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# Quality of Experience (QoE) in LTE GSM UMTS Mobile Networks

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**Abstract:** Quality of Experience (QoE) is a well-established methodology for measuring and understanding the overall level of customer satisfaction with a service, 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. 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. 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. operators to make a better use of QoE in their business operation.

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

## I. Introduction

The development and deployment of mobile network infrastructures in the quest to satisfy the increase demands of voice & data services to businesses and communities have created new opportunities and challenges in Cameroon. The mobile market has served the Cameroon well over the past decade, driven by competition among mobile network operators (MNOs). Mobile services in Cameroon have developed significantly, moving from voice and then SMS through to data services, which have offered higher download speeds and lower latency over time. No generation of telecommunication networks has been originally designed with QoE principles so far. Nevertheless, the system-centric view of QoS provisioning is no longer sufficient, and it needs to be replaced or complemented with more user-centric approaches (Stankiewicz,2011). Therefore, the shift from QoS- to QoE-centric networks is an emerging, open challenge. However, Cisco has predicted a seven-fold increase in the global mobile data traffic between 2016 and 2021, where the vast majority of traffic will be generated by portable devices (Cisco 2017).

In Cameroon, mobile networks have evolved to support very high-speed data transmission between inter operators and end users, since the new generation of mobile users do not only demand telecommunication services but especially data-communication services. Cisco's Visual Networking Index (VNI) Global Mobile Data Traffic Forecast predicts that mobile data traffic will grow at an annual rate of 49% from 2016 to 2020, reaching Exabytes per month by 2021. Video traffic, which currently accounts for per cent of the total mobile traffic, is predicted to reach per cent by (Cisco Visual Networking Index, 2021). Today in Cameroon, statistics shows that between early 2000 and end of 2013, the Cameroonian population was about 20 million inhabitants, with just 5 million of the overall population who could barely afford cell phones, giving an overall percentage of 25% connected users. But by early 2014 till date (June 2023), the Cameroonian population have risen to about 30 million inhabitants with about 19.5 million connected users given an overall percentage of 65% demands in both voice and data services. Mobile operators in Cameroon like MTN-Cam, Orange-Cam, Nextel and Camtel are currently facing challenges on how to ensure an end-to-end QoS/QoE to the general public. Recently, that is in May 2023, Cameroonians have experienced the policy of switching cell phones to flight mode for about 2 to 3 minutes before being able to get internet connection, this policy was brought in by MTN-Cam and Orange-Cam due to degradation of QoS/QoE in their mobile infrastructure. This phenomenon draws the attention of the ministry of posts and telecommunications in Cameroon, who further issued query letters to the two MNOs requesting the state of act of their mobile network, this query letters by the minister to the MNOs triggers fines from the Telecommunication regulatory agency of Cameroon to these operators. MTN-Cam was charged to pay 1.4 billion and Orange-Cam 2.1 billion as fines for not respecting regulatory norms of QoS/QoE service provision.

Network operators in Cameroon should design their network capacity according to traffic estimations for resource provisioning. When the connectivity is lower than a tolerable threshold, the network traffic will pause or slow down. This degradation could greatly impact the user perceived quality, also known as the Quality of Experience (QoE), according to (Mok, 2011).

In the era of Net Neutrality, telecommunication operators cannot apply the techniques and an interconnection tariff to the OTT providers since the operator should serve all traffic without a discrimination. Telecommunication services are paid not on quality but only in terms of quantity.

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## II. Experimental Methods

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.

