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Performance analysis of 4G broadband cellular networks

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ABSTRACT

Mobile and wireless networks have recently seen a remarkable development at the global level. This applies to previous and current generations, which have seen the development of telecommunications networks mainly in GSM, 2G, UMTS and 3G networks. Evolutions are continuing everywhere of specialized networks such as sensors, smart tags, and telecom networks. They now see contend solutions which coming from various horizons: classic telecom world with HSDPA, world of wireless networks with WiMAX even in the world of satellite and terrestrial broadcasting (DVB-T, DVB-H, DVB-S). The fourth-generation (4G) wireless network is truly a turning point in the proliferation and disparity of existing solutions. The main parameters of the 4G network that have made this network the best and the most expensive are its very high bandwidth used, the much lower latency than in the 3G network, a high bandwidth, a flexible frequency band, and a interoperability with other networks so this parameter gives the choice to the user for their use within the 4G. This paper presents an analysis of the performance of 4G networks and its different Quality of Service. A simulation demonstrating the performance of 4th generation cellular networks is presented. Good simulation and good results were obtained using the NetSim simulator.

1. Introduction

For several years the development of mobile networks has not stopped growing, several generations have emerged (1G, 2G, 3G, 4G and soon the 5G) and known a remarkable evolution, providing an exceptional flow and which does not steadily increasing, bandwidth becoming larger and one of the advantages of such bandwidth is the number of users which can be assisted. The networks of the 1st generation (also called 1G) were integrated into the telecommunication network in the 80s. However, these systems were abandoned a few years ago giving way to the second generation, called 2G launched in 1991. It is still active today. We can distinguish two other types of generations within the second: 2.5 and 2.75. The main standard using 2G is GSM. Unlike the 1G, the second generation of standards allows access to various services, such as the use of WAP to access the Internet, so much so that for the 3rd generation known as 3G allows broadband for internet access and data transfer. For the next generation 4G (LTE), it allows very high speed, low latency and many other services (Li and Sampalli, 2007).

Mobile communications services are following the same evolution as fixed services, which is an accelerated transition to very high speed access. It is 4G networks that are able to meet the growing demands of mobile usage, both in terms of the quality of the services offered and the capacity of traffic flow through networks (Baskett et al., 1975).

These frequencies are intended for the deployment of very high speed mobile networks, to bring to the consumer a capacity and a quality of services superior to the current offers of mobile internet. Long Term Evolution (LTE) technology offers users speeds of several tens of Mbps, far superior to the performance of 3G and 3G + technologies, as well as lower latencies for greater interactivity (Chang et al., 2015).

With 4G, we are moving towards the transmission of all information (voice and data) by IP, the same protocol used on the Internet. For suppliers, it's easier and cheaper to manage. It also facilitates the development of multimedia applications. This generation provides faster download speeds and shorter latency (Jameel and Shafiei, 2017).

According to the criteria of the International Telecommunications Union (ITU), which establishes the standards for cellular networks, the true 4G should offer download speeds of 100 Mbit/s for a

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user in motion and 1 Gbit/s in mode stationary (Grondalen and Osterbo, 2012).

We divide the paper as follows: Section 2 provides a brief about the different components and features of the 4G LTE network. Section 3 explains the quality of service performance of LTE technology.

Section 4 clarifies the simulation of the different parameters of the existing QoS in 4G. Lastly, section 5 concludes the final of the paper.

2. 4G LTE network

Long Term Evolution (LTE) or 4G technology relies on an IP packet-switched transport network. It does not provide a routing mode for the voice, other than VoIP, unlike 3G that carries the voice in circuit mode.

LTE radio frequency is used with a different width from 1.4 MHz to 20 MHz, thus making it possible to obtain (for a 20 MHz band) a bit rate of up to 300 Mbit/s in "downlink", while the "true 4G" offers a downstream flow of up to 1 Gbit/s (Hyytia and Virtamo, 2007).

