propose automatically monitoring, collecting and reporting data. The monitoring application starts collecting and reporting information beginning when the user starts an app (e.g., YouTube) until the app is closed. The main advantages of this approach include the following:

- Collecting data is not expensive because it is supported by the installation of a simple application.
- Information can be gathered in real time which might support adjustment of network resources on the fly.
- It provides the ability to conduct historical trend analysis and the capacity to identify application usage patterns so they that can be correlated with network indicators and used to improve/optimise network performance.
- It can provide accurate information on the device and its location that can be used to activate network functionalities or new charging plans.

One drawback of the proposed method is the privacy issues that can arise due to monitoring information directly from the terminal as pointed out by different authors such as Hoßfeld et al. [75], Casas et al. [76] and Schulzrinne and Varela [20]. They coincide on the risks of leakage of information to third parties and remark the importance of a clear communication between the network provider/content provider and the user about the type of information collected, the purpose of gathering the information and for how long the collected information is going to be retained.

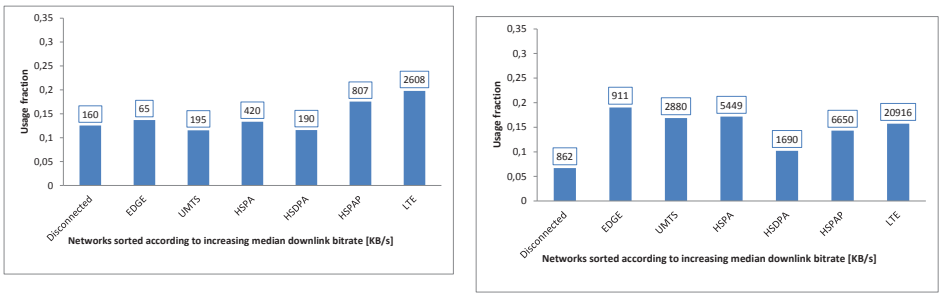
3.3 Influence of Network Performance on App Choice and Usage

In this section we describe how the smartphone monitoring approach described in previous section can be used in the context of mobile networks. Discussion is supported by the results obtained in the paper 'Effects of Network Performance on Smartphone User Behavior' [77]. The application used in this case is EA, which is an app engine for Android smartphones. We make use of the information collected at the mobile terminal and reported to a database to analyze how the network performance influences app choice and usage. The application used in this case is Ericsson Apps (EA), which is an app engine for Android smartphones. EA collects all kinds of app usage data, such as app name, category, session duration and data consumption from all apps that are used in the foreground, i.e., the apps the user has active on the screen. EA also collects a broad range of client-side network data, such as network type (EDGE, UMTS, HSPA, HSDPA, HSPAP, and LTE), uplink and downlink throughput, dropped packages, duration of timeouts and signal strength.

We first investigated the influence of network performance on app choice. In this case, we assume that network performance is directly linked to the network type available before the app was started. The probability of using an app given a particular network type, $p(app|network)$, was calculated and used to compare the obtained results for a specific app across different network types. In the second part of our study, by evaluating session duration and data consumption levels, we identified how network performance affects app usage. For the study, we analysed 3 representative cases: YouTube, WhatsApp, Viber. More details can be found in Paper [77]. For the analysis, the sessions were classified according to the network type that was displayed when the sessions started. This categorisation included those sessions that change network during the sampling time.

The results showed network performance was factored into the users' app choices. Data demanding apps, such as YouTube in Figure 3.1a, have a strong positive correlation between the relative usage and the network performance. Meanwhile, a low data consumption app such as WhatsApp in Figure 3.1b, showed a negative correlation between app choice and network performance.

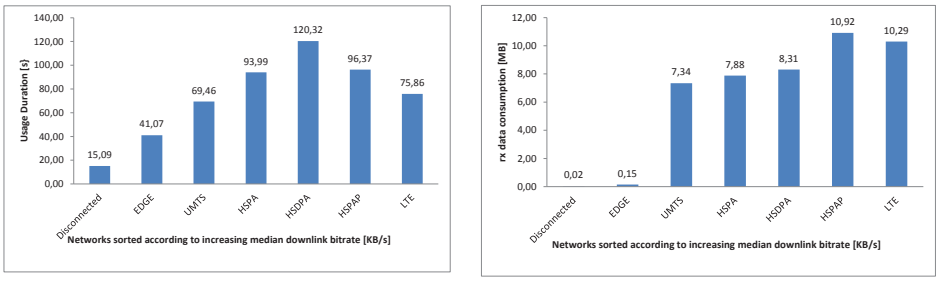
According to the obtained results, the effect of network performance on app



(a) Usage of YouTube in Sweden. (b) Usage of Whatsapp in Sweden.

Figure 3.1: Illustration of the relative usage of YouTube and WhatsApp in Sweden.

usage depends on the type of application. For a data demanding application such as YouTube, shown in Figures 3.2a and 3.2b, there was an initial growth in terms of usage duration and data consumption, even though with HSPAP and LTE the usage duration seemed to decrease. The average duration increased up until HSDPA where it reached $\sim$ 120 seconds, then decreased to $\sim$ 76 seconds for LTE. A UMTS session consumed on average $\sim$ 7.3 MB and lasted for $\sim$ 69 69 seconds. It seems that UMTS is sufficient for YouTube to function, but the users are still restricted somewhat since the average session duration for UMTS was $\sim$ 20 seconds less than for HSPA.

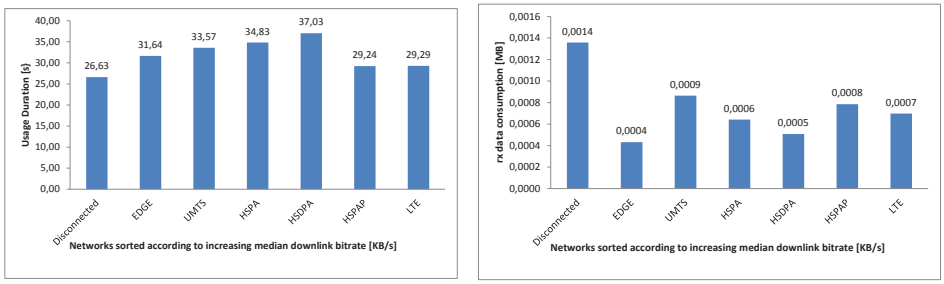


(a) Median Session Duration. (b) Received Data Consumption.

Figure 3.2: Median Session Duration and Received Data Consumption of YouTube.

When evaluating an application with low data demand such as WhatsApp, Figure 3.3a shows that the average duration increased up until HSDPA where it reached $\sim$ 37 seconds. Then, the duration decreased down to HSPAP and LTE where it reached $\sim$ 29 seconds. It seems that users speed up their sessions when they have access to better network performance, or the users are using some other app and therefore keep the WhatsApp sessions shorter. According to Figure 3.3b, WhatsApp presented stable behaviour on received data consumption with small differences among the different network types. It seems the average received data

were not impacted by the increase in the network performance.



(a) Median Session Duration. (b) Received Data Consumption.

Figure 3.3: Median Session Duration and Received Data Consumption of WhatsApp.

3.4 QoE-aware Architecture Proposal for Mobile Networks

In this section we present a QoE-aware architecture proposal for mobile networks. This architecture takes advantage of the approach described in the previous section, with a monitoring application reporting application level data to the mobile infrastructure. Then, reported information is used to activate resource allocation decisions. Figure 3.4 presents the basic elements of the proposed architecture.

The first element to consider is the QoE-aware communication engine. This communication engine receives information from the monitoring app, evaluates the captured data and makes decisions on the networks' resource allocation. In our approach, the main goal of the allocation decision is to avoid negative impacts on the users' QoE. The other element in the architecture is monitoring applications running on the mobile terminal. As described in the previous section, this app keeps the network updated regarding the conditions of the running applications in the terminal.

We evaluated the proposed architecture in a video streaming scenario considering the impact of video traffic in mobile infrastructure. In this regard, different authors such as Hoßfeld et al. [34] and Ickin [78] agree on the impact of video stalling on user's QoE. Therefore, we considered video stalling on the end users' terminals as an indicator to evaluate the performance of the architecture and the resource schedulers fed by the monitoring data. Performance of these schedulers was compared to the proportional fair scheme in order to identify the potential gains/benefits of using monitoring app data in the resource allocation decisions. More details can be found in Papers [79] and [80].

Implementation of a QoE-aware architecture and the use of application data provided by the monitoring app allowed for a reduction in both the total time/duration

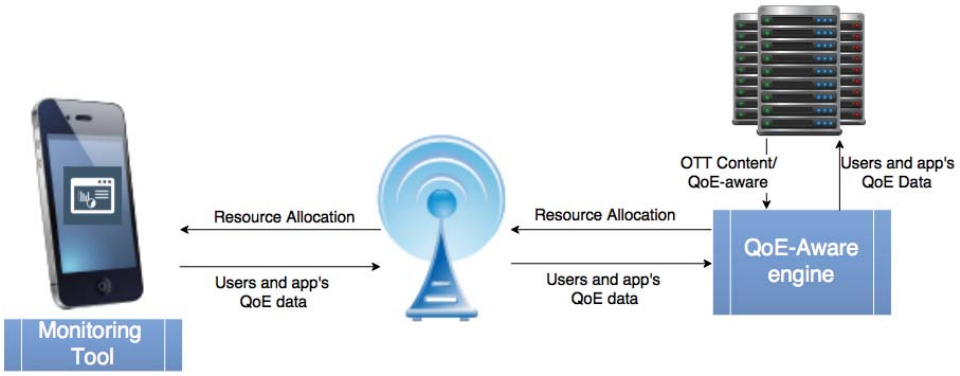


Figure 3.4: Main Elements Comprising the QoE-aware System.

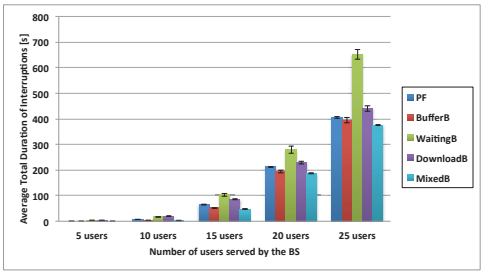


Figure 3.5: Average Total Time/Duration of Interruption by Number of Users for the Different Resource Schedulers.

of interruptions (TDI) and the frequency of the interruptions experienced during a video playback as illustrated in Figures 3.5 and 3.6.

These results reveal that using application level information in the resource allocation decisions reduces the number and frequency of the perceived interruptions during a video playback. We conclude that if the objective is to increase the end users' QoE, mobile networks should take into account the use of application level feedback. Analysis of the proposed implementations provides insights into the potential of using QoE-aware solutions in the resource allocation schemes. However, these results only impacted one domain of the QoE concept (technical). For this reason, a solution including QoE feedback and improving user's perception needs to include other domains, not covered in this section. Therefore, the QoE-aware architecture must be seen as one component within a more complex system from a holistic view of QoE.

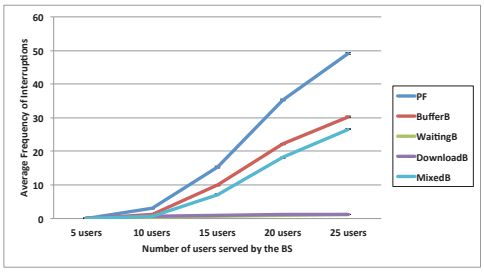


Figure 3.6: Average Frequency of Interruptions by Number of Users for the Different Resource Schedulers.

3.5 Discussion on the Benefits of Incorporating QoE in Mobile Networks

Benefits of incorporating QoE in mobile infrastructure have been widely discussed in several papers by authors such as Gómez et al. [39], De Moor et al. [20] and Seppänen et al. [81]. In this section, we extend the identification of benefits to the energy savings that can be obtained by using application level information and building-in QoE models in mobile networks.

We first conducted in-the-lab power measurements during video streaming in order to quantify the impact of video freezing (stalling) in the energy consumption. Then, we conducted an in-the-wild user study for collecting user opinion scores for video streaming on smartphone and obtain QoE-based models to leverage them in energy savings. These models centred on the impact of frequency and stalling duration on video QoE, as suggested by Hoßfeld et al. [34]. Combining the two parts we can propose solutions to minimise the energy consumption by leveraging the QoE proposed models. More details can be found in Paper [82].

During video streaming, a video playout can take two temporal states: (1) ON state while there is no freeze (basically the latency between two consecutive frames are not perceivable by a user); and (2) OFF state while the video is interrupted (a perceivable latency) that is often caused by a degradation in network throughput. We studied and calculated the total energy consumption at the mobile terminal in three different scenarios:

- (Scenario 1 - *no-freeze*): Video playout without any freezes.
- (Scenario 2 - *without-jump*): Video playout with freezes but without picture jump (i.e., video continues from the exact point where it was paused).
- (Scenario 3 - *with-jump*): Video playout with freezes and picture jumps (i.e., video is skipped by exactly the OFF duration and then is resumed). In this case, less content is presented.

We calculated the total energy consumption of a video stream with and without any freezes. Scenario 1 was considered the reference case for further analysis. Scenario 2 *without-jump* showed the total video session duration increases given the interruptions. As a consequence there is an increase in the energy consumption. We found that in Scenario 3 (*with-jump*), the total video duration was reduced by the total freeze duration generating a reduction in the total energy consumption. Thus, it can be said that Scenario 3 might be saving energy with the cost of displaying less content. Accordingly, Scenario 3 offers an alternative to obtain energy savings while maintaining the QoE.

The power consumption of the smartphone for each scenario is measured via Monsoon power monitoring tool and presented in Figure 3.7. Observe that in Scenario *without-jump* (red line) the energy consumption is higher as compared to the *with-jump* scenario (blue line), due to the extended video duration. The power consumption values drop occasionally for the freeze scenarios as depicted with red and blue.

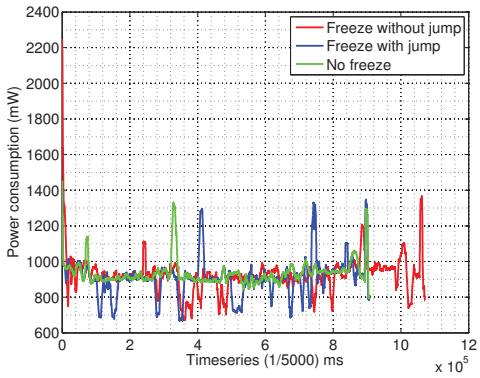


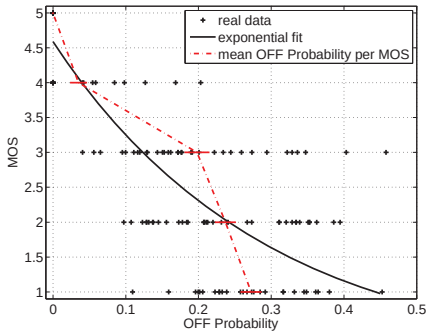
Figure 3.7: Snapshot of Power Consumption for the Three Scenarios ($W = 1.5\,\mathrm{s}$).

To quantify the influence of stalling on video QoE, we conducted a user study with 56 participants. Then, we fit a mathematical model to the data gathered during subjective studies with respect to the three considered scenarios.

The fitted exponential model is given in Eq. (3.1). Figure 3.8a depicts the relation between the OFF probability and the MOS together with the exponential fit. In this figure, OFF probability can be considered as the threshold that distinguishes the unacceptable (i.e., MOS = 1 and 2) and at least acceptable qualities (MOS = 3, 4, and 5). The red line is the average OFF probability for a given MOS value and is presented together with the 95 % confidence intervals.

$$MOS = 4.59\mathrm{e}^{-3.44 \cdot P_{\mathrm{OFF}}}, R^2 = 0.73 \tag{3.1}$$

As a result of the power measurements conducted to find out the wasted energy and the energy savings the $\bar{P}_{\mathrm{freeze}}$ and the $\bar{P}_{\mathrm{saving}}$ were measured as 728 mW, and



(a) OFF Probability vs MOS

Figure 3.8: Distribution of Mean ON Duration, Mean OFF Duration, and the Number of Interruptions of all Data from 56 Users.

185 mW, respectively. The total freeze duration, T_{freeze}, can be written as a function of total video duration and the P_{OFF}, thus MOS can be obtained as:

$$MOS = 4.59\text{e}^{-3.44 \cdot \frac{T_{\text{freeze}}}{T_{\text{video}}}} \tag{3.2}$$

We have obtained $MOS = 4.59 \cdot \text{e}^{-18.59 \frac{E_{\text{saving}}}{T_{\text{video}}}}$ for the relation between the energy saving and the MOS; and $MOS = 4.59 \cdot \text{e}^{-4.72 \frac{E_{\text{waste}}}{T_{\text{video}}}}$ for the relation between the energy waste and the MOS.

In scenario 3, the amount of energy that can be saved depends on the total video duration. When T_{video}, which is 3 minutes in our study, is substituted into the equations, 4.25 J can be saved at $MOS = 3$. Further energy savings above 4.25 J, means that the MOS value decreases below 3. For Scenario 2, i.e., when the frames are not skipped during a video freeze, the energy waste increases with the freezes, thus the video freezes must be avoided to minimise energy waste. The amount of energy saving in a three-minute long video stream is insignificant for a commercial single smartphone with battery capacity of 9.88 Wh. The calculated energy savings are relatively small as compared to potential energy savings in other components in the mobile network, particularly in the base stations. However, as more users (on the order of billions) spend more and more time on video streaming on mobile devices every day, the total amount of energy savings will directly increase and can reach the order of gigajoules.

Generating energy savings in mobile terminals can be proposed/used as added value for MNO and OTT players within their commercial offers and also be considered as part of their value proposition. However, additional work is necessary in order to test this alternative. As mentioned before, the initial tools to achieve this goal can be taken from [82] in an extended scenario. Proposed models can be incorporated into the objective function in the QoE-aware infrastructure as a

mechanism to achieve energy savings in mobile terminals. This can be done while maintaining users' QoE at acceptable levels and be offered as an added value for the end users.

3.6 Industry's View on QoE incorporation in Mobile Networks: Challenges and Requirements

According to QoE definitions provided by ITU [83], Laghari et al. [84] and the Qualinet project [23], technical elements are just a subgroup of what needs to be considered when referring to QoE. Therefore, the incorporation of QoE in mobile networks requires to look at additional elements beyond the technical level. In order to identify the current approach on QoE applied in the mobile industry, we conducted a set of interviews with representative actors in the industry. Interviews revolved around the challenges and requirements for the QoE incorporation in mobile networks operation. Unfortunately, no OTT provider responded to the interview invitation. Details on the interviews can be found in the methodology chapter.