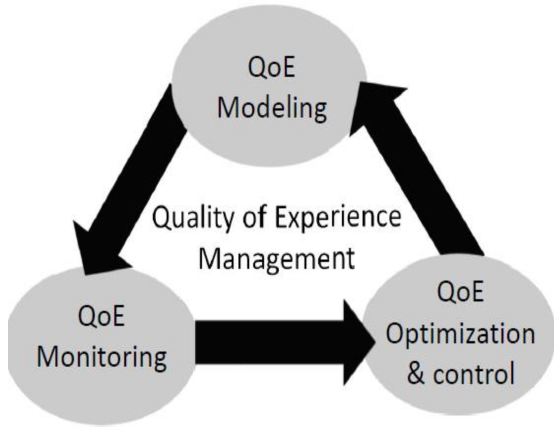


Figure 1 : General block diagram to perform QoE management

Source: Vega and Perra, 2018

Quality of Experience (QoE) has also been stated as the subject's conception of the satisfaction, usability and acceptability of the utility (Chen, 2015). The ITU Standardization Sector (ITU-T) defined QoE as ''the overall acceptability of an application or service, as discerned subjectively by the subject'.

### a) 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 needs 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 in Peffers et al., (2007) and Hevner and Chatterjee (2010).

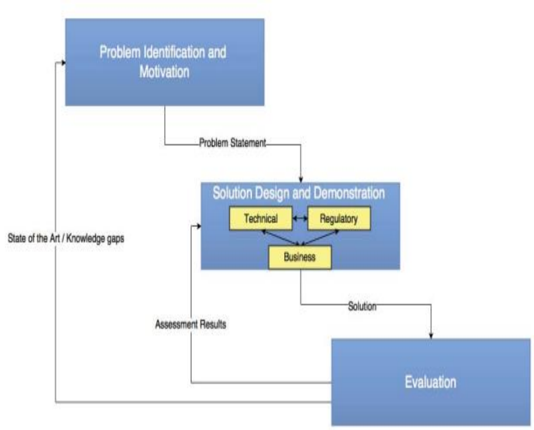


Figure 2 : Design-science process (Vaishnavi and Kuechler, 2007)

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According to Vaishnavi and Kuechler (2007) and Peffers et al. (2004) the design-science process is structured in three phases: 'problem definition', 'solution design' and 'evaluation' as illustrated in Figure 3.1. These phases are connected throughout the research process and divided into steps that contribute to devise the artefact. Hevner and Chatterjee (2010) argued that design science activities within IS work describe data under a conceptual framework of IS, as shown in Figure 3.3. The aim of design science is to develop an artifact using valid knowledge to support problem solving in a certain context, whether directly, such as via a model, or indirectly, such as giving an instruction; in this regard, design science is a solution oriented in considering human activities.

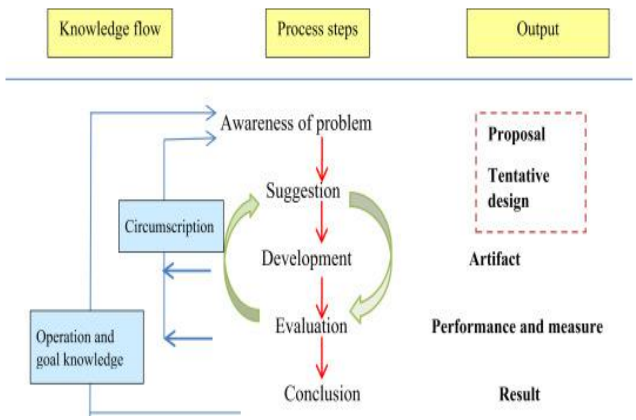


Figure 3 : General methodology for design science research

**b) Mathematical Modelling & Discussions**

In this section, this paper tries to view at QoE incorporation feedback mechanism in three principal dimensions, which are Technical, Regulatory & Business levels. In this regard, we develop the idea mathematically as follows:

QoE incorporation feedback mechanism (QoE-IFM) = [Technical (T)+ Regulatory(R) + Business(B)] Levels

That is QoE-IFM= T+R+B ……………………………………………………………1

Knowing that this QoE incorporation feedback mechanism is done in mobile networks and the main actor are mobile network operators (MNOs), therefore QoE-IFM becomes in function of MNOs. At this level, we developed a function which gives:

**QoE-IFM(MNOs) = T + R + B**……………………………………………………2

MNOs ranges from Operator_1($O_1$) to Operator_n($O_n$)

Implies **MNOs = $O_1$ + ………+ $O_n$** …………………………………………………...3

But in Cameroon, we have four mobile network operators: Camtel, **MTN**, Orange & Nextel

Substituting equation 3 in to 2, we got:

**QoE-IFM ($O_1$ + ……+ $O_n$) = T + R + B**……………………………………………….4

Practically speaking, from either equation 2 or 4.

