Performance Evaluation of Downlink LTE-Advanced CELL by MOSEL-2 Language

AYMEN I. ZREIKAT

Faculty of Science, Dep. of Information Technology,
Mutah University, P.O. Box 7, (61710), Mutah,Jordan
siayzrei@yahoo.com

KEYWORDS:
MOSEL-2 language, LTE, wireless networks, performance evaluation, 4G.

ABSTRACT:
LTE or the Long Term Evolution is the biggest jump on the evolution path from 3G towards 4G, whereby data rates are 10x those of 3G using an all packet network. LTE-advanced is a 4G recognized mobile technology satisfying the IMT-Advanced of the ITU, which will provide peak data rates in the order of 1 Gbps on the downlink and 500 Mbps on the uplink. In this work, performance evaluation of one LTE cell with three types of service (i.e. content download, video streaming and Voice over LTE (VoLTE)) will be investigated via model using MOSEL-2 language. The LTE cell will be divided into three zones according to LTE-Advanced modulation scheme, which can be quadrature phase-shift keying (QPSK), 16-phase quadrature amplitude modulation (16QAM), or 64-state quadrature amplitude modulation (64QAM) depending on the speed needs. The related performance measures of interest will be studied such as: blocking of the cell, utilization, the average bit rate per cell, throughput, aggregate average bit rate per cell to all zones as well as the aggregate average bit rate per service in each zone. The suggested model and the investigated performance measures of this research work can be useful to the planning department of mobile operators as it may provide an easy way of comparing service deployment scenarios.

1. INTRODUCTION

1.1 LTE-Advanced

Long Term Evolution (LTE) Advanced is a mobile communication standard. It was formally submitted as a candidate 4G system to ITU-T in late 2009. It was approved by the ITU as meeting the requirements of the IMT-Advanced standard, and was finalized by 3GPP in March 2011 (Parkval 2008; 3GPP spec. 2015). It is standardized by the 3rd Generation Partnership Project (3GPP) as a major enhancement of the LTE standard. Telecommunications is a key input factor in economic growth. A forecast that total telecommunications revenue will grow from \$2.1 trillion in 2012 to \$2.7 trillion in 2017 at a CAGR (Compound Annual Growth Rate) of 5.3 percent (The 2014 Telecommunications Industry Review 2014). On the other hand, mobile data is one of the fastest growing segments in wireless. It is expected that mobile data traffic will grow at a CAGR of 66 percent between 2012 and 2017, reaching 11.2 Exabyte's per month by 2017. Three times faster than fixed IP traffic (Cisco 2013). Toward the end of year 2015, it is expected (Cisco 2013) that traffic from wireless devices will exceed traffic from wired devices.

A number of options are available today for broadband bandwidth delivery. These are either wired or wireless. The wired part includes options like the digital subscriber line (DSL) and hybrid fiber/coax (HFC). Wireless is empowered by the trend that wireless services are growing at a much higher rate in comparison to wireline services. Next generation technologies and networking infrastructure are driven by increased demand for bandwidth due to the billions of multimedia and other applications. Although wireless systems have existed for more than 100 years by now, their actual use in networking is a recent one. The first public, non-proprietary wireless standard was the IEEE 802.11 of the 2 Mbps WiFi, a wireless local area network standard; that was later upgraded to 11 Mbps of IEEE 802.11b in 1999. New entries started to show up very rapidly after that aiming at providing broadband high-speed data rates to mobile users over the wireless channel. Two paths of progress appeared; one followed up the IEEE path whereby many new technologies showed up on this path; at first the 802 standard of the wireless LAN was boosted by the IEEE 802.11 a/g with data rates up to 54 Mbps and IEEE 802.11n with data rates up to 108 Mbps. Then a series of standards, IEEE 802.16 series, for metropolitan area networks started in 2000 which experimented with a number of parameters; from which the IEEE 802.16e forms the reference for the nowadays' WiMax Release 1.0 and 1.5. This was officially recognized as a 3G technology (ITU 2007). The latest one in the series is IEEE 802.16m, which was standardized in March 2011, and soon adopted as WiMax Release 2.0. It offers many folds higher data rates than release 1.0 and it is considered a 4G technology (ITU 2010). The second path, which originated from the mobile telecommunications industry path of development, was led by 3GPP and 3GPP2 organizations. Mobile technology, from its pre-cellular times in 1940s through its cellular and recent generations of the first analog and second digital generation, aimed mainly at serving voice calls. Second generation, in addition, offered very low rate data service of 9.6Kbps, which, in addition to being at a low rate, was a form of voice. This is because data and voice were provided using a circuit-switched network, and the data itself was