The main challenges and requirements identified in the interviews covered aspects such as:

- **Integrating everyone in the QoE incorporation process.** QoE is mainly perceived as a technical issue and it is necessary that areas such as marketing and customer care see the benefits of a shared and common view on QoE. Quality is not only one actor responsibility and requires coordinated actions among different actors/areas to understand what is affecting users experience and identify mechanisms to improve QoE. For instance, users' feedback collected by marketing and customer care areas can be used to identify non-technical elements affecting the user's QoE and provide elements to make adjustments that benefit the company and its users. So far, even though there is exchange of information, we could see there is still a need for a joint and proactive approach on the QoE and its use in the service provision.

- **Evaluation and Information management.** Monitoring and evaluating QoS/QoE for every service and customer represents a challenging task, which not only implies defining both the collecting and evaluation mechanisms but knowing how and when to apply the gathered information. In that sense, it is important to make all the company's areas (e.g., customer care, network engineering, marketing) can get benefits from the collected data. This means giving each section the tools to extract the info they need while allowing a shared identification of potential correlations.

- **Coordination with the ecosystem actors.** As pointed out by Stankiewicz et al. [24], users' QoE is affected by different factors, which include, among

others, the type of device, the content/applications, or the network infrastructure. Therefore, managing QoE will imply a coordination among actors such as MNOs, OTT providers and device manufacturers, since any action taken by the one of these actors might impact the user's QoE. Coordination might require not only technical arrangements but business agreements that define conditions to minimize potential QoE affections and the mechanisms to activate in case of any problem.

- **Integrating subjective data.** Collecting information from different sources includes the end-users' feedback, which would require mobile business actors to take this information and find the correlations between the subjective and objective domains. Additional challenge is to make use of the user experience in the service offerings.

- **Security and Privacy concerns.** Telecom actors could use tools/mechanisms to monitor their customers, the network performance, and the operation of the devices/ applications to ensure QoE. However, customers might express concerns on the security and privacy issues that monitoring tools could create. On the other hand, the regulatory framework, especially regarding Net Neutrality, might limit the way mobile business actors make use of the collected data in the adjustment of the service provision.

Mobile industry actors expressed that QoE can provide elements to understand and improve the customer experience and the relation between a company and its users. In this regard, they coincide with Perkis et al. [47], who expresses that '*assessing the QoE of the users constitutes the key element in any customer management system*'. However, as pointed out by Cuadra et al. [22], extending the QoE concept to understand the customer experience requires not only a constant evaluation considering user feedback and monitoring in order to understand what is behind the customers' behaviour; it also requires MNO and OTT to assess their internal capabilities across the customers' touch points (i.e., service/content development, customer acquisition, billing, etc.). This evaluation may drive improvements in terms of organisational structure, processes, and technology. On the other hand, coinciding with Perkis et al. [47], Reichl and Zwickl [85] and Cuadra et al. [22], MNOs consider that '*QoE may well support for increasing the customer satisfaction and achieve loyalty gains*' [85]. Therefore, the mechanisms used to incorporate QoE in mobile networks need to offer different alternatives to capture in real time users' feedback (from different types of devices) and performance data in a way that allow the identification of any type of service quality deterioration.

3.7 QoE Incorporation in Mobile Networks

In recent years, different authors such as Perkis et al. [47], Jian et al. [86], Cuadra et al. [22] and companies such as Ericsson [87] or ZTE [88] have considered the

best way to manage the customer experience and the associated business aspects of a provisioned service is to develop a Customer Experience Management (CEM) approach in the mobile industry. According to Perkis et al. [47], the '*CEM system consists of a set of tools which allow the management of the user experience and the associated business aspects of the provisioned service*'. In that sense, following a CEM system approach can be the mechanism to incorporate QoE in mobile networks.

In this study, we have shown that the use of QoE models, and the combination of application and network level information brings to mobile networks the following:

1. **The potential to find correlations between network performance and application usage patterns.** By analysing correlations and trends that can reveal the type of experience each user is having, mobile business actors can identify mechanisms to optimise the performance of the services, detect services that might appeal to the users, and generate business alternatives based on the personalisation/customisation of services.

2. **The possibility to integrate application level information in resource management decisions.** Network resources could be adjusted according to the application requirements and the users' profiles and interests.

3. **Alternatives to generate additional benefits to the end user beyond simply content provision.** Users' and applications' information can be used to create models to improve the use of network resources and the energy consumption at the terminal.

In this section, we propose a conceptual QoE/CEM framework that enables the integration of the QoE-aware architecture proposed in section 3.4 in the mobile network. The goal of this framework is to guide the incorporation of QoE in the operation of mobile networks operation. The structure of the framework is presented in Figure 3.9

The core of the framework is the QoE management layer, which is responsible for collecting QoE data and implementing the technical/business decisions based on the collected data. It consists of two building blocks: the QoE-aware engine and the User Experience monitor. The QoE-aware engine is responsible for collecting the per user's session information provided by the monitoring app on network/terminal/application performance and applying resource allocation decisions.

On the other hand, the User Experience monitor gathers direct (e.g., surveys), indirect (e.g., checking the way customers use a service) and inferred (e.g., reports on transactions) customer feedback, from device perception aspects to users' expectations of service provision. The goal with the framework is that the QoE-aware engine and the User Experience monitor exchange information that make possible to provide service offerings based on the analysis of subjective and objective data. Decision made at the QoE layer will be reflected in the Service Layer an the way technical resources, business strategies or commercial offers are implemented.

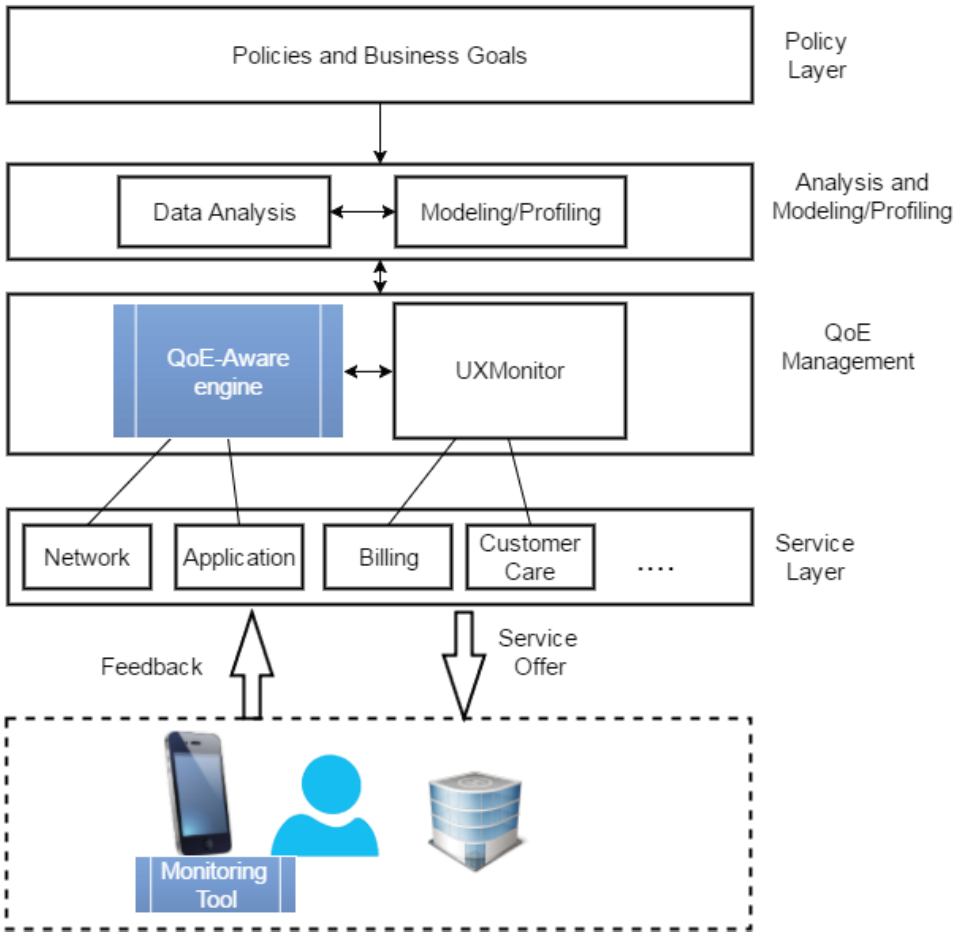


Figure 3.9: QoE/CEM Framework

The Service Layer represents the different touch/interaction points between the user/subscriber and the service provider. This layer defines the QoE/CEM framework boundary and provides the available operations from the perspective of the client. It encapsulates the technical, business and market touch points that offer service provider and client interaction channels. Service Layer channels/interfaces adapt their behaviour/performance based on evaluation of QoE feedback by the Management Layer. Examples of the interaction points are the network interface, customer apps, customer care, billing and marketing areas.

The Analysis and Modeling/Profiling Layer is in charge of taking the information gathered by the QoE layer, finding correlations between subjective and objective metrics and defining the models and elements to consider when implementing

management decisions at technical, business, and commercial levels. It consists of two building blocks: Data Analysis and the Modeling layer.

Data Analysis layer process the information captured from the different touch points and transform it into adequate input for the different QoE-oriented actions in the network (i.e., network resource management, billing, customer care, commercial offers, etc.). Data Analysis layer can process both online/real-time data and information previously stored in a data warehouse. The Modeling/Profiling Layer is in charge of structuring and defining the QoE models and User Experience profiles that will be considered in the operation of the mobile network. This layer takes into account both the input generated by the Data Analysis and the Policies and Business Goals layer. Technical and User Experience management decisions made at the QoE layer will consider the QoE model, the Users' profiles and the elements provided by the Analysis block.

Finally, the Policies and Business Goals layer incorporates the guides, business goals and regulatory/corporate bounds (limitations) identified and set by the organisation. Based on the combination of the aforementioned elements with the outcome provided by the Analysis and Modeling/Profiling Layer, QoE management layer decisions are made.

3.8 Conclusions

This chapter offers an answer to RQ1 and analyses how QoE feedback can be incorporated into the technical operation of mobile network infrastructure. Our approach was based on the use of monitoring applications installed on mobile terminals. By using the application level information provided by monitoring software, mobile network players can establish correlations with network performance and identify trends and app usage patterns. We exemplified the use of this principle by analysing the influence of network performance on app choice and usage.

Based on the same principle, we proposed a QoE-aware architecture. We showed that mobile networks can use app information in the resource allocation decisions and generate improvements in the end users' QoE. Our study extended the analysis by identifying the additional benefits that QoE incorporation can bring to the mobile network users. Discussed benefits focused on the potential energy savings at the mobile terminal by leveraging QoE models.

Finally, discussion on the incorporation of QoE in mobile networks showed that it is necessary to extend the pure technical approach when dealing with QoE to a broader concept that involves business and market related elements. In that sense, the incorporation of QoE in mobile networks starts with collecting and using app information but needs to consider the entire customer experience at each step in the service delivery, including the different contact points between users and mobile networks. This entails considering the components that set up the service, the business processes related to the service, the resources on which the service provision is supported and the performance of the underlying network.

Chapter 4

Regulatory Implications on the integration of QoE feedback in Mobile Networks

In this chapter we focus on answering RQ2:*How can the incorporation of QoE best be aligned with Net Neutrality regulation?* In order to answer this question, first we present elements guiding the current discussion and the evolution of the debate. Later, we present a regulatory analysis centred on two cases: US and EU due to the relevance of these markets and the impact of their regulatory decisions on the telecommunications market.

With the results obtained in the comparative analysis of the US and EU regulation, we identify the implications that Net Neutrality principles might have on the incorporation of QoE feedback in mobile networks. The results of this chapter will be integrated with scenarios proposed in Chapter 5 to evaluate the business implications of incorporating QoE feedback in mobile networks.

4.1 Introduction to the Net Neutrality Debate

During the past decade, Net Neutrality (NN) has become a central issue in the debate about the development of the Internet, as stated by Scott et al. [89]. With the Internet becoming an essential platform for information, entertainment and communications, the role of network infrastructure owners have shifted to an essential gatekeeper position in the information society (Wiewiorra [90] and Mønichen [91]). According to Krämer et al. [92], this phenomenon has led regulators and some society representatives to express concerns about how infrastructure owners are going to monetise access and usage of the network in the future.

The term NN was first proposed by Tim Wu [43] in 2003. He discussed private interest and public interest in the broadband industry and used the NN concept to signify that the Internet is merely a carrier of online content that does not

distinguish one website from another [43,91]. In another document [93], Wu claimed that '*NN is best defined as a network design principle. The idea is that a maximally useful public information network aspires to treat all content, sites, and platforms equally. This allows the network to carry every form of information and support every kind of application*'.

With the debate evolution, new NN definitions proposed by experts, regulators, and NN activists have emerged. Hahn and Scott [94] stated that '*Net neutrality usually means that broadband service providers charge consumers only once for Internet access, do not favor one content provider over another, and do not charge content providers for sending information over broadband lines to end users*'. Krämer et al. [92] affirmed that: '*Net neutrality prohibits Internet service providers from speeding up, slowing down or blocking Internet traffic based on its source, ownership or destination*'.

According to the movement 'Save the Internet' [95] '*Net Neutrality means an Internet that enables and protects free speech. It means that Internet service providers should provide us with open networks and should not block or discriminate against any applications or content that ride over those networks*'. The same group affirms that '*without Net Neutrality, cable and phone companies could carve the Internet into fast and slow lanes. An ISP could slow down its competitors' content or block political opinions it disagreed with. ISPs could charge extra fees to the few content companies that could afford to pay for preferential treatment relegating everyone else to a slower tier of service. This would destroy the open Internet*'.

The social group European Digital Rights (EDRI) [96] affirms that '*Net Neutrality is the principle that every point on the network can connect to any other point on the network, without discrimination on the basis of origin, destination or type of data*'. According to EDRI '*Net Neutrality gives the Internet its ability to generate new means of exercising civil rights such as the freedom of expression and the right to receive and impart information*'.

From a regulatory perspective, US and European based authorities have made efforts to define NN. The Body of European Regulators for Electronic Communications (BEREC) [97] mentions that NN refers to '*a debate about the way that Internet Service Providers (ISPs) manage the data or 'traffic' carried on their networks when data is requested by broadband subscribers (known as 'end-users' under EU law) from providers of content, applications or services (CAPs) such as YouTube or Spotify, as well as when traffic is exchanged between end-users*'. Meanwhile, the US Federal Communications Commission (FCC) equates the concepts Open Internet and NN, mentioning on its website [98] that '*An Open Internet means consumers can go where they want, when they want. This principle is often referred to as Net Neutrality*'. In that sense, FCC adopted the Open Internet rules which are designed 'to protect free expression and innovation on the Internet and promote investment in the nation's broadband networks'. [99]. Even though there is no formal definition of NN as such, the FCC's Open Internet rules define the so called 'Bright Rules', which expressly forbid blocking, throttling and paid prioritisation. With these rules, the FCC's aim is to '*prohibit harmful practices that target specific*

applications or classes of applications' [99] and ban paid prioritisation.

In general, definitions and on-going discussion reflect a debate centred on data traffic and the way the content reaches the end user. This control can be exercised through technical (e.g., network management policies) or economic (e.g., differentiated services offer, termination fees) mechanisms. In both cases, there are arguments in favour and against keeping NN regulation.

From a technical perspective, the basic arguments in favour of NN start with the idea that the 'best effort' principle has enabled new applications to flourish on the edges offering low entrance barriers to the open platform of Internet and creating a competitive environment. The latter is recognised by FCC [99] and BEREC [100]. According to authors such as Frischmann and Schewick [44] or Lemley and Lessig [101], the non-discriminatory nature of the Internet was introduced in its architecture with the application-blind approach of IP protocol. As per Lennet [102], traffic discrimination could turn ISPs into gatekeepers deciding which applications succeed or fail. On the other hannd, authors such as Crocioni [103], Hazlett and Wright [104] and Renda [105] state that traffic discrimination make services more valuable to users while increasing the network performance.

Another point of discussion is the impact of NN principles on the methods to address network congestion. On the one hand, EDRI [96], Lennet [102] and the Dutch regulation [106] state that the solution for network congestion is investing more on capacity. On the other hand, Faulhaber and Farber [107] argue that traffic prioritisation and network management mechanisms have been always part of the Internet. Therefore, banning traffic discrimination via regulation would needlessly affect the telecom market, especially the mobile broadband one, where resource management is critical.

Even though technical arguments are relevant in the NN debate, it is also important to take into account that the discussion also involves economic arguments for and against NN. Arguments against NN, such as the ones expressed by Renda [105], Yoo [46] or Weisman [45], tend to focus on the benefits of discrimination and how it can enable a new market with offerings adjusted to consumer demands, making the services more valuable for users. Meanwhile, Faulhaber and Farber [107] argue that traffic discrimination can be the alternative for network operators to increase their benefits by introducing charging policies based on type of consumption. Another argument in favour of traffic discrimination is that traffic discrimination creates the potential to allocate resources to those applications that need them most, maximising the welfare of all network users, as pointed out by authors such as Crocioni [103] and Krämer and Wieworra [42].

Arguments for NN state that keeping their principles prevent network operators from discriminating against competitive services and discouraging application innovation. As expressed by Atkinson and Weiser [108], network operators might create a market monopoly situation by having the power to manipulate the quality of some applications. On the other hand, EDRI [96] expresses that preserving NN is a way to foster innovation and eliminate potential entry barriers for small content and application companies. Regarding the potential benefits of traffic discrimina-

tion, NN supporters use the model from Economides and Hermalin [109] to show that traffic discrimination can lead to re-congestion by increasing the demand on high priority content and services.

The majority of academic research has explored the technical and economic implications of NN and the implications of different regulatory approaches on the telecom market development. Although authors such as Lennet [102], Faulhaber and Farber [107] or regulatory bodies such as BEREC [110] discuss the mutual implications of the relation QoS-NN, we think this analysis should be extended to show how mobile operators interested in QoE-based service differentiation, that goes beyond the pure technical and network related considerations, need to consider the NN regulatory framework when structuring business models and commercial strategies.

4.2 Regulatory Framework on Net Neutrality in the US and Europe

In this section, a summary and analysis of the current regulatory frameworks on NN in US and EU are presented. These two markets are considered because of the impact of their policies in the development of regulation in the telecom market around the world. The analysis covers key issues in the NN debate such as the regulatory approach on blocking, paid prioritisation, specialised services and zero-rating.

4.2.1 NN in the US

NN has been under public discussion for more than a decade and debated at academic (e.g., Wu [43] and Hazlett and Wright [104]), social (e.g., Save the Internet [95]) and regulatory levels (e.g., FCC [99]). During this time, the FCC has released different documents to define the principles of Internet Policy (2005) [111] and Open Internet (2010) [98]. Finally, in 2015, the FCC [99] voted to adopt strong NN rules and classified broadband services as common carrier services under the telecommunication act. The key aspects of the Open Internet rules or 'Bright Line Rules', as defined by FCC [99] are:

1. **No Blocking:** broadband providers may not block access to legal content, applications, services, or non-harmful devices.
2. **No throttling:** broadband providers may not impair or degrade lawful Internet traffic on the basis of content, applications, services, or non-harmful devices.
3. **No paid prioritization:** broadband providers may not favour some lawful Internet traffic over other lawful traffic in exchange for consideration of any kind, in other words, no 'fast lanes.' This rule also bans ISPs from prioritising content and services of their affiliates.