T = Optimal Network Coverage (ONC), note that once there is no network, Regulators won't issue mobile concessions to mobile network operators or oblige them with some key performance indicators to guarantee good QoS/QoE in a community or country. And subsequently, there will be no Business activities because of non-existence of mobile services.

Therefore, Optimal Network Coverage (ONC) = Network Planning (NP)/Capacity Estimation (CE).

Mathematically, it can be express as:

**Optimal Network Coverage** = $\frac{\textit{Network Planning}(NP)}{\textit{Capacity Estimation}(CE)} = ONC = \frac{NP}{CE}$……………………..5

From equation 5, and as per area of study, we notice that, at the technical level, it could mean just a lot of things, but in our case, this paper considers Optical Network work coverage which entails a lot of knowledge in the domain of mobile networking and is a key factor to guarantee QoE.

However, taking into considerations equation 5 above, relating the recent constant flight mode switching scenario that occurs in Cameroon due to poor QoS/QoE, reamplifying my vision towards this research area, and as per the ministerial workshop call in regard to this scenario to find a lasting solution, and trying to put this idea within the perimeter of Cameroon, we can clearly see that:

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If there is no innovation in network planning, while user number keep rising with no capacity expansion to meet up with the usage demands, degradation of network will occur.

Moreover, capacity estimation (CE) here involves operators Core and access equipment's plus the population density of user's equipment's (ϱUE), but operators' access (RAN) & core (Co) equipment's capacity must be projected for about 10 years population growth taking into considerations future evolving technologies 4G+/5G/5G++++.

**III. Results 1 & Discisions**

Developing this mathematically, lead us to:

**CE = (ϱUE) +(RAN + Co)**……………………………………………………………6

Substituting equation 6 in to 5 gives

$$ONC = \frac{NP}{(\varrho\mathrm{UE}) + (\mathrm{RAN} + \mathrm{Co})} \text{……………………………………………………………….7}$$

**Therefore, replacing T in equation 4 above by equation 7 we obtained:**

$$\text{QoE-IFM } (O_1 + \ldots\ldots + O_n) = \frac{NP}{(\varrho\mathrm{UE}) + (\mathrm{RAN} + \mathrm{Co})} + R + B \text{…………………………8}$$

**Where:**

R= Regulator (Measures and controls KPIs of the mobile concessions in strict and liberal Net Neutrality (NN) environment)

B= Business level (business Organisations & Communities)

Stretching on the concept of net neutrality (NN), equation 8 becomes:

$$\text{QoE-IFM } (O_1 + \ldots\ldots + O_n) = \left[\frac{NP}{(\varrho\mathrm{UE}) + (\mathrm{RAN} + \mathrm{Co})} + (R + B)\right] NN \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 9$$

**At the business level B, we take into considerations:**

Product Value (Pv), Financial aspect (Fa) and Infrastructural management (Im)

Therefore:

**B = Pv + Fa + Im**…………………………………………………...10

Substituting equation 10 in to 9, we obtained:

$$\text{QoE-IFM } (O_1 + \ldots + O_n) = \left[\frac{NP}{(\varrho\mathrm{UE}) + (\mathrm{RAN} + \mathrm{Co})} + (R + \mathrm{Pv} + \mathrm{Fa} + \mathrm{Im})\right] NN \ldots 11$$

Note that Equation 11 is a strict Net Neutrality scenario.

