The Analysis of Key Performance Indicators (KPI) in 4G/LTE Networks

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Abstract. The main challenge of MNOs (Mobile Network Operators) is providing multimedia services with high performance. The 4G/LTE technology has been developed to meet user requirements and provide high network performance. In order to monitor and optimize the network performance, there is a need of using Key Performance Indicators (KPIs). The KPIs can control the quality of provided services and achieved resource utilization. These indicators are categorized into the following subcategories: accessibility, retainability, mobility, integrity and availability. The presented analysis is performed on real network implemented by Telecom of Kosovo (TK) that is the main mobile Operator in Kosovo. Measurements and analysis are focused on a 24-cell cluster of 4G/LTE TK.

Keywords: Multimedia · Mobility · Integrity · Availability · 4G/LTE

1 Introduction

We are living a digital revolution where information is mostly presented in a multimedia context. Costumers do not use only voice and data services, but they are keen to use multimedia services as well. Mobility, supported by mobile communication systems and necessity to communicate at any time and from everywhere, add additional requirements to networking paradigms. In order to meet these growing requirements, mobile technologies have passed through a number of generations from the first generation (1G) to nowadays fourth generation (4G) [1–9], and future 5G and beyond.

A tremendous demand for mobility and higher data rates has resulted in development of more reliable mobile networks. To support these demand,, Telecom of Kosovo (TK) offers different services to its customers, such as voice and data services through various mobile systems, such as 2G, 3G and 4G/LTE [2].

The 4G/LTE technology is still facing some problems such are uninterrupted communication, security and high performance [10–18]. Moreover, the QoS (Quality of Service) and security issues are critical for some basic services, such as VoIP [19–26] and IPTV services [2, 27–30]. The TK also aims to address these issues with high attention, in order to provide services with high quality to its users.§

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This paper focuses on performance analyses of TK's 4G/LTE network, based on the main KPI performance indicators. More specifically, it is focused on analyzing the following key indicators: *mobility, integrity* and *availability*. The measurements are performed on a segment of the TK's 4G/LTE network in Pristina, consisting of 24 base stations. The notified indicators are measured at network level.

The paper is organized as follows: the next section presents a literature review related to KPI performance analysis in 4G/LTE technology; Sect. 3, delves into general aspects and explains the 4G/LTE network architecture; Sect. 4 and Sect. 5 introduce the KPI performance indicators and demonstrate the importance of their analysis in offering services with high quality in 4G. Section 6 provides analysis of the KPI parameters in TK and Sect. 7 gives concluding remarks.

2 Literature Review

Recently, we are witnessing growing interest in research focusing on KPI performance analysis in 4G/LTE networks. Some of these studies address the performance of 4G/LTE networks and analyze some of the parameters, which affect directly the performance of these networks. Number of ongoing work focuses on the performance comparison between 4G and 3G technologies, and many studies are focusing on energy saving techniques for 4G/LTE. The authors in [2] address some of the main parameters, which affect the network performance (KPI indicators), such as: accessibility and retainability in real network. But, according to our knowledge, none of these studies has addressed jointly the *mobility, integrity* and *availability* in a real and active network.

Authors in [1] analyze the performance and power characteristics of 4G/LTE in comparison with 3G/Wi-Fi networks. They designed a tool for android devices called *4Gtest* attacking more than 3000 users within a two months period of time. They also observed the network performance of LTE networks. Using a comprehensive data set consisting of 5-month traces of 20 smartphone users, the authors in [1] investigate also the energy usage in 3G, LTE, and Wi-Fi networks and evaluate the impact of configuring LTE-related parameters.

Authors in [2] address the KPI performance indicators in order to monitor and optimize the mobile network performance. They are focusing only on two parameters, such as accessibility and the retainability. Measurements and analysis are performed for a 24-cell cluster of real 4G/LTE network. The authors found out that the performance of the 4G/LTE network stays within the recommended values of 3GPP standard and manufacturers. Our work will be a continuation of this work and will analyze some different parameters, which are very important for quality optimization in 4G/LTE networks.

Knowing that one of the main challenges of 4G is security that can prevent a network to be entirely compromised by malicious devices, the authors in [3] are focusing on security aspects of 4G networks. They identify the vulnerability of the handover key management as so called desynchronization attacks. Such attacks jeopardize secure communication between users and mobile networks and are influencing the entire network performance. They explore how the network operators can determine an optimal interval for updates that minimizes the signaling load, while protecting the security of user traffic. The analytical and simulation studies demonstrate the impact of the key update interval on performance criteria such as network topology and user mobility.