LTE technology is based on a combination of sophisticated technologies that can significantly increase the performance level (very high speed and latency) over existing 3G networks. Orthogonal Frequency Division Multiple Access (OFDMA) multiplexing provides optimization in frequency utilization by minimizing interference. The use of multiple antenna techniques (already used for Wi-Fi or WiMax) increases the number of parallel communication channels, increasing total throughput and range (Huang et al., 2014).

LTE networks are cellular networks made up of thousands of radio cells that use the same radio frequencies, including the radio frequency cells, OFDMA and SC-FDMA radio coding. Fig. 1 illustrates the architecture of the LTE network.

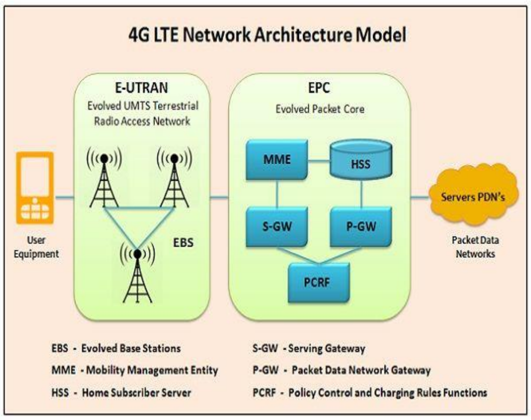

Fig. 1: General architecture of LTE

The new blocks specified in the architecture, also well-known as Evolved Packet System (EPS), Evolved Packet Core (EPC) and Evolved UTRAN (E-UTRAN) (Huang et al., 2014). Fig. 2 shows a simplified architecture of the EPS part of the LTE network.

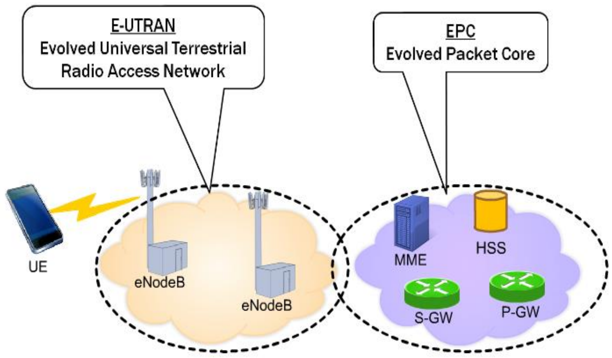

Fig. 2: Evolved packet system architecture

The main network called Evolved Packet Core (EPC) uses technologies "full IP", that is to say based on Internet protocols for signaling that allows reduced latency, the transport of voice and Data. This backbone enables interconnection via routers with other remote eNodeBs, networks of other mobile operators, fixed-line networks and the Internet (Li and Sampalli, 2007).

The radio portion of the network, called "eUTRAN" is simplified compared to 2G (BSS) and 3G (UTRAN) networks by integrating into "eNodeB" base stations with fiber optic links and IP links connecting the eNodeB between them (Li et al., 2013). As well as control functions that were previously implemented in the RNC (Radio Network Controller) of 3G UMTS networks (Chahed et al., 2008). This part is responsible for radio resource management, compression, security, carrier, and connectivity to the advanced core network. The eNodeB is the equivalent of the BTS in the GSM and NodeB network in the UMTS, the handover functionality is more robust in LTE. These are antennas that connect the UEs to the core LTE network via the RF air interface. As well as providing the functionality of the radio controller lies in eNodeB, the result is more efficient, and the network is less latent, for example, mobility is determined by eNodeB instead of BSC or RNC (Lobinger et al., 2010).

The IP Multimedia Sub-System (IMS) is a NGN (Next Generation Network) standardized technique for telephony operators that provides fixed and mobile multimedia services. This architecture uses VoIP technology as well as a standardized 3GPP implementation (Hayat et al., 2016).