According to the FCC [99], '*the bright-line rules against blocking and throttling will prohibit harmful practices that target specific applications or classes of applications. And the ban on paid prioritization ensures that there will be no fast lanes*'. In the same statement, the FCC recognises that broadband providers need to implement network management mechanisms considering the the features of the technology (e.g., fibre, Wi-Fi, mobile). This network practice must be motivated by a technical justification and not by a business goal. The FCC [99] also mentions that '*A person engaged in the provision of broadband Internet access service shall publicly disclose accurate information regarding the network management practices, performance, and commercial terms of its broadband Internet access services sufficient for consumers to make informed choices regarding use of such services and for content, application, service, and device providers to develop, market, and maintain Internet offerings*'.

Regarding specialised services, the FCC [99] recognises that '*some data services-like facilities based VoIP offerings, heart monitors, or energy consumption sensors-may be offered by a broadband provider but do not provide access to the Internet generally*'. In that sense, the FCC offers an exemption from the NN rules for those service not providing broad Internet access but offered using the same infrastructure (e.g., VoIP, Cable TV, health monitoring, energy consumption sensors and automobile telematics).

The FCC supports its analysis and the definition of rules in two principles: the open Internet architecture based on non-discrimination principles expressed in the 'bright rules' and a 'virtuous cycle' in which new applications and services developed at the edges of the network contribute to increase the consumer demand. As a consequence, the growth in the demand leads to more investments in infrastructure that accelerate new innovations at the edge. In that sense, the best response to rising levels of traffic is increased capacity rather than monetised congestion. It is worth noting that the FCC states in the NN rules [99] that '*broadband providers not only have the incentive and ability to limit openness*' and concludes that without clear NN rules the broadband providers could negatively impact the development of the Internet. In that sense, the prohibition on blocking, throttling and paid prioritisation wants to protect the current market structure.

In the 2010 Open Internet Order [98], the FCC set the Internet rule within the 'last mile' context, without considering the traffic between networks. In 2015, the FCC [99] expanded the open Internet rules to cover the interconnection between content providers and the broadband provider's network. With the changes in the content delivery market, the settlement-free scenario (i.e., a way to exchange traffic with neither party incurring an Internet Transit fee) might be affected. Two aspects are relevant in this potential change. First, the high demand for video streaming content and the increase in the downstream traffic. This phenomenon is leading to capacity expansions, that have caused network operators to reconsider the current Internet peering structure. The second aspect is the power consolidation of ISPs in the US market, as mentioned by Scott et al. [89]. According to Leichtman Research Group [112], over 75% of the broadband subscriptions in the US market

are controlled by the five largest cable and telephone companies. The control of the broadband market combined with the concerns about the traffic management responsibilities and the success of OTT players has opened the door for discussions on the way interconnection agreements are signed. The 'Netflix dispute' [113] is one of the representative cases of this new scenario. Even though the 'Netflix dispute' did not involve prioritisation, it showed the risks for the consumer interests of degradation implemented at the interconnection points. FCC identified this kind of dispute as a risk to the 'virtuous cycle'.

Criticism towards FCC rules has focused on aspects such as the effect of the new rules in the broadband business structure. Scott Belcher [114], chief executive of the Telecommunications Industry Association (TIA), expressed that NN rules can negatively impact network operator's investment on infrastructure: '*The internet is built on infrastructure. Even to keep at a steady state providers are going to have to invest in infrastructure but they need certainty that they can get a return on their investments*'. As per Scott et al. [89], the critique of the regulatory approach expresses concerns on how the regulation closes the door for new revenues stream alternatives while asking for investments in infrastructure.

Even though the FCC clearly stated rules on NN, for some consumer organisations and activists, such as Fight the Future, the Center for Media Justice and Free Press [115], there is still a need for a clear definition on zero-rating programmes. Zero-rating is a practice recently implemented by some MNO, mobile virtual network operators (MVNO), and ISPs to not charge user for data linked to specific applications or Internet services. For some critics, such as Marsden [116], FCC regulation has focused on the 'Negative' neutrality (e.g., blocking and throttling) leaving aside the 'Positive' net neutrality violations that do not involve blocking, but treating some content better than general Internet traffic. According to Fight the Future, the Center for Media Justice and Free Press [115], FCC's NN rules do not specifically forbid zero-rating. The FCC has stated that it may use the 'general conduct' portion of the rules to stop anti-competitive implementations of zero-rating on a 'case by case basis', but so far has given little to no indication this will actually happen.

Meanwhile operators in the US have implemented zero-rating offers. In 2015, T-Mobile launched 'Binge On' expanding its zero-rating offer to video streaming services. In January 2016, Verizon joined AT&T by creating FreeBee Data, which enables businesses to sponsor the content consumed on their mobile app/website by Verizon/AT&T users.

The FCC [99] announced in July 2015 how it will follow a case-by-case approach with regard to zero-rating schemes or Specialised Services, that may risk NN.

4.2.2 NN in the EU

The European regulatory framework adopted in 2002 did not mentioned NN, but the European Commission (EC) engaged in the NN discussion in 2006. The issue of NN was addressed mainly from an end user perspective. A key concern was

to ensure that the Internet remains 'open', open for new and innovative services implemented by different service providers and open, from the user's perspective, to create, access and distribute the content and services of its choice, as Ericsson stated [117].

According to the revised European regulatory framework approved in 2009, the national regulatory authorities (NRAs) should promote the interest of citizens and recognised Internet access as a fundamental right, as indicated by Scott et al. [89], and by BEREC [110]. Besides these changes, the European Parliament (EP) [118] introduced the following aspects:

- *Amendment of Article 8 of the Framework Directive to establish the ability of end users to access content, applications or services of their choice as an explicit goal of European policy.*
- *Amendment of Article 20 of the Universal Service Directive to oblige providers of electronic communication services to inform their end users of their practices in regard to traffic management, and providing end users with the right to change providers without penalty if they are dissatisfied with a change in these practices.*
- *Empowerment of NRAs through Article 22 of the Universal Service Directive to impose, if necessary, minimum QoS obligations on an SMP operator.*

In 2009, the Swedish Post and Telecom Agency (PTS) undertook a review of potential issues on NN in Sweden. In the memorandum on NN [119], PTS did not see any reason to act in any matter related to NN. In the same document, PTS recognised that '*resource allocation, or a prioritization of data traffic, is already taking place now through the various rates being offered to end users*'. In the same document, PTS expressed that '*the Internet access capacity may also vary between the offerings of different service providers, which could result in poorer capacity in areas where fewer service providers are established*'. PTS also mentioned that as opposed to the USA, European regulation of electronic communications focuses on network access competition, which aims to guarantee that users are able to choose between several different service providers for their broadband access if they feel the service provider restricts access to content services in a way that goes against the users' needs.

In 2010, the EC conducted a public consultation on NN. EC did not identify problems with NN in the EU [120]. In the same year, the Autorité de Régulation des Communications Électroniques et des Postes (ARCEP) in France presented the 'Internet and Net Neutrality proposals and recommendations' [121]. Document discussion revolved around the need for: i) a transparent and non-discriminatory access to contents and networks; ii) enough bandwidth to meet demands; and iii) reconciling the open internet goals with the business goals of the network annd service providers. According to ARCEP, this type of consideration requires healthy and open competition.

BEREC launched consultations on NN and published a report titled 'Guidelines on Transparency in the Scope of Net Neutrality: best practices and recommended approaches' [122] in 2011. Although this document does not offer a NN definition, it considers NN as a network design principle, coinciding with Tim Wu's definition [93]. The purpose of this report is to explore the subject of transparency in relation to NN and to discuss guidelines for NRAs on the importance of transparency policies when users choose their service provider.

BEREC [123] also conducted consultation on QoS in the scope of NN. In this study, BEREC remarks on the importance of transparency in the development of a competitive market. As mentioned by BEREC [110], users need appropriate means or tools to monitor the quality of their services and detect potential degradation in the operation of the network. Complementing its work on NN, BEREC published a document titled 'An assessment of IP interconnection in the context of Net Neutrality [124]' where NN is defined as '*the principle that all electronic communication passing through a network is treated equally. That all communication is treated equally means that it is treated independent of (i) content, (ii) application, (iii) service, (iv) device, sender address, and (vi) receiver address*'. In the same document, BEREC noted that the NN concerns were limited to the last mile network of ISPs. Finally, BEREC remarks on the importance of competition and open market as the solution for situations that potentially impact NN.

In 2012, the Netherlands adopted legislation to safeguard the open and secure Internet including NN provision [106]. This step was a reaction to the plans for charging users with extra pay for using OTT applications (e.g., Skype, Whatsapp) announced by KPN in 2011. Dutch law prohibits obstructing Internet services and applications. However, the law establishes exceptions in certain limited cases. The first exception allows prioritizing time-sensitive traffic (e.g., VoIP) only in case of network congestion. However, providers are encouraged to invest in network capacity to avoid congestion situation and satisfy users' demands. The second exception is about blocking traffic that affects network, terminals and end users' safety. Measures should be temporary. The third exception is for blocking unsolicited commercial content (e.g., spam) or certain traffic under a court order. Finally, network operators cannot offer price differentiation for the Internet access depending on the services and applications used by customers. On the other hand, Slovenian parliament and the Agency for Communication Networks and Services of the Republic of Slovenia (AKOS) introduced legislation on NN [125]. This regulation aims to preserve the open and neutral character of the Internet and bans traffic discrimination. Slovenian law follows the same exemptions proposed by the Netherlands in its NN regulation.

Meanwhile, the European Parliament (EP) calls on the Commission to promote and preserve digital freedom in the EU, by incorporating NN in the regulation. In the report 'Digital Freedom Strategy in EU Foreign Policy' [126], EP expressed its support for '*the principle of net neutrality, namely that internet service providers do not block, discriminate against, impair or degrade, including through price, the ability of any person to use a service to access, use, send, post, receive or offer any*

content, application or service of their choice, irrespective of source or target'.

EC included NN as part of the discussion on creating a single European telecommunications market in 2013, which is reflected in [127]. In the same document, EC introduces the 'specialised services' concept and the possibility that end users can pay for the provision of content and applications with an enhanced quality of service, as long as transparency principles are respected. Even though the EC adopted the spirit of FCC's open Internet rules, some critics pointed out that the proposal allowed ISP to implement paid prioritisation (Scott et al. [89]).

In 2014, the EP voted to strengthen the protection of NN principles [128]. This legislation includes the following definition on NN: '*Net Neutrality means that traffic should be treated equally, without discrimination, restriction or interference, independent of the sender, receiver, type, content, device, service or application*'. Regarding specialised services, the EP says that '*Providers of internet access, of electronic communications to the public and providers of content, applications and services shall be free to offer specialized services to end-users. Such services shall only be offered if the network capacity is sufficient to provide them in addition to internet access services and they are not to the detriment of the availability or quality of internet access services. Providers of internet access to end-users shall not discriminate between functionally equivalent services and applications*' [128].

In March 2015, the European Council adopted a final position on NN and the telecom single market [129], reintroducing QoS differentiation into the regulation and opening the door to paid prioritisation and specialised service agreements. In this regard, agreements are allowed as long as they do not impair the general quality of internet access services.

BEREC opened a public consultation on the 'Guidelines on the Implementation by National Regulators of European Net Neutrality Rules' [130]. At the time of this publication, the process is closing. According to the text, '*any traffic management practices which go beyond such reasonable traffic management measures, by blocking, slowing down, altering, restricting, interfering with, degrading or discriminating between specific content, applications or services, or specific categories of content, applications or services, should be prohibited, subject to the justified and defined exceptions laid down in this Regulation. Those exceptions should be subject to strict interpretation and to proportionality requirements*'.

Regarding specialised services, BEREC states [130] those are '*services other than internet access services which are optimized for specific content, applications or services, or a combination thereof, where the optimization is necessary in order to meet requirements of the content, applications or services for a specific level of quality*'. The guidelines leave it up to the NRAs to interpret whether the QoS parameters are adequate to provide the services and whether sufficient bandwidth in the networks allow for Internet access service. According to BEREC guidelines examples of what may be considered specialised services include VoLTE (high-quality voice calling on mobile networks) and linear (live) broadcasting IPTV services with specific quality requirements. Another example would be real-time health services (e.g., remote surgery).

Table 4.1: Net Neutrality Regulatory Comparison.

	United States	European Union
Market Situation	Duopoly-like situation.	Unbundling policy implemented.
NN Principles	No blocking. No throttling. No paid prioritization.	No blocking. No throttling. No paid prioritisation.
Specialized Services	No broadband Internet Access Service.	No broadband Internet Access Service NRAs able to interpret the QoS requirements and the sufficient bandwidth to allow specialized services provision.
Zero Rating	FCC approach recognises that sponsored data plans have the potential to distort competition. Also recognises that depending on the business model and its structure, new service offerings could benefit consumers and competition. FCC,will assess such practices under the no-unreasonable interference/disadvantage standard.	Those situations where all applications are blocked or slowed down once the data cap is reached except for the zero-rated application(s) are forbidden. Others are less clear-cut and will be need to be assessed by NRAs against a number of criteria set out by BEREC in its guidelines [130].

According to the same guidelines [130], '*zero-rating is when an ISP applies a price of zero to the data traffic associated with a particular application or class of applications (and the data does not count towards any data cap in place on the Internet access service)*'. The BEREC guidelines explain that zero-rating practices where all applications are blocked or slowed down once the data cap is reached except for the zero-rated application(s) are clearly prohibited. In other cases, the NRAs need to apply a case by case analysis considering criteria suggested by BEREC in the guidelines.

4.2.3 Comparison between US and EU approaches on NN

In spite of the similarities of the approaches on NN about basic principles such as blocking and throttling, there are some differences between US and EU including the market structure, the regulatory interpretation and the competition law, which impacts how the NN rule is interpreted. This comparison is summarised in Table 4.1. Discussion on NN originated in the US, where the duopoly-like situation prevailing in the broadband access market represented one of the main reasons behind the NN debate. Operators owning the network infrastructure claimed an unbalanced revenues situation compared to the content providers. In contrast, the European market has seen how the unbundling policy implemented since 2000 reduced the power of infrastructure owners. This ensures that users can switch to a network provider offering better terms and a neutral Internet access service.

Another aspect to consider in the two regulatory approaches is the political scenario in Europe and US. The most successful OTT players are US-based companies. This provides them with a political and market power in the US context to counterbalance the telecommunications industry efforts to weaken the NN regulation. To FCC and its virtuous cycle approach OTT players are a key factor in the market development while the network operator acts as a gatekeeper towards their subscribers and its growth is attached to the openness of the Internet.

Non-blocking and non-throttling are principles that both US and EU regulatory frameworks recognise and reflect. Regarding prioritisation, both regulatory frameworks recognise its application by network operators in order to allocate resources for applications requiring more bandwidth. However, the FCC regulation is clearer and adds non-prioritisation to the NN principles. The EU regulatory approach, probably due to its market structure, seems to recognise that prioritisation is an effective tool as long as there is open competition and transparency. Thus, the user has all the information to choose what they prefer. By taking off the table the paid prioritisation, EU regulation seems to open the door for alternative business models, where service provision can be done in accordance with predefined standards (i.e., quality) previously agreed with the users. This is without compromising the freedom of expression and fairness principles.

Definition of specialised services is also an important element in the NN debate and might provide exceptions from NN. Both FCC and EU agree on describing them as not a broadband Internet access service. However, the EU framework goes further by leaving the NRAs to interpret the quality of service requirements and the sufficient bandwidth in the network to allow the specialised services provision. In an open and competitive scenario, specialised services might be the scenario for the provision of QoE-differentiated services when the NRAs specify the regulatory framework applicable in each case.

Finally, it is necessary to look at the regulatory consideration on zero-rating and price discrimination. The FCC approach [99] recognises that zero-rating and other sponsored plans can distort competition by allowing service providers to work with selected OTT players to feature on different service plans. However, it also recognises that depending on the business model and its structure, new service offerings could benefit consumers and competition. Therefore, the FCC indicates that it will assess such practices case by case, and take action as necessary. In Europe, according to BEREC [97] those situations '*where all applications are blocked or slowed down once the data cap is reached except for the zero-rated application(s) are forbidden*'. Other cases will need to be assessed by NRAs considering criteria set out by BEREC in its guidelines [130].

In summary, in both the US and EU context, the discussion on NN has a long history and common areas; however, the motivation and goals of their regulatory efforts are not similar. The differences in the government and market structure, the overall regulatory environment, the power of the different actors in the discussion, and the number of NN related incidents have defined the way regulatory authorities have approached the NN issue on both sides of the world. Then, proposed NN rules were motivated by different concerns and realities. This environment and the regulatory decisions made by each regulator will define how the two markets will develop in the future.

4.3 NN principles and its Implications for QoE Feedback Incorporation

In this section, we identify how the incorporation of QoE feedback in mobile networks might be affected by the current regulation on NN. We first discuss the main requirements to incorporate QoE feedback in mobile networks and make use of this feedback in the service provision. Then, we summarise the focal points on the NN regulation identified in the US and EU context and discuss how these regulatory elements can affect the use of QoE feedback in mobile networks.

4.3.1 Requirements for the Incorporation and Use of QoE Feedback in Mobile Networks

The identification of the requirements for the incorporation of QoE feedback in mobile networks combines the analysis of existing literature on QoE-based architectures and frameworks, like the one presented in the technical chapter of this dissertation, and the insights provided by representatives of the mobile industry. This was achieved through a half-day workshop and subsequent interviews with representatives of the mobile industry. The experts represented Telia, Tele2, Edgeware, PTS (Swedish Post and Telecom Authority), Ericsson, NTK (the Swedish Telecom Users Association), Northstream and Telemanagement.

From a technical point of view, in order to offer QoE-based services it is necessary to understand, design and deploy suitable technical solutions to provide users with the best possible experience. According to the ideas expressed by authors such as Barakovic and Skorin-Kapov [131], De Moor et al. [20] and Zhang and Ansari [72] and the collected information, the implementation of mechanisms to model, monitor and measure, control and monetise QoE represent important challenges to incorporate QoE feedback in mobile networks. A description of the challenges and the requirements to overcome them is presented below.

- ***QoE Modeling.*** The goal of QoE modelling is to understand the factors influencing human perception and offer models to quantify the human response to measurable QoE factors. QoE estimations generated with such models can be used to implement QoE management in mobile networks. QoE modelling requires among others a good understanding of the users' behaviour, the identification of service use patterns, and a constant interaction with the user in order to enrich the accuracy of the models. QoE estimation may require active inspection of the packets running within the network in order to extract input information for the QoE models, or the use of big data analysis based on consumption/use patterns to address the estimation of user's behaviour, expectations and perceived quality.
- ***QoE Monitoring and measurement.*** It includes data collection on QoE at different levels (i.e., technical, business and market) and the implementation of monitoring probes in different points of the mobile infrastructure (e.g.,

base stations routers within the core network, users' devices and customer service areas). The challenge lies not only in collecting QoE-related information and reporting QoE feedback from the user to the network to optimise network performance, but also on managing the privacy and transparency issues associated with collecting and using this information.