The authors in [4] study the security issues and the impact on the performance of 4G/LTE. In 4G networks, the forward key separation plays a vital role in handover process and it can be vulnerable due to the presence of rogue base stations. The periodic update of the root key stored in the base stations can reduce the consequences from different attacks. But, the selection of the best possible key update interval is a vague issue and therefore it is difficult to achieve stability between the degree of the exposed messages and the signaling load. The competitors can sign up into the website multiple times and degrade the performance of a certain web server in 4G network. This paper proposes a method that maintains history/status tables to keep a record of the media access control address in an intranet environment. The performance analysis shows that this proposed system provides better security and significant reduction in latency, and thus improves the overall quality of the 4G.

Authors in [5] observe the performance analysis and optimization of LTE key features. They conclude that the current deployment of the LTE system involves several levels of optimizations and enhancements offered to the users. Authors in [5] focus mainly on LTE features of 3GPP's Release 8 and 9 standards. The performance aspects explain in details the following features/enhancements: LTE connected mode Discontinuous Reception (C-DRX), which is used to conserve the battery of mobile devices, the circuit switch fallback solution (CSFB, a protocol which allows voice to be transmitted over LTE) used to support voice calls over LTE, and multi-input–multiple-output (MIMO) techniques.

Recently, a lot of studies addressed the performance analysis of the 5G networks [6–13]. However, since the 5G era still is not completely standardized and tested, this paper focuses on the most advanced features and performance improvement in 4G/LTE systems, since they will be present for some years from now, especially in the developed countries. The aim in this paper is to analyze the key performance indicators in the real TK's 4G/L network. Moreover, we are focusing on optimizing network parameters in order to offer high perceptual quality to the end users.

3 General Aspects and Network Architecture of 4G/LTE

Due to the continuous increase in requirements for higher capacity and QoS, UMTS technology has faced some design constraints, similar to the limitations that GSM and GPRS faced a decade ago. The 3GPP (Third Generation Partnership Project), decided to redesign two segments of the system; the radio and the backbone segments [2].

The results in today's LTE (Long-Term Evolution) system. The development of the network from the perspective of data rates is presented in Fig. 1. A key requirement for LTE was to facilitate a smooth transition from the current mobile communications systems to the new systems. This is enabled by reusing the current spectrum of previous technologies, resolving interaction between the current and the future systems and the reusing of the existing network infrastructure. All 4G/LTE network interfaces are based on IP (Internet Protocol).

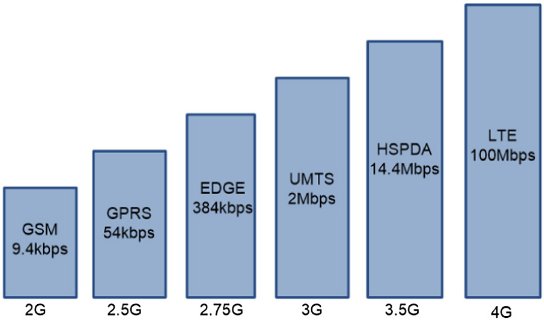

Fig. 1. Network development from GSM to LTE from the perspective of data traffic rates [17]

The overall architecture of the LTE network is similar with the GSM and UMTS networks. In principle, the network is divided on radio network part and central network part, as shown in Fig. 2. However, the number of logical network nodes has been reduced to simplify the architecture leading to flat architecture design. That reduces the implementation cost and the overall delays in the network [2, 18, 26]. Figure 2 presents the general LTE architecture. The tasks of each element is clarified below:

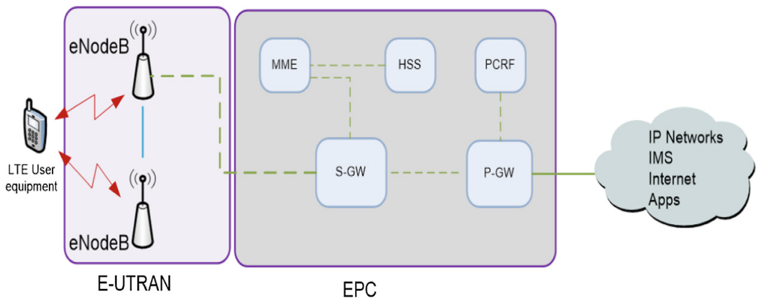

Fig. 2. General LTE architecture according to 3GPP release 8

- *E-UTRAN:* Is responsible for establishing radio communications between the EU (User Equipment) and the Evolved Packet Core (EPC) network. The E-UTRAN consists of eNodeBs, which are base stations (similar to BTS in 2G or NodeB in 3G) that connects and controls the EU's activities with the EPC [2].
- *P-GW (Packet Data Network Gateway):* P-GW is responsible for allocating IP addresses to the UE, QoS implementation and traffic-based charging.
- *S-GW (Serving Gateway):* All IP packets are transmitted via S-GW. Also, the S-GW is used to hold information for carriers when the UE is in idle state.
- *MME (Mobility Management Entity):* MME is considered as the control node that is used to process signaling between the UE and CN.