Existing telephone systems (packet switching and circuit switching) are confirmed. The goal of IMS is not only to allow new services, existing or future, offered on the Internet, users must also be able to use these services both on the move (roaming situation) than from home. For this, the IMS utilizes IP protocols. Thus, a multimedia session, whether it is, among IMS user, or even among two Internet users, is decided to use exactly the same protocol. In addition, service development interfaces rely on IP protocols. That is why IMS is really converging the Internet and the world of cellular telephony. Cellular technologies are also used to reach anywhere and use Internet technologies to supply all services (Grondalen and Osterbo, 2012).

The 4G makes it possible to have very reliable QoS performances, by citing in the following some parameters. The use of OFDMA coding is FDMA type radio coding technology for the downlink and SC-FDMA (Single- carrier FDMA is a frequency division multiple access radio coding technology for the uplink instead of W-CDMA in UMTS).

The OFDMA and its SC-FDMA variant are derived from the OFDM coding (used, for example on the ADSL links and in the WiFi networks), but unlike the OFDM, the OFDMA is optimized for the multiple access, it is the simultaneous sharing of the spectral resource (frequency band) between several users distant from each other. The OFDMA is compatible with the MIMO antenna technique.

Mobility is a key function for mobile networks. The LTE aims to remain functional for EU moving at high speeds (up to 350 km/h, and even 500 km/h dependent on the frequency band), while being optimized for EU speeds low (between 0 and 15 km/h). The effect of intra-system handovers (mobility procedure between two LTE cells) on voice quality is less than in GSM, or equivalent (Li et al., 2013). The system also incorporates mechanisms that optimize delays and packet loss during intra-system handover (Yeo and Alwi, 2012).

Mainly by the implementation of 16 QAM 16 (16 Quadrature Amplitude Modulation with 16 states): This modulation makes it possible to double the transfer capacity compared to the modulation used for UMTS, the QPSK (Quadrature Phase Shift Keying) which is based on two carriers of the same frequency out of phase by 90 degrees, i.e., 4 states of information. For its part, the 16 QAM combines two amplitude levels with two quadrature carriers, i.e., 16 information states. Each of these modulations is used for a specific link such as: Downlink Modulations (QPSK, 16 QAM, and 64 QAM) and Uplink Modulations (QPSK and 16 QAM) (Liu et al., 2005).

3. Quality of service performance of LTE technology

In every network to set up whether in telecommunication, computer or other, the biggest goal is to have the best performance. For this the rate of Quality of Service must be at least at the level of user requirements, for their full satisfaction.

The key objective of an operator is to regroup the largest number of subscribers to be able to increase its turnover, for that each mobile operator will have this focused on the requests of these customers thus to increase its rate of popularity, for that he must be concerned about the improvement of his network and the parameters of the Quality of Service.

(QoS) is the capability to transmit a certain number of packets in a connection between a transmitter and a receiver in good conditions, and this can be presented under several terms such as availability, speed, delays, transmission, jitter, packet loss rate. It groups together a set of technologies implemented to ensure sufficient and constant flows on all types of networks (Wang and Sheu, 2006).

The goal of QoS is to optimize network resources and ensure good application performance. The quality of service on the networks makes it possible to offer users speeds and response times differentiated by application according to the protocols implemented at the level of the network layer. It enables service providers to formally engage their customers on application data transport characteristics on their IP infrastructures (Wang et al., 2005).

Within a given network, the quality of service is evaluated according to the various equipment that make up this network, as well as the traffic that circulates there, etc. Multimedia applications, for example, video on demand or voice over IP, in addition to conventional applications, will be increasingly used in this type of network. These multimedia applications require a low level in quality of service in terms of several factors such as jitter, latency, bandwidth or packet loss rates (Vassoudevan and Samundiswary, 2016).