- ***QoE Control and Optimisation.*** Maintaining an adequate use of the network resources while guaranteeing the users' satisfaction level with the service provided are the goals of QoE control and optimisation. In this context, QoE-based resource management and scheduling mechanisms should look at the quality perceived by end users. In the same way, QoE-based resource management would require implementing mechanisms to prioritize certain types of content depending on business goals.

- ***QoE Monetisation.*** Monetisation is related to the exploitation/utilisation of QoE information in a business context as a new revenue source for the mobile networks' ecosystem players. One of the challenges in this regard is the problem between willingness-to-pay and service perception stated by Reichl et al. [132]. QoE monetisation also requires a deeper understanding of user's interests, and the integration of other factors such as socio-economic classification of users and the service usage preference when applying QoE-based charging policies. In addition, the users' segmentation, and the offer of different quality levels and contents, according to users' categories might imply the implementation of resource management policies to achieve the business goals. Finally, an open question is the use of the QoE information beyond structuring the MNO's and OTT's commercial offer. Privacy and transparency issues might arise when mobile business actors use profile information for commercial purposes.

4.3.2 View on the Implications of NN on the incorporation of QoE Feedback in Mobile Networks

As discussed in the previous section, the incorporation of QoE feedback in mobile networks requires taking actions on both the mechanisms to capture/collect QoE-related information and the implementation of resource management strategies that make use of the captured data. Regarding NN and current regulation, particular concerns may appear with regard to privacy and transparency in the users' data management and on the traffic management implemented with commercial goals.

On the use of customers' data and the protection of customers' data, both US and EU regulation rely on consumer protection laws defined for each country/region. What prevails in both cases is the importance that both FCC and BEREC give to the role of transparency in the telecom ecosystem. Network operators are required to provide clear description of promotional rates, data caps, fees and any additional charges related to the service provision. Transparency with end

users must include information on network management practices and their impact on the service operation. BEREC [120] even extended the importance of transparency by indicating that NRAs should ensure that ISPs include in the contract and publish a clear and comprehensive explanation of traffic management measures applied in the network. The information provided by the ISP has to include any measures applied when managing traffic which uses personal data and how ISPs ensure the privacy of end users and protect their personal data when managing traffic. In that sense, collection and use of QoE related information needs to consider these aspects.

In light of the current FCC regulation, the alternatives for traffic prioritisation are limited to those that guarantee the normal operation of the network and not business purposes. In that sense, this approach would close the door to any potential creation of fast-lanes or the definition of QoE-based lanes in the network infrastructure. Even though EU regulation prohibits blocking or slowing down Internet traffic, except where necessary, its approach does not close the door to paid prioritisation and reinforces the importance of full transparency to empower users in their choice of network provider. In that sense, operators must provide a clear description of the effects of policies over the users' QoE.

Specialised services can be the alternative to exploit the full potential of QoE information, since both regulatory frameworks offer an exemption from the NN rules. According to both regulations, specialised services have limited purpose and do not provide access to the Internet. BEREC [120] went beyond this definition and leaves it up to the NRAs to evaluate and interpret whether QoS parameters are adequate to guarantee the operation of both the specialised services and Internet access service. In this regard, those actors interested in implementing QoE-based services might consider using specialised services.

An alternative that has been considered by MNO as a revenue stream is establishing alliances with OTT players by offering zero-rating. In this scenario, the segmentation/prioritisation is not directly implemented at the network level but at business and market levels by applying zero-rating to a particular application or type of applications. Although in most cases the QoE differentiation is not directly invoked when offering zero-rating, implementation cases such as Binge On offered by T-Mobile may have implications on users' QoE. With Binge On users on a qualifying plan can freely stream unlimited video without using any high-speed data.

Even though T-Mobile has insisted that it is not violating NN, the study by Kakhki et al. [133], found that Binge On reduces video quality more than T-Mobile claims and throttles the non video content flows. On the other hand, T-Mobile may argue that its zero-rating offer is respecting the following principles:

- **Transparency principle:** Customers are aware of what the operator is doing and are free to choose to be part of the plan.
- **No paid prioritisation:** The operator is not charging OTT players to be

included in the offer. They are implementing reasonable network management principles to optimise network performance.

- **No discrimination:** The operator is including all the video content providers (a type of traffic) and not working only with one of them, for example Netflix, to give them a competitive advantage over the others.

In this regard, some of the grey zones in the regulation may be used to support the deployment of QoE-aware service provision.

4.4 Conclusions

The analysis in this chapter provides answers to RQ2 by understanding the main elements guiding the current discussion on NN in the US and EU market because of their impact and relevance in the telecom market. The results of this study show that the main elements guiding the discussion in both markets focus on basic principles such as blocking and throttling. However, there are differences between US and EU including the market structure, the regulatory interpretation and the competition law, which impacts how the NN rule is interpreted in each case. A difference between the US and EU approaches appears with banning paid-prioritisation. While FCC regulation is clearer and adds non-prioritisation to the NN principles, the EU does not include its prohibition in the NN guidelines and seems to recognise that prioritisation can be used within a scenario of full competition and transparency.

The incorporation of QoE feedback in mobile networks would require mechanisms to capture/collect QoE-related information and the implementation of resource management strategies that make use of the captured data in order to achieve business goals. Regarding the customers' data and its use with commercial purposes, both US and EU regulations rely on consumer protection laws defined for each country/region. In both cases, what prevails is the role of transparency in the telecom ecosystem. Regulators indicate that the information provided by the ISP has to include any measures applied when managing traffic which uses personal data, and how network operators ensure the privacy of end users and protect their personal data when managing traffic. Information should offer a description of the possible impacts of traffic management on users' QoE. In that sense, collection and use of QoE related information needs to consider the described aspects.

On the implementation of QoE-based resource management policies, FCC regulation reduces the alternatives for traffic prioritisation to those that guarantee the normal operation of the network and not business purposes. This approach may close the door to any potential creation of fast-lanes or the definition of QoE-based lanes in the network infrastructure. When looking at the EU regulatory framework, paid prioritisation is not strictly forbidden, which combined with an adequate implementation of full transparency principles in the commercial offer may offer less regulatory barriers for the implementation of QoE-based service provision and categorisation.

Another scenario to guarantee the incorporation of QoE feedback in mobile networks and the development of new business models based on QoE is specialised services. In both regulatory scenarios, this type of service is exempted from the NN rules because they have limited purpose and do not provide access to the Internet. An important consideration when deploying specialised services is the evaluation of QoS parameters that shows it is possible to guarantee the operation of both the specialised services and Internet access service.

An alternative that has been considered by MNO as a revenue stream is establishing alliances with OTT players by offering zero-rating. In this scenario, the segmentation/prioritisation is not directly implemented at the network level but at business and market levels by applying zero-rating to traffic of a particular application or type of applications. In both regulatory scenarios, a case by case approach is used to evaluate the commercial offers and allow the implementation of zero-rating offers.

Chapter 5

Business analysis of the incorporation of QoE feedback in Mobile Networks

In this chapter, we discuss RQ3: *How can QoE feedback impact mobile operators' service provision at the business level?* Specifically, we focus on how the incorporation of QoE feedback affects the mobile network ecosystem and its value configuration. The majority of academic research on QoE and its business implications explores problems related to QoE-based SLA, QoE-based charging, and end users' willingness to pay. However, focusing on charging or contractual issues is not enough to explain the business effects of using QoE in mobile networks. Therefore, it is necessary to explore how the incorporation of QoE feedback might impact mobile networks' value configuration in distinct deployment scenarios and under different regulatory conditions.

To analyse the impact of incorporating QoE in mobile networks at the business level, we have used the scenario planning method and value network configuration (VNC) analysis. With scenario planning, we can identify trends and uncertainties in the development of mobile networks with regard to the incorporation of QoE while describing the alternatives the mobile network ecosystem might face with this technical development. The scenario analysis considers the role of NN regulation on the business alternatives within the mobile network scenarios. The considered scenarios give boundaries to how the value network could configure around QoE incorporation and give a rough idea of the power positions of the relevant actors. VNC is used to describe how the value configuration is affected under the different scenarios and provide insights on potential business ideas with QoE feedback incorporation.

5.1 Research on QoE at the Business Level

Academic research recognises the potential of using QoE to improve the mobile network business. According to Aznar et al. [48], the integration of QoE in the value chain of mobile actors might be a mechanism to increase telco revenues. In the same vein, Perkis [47] acknowledges that '*the change of paradigm towards QoE has consequences for corresponding economic and business models in the telecommunications market*'. In that sense, different research efforts have analysed the implications of QoE at the business level. The main focus has been on areas such as CEM, QoE-based SLA, QoE-based charging and end users' willingness to pay.

Stojanovic et al. [134] pointed out that the '*development and implementation of QoE-aware business models and the definition of appropriate SLA is needed when addressing the QoE management issues*'.On the other hand, Frangoudis et al. [135] proposed an SLA selection framework that incorporates the desired user's QoE considering budget constraints. Authors demonstrated its application in a cloud-based teleconferencing service without considering how the framework will impact the telco market.

Varela et al. [136] argued that the '*introduction of Experience Level Agreements (ELA) based on QoE would provide a key step towards being able to sell service quality to the user*'. The authors investigated alternatives to exploit QoE for improving SLA and discussed challenges and problems of the proposed approach. In the same paper, Varela et al. remarked on the need for applying QoE in the networks and services operation. So far, SLAs do not deal with QoE by users, which limits the possibilities for the market actors to create business models and revenue streams based on providing a minimum/differentiated QoE. According to Varela et al., challenges for achieving the goal of ELA include the definition of a structured framework that includes the ELA definition. On the other hand, more research is required on the evaluation of the marketing side and the structure of a QoE-based service offer. Finally, Fiedler [20] expressed that besides devising QoE-based SLA, QoE area needs to explore new domains such as Internet of Things (IoT) and business-to-business (B2B) communications exploring the QoE implications in monetary values.

On the relation between QoE and charging, Sackl et al. [137] recognised the fact that QoE-based charging mechanisms are needed. However, it is necessary to examine with more detail the interrelation of payment and quality perception. Sackl et al. also argued that 'QoE may serve as a principal tool for investigating the customers' service satisfaction which may on economic terms be related to customers' loyalty and their willingness to purchase network products' [137].

Wahlmueller et al. [26] proposed a pricing mechanism based on quality differentiation (i.e., QoE). Reichl et al. [138] described the conceptual relationship between QoE and charging. In their paper, Reichl et al. addressed the question of how to charge for QoE and provided an initial indication that a stronger focus on user perceived quality might also change the perspective on charging mechanisms. Zwickl et al. [139] developed an empirical study to measure the users' willingness-to-pay for

high definition (HD) and video on demand (VoD) services. The study focused on market entrance pricing strategies linked to the differentiation in content delivery. Finally, Nesse et al. [25] explored the service differentiation aspect and presented a model that shows that introduction of end-to-end differentiated services can bring substantial benefits to ISPs and demanding users, while preserving the quality of basic services. However, the use of the model requires further market considerations.

In general, the research on QoE at the business level considers there is potential to leverage new revenue streams and business models by implementing QoE-based differentiation. However, and as remarked by Varela [20], mobile actors need to adapt their structure not only to make money by offering differentiation but also by internalising the required adjustments to make this new approach possible in service provision. Even though current research has addressed the analysis of some of the business implications of using QoE in the mobile networks, the studies have mainly focused on a generic business analysis without considering the definition of a technical mechanism to incorporate QoE feedback in the operation of mobile networks. In addition, the business considerations of these studies do not include regulatory elements in the analysis of QoE in the context of mobile networks.

In that sense, our research adopts a technical mechanism to incorporate QoE in mobile networks and gives insights into its impact on mobile operators' business model. The business analysis is supported both in the construction of potential implementation scenarios for the incorporation of QoE and the value network analysis of each one of the proposed scenarios. Scenarios consider the impact of the regulatory framework on NN, while the VNC analysis applied to the scenarios makes the identification of changes possible in the value creation when QoE is used in mobile networks.

5.2 Theoretical Foundation for Research

This section introduces the theoretical framework used to carry out the business analysis of the impact of incorporating QoE in mobile networks by implementing the technical mechanism proposed in Chapter 3. Tools include scenario planning method and VNC analysis. First, we describe the background of the scenario planning and VNC analysis. Then, we explain how these tools are applied in the context of this dissertation.

Scenario planning is a popular tool used in the ICT industry to predict the future outcome through calculated construction of different potential scenarios. In the field of mobile communications and the Internet, several examples can be cited. Karlson et al. et al. [140] constructed four scenarios involving the development of the wireless industry from 2003 to 2015. Ballon [141] developed scenario planning for the future 4G (fourth generation) mobile systems and services in Europe defining major trends and uncertainties. Levä et al. [142] applied scenario planning to identify key trends and evaluate the future of the Internet. Smura and Sorri [143]

constructed four future scenarios describing the wireless local access industry. In all these cases, scenario planning is used as a business tool to test assumptions, future developments, technology incorporation or evolution in order to prepare for an unknown future and help adapt as the future evolves.

Scenario construction is based on the identification of two elements: trends and uncertainties. Trends are framed by the industry knowledge about the future. Uncertainties are elements whose outcomes are not very predictable. By analysing the interaction among trends, uncertainties and organisation structures, the scenarios provide new ideas for a planning stage. In this thesis, we use Schoemaker's method of scenario planning [59].

Each scenario is analysed in more detail with the help of VNC. Value network, as stated by Wang et al. [144], '*does not focus on the company or the industry, but on the value creating system itself, within which different network actors-supplier, partners, allies, and customers-work together to co-produce the customer value*'. According to Allee [145], a value network is defined as '*any purposeful group of people or organizations creating social and economic good through complex dynamic exchanges of tangible and intangible value*'. Value network analysis gives a solid foundation for the two-sided market analysis, because it shows graphically the stakeholders and the value exchanges between them. Casey et al. [60] defined a value network as '*a set of interlinked (business) actors and technical (or more generically functional) resources that work together to create economic value through services and products*'. Hence, by understanding relationships between network members, it is possible to understand the network business structure and dynamics for value co-creation.

Casey et al. [60] introduced VNC as a tool for performing value network analysis. It is a visual way of representing the relationship between the stakeholders (actors) in an industry by mapping together the value network and technical architecture of a value creation activity. According to Casey et al., '*VNC allows for easy mapping of deployment actions to actors and comparison of the different VNCs that can form from the same underlying technical architecture while considering the business implications of a technical solution*'.

For the purpose of this dissertation, scenario planning describes the conditions affecting the value network and its stakeholders. Conditions include the trends and uncertainties faced by the market, and a rough idea of the power positions of the relevant actors. Then, building the VNC allows for a more granular analysis of each one of the considered scenarios by identifying the roles that arise around the technical components, assigning these roles to the actors and making explicit the emerging business interfaces between the actors (e.g., contracts and monetary exchanges).

The combination of scenario planning and VNC analysis can facilitate the identification of the business implications of incorporating QoE in the operation of mobile networks. On the one hand, it provides a description of the evolution paths for QoE incorporation considering the effect of NN regulation and the market evolution. On the other hand, it facilitates the recognition of business opportunities

within each one of the proposed scenarios.

5.3 Analysis of Scenarios for the Incorporation of QoE Feedback in Mobile Networks

We analyse the effect of incorporating QoE feedback in mobile networks at the business level using scenario planning. This method is used to analyse the key uncertainties affecting the mobile networks and the business models when incorporating QoE in mobile networks. Then, we analyse the possible VNC that could arise in the proposed scenarios. VNC further investigates the different possible evolution paths that might be considered for potential new business models.

5.3.1 Key Trends and Uncertainties

In order to get insights on the trends and uncertainties affecting the incorporation of QoE feedback in mobile networks, we organised a half-day workshop with representatives from the mobile industry. The experts represented Telia, Tele2, Edgeware, PTS (Swedish Post and Telecom Authority), Ericsson and NTK (the Swedish Telecom Users Association). The workshop included business developers and technology and regulatory experts. The workshop was structured into a brainstorming session on trends and uncertainties. The brainstorming session was followed by a group discussion.

The participants listed their ideas, introduced and explain their inputs on trend and uncertainties. Each session ended with the evaluation and prioritisation of trends and uncertainties. After this workshop, we conducted semi-structured interviews with industry experts to discuss in more detail the identified uncertainties and trends. The interviewees were also asked about the role that QoE plays for them in the industry and the challenges the industry faces on that matter. Groups of interviewees included both participants in the workshop and a new group of experts invited after the workshop. Interviews and workshop recordings and discussion material constitute data for the scenario construction.

Based on the collected data, we identified 8 major trends that might affect the incorporation of QoE feedback in mobile networks.

- **Trend 1.** Mobile traffic will continue growing. According to Cisco [2] 'mobile data traffic will increase eight-fold between 2015 and 2020, reaching 30.6 EB per month by 2020'. This traffic growth will be driven by digital TV, gaming content and social networking.
- **Trend 2.** The number of online devices continues growing as the use of mobile/smart devices expands. This phenomenon is linked to the popularity of IoT and growing popularity of wearable devices.
- **Trend 3.** Telecommunications companies will continue looking for business opportunities to increase their revenues. This situation requires not only

focusing on their core business but also requires new products and services that are enabled by these core businesses. Personalisation/customisation and content differentiation are part of the new offers. Consumers want to feel valued as unique individuals, with companies taking special care of their ideas, thoughts and demands.

- **Trend 4.** Telecom market will face a continued increase in alliances and partnerships. This phenomenon will help mobile ecosystem actors to expand their market, generate new business models and speed time-to-market while reducing risks and investments. There also remains an opportunity for cross-sector merger and acquisitions (e.g., telecom + media, telecom + tech) as a way to generate some competitive advantages.

- **Trend 5.** Development of more personalized services that make everything more convenient and efficient for consumers. Privacy protection is a key issue for this trend.

- **Trend 6.** Network performance improvements offering better QoS indicators. The emergence of fifth generation mobile networks (5G) represents this trend.

- **Trend 7.** Mobile industry actors changing from a growth model to a value-added strategy. This trend needs to be aligned with the development of strategies oriented to differentiate from competitors and the creation of strategies to attract and retain customers.

- **Trend 8.** Growth in the traffic from the mobile to the cloud due to the rise of wearable technology and cross platform apps. This trend means telecom actors can implement Big Data analytics to get a better understanding of users' profiles. On the other hand, there will be more cloud offerings which will make it easier for the consumer to pick and choose their provider independently of the network infrastructure provider.