At the Regulatory level R, definition & control of measurable key performance indicators per RAT (Radio Access Technology)

$$R(\quad KPIs) = \begin{matrix} 2G & [GSM] \\ 3G & [UMTS] \\ 4G & [4LTE] \end{matrix}$$

And within a strict Net Neutrality principle, three key aspects are considered:

1. No Blocking ($B_{No}$)
2. No Throttling ($Throl_{No}$)
3. No paid prioritisation ($Pp_{No}$)

   Therefore:

   **R = $B_{No}$ + $Throl_{No}$+ $Pp_{No}$** …………………………………………….12

Implies the general mathematical model for the incorporation of QoE feedback in the mobile network considering strict Net Neutrality scenario is:

$$\text{QoE-IFM } (O_1 + .. + O_n) = \left[\frac{NP}{(\varrho\mathrm{UE}) + (\mathrm{RAN} + \mathrm{Co})} (\mathrm{BNo} + \mathrm{ThrolNo} + \mathrm{PpNo} + \mathrm{Pv} + \mathrm{Fa} + \mathrm{Im})\right] NN \ldots 13$$

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### c) Traffic Engineering base on Physical Cell Identities

***Scenario 1: QoE incorporation led by MNO-PCI algorithmic function***

In this section, the PCI conflict detection and self-optimisation algorithm is proposed for MNOs to integrate/activate features in their Network management platforms in order to ensure optimal E2E QoE. PCI is very important in LTE in terms of accessibility and retainability of Key Performance Indicators. Physical cell identifier (PCI) identifies a physical cell. Each evolved universal terrestrial radio access network (E-UTRAN) is assigned one PCI. There are 504 PCIs in the LTE system. PCI reuse is inevitable when there are a large number of E-UTRAN cells on the LTE network. If two intra-frequency E-UTRAN cells using the same PCI are too close to each other, there will be PCI conflict between the cells. As a result, the service drop rate increases and handover success rate decreases thereby affecting QoS/QoE. To eliminate or reduce PCI conflict on the mobile network, we proposed an algorithm for PCI conflict detection and self-optimisation function. However, this function is made up of two subfunctions:

1. PCI conflict detection: Detect PCI conflicts between E-UTRAN cells
2. PCI self-optimization: reallocates appropriate PCIs to conflicting cells based on the PCI conflict detection

**Results 2 & Discussion**

The PCI consist of two elements:

$$PCI = PSS + SSS$$
$$\Downarrow$$
$$(0,1,2) + 3(0, 167)$$

Where:

PSS = Primary synchronisation signal

SSS = Secondary synchronisation signal

$$PCI = PSS\,(0,1,2) + SSS\,[3(0\text{-}167)]$$

PCI is any number between 0 to 503 [504 PCIs]

If your LTE network has thousands of sectors, you will have to reuse your PCI, that is 504 PCIs, and this can greatly affect the QoE in the operators' network.

### a) PCI assignment strategy

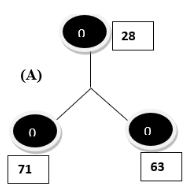



Figure 16 : PCI assignment strategy A

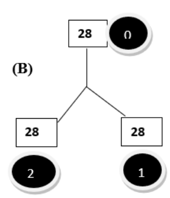
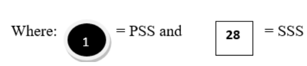



Figure 17 : PCI assignment strategy B




**Strategy A** removes all interference from resource elements coming from the PCI collision which are used for traffic channels (Gives clean reference signal for traffic)

**Strategy B** removes all the interference from the reference signal resource element (Gives clean reference signal) use to estimate the channel.

How ever, we divide 504 PCI in to four groups, all the groups have 126PCIs in each of them

504

| | | | |
|---|---|---|---|
| 126 | 126 | 126 | 126 |

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4. **PCI algorithm:** Automatic PCI allocation, this minimizes the cell reference signal interference, and also maximizes the PCI re-use distance. Distance is measured in terms of "path loss" measured in dB [10dB is the bench-mark]

***PCI collision/confusion analysis:***

PCI collision occurs at the level of accessibility, that is, it affects accessibility KPI (Call success rate, E-RAB success rate). Alternatively, the radio network controller configuration/reconfiguration setup (RNC) can be sent to a call which is not actual your particular cell, and therefore, your mobile will never receive that acceptance. This is called Accessibity Failure. Why PCI confusion happens in terms of handovers, the targeted cell has been given a command, that is mobile sends a command to connect a particular cell but turns to get a different cell with the same PCI which is not the target cell there leading to poor QoE.