Let consider C classes of services. For a mobile of class i ($i \in S = \{1, \dots, C\}$), its signal-to-noise ratio plus interference (SIR) at the base station shall satisfy the condition below, in order to guarantee an uninterrupted communication

$$\frac{P_i}{N + I_{own} + I_{other} - P_i} = \alpha i \geq \left(\frac{E_i}{N0}\frac{R_i}{W}\right) = \chi, \quad (1)$$

where Pi is the power received from a mobile of class i by the base station; N is the power density of the background noise; Ei is the transmitted bit energy of type i, Ri is the transmission rate of service class i; W is the spread spectrum of the bandwidth; $Iown$ denotes the intra-interference received from all the mobiles belonging to the same cell and $Iother$ denotes the inter-interference received from all the mobiles of the other sectors. We recall that inter and intra cellular interferences are respectively:

$$I_{own} = \sum_{j=1}^{C} M_j P_j$$
$$I_{other} = g I_{own} \quad (2)$$

where g is the interference constant given by experiment and Mi is the number of mobiles of class i.

The SIR ratio must be greater than or equal to $\frac{E_i}{N_0}\frac{R_i}{W}$. For a better satisfaction of calls of the class i, without degradation of the quality of service, and in order to serve a large number of users, the minimum power received (Pi) must satisfy the following equation

$$P_i = \frac{N\Delta_i}{1 - (1+g)\sum_{j=1}^{C}\Delta_j} \quad (3)$$

where $\Delta_i = \frac{\gamma_i}{1+\gamma_i}$ and $\gamma_i = \frac{E_i}{N_0}\frac{R_i}{W}$. The system load rate is defined as follows

$$\theta = \sum_{j=1}^{C} M_j \Delta_j. \quad (4)$$

We get a new expression of the minimum received power P_i according to the load rate

$$P_i = \frac{N\Delta_i}{1-(1+g)\theta} \quad (5)$$

This power must be finite and positive in order to limit interference.

The development of the Internet and the number of users that can connect to this network requires the use of significant levels of QoS. In this perspective, several working groups have emerged for 4G networks. The new needs in terms of user mobility and the growth of networks allowing the nomadism of the users have migrated the problem towards the wireless networks (Peyre et al., 2008).

One of the challenges of mobile networks is to be available everywhere and all the time. For this, 4G networks have been designed to work in both dense and rural areas. A 4G cell can cover 5 km in diameter in densely populated areas and extend up to 100 km in the most remote areas (Zhu et al., 2016).

The bit rate of the 4G is 100 Mbit/s downstream and 50 Mbit/s amount. The E-UTRAN radio interface shall be capable of supporting an instantaneous 100 Mbit/s (network-to-terminal) maximum downlink rate assuming a downstream 20 MHz frequency band allocation and a maximum instantaneous uplink rate (from the terminal). 50 Mbit/s also considering a 20 MHz frequency band allocation. The technologies used are OFDMA for the downstream direction and SC-FDMA for the upstream direction (Fodor and Telek, 2005). This match to a spectrum efficiency of 5 bit/s/Hz for the downstream direction and 2.5 bit/s/Hz for the upstream direction.

Considering HSDPA at 14.4 Mbit/s with an allocation of a 5 MHz band, the spectral efficiency is 2.9 bit/s/Hz in the downstream direction. With 3G it is necessary to allocate a frequency band of 5 MHz. With LTE, it is possible to operate with a different size band with the following possibilities: 1.4, 3, 5, 10, 15 and 20 MHz, for downstream and upstream directions. The goal is to let a flexible deployment according to the needs of the operators and the services they wish to offer (Chayon et al., 2017).

With an ever-increasing speed offered to users, network applications have evolved, or more exactly new applications have appeared: multimedia applications. These applications include: IP telephony, music streaming, video conferencing, and video on demand. As these new applications are resource-intensive, traditional networks must implement QoS mechanisms for these so-called continuous flows (Jansen et al., 2010).

4. Results and interpretations

Computer networks are expanding significantly in a number of ways that may have developed over time, so it is too expensive to organize a comprehensive test that contains several devices and computers also data links to verify and validate the network protocol. This is why network simulators are used.

Network simulators offer significant savings, time and money for performing simulation tasks and are also used for network designers in order to test and analysis new protocols, modify existing protocols in one way or another, and monitor the product.

The problem studied in this paper is the simulation of the performance of 4G networks, and in particular the parameters of the QoS. Our interest is to evaluate the parameters that influence the overall performance of the 4G network.