We also identified 5 key uncertainties:

- **Uncertainty 1.** Regulatory environment on NN. For MNOs, current NN guidelines create uncertainties affecting their next steps and investments. On the one hand, strict regulation can limit their chances to offer services or content with differentiated levels of QoE.

- **Uncertainty 2.** OTT providers and MNO relationship. Linked to the regulatory view on NN, there are on-going discussions on the role of regulation before the OTT providers and the need for including these actors under the same rules as normal telecom services. On the other hand, the regulatory approach can also affect the way alliances/partnerships between MNO and OTT providers are set.

- **Uncertainty 3.** Mobile networks' industry structure. Mobile industry and the business models may be oriented towards a vertical structure scenario (i.e., MNO offers access and content service together) or a horizontal scenario (i.e., access and content service separated). Mobile structure and the possibility of setting alliances between different actors is impacted by the regulatory framework.

- **Uncertainty 4.** QoE management and customers' relationship handling. Mechanisms to manage users' QoE, administrate the resources and collect customers' feedback can be implemented at the MNO or OTT level. However, where to deploy a QoE-aware mechanism to incorporate users' feedback will depend on decisions on NN, and the type of agreement OTT and MNO actors can reach in light of the regulatory framework.

- **Uncertainty 5.** Impact on the level of MNO-OTT competition: MNO have more control on the networks' resources management but the OTT providers are responsible for the content running on the networks. Even though these two activities can be seen as complimentary, MNOs do not want to be type casted as a dumb-pipe.

5.3.2 Scenario Construction

The next step in our analysis is to cross in a scenario matrix the two most important uncertainties. This was achieved by analysing interviews and identifying the impact of uncertainties on the issue of interest (QoE feedback incorporation). The first uncertainty is whether there will be a strict or liberal regulation on NN. The implementation of QoE-aware architecture and the use of users' feedback in service provision will evolve around it. The second most important uncertainty is about who is responsible for QoE incorporation: the MNO or the OTT provider? This aspect can impact the mobile networks' industry structure, the relation between MNO-OTT and the level of competition between these two actors.

Combination of uncertainties bring different scenarios, with specific characteristics and outcomes. We defined one scenario for scenario matrix quadrant. The scenario matrix and the scenario names are presented in Figure 5.1, and described below.

5.3.2.1 Scenario 1: QoE incorporation led by MNO in a strict NN scenario

In this scenario, the QoE incorporation mechanism resides with the MNO. The regulator has set strict rules on NN that do not allow any kind of commercial agreement to favour one OTT provider over the others. In the same vein, MNO cannot work on commercial offers based on content segmentation/classification that require throttling, blocking or content prioritisation. Network operation is based on

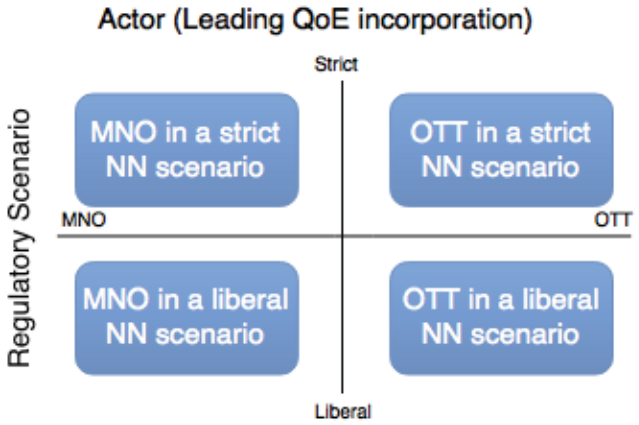


Figure 5.1: Scenario Matrix

the best-effort principles and the regulator only allows the implementation of 'reasonable' resource management principles (e.g., radio resource management, routing policies at the core network) to allow for network operation. This network practice must be primarily used for network management and not for business purposes. Users pay for mobile broadband data plans based on capacity. Users have one MNO contract and many business relationships with different OTT providers.

As long as the user authorises it, MNO can implement a mechanism to monitor the network operation as well as keep track of the users' experience with the service provision, collecting information from the users' devices.

5.3.2.2 Scenario 2: QoE incorporation led by OTT provider in a strict NN scenario

Within a strict NN scenario, the OTT provider acts as content distributor and the MNO as a pipeline. MNO cannot engage in 'paid prioritisation' practices. Network management mechanisms are allowed only with technical purposes, not commercial ones. Disclosure of network management practices to consumers is required. However, the OTT can implement mechanisms to improve the quality of the content received by the customers (e.g., compression mechanism, pre-buffering, etc.).

The OTT provider, with the authorisation of the end user, monitors the quality perceived by the users on the content provided. However, the gathered information cannot be used to implement network management mechanism oriented to prioritise any type of content.

5.3.2.3 Scenario 3: QoE incorporation led by MNO in a liberal NN scenario

In the third scenario, the market is self-regulated. MNO can offer differentiated services based on monitoring users' QoE and their expectations. Zero-rating and specialised services can be developed with no regulatory restrictions. This scenario includes commercial agreements between MNOs and OTT providers to offer fast lanes and activate paid prioritisation. Therefore, MNO might generate new revenue streams by favouring OTT providers/type of content over others. On the other hand, MNO can offer QoE-differentiated services, contents and charge customers for this differentiation.

Resource management policies are implemented considering both the technical performance and the commercial goals of the MNO. Users have the opportunity to pay for QoE-differentiated services and content adjusted to their requirements and needs, not only attached to a data capacity plan. MNO uses monitors and captures QoE data from end users' devices and uses this information to implement mechanisms to manage/prioritise traffic as the basis of its commercial offers. MNO has the opportunity to share with or sell to OTT providers the QoE data captured using the monitoring tool. In addition, MNO has the possibility to segment its customer base according to the expected QoE, the type of content or the priority users want to pay for.

5.3.2.4 Scenario 4: QoE incorporation led by OTT provider in a liberal NN scenario

The fourth scenario is similar to the third scenario. However, the incorporation of QoE is led by the OTT provider. This means the OTT provider monitors and captures QoE data and implements quality provision mechanisms. The OTT provider has the possibility of implementing commercial agreements with MNO in order to receive priority to access the network infrastructure. These agreements also allow the OTT provider to gain access to network performance indicators and act accordingly offering better QoE to final users. MNOs should ask the OTT provider for access to users' profiles and QoE data in order to implement resource management policies in their network infrastructure.

By incorporating QoE feedback, the OTT provider might allow for cooperative work with the MNO in order to generate improvements in the services offered both at the MNO and the OTT levels. OTT providers can also charge for subscription and for quality level.

5.4 Value Network Analysis of Proposed Scenarios

After defining the scenarios, we describe them in terms of possible VNC between the key stakeholders. While scenario planning sets the scene on the general considerations (trends and uncertainties) affecting the value creation, VNC allows a

granular analysis on how the conditions of each scenario affect the value configuration. VNC analysis enables the identification of the actors in the ecosystem and the roles they can play around the technical mechanism proposed to incorporate QoE feedback in mobile networks,. In the same line, VNC analysis makes possible the identification of emerging business interfaces between the involved actors while providing insights on potential business ideas generated with the incorporation of QoE feedback by implementing the technical mechanism proposed in Chapter 3. As mentioned in the methodology section, we consider VNC approach by Casey et al. [60]. According to the authors, VNC is used to describe how actors perform a role and use a technical resource to generate value. Within this configuration, the considered actors establish technical and business interfaces with each other.

We begin the VNC analysis by introducing the roles identified when examining the architecture proposed in Chapter 3 to incorporate QoE in mobile networks, with the help of the discussion and findings from the interviews and workshops. Next, we describe four different VNCs, according to each identified scenario. Together with the identification of the roles fulfilled by each actor in the value network, we include the identification of the key resources needed, the perceived advantages and disadvantages of value network actors and the value exchanges between actors. As a mechanism to structure the description of each VNC, the business model ontology proposed by Osterwalder [146] is used in this section. The business model definition by Osterwalder contains the following elements:

- **Product (Value Proposition):** What business the company is in, the products and the value propositions offered to the market.
- **Customer Interface:** Who the company's target customers are, how it delivers them products and services, and how it builds a strong relationships with them.
- **Infrastructure Management:** How the company efficiently performs infrastructural or logistical issues, with whom, and as what kind of partners.
- **Financial Aspects:** What is the revenue model, the cost structure and the business model's sustainability.

Regarding the VNC analysis, it is important to consider the different roles/activities assumed by the actors in the value network. As QoE information could be utilised in multiple use cases, the VNC does not focus on a specific core service, but rather at how the building blocks (the roles and their technical components in the VNC) could be arranged in the market and what conclusions may be drawn. This assumption does not alter or limit the roles that need to be fulfilled in order to deliver any type of service using the QoE information captured with the technical solution proposed in Chapter 3. The technical components in each role may need some changes depending on the actor implementing the QoE incorporation (for example, software/hardware elements to implement the solution), but the roles and their allocation to actors would remain with no changes.

Consequently, the main roles that need to be fulfilled by the different actors in the value network are listed below:

- **Application/content provisioning**. This role is related to the provision of application functionality and associated services/content over the network to the end user. The applications would typically have both server and client parts, with an application running in the users' terminal and the server facilities providing content requested by the users.
- **Wireless Access Network (WAN) Operation**. This role covers maintaining and operating the access and core network infrastructure. It also includes the connectivity provision to the end user.
- **Usage**. This role denotes the consumption of the mobile services and applications.

Based on these main roles, a generic role configuration can be constructed. This is presented in Figure 5.2. Each oval represents a technical component, while the red lines between the technical components show the technical interfaces as well as the functional protocols of the technologies used in the technical components. The black lines represent the business interface between the actors, such as contracts and monetary exchanges.

This first configuration shows a basic scenario where the MNO provides broadband wireless access to end users. This typically includes a direct contractual relationship with the end user including the definition of the terms and conditions of the service (e.g., price, data plan). In this basic scenario, the MNO owns the network infrastructure and the main revenue source comes from the connectivity services charged to the users. Costs associated with the network operation are assumed by the MNO. Another cost associated with the business operation, but not associated with the network management, comes from marketing operations, implementation of billing systems and customer support operations. The MNO's user can be either individual users or business organisations with different requirements on network performance, coverage and prices.

Various OTT providers have gradually expanded their position in the value network thanks to the growing popularity of OTT services. In some cases, beyond content distribution, OTT providers have developed services that compete directly with some of the traditional services offered by MNO (e.g., Voice transmission, SMS) which have impacted the revenue of traditional MNO. Main revenue sources are subscription fees for access to their content/services, usage fees, marketing agreements with different companies to advertise their services and products.

Users have a contractual relationship with the OTT provider, which does not necessarily imply a money exchange. When the service is offered for free, there is an exchange of intangible value in both directions; the user gains value by using the service and the OTT provider may find value in having the users' attention, profiling the users or understanding their behaviour. Both users and OTT providers depend

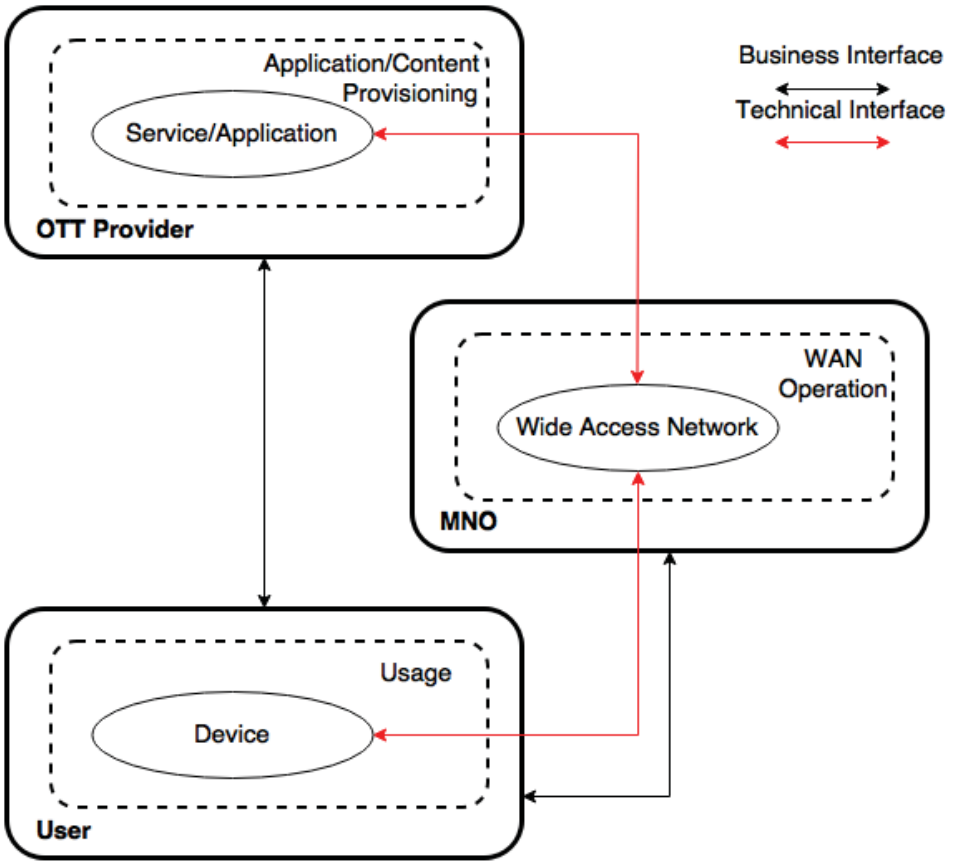


Figure 5.2: Generic Role Configuration for Mobile Network Operation.

on the availability of the network infrastructure to guarantee their value exchange. It is also important to remark on the important role that OTT providers play in the value network, since the increase in the number of mobile users and connections is linked to the growing number of OTT applications and services, as reported by Ericsson [147] and Cisco [2]. OTT provider's costs come from the deployment and administration of the infrastructure to store content and distribute it to the end users.

Apart from the main roles, which are part of the mobile networks' VNC, two additional roles are identified, relating to the incorporation of QoE in the mobile network operation and the role that regulatory framework plays in the considered scenarios. These new roles are:

- **Regulation definition**. This role covers the regulatory activities and poli-

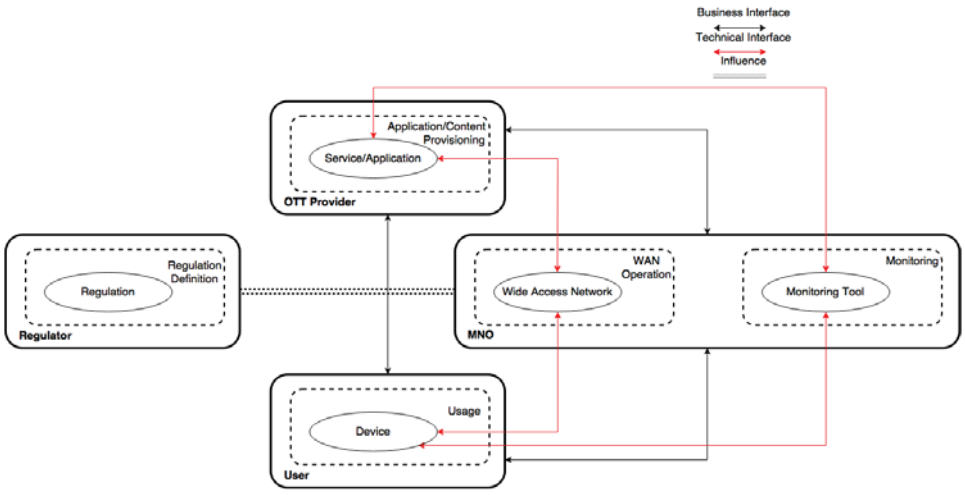


Figure 5.3: VNC for Scenario 1 (QoE incorporation led by MNO in a strict NN scenario).

cies that may affect the way different actors exercise their roles in the value network.

- **Quality provision**. This role covers all the activities required for incorporating QoE feedback in the operation of the mobile networks' service provision, and the actions that can be taken to offer differentiated services, for instance, traffic management/prioritisation actions.

- **Monitoring**. This role is related to the activities required to capture QoE data on apps, network and end users.

In the following, we describe four different VNCs that could emerge around QoE incorporation. The essential differentiating factor between the VNCs are both the actor controlling the QoE incorporation and the regulatory framework on NN. Each VNC is driven by changes in importance of the actors and their corresponding role.

5.4.1 VNC and Business Analysis for Scenario 1 (QoE incorporation led by MNO in a strict NN scenario)

5.4.1.1 Product (Value Proposition)

As illustrated in the VNC, Figure 5.3, the MNO and the OTT keep the business interfaces formed with the end users. On the one hand, the MNO provides ubiquitous communication services (physical connectivity) to end users, giving them access to their network and different content/application services. End users pay

for this access with a subscription/usage fee determined by data capacity. With the use of QoE data, MNO can get a better understanding of the users' interests and profiles, the usage of applications and the impact of network performance on QoE. This information can be used by MNO in the network improvements (coverage and capacity) to offer users non-disrupted and fast access to their favourite applications/contents.

On the other hand, the OTT provider offers different application related services and relevant data and information products, such as news, music, video, and distributes them using the mobile channel. In this scenario the business interface between the OTT and the user may or may not involve money exchange, since the user gains value by using the service and the OTT may find value by having the user's attention, and offering its platform for marketing operations.

A business interface can be created between the MNO and the OTT provider based on the exchange of collected QoE data by the MNO. Information on network performance, patterns of usage and trends may be of interest for OTT providers interested in both improving their commercial relationship with the end users by knowing more about them and improving the applications and content use of network resources to reach their customers.

5.4.1.2 Customer Interface

Within Scenario 1, the value proposition of MNO and OTT providers can be directed to the traditional segments: consumers and business. Segments based on data plans or price continue to be implemented. However, the accuracy of the gathered information by MNO can improve the scope of the offers aiming at more granularity within the broad group of users. OTT providers get similar benefits, which are complemented with the knowledge they can capture on network performance and its effect on the usage of the applications. An alternative would be the categorisation of the users according to their level of consumption, by volume or time. For the business market, QoE differentiation might target premium corporate users targeting not only the standard quality requirements but the specific business considerations regarding security, reliability and stability during critical business sessions.

MNO benefits from a closer relationship with the user, through an efficient use of the collected QoE data. The operator can establish relationships with its customers through a price plan based on the identification of consumption trends and app usage patterns and build this relation with direct communication about their interest in the service provision and the service quality perceived.

With regard to how the MNO communicates the value proposition to the customers, this would happen through MNO's retail network, web platform and through partners' channels. An additional channel can be the through stronger presence in social networks and media. On the other hand, content providers can reach their customers using their web channels as well as using partners' ecosystem.