However, a PCI collision occurs when the signal overlapped area two or more cells using the same frequency and PCI cannot implement signal synchronisation and demodulation because of the insufficient physical location spacing between these cells as shown below in figure.

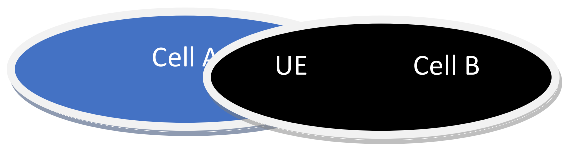



Figure 4 : PCI collision

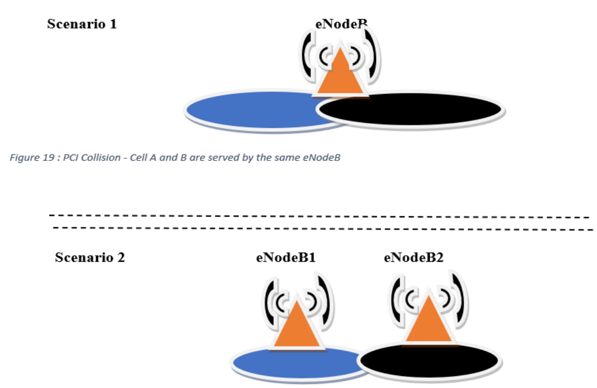
Cell A and Cell B use the same frequency and PCI

**Detection method**

The eNodeB checks whether some local cells use the same frequency and PCI, whether a local cell and an external cell in the neighbouring cell list (NCL) use the same frequency and PCI. If they do, the eNodeB detects PCI collision which consequently lead to QoS/QoE degradation in the mobile network.

According to the LTE configuration rules, the same PCI cannot be configured for a local cell and its intra-frequency neighbouring cell. Therefore, an LTE cell and its neighbouring cells will not have the same frequency and PCI. However, an LTE cell may have the same frequency and PCI as its external cells or multiple local cells under an eNodeB may have the same frequency and PCI.

As illustrated in the figure below, cell A and B use the same frequency and PCI. In the two scenarios, PCI collision can be detected using this feature.




Cell A is an NCL external cell of eNodeB2, or cell B is an NCL external cell of eNodeB1

**PCI confusion analysis**

Base on critical MNOs system study in the quest to incorporate QoE feedbacks, PCI confusion was discovered as a factor that could contribute to network degradation if not well plan, this consequently led us to conduct a critical analysis.

PCI confusion occurs between a detected cell and a neighbouring cell configured for a serving cell, if the detected cell meets handover conditions and the two cells have the same frequency and PCI. In this case, UE handover failures and service drops may occur.

However, MNOs should note that, PCI confusion occurs in the following scenarios:

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- The detected cell is a configured neighbouring cell of the serving cell. As illustrated in the figure below, cell B is the detected cell meeting the handover conditions and is a configured neighbouring cell of the serving cell A. when the UE does not support automatic neighbour relation (ANR) or the eNodeB is not enabled with ANR, if the UE reports information about the detected cell B to the eNodeB, the eNodeB cannot determine whether the neighbouring cell detected by the UE is cell B or C. As a result, handovers from cell A cannot be initiated and service drops occur. And also, if the intra-Radio Access Technologies (RAT) event-triggered ANR is enabled and the UE supports ANR, the eNodeB can identify cell B based on the E-UTRAN cell global identifier (ECGI), reported by the UE and initiate a handover to cell B if required.

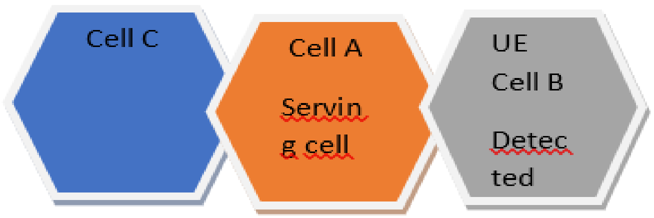


Figure 4.1.6

Figure 5 : Cell B and C use the same frequency and PCI. Cell B and C are neighbouring cells of cell A.