The study of communication system performance at the network level is a complex task where specialized simulation tools must be used. In our case study, knowing that we are interested in current and future cellular systems, support for the LTE model is of paramount importance. We will then discuss the choice of the network simulator chosen to produce the results and we will expose the performances at the level of this network, according to different scenarios.

In general, the network simulators consist of many other networking technologies and protocols that help researchers to construct complex networks of existing connections and nodes. There are several network simulators such as NetSim, OPNET, OMNeT++, NS-2, NS-3, J-Sim and QualNet. NS-2 and all of them are used in the research community, the simulation code has been contributed by more than one hundred people and organizations, and the use of the simulator is still referenced in many network research works. However, a major gap in NS-2 is its scalability in terms of memory usage and simulation runtime. This is particularly a problem with regard to new areas of research in computer networks, or mesh architectures that require very wide network simulation.

In addition to NS-2, more than a dozen network simulators are currently used in universities and industry. Among the best-known simulators we choose the NetSim simulator to do our work.

The LTE standard defines quality indicators that serve as a measure of downlink and uplink transmission quality. These indicators include the Channel Quality Indicator (CQI) but also the Signal Interference Noise Ratio (SINR) and the Transport Block (TB). The CQI is a very important element in the LTE network, this indicator is mainly evaluated on the downlink in a communication so to test the quality of the transmission channel, so it is received by the EU, while the latter the reference to the eNodeB to know if it needs to increase to have good communication. SINR (Signal Interference Noise Ratio) is an indicator of the quality of the transmission of information, which is usually expressed in decibels (dB). A transport block (TB) is a set of data that is accepted by physical layer to be coded simultaneously. The timing (the choice of time) (TB) is linked precisely to the physical layer. For example, each transmission block is produced specifically every 25 milliseconds, or a multiple of 25 milliseconds.

We were able to test some QoS parameters (CQI, SINR, TB) to see the influence of some factors on these parameters by using NetSim simulator.

Fig. 3 shows the SINR as a function of the distance UE-eNodeB. We clearly see an excessive decrease of the SINR ratio, which is close to the value 0 at almost 1km distance separating the user (UE) and the antenna (eNodeB) while considering a fixed value of the noise at -148.947 dB, this is mainly due to signal attenuation, fading, dispersions and multipathing.

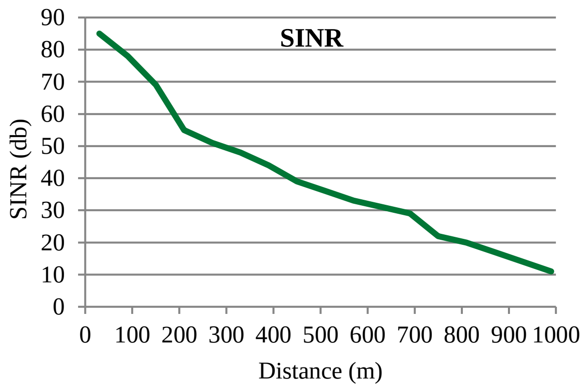

Fig. 3: SINR according to the distance UE-eNodeB

Fig. 4 shows the quality of the channel according to the distance between the UE and the eNodeB. Fig. 5 shows the number of blocks carried according to the distance between the UE and the eNodeB. It is noted that the quality of the channel and the transport are better from 12 to 430 m, after this value one observes deterioration in staircase, this degradation and due mainly to the decrease of the intensity of the signal, the increase of the rate of binary error but also to interference.