5.4.1.3 Infrastructure Management

In this VNC, illustrated in Figure 5.3, the MNO leads the incorporation of QoE in the operation of mobile infrastructure. In addition to the WAN operation role, the MNO undertakes the monitoring role to capture QoE-related data as long as the MNO and the end users sign a transparency agreement, where end users authorise the MNO to collect apps/user data and use this data for commercial purposes. The monitoring tool is a software app with the capacity to collect data from the terminal on application/end user and network performance and report. Its development may be the responsibility of the MNO, an independent software developer, or the result of an alliance between OTT provider and MNO with a common purpose. Therefore, software development resources (e.g., platform, developers) are required by the MNO to implement the monitoring tool.

The importance of the monitoring role here is directly dependent on the use of the collected information. On the one hand, MNO can use the QoE data to improve both the network and business operation. Network operation improvements can be guided by a better understanding of the use of network resources which can lead to capacity and coverage expansions. At the business level, the use of QoE data can be used to get a better understanding of users' demands and expectations, so that the MNO can structure its commercial offers. On the other hand, MNO could sell the collected information to those OTT providers interested in getting more insight on the users' QoE/application performance/network performance. Due to the restrictions on NN, the MNO cannot use the QoE data to offer services based on paid prioritisation. However, the offer of specialised services or zero-rating plans may take advantage of the collected information, which can drive the way these commercial offers are structured. Regulators in this case are responsible for studying the legal feasibility of the commercial offers proposed by the MNO or its associates.

Meanwhile the OTT provider keeps its role as application/content provider, impacting the use of the MNO infrastructure with the content generated by different types of applications demanded by the end users. OTT is benefited by the network improvements driven by the use of QoE data and implemented by the MNO. Access to the monitoring information can generate additional benefits for the OTT provider, which can use the obtained data to improve the application operation and the content distribution. Data obtained through the monitoring tool can include content/application use of resources, trends on apps and content consumption and patterns of usage by the application. End users (private and corporate) consume the content provided the OTT provider and continue using the MNO's infrastructure. With the expansion in the capacity and coverage of the network, and the improvements in the applications/services performance, the end users can obtain improvements in their QoE.

5.4.1.4 Financial Aspects

The MNO operator will typically have costs related to the deployment and operation of its infrastructure. By assuming the monitoring role in the Value Network, the MNO has to assume the costs associated with developing and running the monitoring tool. This includes the development of a software platform and the human resources required to create and operate the monitoring system. In addition to these costs, MNO assumes the costs of the billing system, the administration of its customer base and the activities of marketing and support linked to the service offer.

From the OTT provider perspective, costs are linked to the application/content development, the integration and application management (versioning, portability checking), the operation of the required infrastructure for its operation, as well as the investments on technical/customer support and consulting services. With the implementation of the monitoring by the MNO, the OTT providers may need to access the collected information, which also generates a cost for the OTT provider.

Regarding revenue streams, MNO continues with revenues attached to subscription fees. In addition, the use of QoE data can create a new revenue stream, by commercialising the collected information for OTT providers or other businesses interested in a closer relationship with the end user. It might be possible to generate revenues by charging fees for ads in content or for charging the content/service provider to guarantee users' access to their services even when 'there are no bits in the bucket' or zero-rating. However, this case needs to be studied in light of the regulatory framework. Meanwhile, OTT provider does not experience a change in the traditional revenue streams.

5.4.2 VNC and Business Analysis for Scenario 2 (QoE incorporation led by OTT provider in a strict NN scenario)

5.4.2.1 Product (Value Proposition)

In scenario 2, business interfaces towards the end-user remain intact, as illustrated in Figure 5.4. The MNO continues providing ubiquitous communication services (physical connectivity) to end users, giving them access to their network while making it possible for the end user to enjoy the different content/application services of their interest. On the other hand, the OTT provider offers different application related services and relevant data and information products, such as news, music, video, while using the mobile channel to distribute them among the end users.

With the monitoring tool, OTT can have more details on users' QoE, trends and patterns of consumption, which can be used to offer content/applications based on the specific customer demands. For instance, the quality of the content (e.g., video resolution) can be adapted according to the users' terminal considering screen size, light conditions, proximity to the end of the data cap, or the users' location

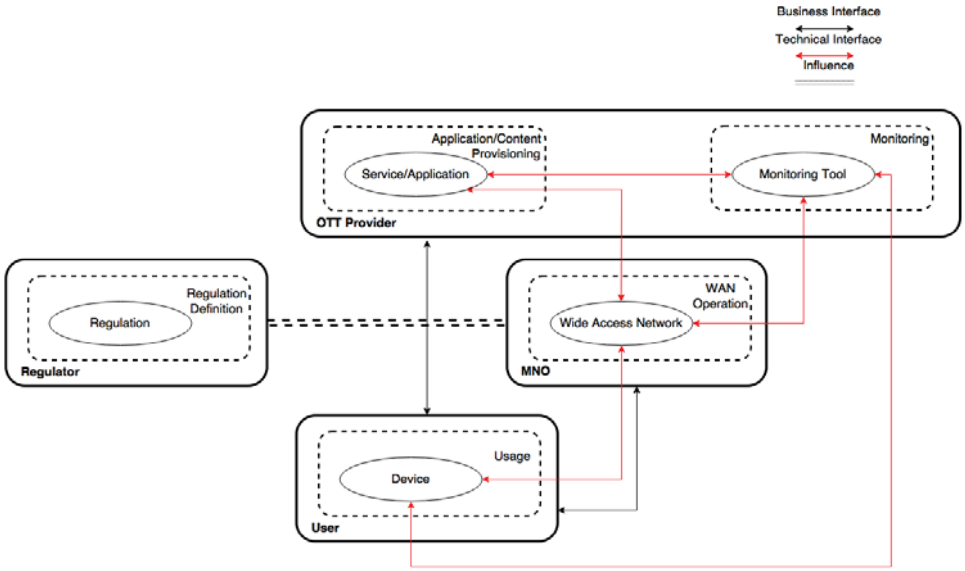


Figure 5.4: VNC for Scenario 2 (QoE incorporation led by OTT provider in a strict NN scenario).

and type of network connection. In this scenario, the business interface between the OTT and the user may or may not involve money exchange, and the grade of service personalisation can lead to different price schemes/segments. Another revenue source for the OTT provider is the commercialisation of collected information. Some of the OTT provider's customers can find value on a high granularity level in the customers' information in order to structure commercial offers of high interest for users due to matching the commercial offer with the users' interests.

5.4.2.2 Customer Interface

Within Scenario 2, the value proposition of MNO and OTT providers can be directed to the traditional segments: consumers and business. Segments based on data plans or price continue to be implemented. However, the OTT can also have business alternatives by commercialising the collected QoE data to MNOs interested in using the information to improve their network performance and to other commercial companies interested in reaching end users with their services and products.

The OTT provider can apply its knowledge on end users' interest and profiles to deepen their segmentation/categorisation according to type of content consumed, levels of consumption, their interest on high or standard content quality. For the business market, QoE differentiation might target premium corporate users focusing

not only on the standard quality requirements but specifically security, reliability and stability during critical business sessions.

The OTT provider benefits from a closer relationship with the user, through efficient use of the collected QoE data. The OTT provider can establish relationships with its customers through a price plan based on the identification of consumption trends and app usage patterns and build this relation with communities via direct communication about their interest in the service provision and the service quality perceived.

With regard to how the OTT provider communicates the value proposition to the customers, this would happen through the web platform and through partners' channels, which can be MNOs paying for access to the information captured with the monitoring tool. An additional channel can be the through stronger presence on social networks and media. On the other hand, MNO can reach their customers using their traditional retailers and channels such as web channels.

5.4.2.3 Infrastructure Management

In this scenario, we examine a VNC where the monitoring role is assigned to the OTT provider, instead of the MNO. Therefore, the OTT provider captures the QoE-related data with no intervention by the MNO. The VNC for scenario 2 is presented in Figure 5.4.

Scenario 2 is characterised by the strict regulation on NN which affects most possibilities of the MNO to develop business alternatives based on traffic management and prioritisation. In contrast, OTT providers do not see strong limitations on their commercial alternatives since they are the engine behind the virtuous cycle, as stated by the FCC [99]. Exceptions can cover zero-rating or other commercial alliances with the MNO. Besides the monitoring role, the OTT provider maintains its role as application/content provider, impacting the MNO and its WAN operation role. By implementing the monitoring role, the OTT provider increases its awareness of the end users' patterns of usage and data consumption, which can be used in both a granular profiling aiming at commercial goals and the improvement in the use of network resources by the content/applications developed by the OTT provider.

Gathered information can be added to the users' profile data already collected by the OTT provider increasing the commercial value of this information in the transactions with other organisations. End users are required to sign a transparency agreement, where they authorise the OTT to collect apps/user data and use it for commercial purposes. As described above, the monitoring tool is a software app with the capacity to collect data from the terminal on application/end user and network performance. The OTT provider may develop the software tool or hire an independent software developer.

OTT provider can use the QoE data to improve the use of network resources, for instance less bandwidth requirements, and get more insights on user behaviour, which may result in more personalised/customised offers with commercial benefits.

The OTT provider can develop the monitoring tool for its own benefit, collecting data strictly related to its content/application, or can develop a generic tool with the potential to collect other OTT providers' data. In this last case, through a commercial agreement the monitoring tool developer can sell the required data to the interested stakeholders.

Meanwhile the MNO continues operating the network assuming a pipe-line role, with no direct use of the QoE data in its commercial strategies. With OTT providers playing a central role in the Value Network, the growing trend on content/application demand is expected to continue, which forces the MNO to keep investing on network capacity to respond to the demand for more content. Therefore, MNO will continue facing a situation similar to the current one: high demand on network resources and quality but few revenue stream alternatives. However, zero-rating packages can be offered as a result of MNO/OTT provider alliances. In this case, the regulator continues with the role of evaluating and defining the legal feasibility of such commercial offers. Finally, in Scenario 2, the end users (private and corporate) are expected to have a closer relationship with OTT providers due to the increase in the level of customisation/personalisation in the services offered. End users continue with their usage role, consuming the content/applications provided by the OTT provider while using the MNO's infrastructure by paying a subscription fee.

5.4.2.4 Financial Aspects

From the OTT provider's perspective, costs are linked to the application/content development, the integration and application management (versioning, portability checking), the operation of the required infrastructure for its operation, as well as the investments in technical/customer support and consulting services. By assuming the monitoring role, the OTT provider assumes the cost of developing and running the monitoring tool. In addition to these costs, the OTT provider assumes the costs of the billing system, the administration of its customer base and the activities of marketing and support linked to the service offer.

On the other hand, the MNO costs are associated with the deployment and operation of its infrastructure. Other costs for the MNO include the billing system, the administration of its customer base, marketing and customer support. In addition, MNO could incur additional costs associated with buying QoE data for improving its network operation from the OTT provider.

Regarding revenue streams, in addition to the traditional OTT provider's revenue streams (e.g., subscription fees, advertisement), the OTT provider can sell QoE data to those MNOs interested in improving network performance. QoE data may also be sold to other companies interested in getting a closer understanding of users' profiles to reach them with commercial products and services. Meanwhile, the MNO continues with revenues attached to subscription fees. It might be possible to generate revenues by charging fees for ads in content or for charging the content/service provider to guarantee users' access to their services even when

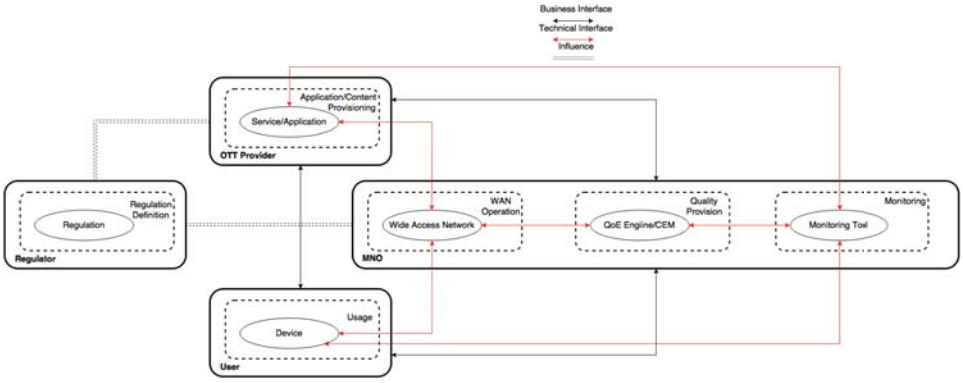


Figure 5.5: VNC for Scenario 3 (QoE incorporation led by MNO in a liberal NN scenario).

'there are no bits in the bucket' or zero-rating. However, this case needs to be studied in light of the regulatory framework.

5.4.3 VNC and Business Analysis for Scenario 3 (QoE incorporation led by MNO in a liberal NN scenario)

5.4.3.1 Product (Value Proposition)

As presented in Figure 5.5, the MNO and the OTT providers keep the business inter- faces formed with the end users, which implies a transaction between the end user and the MNO based on the use of the network capacity as a platform to receive and share content/applications. On the other hand, the end user maintains the business interface with the OTT provider based on access to different types of content and services. In addition to the aforementioned business interfaces, a new business channel appears between the OTT provider and the MNO. This business interface represents commercial exchanges based on paid-prioritisation (access to fast-lanes offering better network conditions) and the commercialisation of QoE data obtained through the monitoring tool. Information on network performance, patterns of usage and trends may be of interest for OTT providers who aim to improve their commercial relationship with the end users by knowing more about them and improve the applications and content used by their customers.

With the monitoring tool and assuming the quality provision role, the MNO can get closer to the user's expectations, profiles and demands. This information can be used to offer personalised services, including tailor-made content distribution, adapting the content delivery to the users' demands on favourite applications, a guaranteed throughput level to support the applications, or recommending content features or applications that make better use of the available network resources or the plan paid by the end user. Another revenue source for the MMO can come

from the paid prioritisation schemes, where the MNO can guarantee to special OTT providers fast-lanes and high level network performance (previously stipulated in SLA). In this case, the OTT provider can have exclusive access to more network resources and improve the content distribution/application performance while guaranteeing good users' QoE.

5.4.3.2 Customer Interface

With the possibility to implement traffic management/prioritisation techniques in the network operation, MNO can segment the customer base into different categories (e.g., premium, non-premium users), considering their interest in paying for specific quality levels associated with different types of content. Segments based on data plans or price can be implemented as well. The accuracy of the gathered information by MNO can be used to improve the scope of the offers aiming at more granularity within the broad group of users. For the business market, the differentiation based on QoE might target premium corporate users targeting not only the standard quality requirements but the specific business considerations of security, reliability and stability during critical business sessions.

MNO benefits from a closer relationship with the user, through an efficient use of the collected QoE data. The operator can establish relationships with its customers through a price plan based on the identification of consumption trends and app usage patterns and build this relation with direct communication about their interest in the service provision and the service quality perceived.

With regard to how the MNO communicates the value proposition to the customers, this would happen through MNO's retail network, web platform and through partners' channels. An additional channel can be through stronger presence on social networks and media. On the other hand, content providers can reach their customers using their web channels as well as using partners' ecosystem.

The OTT provider can buy the QoE data captured by the MNO and apply this knowledge on end users' interest and profiles to deepen their segmentation/categorisation according to the type of content consumed, levels of consumption, their interest on high or standard content quality. The OTT provider can establish relationships with its customers through a price plan based on the identification of consumption trends and app usage patterns and build this relation with communities via direct communication about their interest in service provision and the service quality perceived.

5.4.3.3 Infrastructure Management

Scenario 3 represents the incorporation of QoE in the network led by the MNO within a liberal regulatory scenario. This represents low regulatory barriers regarding NN. Therefore, the MNO assumes the roles of operating the network infrastructure, monitoring and quality provision. This last role is supported by the QoE data captured from the users' devices.

Within this scenario, in addition to the implementation of the monitoring tool, the MNO requires deploying a quality provision platform, which includes software/hardware-based solutions to use monitoring data as input in the required traffic management/prioritisation mechanisms to offer QoE-based services. Additionally, MNO requires changes/adjustments on its business/commercial operations in order to centre its offer on a user-centric approach. Using QoE as the basis of the business offer requires an increase in the collaboration and communication between the commercial and technical areas, so area goals need to be aligned. On the other hand, incorporation of QoE requires a closer relation with the user and better understanding of his/her requests and demands, which involves broadening the channels of communication with the user. As in scenarios 1 and 2, a transparency agreement between end user and MNO is required to use gathered information with commercial purposes.

In scenario 3, MNO has no restrictions on implementing traffic management mechanisms with a business purpose (e.g., offer differentiated video qualities according to price plans) and to establish paid prioritisation agreements with OTT providers. Both cases are not banned as long as there is full transparency on the effects and implications of the technical mechanisms implemented in the network and the scope of the paid-prioritisation agreements. In addition, MNO can sell/exchange users' data, including the identified patterns and trends on applications usage, to/with those OTT providers interested on a closer understanding of users' QoE.

Meanwhile OTT providers continue playing the application/content provisioning role using the MNO infrastructure to reach end users. However, the possibility of some OTT providers being favoured by paid-prioritisation agreements with the MNO could make the competition at the OTT level stronger. This type of agreement may close the door for those newcomers working with content whose quality highly depends on network performance and without enough negotiation power with the MNOs. An example of this situation is a start-up interested in offering video solutions. In this situation, regulators may intervene in order to ensure that there are no market distortions.

OTT providers could benefit from the improvements in the network operation thanks to the use of QoE data by the MNO. However, they need to consider that the conditions offered by the MNO regarding the use of the network infrastructure may change. In fact, MNO can use its power to leverage their own content/application solutions. Again, the regulator has to be alert to guarantee open competition and the best interests of the users. On the other hand, OTT providers may benefit from having access to the monitoring information, since they can use the obtained data to improve the application operation and the content distribution. Data obtained through the monitoring tool can include content/application use of resources, trends on apps and content consumption and patterns of usage by the application.

The monitoring role is maximised by the possibility of the MNO using the QoE information in both the network operations and the commercial offers. Network operation improvements can be guided by a better understanding of the use of net-

work resources which can lead to defining traffic management mechanisms oriented to get a smarter use of the network resources based on the identification and use of traffic consumption trends. At the business level, the use of QoE data can be used not only to get a closer understanding on users' demands and expectations, but also as the basis for new business models (e.g., paid prioritisation, differentiated quality and content distribution, commercial exchange of the QoE data) and commercial offers. In this regard, the offer of specialised services or zero-rating plans may take advantage of the collected information, which can drive the way these commercial offers are structured. The regulator in this case is responsible for studying the legal feasibility of the commercial offers proposed by the MNO or its associates.

End users (private and corporate) consume the content provided by the OTT provider and continue using the MNO's infrastructure. With the expansion in the capacity and coverage of the network, and the improvements in the applications/services performance, the end user can obtain improvements in their QoE. In this scenario, where transparency of OTT providers/MNO with end users is a key aspect, the end users with their decisions and choices may shape the market development and motivate some regulatory decisions when necessary.