4 The KPI (Key Performance Indicators) in 4G/LTE Network

The 4G/LTE optimization process is very complex task for the Mobile Network Operators (MNOs). This process includes the effects of multiple factors, which should be considered separately. Today, the MNOs are facing many challenges such as dynamically changing service requirements, technologies, competition, etc. In some ways, this has changed the MNOs' business model and new tools are required not only to manage the network, but also the subscribers. The KPI indicators are used to measure the network performance. These indicators should be selected in a way that they measure end-user performances and the resource utilization [2].

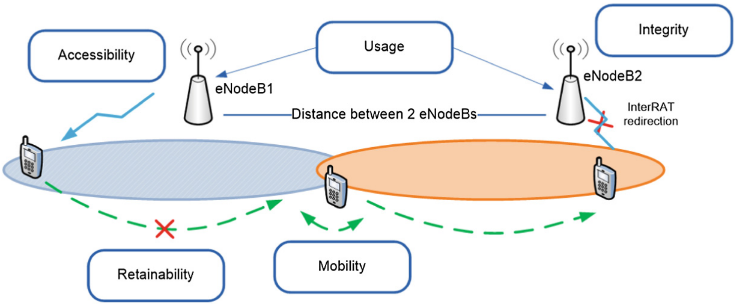

Fig. 3. 4G/LTE Key performances indicators

The main optimization target is to maximize the KPI performances while minimizing the resource utilization [14]. These indicators can be also used to detect unacceptable performances features. In most states, regulatory authorities publish target levels of the KPIs values and the MNOs are obliged to meet them. The 3GPP standardized 4G/LTE networking KPIs are presented in Fig. 3 and are categorized as follows: accessibility, retainability, mobility, integrity and availability [2, 15–17].

5 Key Performance Analysis in 4G/LTE Network; Mobility, Integrity and Availability

The process of optimization of the 4G/LTE network includes the *effects of multiple factors*, which should be considered carefully. The KPI indicators should be selected in a way that they can measure end users' performance [14]. The KPIs can be used for monitoring and optimization of the radio network performances in order to provide better QoS in the 4G/LTE network. In this section, we analyze only three parameters: *mobility, integrity* and *availability.*

5.1 Mobility

Mobility is one of the fundamental functionalities, which enables continuous services for the mobile users inside one particular zone, when they are mobile. Mobility KPIs are related to Handover (HO). The measurements include the number of HOs inside the E-UTRAN (intra HOs) and between the different radio technologies (interRAT HOs). These measurements should be performed on the cell level or for group of cells. The relevan KPIs are:

- *Intra-frequency Handover Success Rate:* This KPI is used to evaluate the intra-frequency HO success rate. This parameter is shown better with the Eq. (1) below:

$$\text{IntraFHOSR} = \frac{IntraFHOSuccess}{IntraFHOAttempt} \times 100\% \tag{1}$$

- *Inter-frequency Handover Success Rate:* This KPI is used for evaluating inter-frequency HO success rate. The equation for this KPI parameter is given in Eq. (2):

$$\text{InterFHOSR} = \frac{InterFHOSuccess}{InterFHOAttempt} \times 100\% \tag{2}$$

- *Inter-RAT Handover Success Rate (LTE to WCDMA):* This KPI is used to evaluate inter-RAT HO success rate from LTE to WCDMA network. The equation for this KPI parameter is given in Eq. (3).

$$\text{IRATHO}_{\text{L2W}_{\text{SR}}} = \frac{IRATHO\_L2W\_success}{IRATHO\_L2W\_Attempt} \times 100\% \tag{3}$$

- *Inter-RAT Handover Success Rate (LTE to GERAN):* This KPI is used to perform the Inter-RAT HO success rate from LTE network to GERAN (Eq 4).

$$\text{IRATHO}_{\text{L2G}_{\text{SR}}} = \frac{IRATHO_{L2G_{success}}}{IRATHO_{L2G_{Attempt}}} \times 100\% \tag{4}$$

5.2 Integrity

The integrity KPI parameters show the impact of E-UTRAN in the quality of service. The following parameters are calculated on the level of cells or clusters:

- *Service Downlink Average Throughput:* This parameter has some indicators, which could be used for actual downlink traffic during the busy hours.
- Service Uplink Average Throughput: This parameter is used to evaluate the uplink traffic during the busy hours.
- *Cell DL Average Throughput:* This parameter evaluates downlink data rate in kbps.
- *Cell UL Average Throughput:* This parameter evaluates uplink data rate in kbps

- *Cell DL Maximum Throughput:* This parameter is calculated based on the maximal bitrate in downlink, measured every second.

$$CellDLMaThp = \frac{CellDLMazTrafVolforEach1s\,(\mathrm{bit})}{1000\,(\mathrm{ms})} \tag{5}$$

- *Cell UL Maximum Throughput:* This parameter is calculated based on the maximal bitrate in uplink, measured every second.

$$CellMaTh = \frac{CellULMazTraffVolforEach1s(bit)}{1000(ms)} \tag{6}$$

5.3 Availability

The availability KPIs measure the percentage of time during which the network cells have not been available. According to 3GPP, one cell is considered to be available when eNodeB can offer E-RAB services in that particular cell.

The E-UTRAN Cell Availability measures the percentage of time in order to evaluate the service degradation and the network performance. This parameter can be measured in the cluster level (eq. 7).

$$\text{Availability} = \frac{meas. - \sum RRU.CellUnavailableT}{Meas_{period}} \times 100\% \tag{7}$$

6 Case Study: Analysis of KPI Parameters in TK

This section analyze some of the main KPI indicators in 4G/LTE network implemented in TK: *mobility, integrity* and *availability*. These indicators are measured at the cluster level, whereas the measurements have been performed in a cluster in Pristina City that includes the neighborhoods like “Dardania”, “Ulpiana” and part of the “Sunny Hill” [31]. Drive testing are performed using the Swiss Qual Diversity Ranger and Free Rider III equipment. This cluster consists of 24 eNodeB (sites) with a total of 63 cells. The details for a cluster created for measurements in TK network are shown in Table 1.

Table 1. The cluster created for measurement purposes in TK 4G/LTE network [31]

Technology	Sites	Cells
2G	41	115
3G	24	63
4G	24	63

The data is derived from the terminals installed in TK by different manufacturers. The results of the drive test for quality of radio coverage are shown in Fig. 4. They present average values for the entire measurement cluster. The results in Fig. 4 show that generally the value of 67.7% of moderate coverage and quality is achieved and that we are dealing with good coverage and quality in 15.7% of measured samples. Poor coverage areas have been identified also in 15.7% of the measured samples, whereas poor quality and interference in 0.9% of the measured samples.

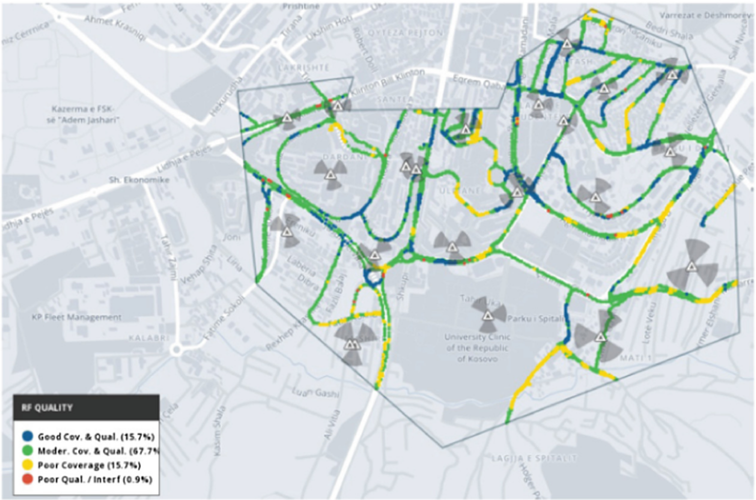

Fig. 4. Drive test results for radio coverage [31]

The results for the measured metrics (number of 4G-4G handovers, number of 3G-4G handovers, number of location update, etc.) in the selected 4G/LTE TK cluster are presented in Table 2. Based on these activities we calculate the 4G network's KPIs (mobility, integrity and availability) for this cluster.

Table 2. Drive Test measurements in the considered cluster [31]

Ping Delay Avg (ms)	53.40
Ping Delay Max (ms)	53.81
Ping Delay Min (ms)	52.99
Call attempt	140
Call reselection from UTRAN	119
Location area Update	254
Handover 4G-4G	978
Handover 3G-4G	289

Based on the technical specification for 3G and 4G networks, the measurements were performed in several TK's clusters. The measured results for mobility are presented in Table 3.