Proceedings 29th European Conference on Modelling and Simulation ©ECMS Valeri M. Mladenov, Petia Georgieva, Grisha Spasov, Galidiya Petrova (Editors)
ISBN: 978-0-9932440-0-1 / ISBN: 978-0-9932440-1-8 (CD)

converted to voice tones in order to be transmitted on the circuit-switched mobile network. The first real try to provide data was the addition of a packet part to the core network on the second generation GSM to provide packet switched data services in addition to the circuit switched voice services. This was called GPRS or the Generalized Packet Radio Service, which provided data at rates typically 144 Kbps, and more up to 384 Kbps when combined with some other enhancements to produce what is called EDGE, or the Enhanced Development for Global Evolution. The IMT2000 initiative of the ITU aimed at higher data rates and other features of a new (3G) mobile technology generation. The UMTS, or the Universal Mobile Telecommunication Service of the third generation partnership project (3GPP), and the CDMA2000 (of the 3GPP2 organization in the US) were the two main technologies that came satisfying the 3G requirements. They aimed at 2Mbp peak data rates. 3G technologies were also both circuit switched and packet switched. Enhancements to 3G UMTS were the HSDPA, High Speed Downlink Packet Access, and HSUPA, the High Speed Uplink Packet Access, where they provide up to 1.8-7.2 Mbps on the downlink and 5.8 Mbps on the uplink. Similar enhancement was also provided to CDMA2000, the CDMA2000 for data evolution 1xEV-DO and 1xEV-DV for data and voice evolution.

1.2 Related Work

LTE is being adopted around the world as the primary cell-phone communications service (Louis 2013). The next phase of LTE standards is called LTE-Advanced and is being deployed by Third Generation Partnership Project (3GPP). Performance evaluation of such systems is important, and it has been intensively studied in the literature (Wu 2012;Rezaei 2012; Rosa 2010; Passas 2014; Bechir 2014). In (Wu 2012), the performance of indoor and outdoor LTE network is compared at 700 MHz. The purpose of the study was to determine the performance of indoor and outdoor LTE MIMO and compare the throughput with other key performance indicators of LTE with respect to the correlation. Performance analysis of LTE and mobile WiMAX are studied and analyzed in (Rezaei 2012) for different antenna diversity in both downlink and uplink for TDD and FDD scenarios with respect to the physical layer maximum throughput. It has been found that with the same configuration, LTE outperforms Mobile WiMax. In (Rosa 2010) the focus was on the performance evaluation of uplink LTE with bursty data traffic under different power control strategies. Simulation results demonstrate that in low load conditions applying no power control (PC), can provide significant gains compared to full compensation PC. The gain is achieved both in terms of average and percentile user throughput performance. In (Passas 2014), an efficient scheme for cell planning by employing spectrum sensing techniques in LTE-A is proposed for the downlink channel. The center frequency inside the operating band is appropriately selected towards maximizing the quality of the end user experience. Performance evaluation of downlink LTE system for orthogonal frequency division multiple accesses (OFDMA) under LTE parameters is carried out in (Bechir 2014) under different schemes of configurations. It is shown that LTE performance is increased when the system is adapted to the state of the transmission channel.

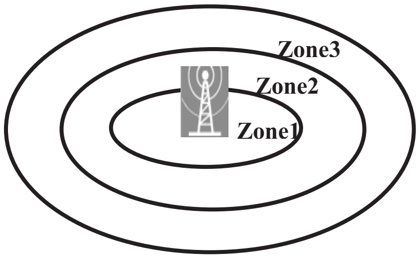
2. MODELLING

2.1 Modelling Assumptions

1. We assume a single LTE cell with maximum bit rate which is based on the used modulation technique in LTE and the maximum number of users in the cell.
2. Regarding the technical aspects of LTE. LTE uses the popular orthogonal frequency division multiplex (OFDM) modulation scheme. It provides the essential spectral efficiency to achieve high data rates but also permits multiple users to share a common channel. OFDM is also a modulation format that is very suitable for carrying high data rates - one of the key requirements for LTE. Within the OFDM signal it is possible to choose between three types of modulation for the LTE signal (LTE Modulation 2015):
   1. QPSK (= 4QAM) 2 bits per symbol
   2. 16QAM 4 bits per symbol
   3. 64QAM 6 bits per symbol

According to this, the modulation on each can be quadrature phase shift keying (QPSK), 16-phase quadrature amplitude modulation (16QAM) or 64-phase quadrature amplitude modulation (64QAM) depending on the speed needs (Louis 2013).