5.4.3.4 Financial Aspects

The MNO operator will typically have costs related to the deployment and operation of its infrastructure. By assuming the monitoring and quality provision roles, the MNO has to cover the costs associated with developing and running the monitoring tool as well as costs associated with the traffic management/prioritisation in the network. This includes the development of a software platform, the human resources required to create and operate the monitoring system and the quality provision system, the equipment to implement tasks associated with quality provision. In addition to these costs, MNO assumes the costs of the billing system, the administration of its customer base and the activities of marketing and support linked to the services offered.

From the OTT provider's perspective, costs are linked to the application/content development, the integration and application management (versioning, portability checking), the operation of the required infrastructure for its operation, as well as the investments on technical/customer support and consulting services. In addition, the OTT provider may incur costs for fast-lanes after signing paid-prioritisation agreements. In the same way, the OTT provider can buy QoE information in order to improve its relation with the customers.

Regarding revenue streams, MNO continues with revenues attached to a subscription fees. In addition, the use of QoE data can create a new revenue stream by selling QoE data to OTT providers interested in using that type of information. Similarly, MNO can obtain new revenues by charging for prioritisation of content. It might be possible to generate revenues by charging fees for ads in content or for charging the content/service provider to guarantee users' access to their services even when 'there are no bits in the bucket' or zero-rating.

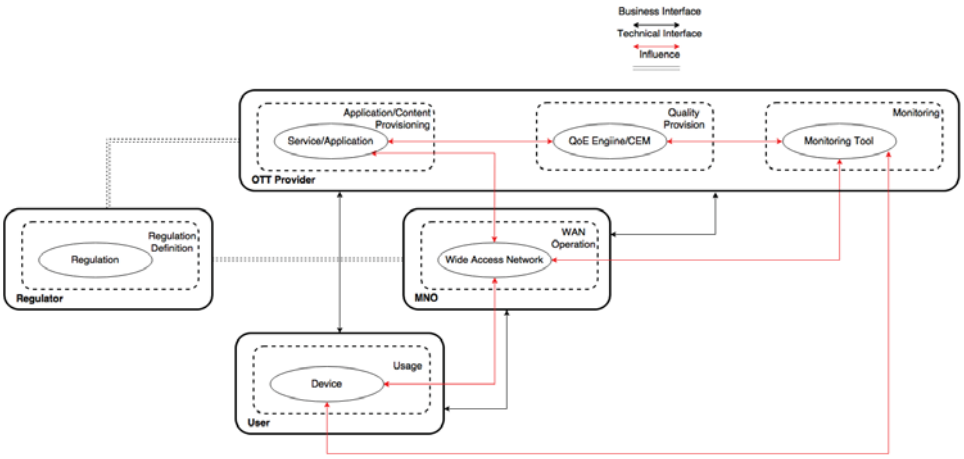


Figure 5.6: VNC for Scenario 4 (QoE incorporation led by OTT provider in a liberal NN scenario).

Meanwhile, the OTT provider does not experience a change in the traditional revenues streams (e.g., subscription fees, advertisement). However, it can improve its commercial offer by buying QoE data from the MNO and use this data to improve the use of network resources and define new segments of users.

5.4.4 VNC and Business Analysis for Scenario 4 (QoE incorporation led by OTT provider in a liberal NN scenario)

5.4.4.1 Product (Value Proposition)

In scenario 4, as presented in Figure 5.6, the business interfaces towards the end user do not have any changes. MNO provides connectivity service while the OTT provides the content/application the end users demand. As in scenario 3 and due to the regulatory conditions, a business interface can appear between the MNO and the OTT provider, based on the definition of paid-prioritisation agreements. In addition, the MNO can agree with the OTT provider's conditions for using the network based on the exchange of QoE data monitored and captured by the OTT provider. MNO may offer a better deal if the OTT provider facilitates access to QoE data and other relevant user information that can be used to improve MNO's technical and business operation.

With the monitoring tool and assuming the quality provision role, the OTT provider increases its knowledge-base on the end users. With this information, the OTT provider can get closer to the user's expectations, profiles and demands. This information can be used to offer personalised services, including tailor-made con-

tent distribution, adapting the content delivery to the users' demands on favourite applications, offering a more convenient format to deliver content according to the network conditions without affecting the users' QoE. Also, the knowledge of end users' profile will make it possible for the OTT provider to recommend content features or applications that make better use of the available network resources.

On the other hand, the MNO continues assuming the operation of the network infrastructure offering to the end users the platform to consume the content/applications provided by OTT actors. However, due to the liberal approach on NN regulation, MNO can implement paid prioritisation schemes in its relation with the OTT provider. By offering access to fast-lanes, the MNO can guarantee to OTT providers high level network performance (previously stipulated in SLA) so the OTT provider can have exclusive access to more network resources and improve the content distribution/application performance while guaranteeing users have good QoE.

5.4.4.2 Customer Interface

With the possibility to play the quality provision role, the OTT provider can segment the customer base into different categories according to identified trends and patterns of content/application consumption/usage. For the business market, the OTT provider might target premium corporate end users interested not only in the standard quality requirements but the specific business consideration regarding security, reliability and stability during critical business sessions. The OTT provider benefits from getting more awareness of the end users' interests and demands, which can also impact the level of personalisation/customisation of the content and applications provided.

Meanwhile, the MNO can direct its value proposition to the traditional segments: consumers and business. With the possibility of prioritising traffic based on commercial agreements, the MNO can create premium and non-premium segments for the OTT providers. In addition, the MNO can buy the QoE data captured by the MNO and apply this knowledge on end users' interest and profiles to deeper their segmentation/categorisation according to type of content consumed, levels of consumption and their interest on high or standard content quality.

With regard to how the OTT communicates the value proposition to the customers, this would happen through web platform and through some MNO partners' channels. An additional channel can be the through stronger presence on social networks and media. On the other hand, the MNO can reach their customers using their retail channels, web channels as well as using partners' ecosystem.

5.4.4.3 Infrastructure Management

This VNC is driven by the incorporation of QoE led by the OTT provider with a liberal approach on NN regulation. In this scenario, the OTT provider, besides its role as application/content provider, monitors the mobile terminal using the QoE

data to activate its quality provision role. Figure 5.6 illustrates this configuration. Here, as long as there is an agreement with the end user, the OTT provider can use the collected QoE data for commercial purposes.

The OTT provider assuming the quality provision role requires developing both the monitoring tool and the quality provision platform. This includes technical and human resources required to incorporate QoE in the platform operation. Implementation of the monitoring tool and the quality provision platform may be assumed by the OTT provider or by a third-party company.

The collected information can be added to the already existing users' profiles, strengthening the OTT provider's knowledge on its users and interests as well as the commercial value in different transactions between the OTT provider and other organisations within the business ecosystem. By implementing the monitoring role, the OTT provider increases its awareness on the end users' patterns of usage and data consumption, which can be used in both a granular profiling aiming at commercial goals and the improvement in the use of network resources by the content/applications developed by the OTT provider. This can be obtained by implementing proactive and real time quality monitoring and assurance. Besides the possibility to compress the content demanded by the users, the OTT provider assuming the quality provision role may implement new mechanisms and communication channels to involve users in the service improvements. In addition, the OTT provider can collect data from both its own and the competitor's applications/content. In the latter case, through a commercial agreement, the OTT provider can sell the required data to the interested stakeholders.

On the other hand, the MNO continues assuming the operation of the network infrastructure offering to the end users the platform to consume the content/applications provided by OTT actors. However, due to the liberal approach on NN regulation, MNO can implement paid prioritisation schemes through its relation with the OTT provider. Conditions of these agreements depend on the bargaining power of each actor, and the elements considered in the negotiation, including the usage of the QoE data and the relation with the users. For instance, the MNO may offer a better deal if the OTT provider facilitates access to QoE data and other relevant user information that can be used to improve MNO's technical and business operation. Then, the MNO role goes beyond the dumb-pipe line provider to reach a smarter use of the network resources, but without implementing the quality provision mechanism. MNO can agree with the OTT provider's conditions for the use of the network based on the exchange of QoE information. In all commercial agreements, the regulator is required to take an important role defining the conditions and scope of the MN/OTT provider negotiation so the interest of the user will not be affected.

End users (private and corporate) consume the content provided by the OTT provider and continue using the MNO's infrastructure. With the improvements in the applications/services performance, the end users can obtain improvements in their QoE. The end users with their decisions and choices may shape the market development and motivate some regulatory decisions when necessary.

5.4.4.4 Financial Aspects

The OTT provider incurs costs linked to the application/content development, the integration and application management, the operation of the required infrastructure for its operation, as well as the investments on technical/customer support and consulting services. By assuming the monitoring and quality provision roles, the OTT provider needs to consider the costs for developing and deploying both the monitoring tool and the mechanisms to control the quality of the content provided. In addition to these costs, the OTT provider assumes the costs of the billing system, the administration of its customer base and the activities of marketing and support linked to the service offer. Paid-prioritisation agreements signed by the OTT provider also impact its cost structure.

MNO costs are associated with the deployment and operation of its infrastructure. Other costs for the MNO include the billing system, the administration of its customer base, marketing and customer support. In addition, the MNO could incur additional costs associated with buying QoE data for improving its network operation from the OTT provider.

Regarding revenue streams, in addition to the traditional OTT provider's revenue streams (e.g., subscription fees, advertisement), the OTT provider can sell QoE data to those MNOs interested in improving the network performance. Other revenue sources come from the offer of QoE based differentiated services and the categorisation of customers based on interests and profiles. QoE data may be also sold to other companies interested in getting a closer understanding of users' profile to reach them with commercial products and services.

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Meanwhile, the MNO continues getting revenues attached to subscription fees. Similarly, MNO can get new revenues by charging for prioritisation of content. It might be possible to generate revenues by charging fees for ads in content or for charging the content/service provider to guarantee users' access to their services even when 'there are no bits in the bucket' or zero-rating. However, this case needs to be studied in light of the regulatory framework.

5.5 Discussion of Considered Scenarios

The effect of the incorporation of QoE feedback in mobile networks by implementing the mechanism proposed in Chapter 3 of this dissertation has been illustrated using scenario planning process and VNC analysis. Scenarios can be used as a reference when implementing systems to incorporate QoE feedback in the mobile

Table 5.1: Comparison of considered scenarios.

	MNO	OTT
Scenario 1 (Lead by MNO Strict NN)	QoE incorporation limited to monitoring. Revenues from traditional services/QoE data selling. QoE data might impact marketing offers no technical operation.	Revenues from content/ application provision. Indirect benefits of MNO improvements
Scenario 2 (Lead by OTT Strict NN)	Revenues from traditional services. MNO with reduced power acting as a "dumb pipe". QoE does not impact MNO technical operation.	QoE incorporation by monitoring. OTT provider closer to the end-user. Revenues from content/application provision and more personalized/customized services. QoE data might impact service operation/ marketing offers.
Scenario 3 (Lead by MNO Liberal NN)	QoE incorporation monitoring/service operation. MNO with leading role in the value network. (traffic management/prioritization). Revenues from QoE differentiated services/paid prioritization and QoE data selling.	Revenues from content/application provision. QoE data might impact service provision/ marketing offers. It benefits from network operation improvements. New service offer based on paid prioritization alliances with MNO.
Scenario 4 (Lead by OTT Liberal NN)	More balanced correlationof forces MNO/OTT. Revenues from QoE differentiated services/paid prioritization.	QoE incorporation by monitoring/ service provision. OTT provider closer to the end-user. QoE data might impact service provision/marketing offers. New service offer based on paid prioritization alliances with MNO.

network, to identify limitations, required features and alternatives in each one of the proposed scenarios. A comparison of scenarios and the impact on the MNO and OTT provider is summarised in Table 5.1.

One of the key findings is that incorporating and commercially exploiting QoE in mobile networks is highly impacted by the regulatory framework. This framework limits what mechanisms and techniques can be used.

From the point of view of the MNO, those scenarios with strong NN regulation can be the most troublesome. The QoE incorporation scope is limited to monitoring and capturing QoE data. Revenues are limited to the traditional service offering. Scenario 1 might limit alternatives to stand out from competitors by centring the discussion on marketing offers not on the potential for technical improvements. In this scenario, QoE leveraging centres on the market elements but not the technical operation. Scenario 2 reduces the power of MNOs leaving them with the role of a dumb-pipe line. The OTT provider strengthens their position by getting closer to the users' needs and requirements.

Meanwhile, scenarios 3 and 4 offer the best opportunities to exploit the whole potential of QoE incorporation. Scenario 3 offers the MNO the opportunity to consolidate its position within the ecosystem. QoE incorporation scope is extended to include both monitoring and quality provision, which means that QoE data can

be used in the implementation of traffic management/prioritisation techniques with a clear business goal. In this scenario, MNO can generate new revenue streams by offering QoE-based differentiated services and by prioritising content according to commercial interests and alliances with OTT providers. Selling information to OTT providers can also be a revenue source for MNOs.

Scenario 4 offers a more balanced correlation of forces between MNO and OTT. This scenario allows the creation of new business models based on QoE-differentiation. However, the OTT controlling users' QoE feedback might have a negotiation element when discussing potential alliances with MNOs. MNO interested in improving network performance and/or implementing traffic management/prioritisation may need to buy QoE data from the OTT provider.

For OTT providers in general, those scenarios where the QoE incorporation is led by MNO might represent a challenge. Scenario 1, in which QoE incorporation is implemented by MNO under strong regulation, seems to be less risky in terms of revenues for OTT providers. Even though MNO can have closer access to users' feedback and improve network operation, one of the main beneficiaries of the network performance improvements are the OTT providers.

Scenarios 2 and 4 offer the OTT provider the opportunity to get more in touch with users and their feedback. OTT providers can, in both cases, use obtained feedback to improve service provision and the use of network resources. In scenario 2, the incorporation of QoE is limited to monitoring functions while in scenario 4, the monitoring function feeds the quality provision role of OTT provider. Scenario 2, because of regulatory restrictions, might limit the impact of the improvements due to the control of network resources by the MNO and the limitations with the implementation of paid prioritisation schemes. Scenario 4 makes it possible to establish commercial alliances with MNOs while taking advantage of the intelligence provided by QoE data to activate new service offers that fit with the MNO and the OTT provider goals. In both scenarios, by incorporating QoE it might be possible to create new revenue streams for OTT providers. Regarding scenario 3, the OTT provider might see their influence in the ecosystem reduced due to increase in the control capacity by the MNO. Alliances and commercial strategies can be alternatives to maintain an active role in the ecosystem.

From the users' perspective, scenarios 3 and 4 might extend the offer of services, increasing the personalisation of services and QoE-based differentiation with technical features implemented to achieve or satisfy users' demands.

5.6 Conclusions

In this chapter we tried to answer RQ3 and understand the implications of the incorporation of QoE feedback in mobile networks at the business level. We have illustrated this using the scenario planning method combined with VNC analysis. The methods examined the whole QoE-based industry and examined the implications from the perspective of MNO and OTT providers. Our approach adopts the

technical mechanism devised in Chapter 3 to incorporate QoE in mobile networks while evaluating how the regulation on NN identified in Chapter 4 might affect the implementation of the technical mechanism by either the MNO or the OTT provider.

The analysis helped to identify key trends and uncertainties regarding the development of a mobile network ecosystem and the incorporation of QoE feedback. The study finds that value-added offer, differentiation and personalisation of services can be seen as alternatives to generate new revenue streams in the mobile network market. QoEbased service differentiation might be a business alternative for telecom actors.

Considering the existing uncertainties on NN regulation and the mobile actor implementing QoE incorporation, we constructed different scenarios to evaluate implications of using QoE as a basis of the mobile network operation. Strict NN regulation sets limits to what techniques can be employed to implement business models based on incorporating QoE feedback in mobile networks. Services can be differentiated, but from a pure marketing perspective without involving technical features.

Scenarios with a liberal approach on NN rules might open the door for new business models based on QoE differentiation. Revenues can come from the implementation of paid-prioritisation agreements between OTT-MNO, the offer of specialised services with the creation of different service/user categories, or paid access to customers' feedback regarding content/services that can be used to improve service offers.

Independent of the regulatory framework, the incorporation of QoE feedback can impact the power balance in the mobile networks ecosystem. The actor leading the QoE incorporation might have access to richer knowledge of users' interests and expectations. This information combined with a deeper understanding of network performance will make it possible to define and realise value propositions based on a particular customer's interests. In addition, information is a valuable resource that becomes a negotiation tool when establishing commercial alliances with a counterpart. These benefits can be extended within a liberal regulatory approach on Net Neutrality, allowing the MNO to offer personalized/prioritized contents to its customers while also charging OTT providers for fast-lanes access, opening the door for new business models.

Chapter 6

Discussion

My aim with this thesis was to analyse the incorporation of QoE in mobile networks from technical, regulatory and business perspectives by designing the mechanism required for this incorporation, identifying the regulatory framework in which this solution will be implemented, and analysing the business implications associated to the use of QoE in the operation of mobile networks. Discussion of the results obtained in this dissertation are provided below.

6.1 Technical Level Remarks

With regards to the technical incorporation of QoE in mobile networks, our results in Chapter 3 focused on defining the mechanism to collect QoE data from the terminal, the exemplification of the use of this principle in the mobile networks context (via the identification of app usage trends and resource management), and the presentation of potential benefits of using QoE in the mobile networks.

Among the advantages of the proposed approach, this dissertation highlights the possibility of collecting data in real time, inexpensively, which would provide the ability for stakeholders to find correlations between network/terminal performance indicators and the users' usage patterns of certain applications or services. At the same time, this principle might be used to activate charging plans, network functionalities, or resource management mechanisms similar to the ones we present in this thesis.

Another benefit discussed in this thesis is related to the energy savings that can be obtained in the mobile terminals by using information on the perceived disruptions during playback and leveraging QoE models. In this case, the analysis of benefits focuses on the end user side, so further analysis is necessary to identify whether this approach may generate savings at the network infrastructure level and how mobile actors may offer this benefit as added value in their commercial offers. On the other hand, the quantification/monetisation of generated benefits needs to be addressed in future research.

However, looking at QoE incorporation as a merely technical issue reflects a myopic vision of the whole QoE concept. According to QoE definitions provided by ITU [83], Laghari et al. [84] and the Qualinet project [23], technical elements are just a subgroup of what needs to be considered when referring to QoE. Developing a customer/user-centric approach by incorporating QoE in mobile networks requires not only attending to network quality but managing the entire customer experience at each step in the service delivery. In that sense, QoE can be interpreted as an indicator of customer experience.

Extending the QoE concept to understand customer experience requires not only a constant evaluation considering users' feedback and monitoring in order to understand what is behind the customers' behaviour. It also requires MNO and OTT to assess their internal capabilities across the customers' touch points. This evaluation may drive improvements in terms of organisation structure, processes, and technology. A broad end-to-end view requires data collection from different customers' touch points, not only the mobile terminal, as well as the use of the QoE information on the other levels involved in the service provision.