Table 3. Main KPIs for 4G/LTE network in TK for mobility [31]

QoS Area	4G KPI	TK KPIs
Mobility	Intra LTE inter-cell HO SR	–
	Intra eNB HO SR (Src cell)	LTE_5043a
	Intra eNB HO SR (Target Cell)	–
	Inter eNB X2 HO SR (Src C)	LTE_5058b
	Inter eNB X2 HO SR (Tar Ce)	–
	Inter eNB S1 HO SR (Sr. Cell)	LTE_5084a
	Inter eNB S1 HO SR (Targ.C)	–

Mobility: For the TK's 4G observed clusted, according the Table 3, the main KPI parameters that define the mobility are: Intra eNodeB Handover Success rate and Inter E-nodeB X2 HO success rate. The measurement results for these indicators are shown in the Fig. 5.

Fig. 5. Results after measurements in TK network for mobility [31]

For the indicator eNodeB HO success rate, the threshold have been set to 98%, which means that the lower values are reflected in quality, because the performance is degraded. Whereas the values higher than 98% mean that the quality is good. During our measurements, we measured very good values, which are from 99.35% till 99.97%. This means that the mobility from one cell to another is within the recommended values. For the indicator Inter E-nodeB X2 HO, the manufacturer have set the threshold in 96%. Our results show that the values for this indicator in TK network are from 98% to 99.84%.

Throughput (Integrity): In 4G/LTE TK network the main indicators which measure the bit rate in downlink are: Max App DL throughput (kbps) and Avg App DL throughput (kbps), whereas for uplink Max App UL throughput (kbps) and Avg App UL throughput (kbps). The obtained values for Uplink and Downlink for this TK network are the following:

- Max App DL throughput = 60 Mbps
- Avg App DL throughput = 47 Mbps
- Max App UL throughput = 34 Mbps
- Avg App UL throughput = 30 Mbps

These values are achieved using the following transmission environment: bandwidth in LTE TK network is 200 MHz for uplink and downlink, multiplexing used is FDD, mobile devices of CAT 3 Samsung S5, the speed of the car is about 20 km/h. The measurements have been performed during busy traffic hours in Pristina City. Even under these conditions, the measurements show a great network performance.

Availability: The availability is analyzed in the TK's 4G/LTE TK segment. The results are presented in the Table 4.

Table 4. Availability for 4G/LTE network in TK [31]

4G	KPI	Availability
June 2018	ALU	96.92%
	NOKIA	97.68%
	Total	97.21%
	Threshold	>99%

The results presented in Table 4 show that the availability depends on the different manufacturers. These availability's values are lower than the threshold (>99%). Analyzing the entire network, we found that in the network designed and covered by ALCATEL, the indicator that measures availability is 96.81%, whereas in the Nokia part the indicator that measures availability is 97.53%. The average of this indicator (for Alcatel and Nokia) for the entire network is 97.17%.

The KPI indicators allow us to indicate the network performance. The results clearly show that availability has lower values than the threshold (threshold > 99%).

7 Conclusions and Future Work

The innovations of multimedia technologies and services are affecting the way of doing businesses in everyday life. Managing QoS/QoE, attracting and retaining customers, improving user satisfaction and understanding the subscriber base, can significantly contribute to access successful telecommunication services.

In this paper we presented a case study performed over the TK's 4G/LTE network segment.. We analyze three of the main KPI indicators: *mobility, integrity* and *availability*. The data obtained from the measurements and analysis show high performance of the 4G/LTE TK network. The only KPI indicator, which is not within the recommended 3GPP and manufacturers' values, is *availability*. The results shows that the average value of this indicator, for both manufacturers (Nokia and Alcatel), is below the required threshold (higher than 99%). This problem is due to the power shortages in some zones, transmission problems, and hardware defects. The *mobility* and *integrity* are within the recommended values.

The results of this study shows that the main challenge for this real network is the huge increase in the demand for access to 4G/LTE services and the rapid growth in the volume of data traffic that affects the network performance. The possible degradation of the analysed KPIs directs TK to increase the network coverage of 4G/LTE, especially in some areas where coverage does not meet the criteria in accordance with standards and manufacturers. From measurement results and analysis, we have learned that the TK needs to make greater efforts and investments to cover with signal these problematic areas, particularly with 3G and 4G, as the only alternative for having access to Internet and other multimedia services. It is recommended to have particular tools for optimization, that can be implemented on both hardware and software upgrade systems. The constant checking of the KPIs should enable adaptation to increasing data traffic.

Our future work will be focused on analyzing the QoS and QoE in the overall 4G/LTE network implemented in TK. Also, we will try to address the main challenges that the Operators will face during the transition process from 4G to 5G technologies.

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