3. According to the modulation, in LTE, 3 zones are assumed in this analysis (Figure 1). In this model, we are more concerned with the arrival to each zone rather than the area of the zone as the area of the zone depends on the demographical distribution of users over the area served by the cell (Zreikat 2013). Therefore, we assume that the arrival rate to the cell is Poisson arrival with inter-arrival time λ and proportional to the areas of the zones ($\alpha_i \cdot \lambda$, i = 1,..., Zone$_i$), density of the users and the modulation schemes used in each zone.



Zone 1: QPSK 2 bits/symbol
Zone 2: 16 QAM 4 bits/symbol
Zone 3: 64 QAM 6 bits/symbol

Figure 1: LTE adaptive modulation zones.

2.2 QoS services and applications in LTE (QoS LTE 2013, 3GPP Spec. (Rel. 13), 2015)

1. Content download: this technology is used to download different applications; such as movies, music and pictures where considerable amount of bandwidth is needed to satisfy this service. Therefore, in this technology TCP protocol should be used to check the transmitted packets and to retransmit any lost packets. The ratio of this type of service is considered in the analysis to be 60% of the total ratio.
2. Voice over LTE (VoLTE): this technology is used to deliver voice over IP over LTE network, which usually requires low bandwidth. Therefore, this type of service must be given high priority over another service with low latency. For example, the emergency call (i.e. 911) is listed below this type of service. The ratio of this type of service is considered in the analysis to be 10% of the total ratio.
3. Video Streaming: this technology is used to deliver real time on-demand video with voice service. Therefore, the network has to satisfy higher bandwidth to satisfy the quality of service of the network. YouTube is one example of such service. The ratio of this type of service is considered in the analysis to be 30% of the total ratio.

2.3 Performance Measures

The performance measures are generated using the provided solver by MOSEL-2 language (i.e. Continuous Timed Markov Chain, CTMC). The following performance measures are considered and generated in the analysis:

1. Blocking Probability: is defined as the probability to reject the call when the bit rate of the call is below the minimum assumed bit rate of the cell.
2. Utilization: is defined as the mean total bit rate divided by the maximum cell capacity.
3. Average bitrate of the cell: is defined as the mean total bit rate in the cell divided by the average session duration.
4. Throughput: is defined as the mean total bit rate of the cell.
5. Aggregate bit rate of the cell: is defined as the mean total bit rate to all services in the cell.
6. Aggregate bit rate per service: is defined as the mean number of jobs in each service multiplied by the average bit rate of the zone where the service is requested.

3. NUMERICAL SOLUTION BY MOSEL-2 LANGUAGE

The suggested model is solved numerically using MOSEL-2 language. MOSEL-2 is the modeling specification and evaluation language which has the capability to model different types of complex systems, such as computer, communication and production systems and evaluate their performance in an efficient way. The old version MOSEL (MOSEL 2003; AL-Begain 2001) was implemented with all the necessary components to describe any system, generate the state space, derive the stochastic process and find the numerical solution of such systems in an efficient way if this system is described graphically by using either Petri Net or queuing theory models. Based on the above, the new version of MOSEL (i.e. MOSEL-2) (Wuechner 2003), is also implemented using the above characteristics in addition to the possibility by MOSEL-2 to handle both exponential and non-exponential inter-arrival and service time distributions. There was an extensive use of the old version of MOSEL (i.e. MOSEL) and the new version of MOSEL (i.e. MOSEL-2) in the literature in various applications (Zreikat 2012). Most applications of the old version of MOSEL were in performance modeling and evaluation of queueing networks. Afterward, the old version of mosel has been extensively using for modeling of 2G and the 3G of mobile networks. Recently, the new version of MOSEL (MOSEL-2) has been using to model the 4G of mobile networks and beyond (i.e. WiFi, WiMAX). Moreover, performance evaluation of LTE is investigated in this paper, and the suggested model has been solved numerically using MOSEL-2 language. The associated Intermediate Graphical Language (IGL) with MOSEL-2 is used to prepare the given results. This user-friendly package is used to prepare the figures in a very nice way with the help of its friendly environment.