Full use of the advantages generated by the proposed mechanism will require a transparent agreement with the end user to install the monitoring tool, and an open cooperation between the MNO and the OTT provider. Approval from the end user needs to consider the transparency principles stated by the regulatory framework in the respective market.

On the other hand, in order to get a closer approach to the overall end user experience, which is not limited to the network/application performance, it is necessary to devise a mechanism to capture non-technical factors affecting the end user's QoE, including contextual factors or customer care indicators. Therefore, proposed mechanisms need to be integrated into a broader framework that combines the technical data captured with the monitoring tool and the users' feedback on service provision affecting their QoE. The analysis and evaluation of QoE indicators can be used both in the adjustment of network resources and the structuring of business and market level operations implemented by the stakeholders in the proposed framework. However, the implementation of the mechanisms to incorporate QoE in the mobile network operation will depend on the regulatory framework conditions.

In Chapter 3, it was shown how the use of information provided by the monitoring tool can be used to manage the resources in mobile networks and generate improvements for the end users' QoE. Obtained results consider the video delivery scenario as a representative case of content both highly demanded by consumers and highly impacted by network performance problems where it is possible to identify the effect of content disturbances on the end user's perception, as stated by Hoßfel et al. [34,148]. Even though, this can be a representative scenario, it is necessary to extend the analysis to the implications of the proposed mechanism in a mixed-traffic scenario. On the other hand, it would be important to evaluate how the use of a monitoring tool by the OTT player might impact the use of the network resources, especially considering that the OTT provider is not directly involved in the network

operation. The same analysis can be done in a cooperative/collaborative scenario where the resource management decisions can be coordinated between MNO and OTT providers based on the collected QoE data.

Finally, the incorporation of QoE in mobile networks brings the opportunity to improve the MNO and OTT providers while opening the door for implementing business models based on the provision of personalised/customised services, the implementation of 'fast-lanes' under the paid prioritisation model with the goal of fitting the offer with the users' expectations. However, the scope of these business models and the implementation of the technical mechanisms required to incorporate QoE in mobile network operation will be determined by the regulatory framework, especially regarding NN, as discussed in Chapter 4.

6.2 Regulatory Remarks

As discussed in Chapters 1, 2, and 4, the implementation of new technical developments with a business purpose, requires the identification of the regulatory framework boundaries in which the solution and the potential business models arising out of this solution will be implemented. This research found that among the different regulatory topics and discussions, NN is the one with particular relevance in the incorporation of QoE in mobile networks. The use of customers' data, the potential implementation of mechanisms to prioritise/manage traffic with commercial purposes, or the offering of differentiated services based on QoE feedback may conflict with some of the NN principles. The analysis of the regulation on NN focused on the EU and US considering the relevance and impact of these to markets in the development of the telecommunications market. The FCC in the US has set the 'bright line rules' to guarantee NN: 'No blocking, no throttling and no paid prioritisation' ([99]). The FCC based its approach on two basic principles: an open Internet architecture based on non-discrimination of traffic; and the 'virtuous cycle' in which '*new applications and services developed at the edges of the network enhance consumer demand and lead to investments in network infrastructure which sparks new innovation at the edge*' ([99]). In that sense, the best response to data traffic growth is capacity expansion. On the other hand, EU shares the idea of banning blocking and throttling practices in the network. However, it does not expressly forbid paid prioritisation and reinforces the importance of full transparency to empower users in their choice of network provider.

The EU scenario might be more open to MNOs using QoE in both the network operation and the creation of new revenue streams. By taking paid-prioritisation off the table, EU regulation seems to open the door for alternative business models, where service provision can be done in accordance with predefined quality standards, prioritising determined types of traffic under commercial agreements between MNOs and OTT providers, previously agreed with users according to transparency principles and without compromising the freedom of expression, the fairness principles and the users' freedom of choice. In contrast, the US would offer better

conditions for a QoE incorporation process managed by the OTT players. First, the US view is strongly influenced by the 'virtuous cycle' principle, which in most cases leaves the innovation process in the hands of the OTT while the MNOs play the role of network capacity provider, exploring mechanisms to lower the costs while transmitting as much data as possible with the best quality but no clear mechanism to generate a return for the investment.

According to the analysis of US and EU regulation on NN, in both cases the alternative to exploit the potential of QoE incorporation is the specialised services category, since the regulation for this type of service is exempt from the NN rules. BEREC [120] goes beyond this definition and leaves it up to the NRAs to evaluate and interpret whether QoS parameters are adequate to guarantee the operation of both the specialised services and Internet access service. In this regard, those actors interested in incorporating QoE in the service provision might focus on the specialised services category, which includes VoLTE or linear (live) broadcasting IPTV services with specific quality requirements.

Another alternative to generate revenues for MNOs within the current regulation is establishing alliances with OTT players by offering zero-rating. In this scenario, even though the segmentation/prioritisation is not directly implemented at a network level, QoE considerations on what type of content or applications the users like the most or want to use more can be considered. In this case the QoE information might be used to create more informed customers' segmentation at business and market levels by applying zero-rating to a particular application/type of applications.

As stated by Faulhaber and Farber [107], traffic discrimination can be the alternative for network operators to increase their benefits by introducing charging policies based on type of consumption. However, under the NN discussion this alternative may be affected by involving a legal concern with a technical issue (traffic prioritisation) that has always been there. Faulhaber and Farber [107] argued that '*the Internet has always used traffic prioritisation and other network management techniques since the earliest days*', therefore, from this dissertation's perspective, a regulator imposing restrictions on what technical mechanisms are implemented to improve the network performance would needlessly affect the telecom market, especially the mobile broadband one, where resource management is critical.

Regulation can stand on the basic principles and set the rules on how the market should develop, keeping the principles to balance the commercial relation between customer and provider but not defining the technical mechanisms that can or cannot be implemented to guarantee a service offer to the end user. In that sense, regulation might be a tool to control the potential excesses of the market due to market distortions such as monopolistic or oligopolistic positions limiting the freedom to choose within a competitive market. Guaranteeing free access to information and services, with transparency among the actors should be the main focus of the regulation, leaving aside the strict control of technical mechanisms which can distract regulators from their main purpose, ensuring users have access to good telecommunication services within fair and competitive markets.

6.3 Business Level Remarks

Regarding the business impact of QoE incorporation in mobile networks, results in Chapter 5 offer key trends and uncertainties faced by main stakeholders interested on using QoE in the operation of mobile networks. This chapter also offers an analysis of the different value configurations generated under different scenarios.

The implementation of mechanisms to incorporate QoE in mobile networks might bring new business alternatives for the stakeholders in the ecosystem. However, defining and structuring those business alternatives depends on the regulatory framework and the limitations imposed on developing technical solutions. Additionally, regarding the limitations on technical implementation, the regulatory framework might impact the structure of the market and the relation among the relevant actors in the mobile ecosystem.

Considering both the level of uncertainty regarding the NN discussion and the effect of QoE incorporation identified in the interviews/workshops, this work used scenario planning as a business tool to test assumptions on the future developments based on the proposed technical mechanism. Complementing the scenario analysis, the VNC method offered an extended vision on the possible configurations emerging out of the implementation of QoE incorporation mechanisms under different regulatory conditions. The VNCs present an illustrative representation of the potential impact, the possibilities and opportunities of the adoption of QoE incorporation.

From the business analysis, in those scenarios where NN regulation sets strict rules, the first limitation is on the techniques that can be used to incorporate and make use of QoE. The effect of strict regulation might have a stronger impact on the MNO's alternatives. If MNO is in the centre of the QoE incorporation, but the regulatory framework does not allow the technical implementation of QoE-based mechanisms to manage/prioritise traffic, the collected information can be used mainly in marketing offers but not in the technical operation. On the other hand, if the regulation on NN is strict, and the leading role is assumed by OTT providers, the power of MNOs is reduced by limiting this role to a 'dumb-pipe'. This implies the MNOs are focused on lowering cost while transmitting as much data as possible with the best quality but no clear mechanism to generate a return on the investment. Therefore, MNOs wanting to leave the dumb-pipe role and also be active in the value creation need to look into QoE incorporation.

MNOs taking the central role can generate new revenue streams by offering QoE-based services and by prioritising content according to commercial interests and alliances. Another revenue source can be selling information on apps and service usage patterns to OTT players. Meanwhile, a leading role assumed by OTT providers might offer a more balanced correlation of forces between MNOs and OTTs. In this situation, the OTT providers, by controlling users' QoE data might have a negotiation element when devising potential alliances with MNOs. In a regulated scenario, the OTT leading the control of QoE incorporation might be beneficial since the improvement in the network operation will benefit the OTT's content distribution. The OTT controlling QoE incorporation independently of the

regulation can be beneficial by the using the obtained feedback to improve their service provision and the use of network resources. However, within a more liberal scenario, the OTT provider can have more incentives to offer new services in close collaboration with MNOs. From the users' perspective, the incorporation of QoE might extend the offer of services and increase the users' satisfaction levels.

Incorporation of QoE in mobile networks is also an opportunity to have a service offer based on QoE differentiation which gives mobile operators the chance to offer several value propositions to their customers. For instance, in the video streaming scenario, the segmentation would include premium and non-premium users, considering who is interested in free or paid video content. An alternative would be the categorisation of the users according to their level of consumption, by volume or time. For the business market, QoE differentiation might target premium corporate users with standard video quality requirements but also security, reliability and stability during critical business sessions.

MNOs can use their retail network, web platform and partners' channels to communicate the value proposition for their customers. OTT providers can continue using their web channels to reach their customers. On the other hand, OTT providers can establish relationships with customers through a price plan based on the differentiation and build this relation with direct communication about their interest in the service provision and the service quality perceived. From mobile operator's perspective, it is important to establish strategic partnerships with OTT providers in order to develop and operate competitive QoE differentiated services. In addition, this partnership can offer the opportunity to work on the adjustment of the content requirements in order to adapt them to the network conditions and the users' demands.

6.4 Methodological Remarks

The main tool used in this thesis is the research framework proposed in Chapter 2. By incorporating regulatory and business steps into the design science approach, the proposed research framework seeks to enrich the process of devising technical components by being aware of the business and regulatory requirements, implications and consequences of implementing a technical solution in a real scenario.

The main sources of information used to answer the proposed research questions were literature review, interviews and group discussions (workshops). Therefore, the reliability of obtained results largely depends on the reliability of that input. The application of the framework might be affected by some bias as a result of the participant in the interviews and workshops. Researchers using the framework need to filter the obtained data and contrast the information with different sources in order to reach a balance in the analysis.

The research framework followed in this thesis and its operationalisation suggest using specific tools to carry out the technical, business and regulatory analyses; those tools cannot be seen as a straitjacket that limits the role of the researcher.

Tools such as the business model canvas, study cases, and laboratory tests can be incorporated within the methodology framework in order to achieve answers to research questions. The key factor when implementing this framework is to go beyond the technical consideration and include the business and regulatory aspects in the evaluation. This integrated view can offer more decision elements to consider when moving forward with big-scale implementation.

Chapter 7

Conclusions and Future Work

7.1 Concluding Remarks

The main purpose of this study was to analyse how mobile operators can incorporate QoE feedback to improve their service offer considering technical, regulatory and business implications. In order to do this, we have focused on the implications of the proposed integration into the mobile networks from technical, market and business levels. Each level was studied in a separate way but emphasising the interdependence among domains and the importance of a holistic view on QoE. For our work, we have identified the following research questions:

- *RQ1. How can QoE feedback be incorporated in the technical operation of mobile network infrastructure?*
- *RQ2. How can the incorporation of QoE best be aligned with Net Neutrality regulation?*
- *RQ3. How can QoE feedback impact mobile operators' service provision at the business level?*

The answers to the proposed research questions were discussed in Chapters 3, 4, 5 and 6. The main findings are summarised below.

> *RQ1. How can QoE feedback be incorporated in the technical operation of mobile network infrastructure?*

We introduced the technical mechanism to incorporate QoE data in the mobile network infrastructure in Chapter 3 and discussed some of the benefits this mechanism can bring to the mobile network operation. Our approach proposes the use of monitoring applications, installed in the mobile terminals, able to report app data to the mobile infrastructure. By using the application level indicators, the interested stakeholders can find the correlations between network/application indicators and

the patterns of usage of different applications/services, identify trends in the mobile data consumption and take actions on networks' resource management accordingly with the identified patterns.

We provide an example of the use of the monitoring tool in the identification of app patterns of choice and usage. However, in order to provide higher accuracy on the correlation findings it would be important to incorporate a mechanism to collect contextual data (e.g., location, users' age, type of terminal, customer satisfaction levels). QoE research has shown that these elements influence the users' QoE (Stankiewicz [24]). Therefore, it is important to consider contextual factors when analysing trends.

Based on the use of a monitoring tool, we introduced a QoE-aware architecture. Through simulation, we showed the basic operation of the proposed architecture in a mobile network. The information collected at the terminal was used in the resource allocation decisions. Our study shows the use of application data might generate improvements in the end users' QoE. Then, our study extended the analysis of the potential benefits of incorporating QoE in mobile networks operation to the energy savings obtained at the terminal. We showed that energy savings in the smartphone are possible while maintaining end users' QoE by leveraging QoE models and using information about the status of the content processing.

Even though the obtained results present a positive scenario in favour of the incorporation of QoE in the technical operation of mobile networks, the QoE-aware architecture was only tested with one type of traffic (video). Therefore, it is necessary to extend the analysis to a mixed traffic scenario to get a better picture of the benefits generated by the use of the proposed architecture. The same considerations need to be taken into account when measuring the energy savings obtained by using QoE in the the operation of mobile networks.

As discussed in the problem formulation of this thesis, QoE not only depends on the network/application performance. It is highly influenced by external factors such as pricing, users' profile or customer care (Stankiewicz [24]), that involve the construction of customer experience regarding the different actors in the mobile ecosystem. Therefore, incorporating QoE in mobile networks needs to consider mechanisms/channels to capture the non-technical elements associated with the end users' QoE. Thus, the use of our QoE-aware architecture needs to be complemented with a refined analysis of information coming from the customers at each step in the service provision and operation, including the different contact points between the user and the actors in the mobile ecosystem. This entails considering the technical, business and market processes associated to the mobile operation.

> *RQ2. How can the incorporation of QoE best be aligned with Net Neutrality regulation?*

Regulation and policy makers have a high impact on how technical and business alternatives are structured within the telecom industry. Therefore, we consider it

relevant to analyse the regulatory context when talking about developments with the potential to create new business alternatives.

Due to the nature of the technical mechanism proposed to incorporate QoE in mobile networks, which may require collecting data from the terminal and the implementation of resource management strategies with a commercial purpose, analysis of NN regulation is the most relevant for our area of study. Current discussion on NN recognises the importance of banning blocking and throttling in the operation of telecom infrastructure. Differences arise when discussing the paid prioritisation issue. While the US is clear on forbidding paid prioritisation and fast lanes, the European approach seems to recognise that prioritisation is an effective tool when used in circumstances where there is competition and transparency.

A mobile network incorporating QoE in its operation might require and also make it possible to prioritise certain types of traffic based on their commercial relevance or the users' interests. The US approach reduces the alternatives for traffic prioritisation to those that guarantee the normal operation of the network but not business purposes. This view may close the door to any potential creation of fast lanes or the definition of QoE-based lanes in the network infrastructure. The European framework, by not strictly forbidding paid prioritisation and requiring full transparency, may offer less regulatory barriers for the implementation of QoE-based service provision and categorisation.

On the privacy implications and the use of data collected from the end user's terminal and its use for commercial purposes, both US and EU regulations rely on consumer protection laws defined by each country/region. Regulators indicate that network operators must provide clear information on the type of data used, how the operator ensures the privacy of end users and protects their personal data when managing traffic, a description of the traffic management mechanism using the personal data and a description of the potential impact of traffic management practices. In that sense, collection and use of QoE related information needs to consider these aspects.

RQ3. How can QoE feedback impact mobile operators' service provision at the business level?

The incorporation of QoE in mobile networks might affect the business level depending on both the regulatory framework and the stakeholder making use of the technical mechanism proposed in this thesis. According to these uncertainties, we constructed different scenarios to identify the implications of QoE incorporation.

Independently of the regulatory framework, the use of the technical mechanism proposed to incorporate QoE in mobile networks may provide the stakeholders with access to richer knowledge based on users' interests, patterns of data usage and consumption and their expectations regarding the service provision. This information combined with a deeper understanding of the technical resources, their capacity and use would make it possible to define and offer value propositions based on particular customers' interests. In addition, this information might provide a valuable

negotiation tool when establishing commercial alliances with a counterpart. Therefore, we see that QoE incorporation opens the door for business alternatives based on differentiation/personalisation of services and the offer of value added services in the mobile network market.

When considering the uncertainty of the regulatory framework on NN, we found that even though there are economic incentives calling for new business models, strong NN regulation might set limits to the techniques and the mechanisms that can be employed to implement business models based on QoE incorporation. Services can be differentiated but from a pure marketing perspective without involving technical features.

On the other hand, those scenarios with a liberal approach to NN might open the door for business models based on QoE differentiation. Revenues can come from the implementation of paid prioritisation agreements between MNO and OTT players, the offer of specialised services with the creation of different user/service categories, or paid access to customers' feedback regarding content/services that can be used to improve the service offer of one of the involved actors in the mobile ecosystem.

7.2 Future Work

In this thesis, we have explored how QoE can be incorporated in mobile networks and the implications of this process at technical, business and market (regulatory) levels. Therefore, this thesis contributes to the study of QoE as well as the inclusion of new elements to the discussion of business and regulatory domains. Accordingly, there is still room for future work studying QoE in the mobile networks context.

First, the service provision in the mobile networks are provided over a heterogeneous ecosystem, where the technical systems can be coupled but the information about control and management is exchanged only through what is defined in a SLA. Therefore, it is necessary to design and specify how SLA takes into account the users' perception and be integrated into the operation of a user-centric mobile infrastructure. Challenges include the parametrisation of quality features and the user's contextual factors. As mentioned by Xie [20], ELA will describe the service quality in terms of 'experience', which could be better understood by the users and will keep the quantitative specifications of the service quality as references for operators. This ELA concept is expected to bridge the gap between operators and users so that they can communicate in the same language about the service quality.

A second angle suggests considering an analysis of the MNO-OTT provider relation when dealing with QoE-based service provision. It is important to analyse the incentives to cooperate and the levels of cooperation between MNO and OTT. This might impact the level of granularity of the information each actor is willing to share, the process of placing controlling probes in the network and the level of accuracy of the achieved QoE estimation.

Future work can cover the monetisation and utilisation/exploitation strategies for QoE information. The monetisation of QoE involves analysing the problem

between willingness-to-pay and the service perception, which requires the integration of other factors such as the socio-economic classification of users and services, the usage preferences, etc. QoE incorporation will have both short and long term effects that need to be addressed in concert with appropriate QoE marketisation frameworks in order to obtain a sustainable QoE market configuration.

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