Figure 6 : Cell B and C use the same frequency and PCI. Cell B and C are neighbouring cells of cell A.

- The detected cell is not a configured neighbouring cell of the serving cell. As illustrated in the figure below, cell B is the detected cell meeting handover conditions and is not a configured neighbouring cell of cell A. the eNodeB incorrectly considers that the UE detects the neighbouring cell (cell C) and initiates a handover to the cell. If the current area is not covered by cell C but covered by cell B, the handover may fail.

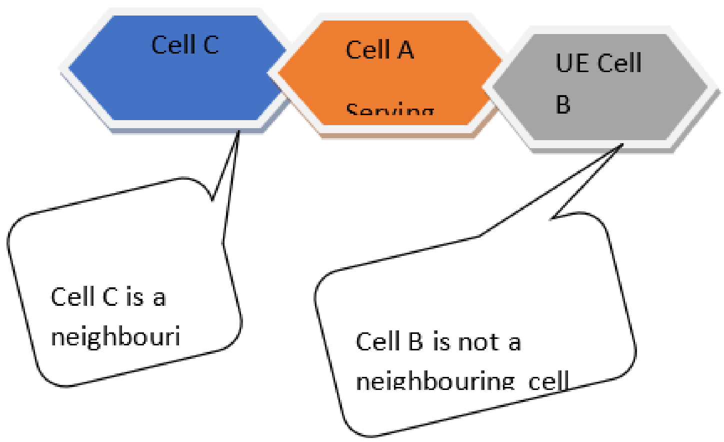


Figure 7 : Cell B and C use the same frequency and PCI. Cell B and C are neighbouring cells of cell A - Cell C is not neighbouring cell of cell A

**Detection method analysis**

The eNodeB checks whether the neighbouring relation table (NRT) of the serving cell contains two or more intra-frequency neighbouring cells with the same PCI. If it does, the eNodeB detects PCI confusion. However, an NRT contains information about the neighbour relations of the a local cell and other cells. As illustrated in the figure below, cells B and C use the same frequency and PCI. The eNodeB detects PCI confusion between cells B and C

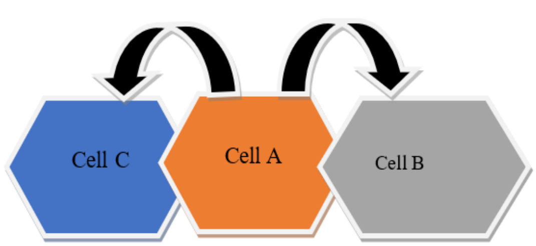


Figure 8 : Cell B and C are neighbouring cells of cell A.

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**PCI Planning**

In this section, we proposed an optimal PCI planning process in order to mitigate the PCI collision/confusion issues on the mobile network. How ever, the optimal process/procedure goes as does:

For each cell, $PCI_i = 3S_j + P_k$

- ✓ i=0------------503
- ✓ j=0------------167 group
- ✓ k=0-----------2 ID

The sequence for the SSS signal is generated as follows:

- ➢ $m_0$ = m' mode 31
- ➢ $m_1 = [m_0 + \text{INT}(\frac{m'}{31}) + 1] \bmod 31$
- ➢ $m' = Si + \frac{q(q+1)}{2}$ ; implies $Si + \frac{1}{2}[q(q+1)]$
- ➢ $q = \text{INT}((Si + \frac{q'(q'+1)}{2})/30)$ ; implies $q' = \text{INT}(Si/30)$

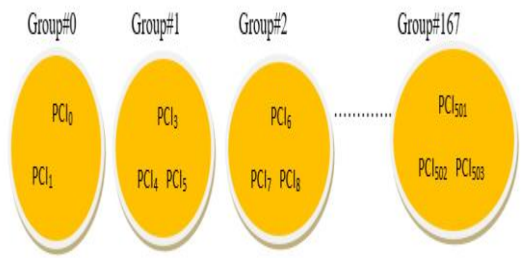

Figure 24 : Simulation scenario

Simulation hint that, the following combinations at adjacent cells will give bad performance in the mobile network, that is long synchronization times and high interferences leading to poor QoE:

- ✓ Same ID, that is same k
- ✓ Same $m_0$
- ✓ Same $m_1$

For example, $PCI_i = 0$ implies $PCI_i$ = 3,6, ……498, 501 and 1, 2, 90, 91,177, 178, 179, 261, 262, 263, 342, 343, 344, 420, 421, 422, 495, 496, 497 are not optimal combinations for adjacent cells. This is only valid in the case where cells are synchronized.

**PCI self-Optimization function for E2E QoE-awareness**

The PCI self-optimization function is implemented on the network management platform. Once a user has created and started a PCI self-optimization task on the platform, it performs PCI self-optimization analysis for eNodeBs based on the reported PCI conflict information within a PCI self-Optimization period:

- If the network management platform reallocates a new PCI to the conflicting cell, PCI self-optimization are displayed on the platform
- If the network management does not reallocate a new PCI to the conflicting cell, this cell continues using the old PCI, and the PCI self-optimization suggestion are not displayed on the platform

**Scenario 2: 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 the best-effort principles and the regulator only allow the implementation of 'rea-sonable' 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.

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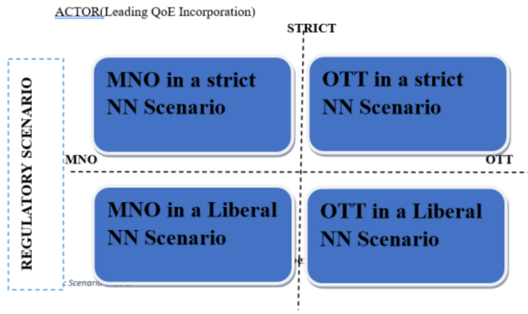



If the user authorises it, MNO can implement a mechanism to monitor the network operation as well as keep track of the users' experience with the service provision, collecting information from the users' devices.

**QoE MNO Technical overview of PCI algorithmic function**

The eNodeB uses the intra-RAT automatic neighbor relation (ANR) function to automatically identify missing neighboring cell configurations, and to maintain the intra-RAT (Radio Access Technology) neighboring cell list (NCL) and neighboring relation table (NRT). If intra-RAT ANR changes neighboring cell parameter settings, the eNodeB will trigger PCI conflict detection.

**Proactive Intra-RAT ANR-based PCI conflict detection overview for optimal QoE**

Proactive intra-RAT ANR-based PCI conflict detection is used to detect PCI confusion between configured and unconfigured neighboring cells, or PCI confusion among unconfigured neighboring cells. This detection requires the intra-RAT ANR function.

When ANR is enabled, the ANR.ActivePciConflickSwitch parameter determines whether to enable proactive intra-RAT ANR-based PCI conflict detection. If this parameter is set to ON, a time range specified by ANR.StartTime and ANR.StopTime will be configured for the eNodeB to read neighboring cell's ECGI and add unknown neighboring cells, and then triggers PCI Conflict detection as the procedure shown in Figure 26 below.