The basic elements of MOSEL-2 model are *nodes* and *rules*. However, MOSEL-2 specification can be divided into six main parts:

1. The optional constant definition part, which includes constant definition, parameter definition, and the enumeration definition.
2. The node definition part, which contains the definition of the nodes.
3. The optional *function* and *condition* part.
4. The *rule* part, which contains MOSEL-2 rules.
5. The optional *result* part. This part contains the computation of the performance measures results.
6. The optional *picture* part. The graphs of the computed performance measures are created in this part.

The reliability modeling and evaluation process by MOSEL-2 language is described in Figure 2. There are six main steps that can be summarized as follows:

- Step 1. The real world system is described by the user via generating a high-level system description using the syntax of MOSEL-2 language.
- Step 2 & 3: MOSEL-2 translates the model description into a specific tool, and the appropriate tool (MOSES, SPNP or TimeNET) is invoked by MOSEL-2. This can be done by given an option in the command line. The MOSEL-2 environment is called from a shell using the following command line syntax:

  >mosel2 options input-file.mos

The parameter input file is the name of MOSEL-2 file (for example filename.mos), which has the suffix ".mos". This MOSEL-2 file is read in, parsed and checked for errors. The options are prefixed by a dash" –" followed by a single letter like "-o". Also, multiple options can follow s single dash, like "-Ts", which has the same meanings as "-T -s". To see the list and description of all command options of MOSEL-2, call MOSEL-2 with option "-h" as:
>mosel2 -h
The option "-s" causes MOSEL-2 to start the selected tool, to read the results and create the result file and if the input file contains picture definitions, an igl file will also be generated, which will contain all the figures specified in the picture part of the file in a nice way.

- Steps 4 & 5: The appropriate tool processes its input file in one of the two following ways (this can be done with different command line options in MOSEL-2):
    - o Numerical analysis: out of the static model description, the whole state space of the model is generated by the tool according to the semantic rules of its modeling formalism. This semantic model is mapped onto a stochastic process. The stochastic process is solved by one of the standard numerical solution algorithms, which are part of the tool.
    - o simulation: the model is evaluated by the tool without building the whole state space, using discrete event simulation.

The results of the numerical analysis or discrete event simulation are saved in a file with a tool specific structure.

- Step 6: The MOSEL-2 environment parses the tool specific output and generates a textual result file (i.e., filename.res) which contains the values of the performance and reliability measures according to the user description in the optional "RESULT" part of the program. Additionally, if the optional "PICTURE" part is specified, then the graphical representations of the results are generated by IGL utility in a file "filename.igl".

4. NUMERICAL RESULTS

The numerical results are generated using MOSEL-2 language and with the help of the Intermediate Graphical Language (IGL), which is associated with the MOSEL-2 package. Eleven figures are generated in the analysis. The x-axis in all figures is labeled with the total offered bit rate (Mbit/s) which is considered to be from 0.42 to 37.6 Mbit/s, while the y-axis represents the required performance measures. The first Figure in the analysis is Figure 3. It shows the blocking probability in the cell. It can be seen from this figure that when high bit rate is required for the service, the probability of blocking this service increases especially when the bit rate of the call is less than the minimum required bit rate in the cell. On the other hand, the utilization of the cell is getting better when high bit rate is gained. Of course, this higher bit rate can be achieved only in zone one where the bandwidth of the cell is high; this situation can be seen in Figure 4. Looking at Figure 5, one can notice that the average bit rate of the cell is high when the load is small and getting worse when the load is high.