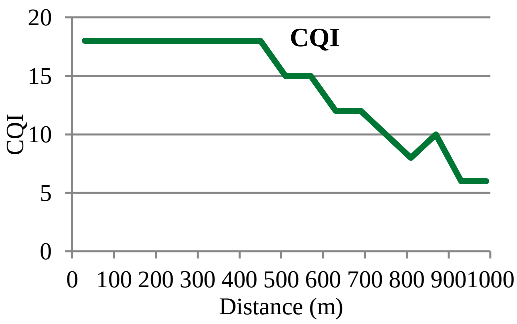

Fig. 4: CQI according to the distance UE-eNodeB

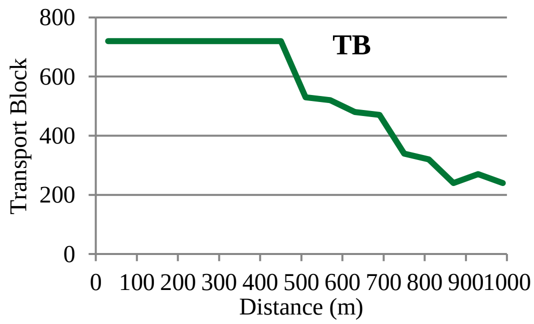

Fig. 5: TB depending on the distance between UE-eNodeB

Fig. 6, Fig. 7 and Fig. 8 show the CQI values as a function of QPSK, 16 QAM and 64 QAM. The values of the CQI vary between 1 and 8 in a communication using QPSK type modulation; this type of modulation makes it possible to transmit 2 bits per symbol. The values of the CQI vary between 7 and 10 for a communication using a 16 QAM modulation that is to say the sending of 4 bits per symbol. The values of the CQI vary between 10 and 14 for a communication using 64 QAM modulations, that is to say 6 bits per symbol.

Thus we note that 64 QAM gives the best CQI that other types of modulation used in LTE networks (16QAM and QPSK), because this type of modulation allows the sending of 6 bits per symbol and therefore a higher important rate.

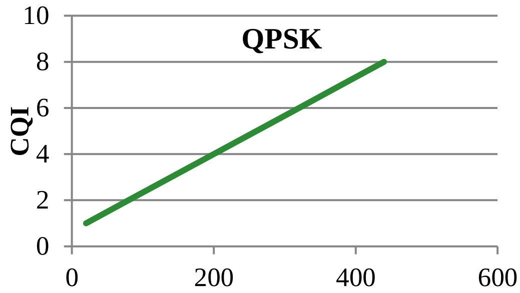

Fig. 6: CQI values according to QPSK modulation

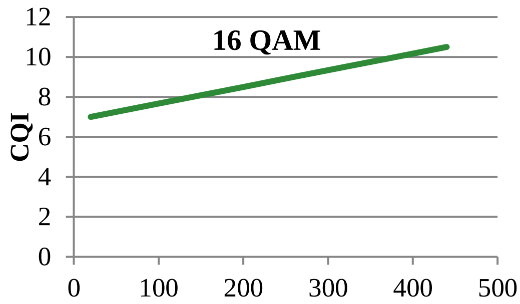

Fig. 7: CQI values based on QAM 16 modulation

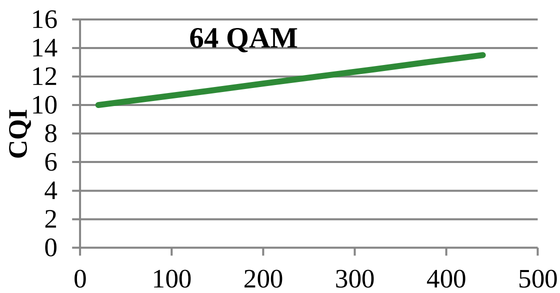

Fig. 8: CQI values according to QAM 64 modulation

5. Conclusion

Nowadays, the latest generation 4G has proven itself and is known by the best existing generation allowing very high speed and interoperability with other networks of an older generation (3G, 2G,.).

The Quality of Service (QoS) is the capability to transmit a certain number of packets in a connection between a transmitter and a receiver in good conditions. The QoS on the networks makes it possible to offer users speeds and response times differentiated by application according to the protocols implemented at the level of the network layer. In this paper, we tested the evolution in time and space of some existing parameters in 4G networks, namely: Channel Quality Indicator (CQI), Signal Interference Noise Ratio (SINR) and Transport Block (TB).

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