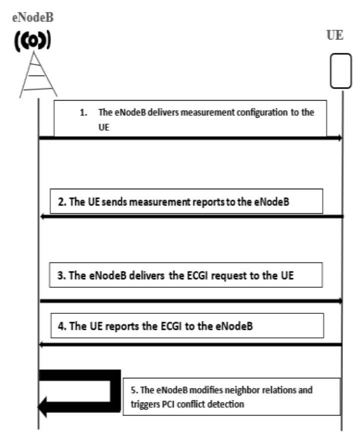



*Figure 26 : Call flow*

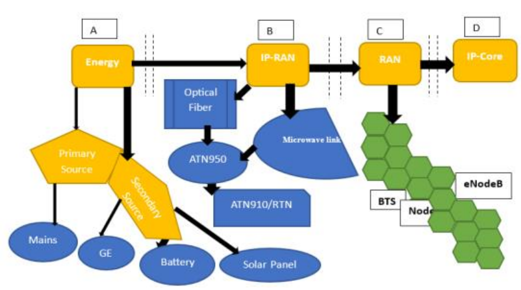
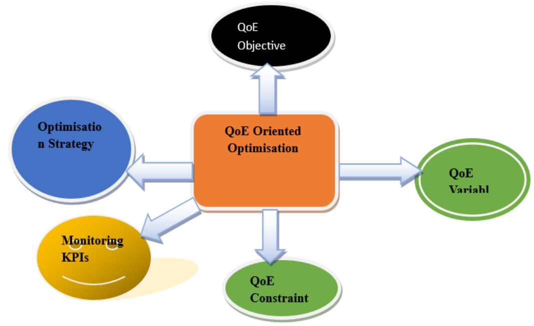



Figure 27: Block diagram of GSM-UMTS-LTE for Cross Layer Oriented Optimisation

For an optimal QoE, A+B+C+D=1 (Logic state 1), because in digital logic, higher voltage is defined as logic state '1' and lower voltage is defined as logic state '0'. Note that everything about mobile networking now is 98.9 Internet protocol based with their corresponding binary combinations.

Considering A=layer 1; B=Layer 2; C=Layer 3; and D= Layer 4

Therefore, we can apply the principle of cross layer-oriented optimisation




**Single Site Verification (SSV) & Multiple site verification (MSV)**

SSV drive test or SCFT drive test is all about performing 5G/4G/3G/2G drive test analysis on a particular site (Example newly installed cell tower) and this is usually performed by drive testing or by walk testing around the site.

In site level testing, site is ready for performing SSV testing after completion of engineering, installation and integration and no active alarms are observed. The main aim of SSV testing is to validate functional performance of the site and identify/flag workmanship issues, product issues & provisioning issues before turning the site on for commercial users. Such kind of SSV testing for site entails stationery and mobility drive tests conducted using smartphone app-based solution. For example, G-net Track, Cellular Z, Network cell info, nPerf, Rant Cell are Android app-based application that can perform SSV tests for a site and includes CSFB (Circuit Switch Fall Back) Calls, Volte Calls, Ping Test, FTP file Uploads and Downloads.

Single cell functionality test or single site verification is a static test which collects each sector information of the cell site in terms of coverage and quality parameters depend upon the technology like 3G, 4G LTE, 5G in the cellular mobile network.

As the name suggests, network tests like drive test 3G, 4G LTE drive test, 5G drive test when performed on a group of cells is termed as a 'Cluster drive test' or 'MSV'.

Initially, in traditional drive test, network testers used to drive along target routes to collect information regarding coverage data through various iterations and field tests with cellular rf drive test equipment. But, as telecom businesses are expanding, it is cumbersome to refine expanded networks in terms of size, capacity, and number of users. With cluster drive test, operators can perform network tests by taking a group of cells and deploy it in a particular location and investigate the network accordingly.

Cluster drive test is executed when the network is in active mode (i.e. providing service to customers) and inspect the interference amid two cells and handover taking place or not. Network parameter details like Drive Route, Quality plots of RSRQ, SINR, PUSCH, Coverage plot, Download and Upload throughput is accumulated. Operators use this data to get output which is further utilized to optimize the mobile network and deliver efficient service to users.

Multiple site verification or 4G LTE drive test must have measurements of radio parameters such as RSRP, RSRQ, SINR, PCI, EARFCN, and WCDMA drive test parameters like RSCP, RSSI, $ECN_O$, PSC, UARFCN etc. at least at basic level to identify primary network issues. Implementation of cell lock / band lock feature allows RF engineers to measure all these parameters on selected bands as per their requirements.

**IV. Conclusion**

The main aim of this thesis was to critically 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. The work is equally supported with mathematical models relating QoE with technical, regulatory & business environments in function of MNOs as key actors. This paper further assesses and unfold a key factor at the technical level that could impaired radio resources management and consequently affects E2E QoE, and proposes a solution for optimization. However, discussion of the results obtained in this dissertation are provided below.

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