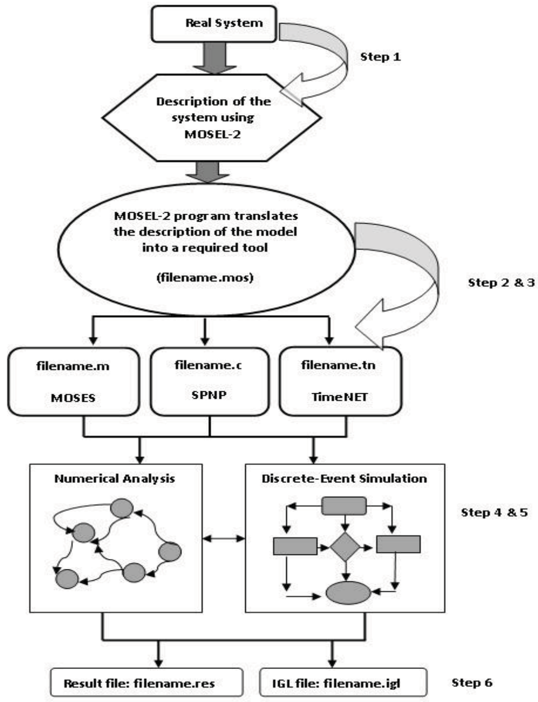


Figure 2: Modeling and Evaluation process in MOSEL-2

This situation can be explained by the fact that the small load (say 0.42 Mbit/s) is usually provided at the border of the cell (zone 3) where the resources of the cell is not broadly shared compared to the inner zone (zone1).

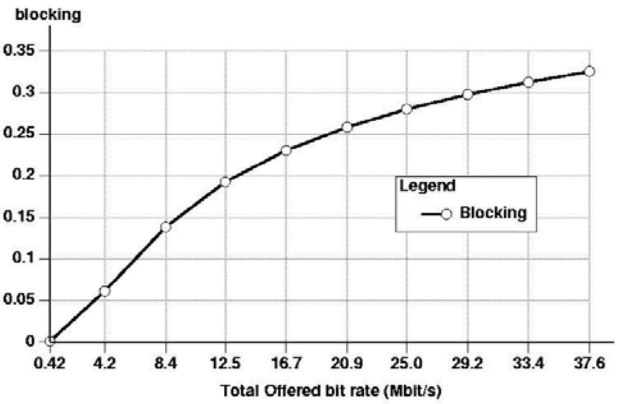


Figure 3: blocking against total offered bit rate

The throughput of the cell in Figure 6 is getting higher when the total offered bit rate increases. At 4.2 Mbit/s load, the total throughput of the cell is 2 Mbit/s while at 37.6 Mbit/s load the throughput is increased to 6 Mbit/s.
Of course, the later throughput can only be achieved in ideal conditions and most probably when the requested service is initiated at the inner zone of the cell. This fact is demonstrated in Figure 7 where the aggregate bit rate is

given in the cell to the three zones. One can notice from this figure that higher aggregate bit rate can be achieved at the inner zone (zone 1). However, less aggregate bit rate can be achieved in zone 2, and the worse result is at zone 3.

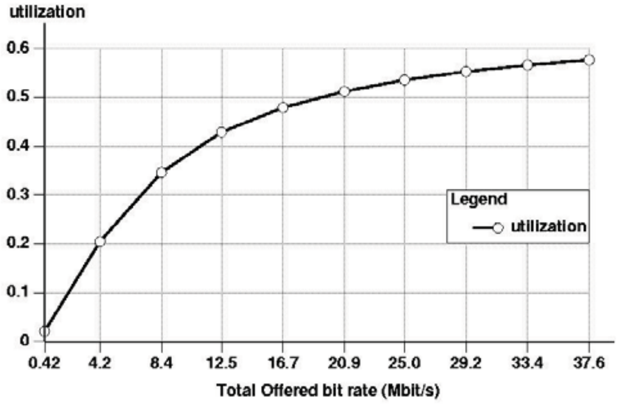


Figure 4: utilization against total offered bit rate

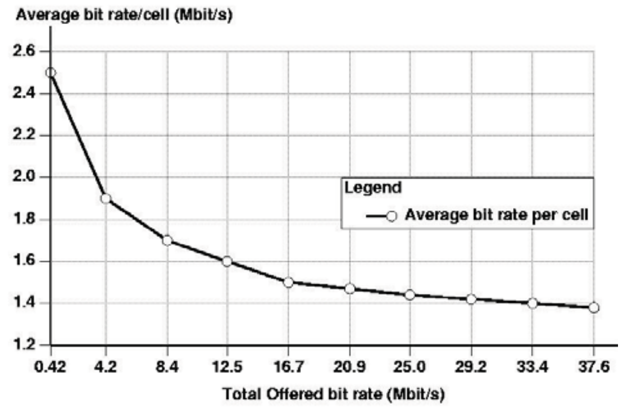


Figure 5: average bit rate per cell against total offered bit rate

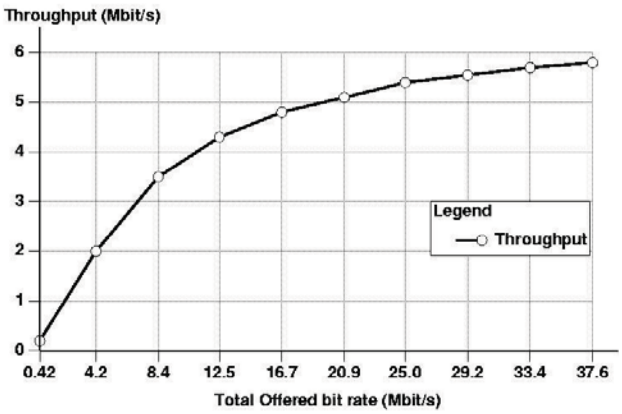


Figure 6: throughput of the cell against total offered bit rate

Figure 8 demonstrates the three types of service over zone 1 (the inner zone). For example, at 25 Mbit/s offered bit rate, VoLTE achieves higher aggregate bit rate (i.e. 2.5 Mbit/s), while video streaming service achieves 2.0 Mbit/s and the content download service achieves 1.4 Mbit/s. Similar behavior can be noticed in zone 2 with the same offered bit rate (i.e. 25 Mbit/s) in Figure 9 but at this time VoLTE achieves only 1.2 Mbit/s, video streaming achieves only 1 Mbit/s whereas the content download only achieves 0.60 Mbit/s. The numerical results shows that the traffic distribution of 60% ratio for content download has negative effect on the Aggregate ABR in all zones, while 30% ratio for video streaming gives better Aggregate ABR or even 10% ratio for VoLTE gives the best result for Aggregate ABR in all zones.

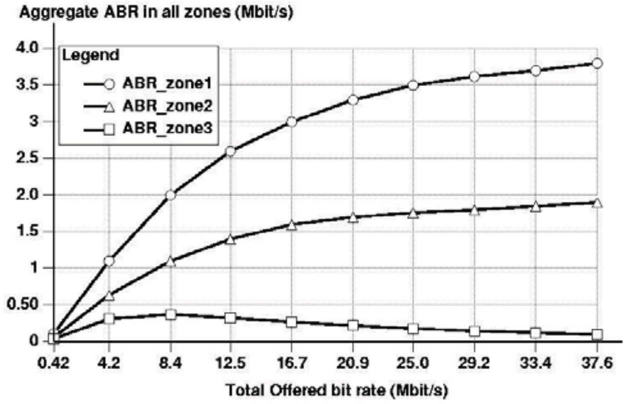


Figure 7: aggregate ABR/all zones against total offered bit rate

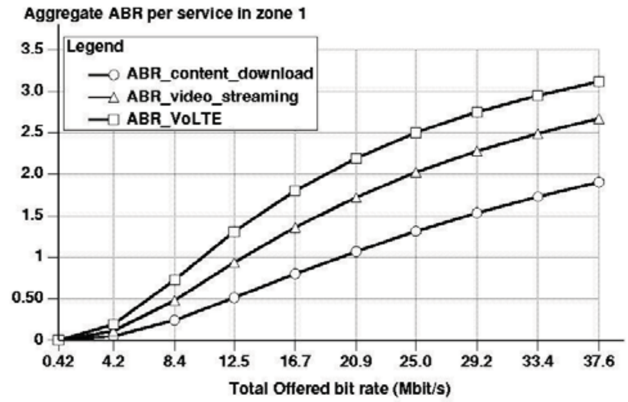


Figure 8: aggregate ABR/service in zone 1 against total offered bit rate.

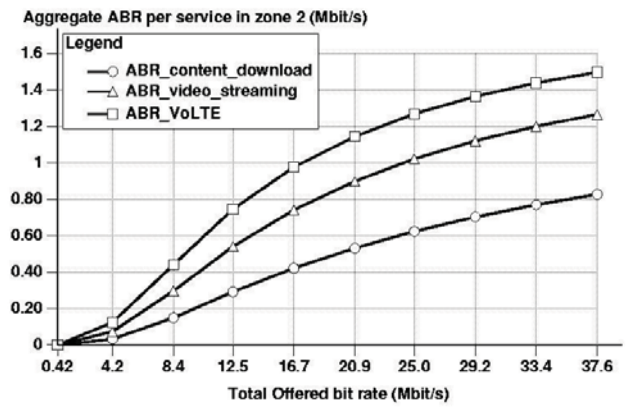


Figure 9 aggregate ABR/service in zone 2 against total offered bit rate.

An amazing behavior can be noticed in Figure 10 where the aggregate bit rate is demonstrated at zone 3. In this figure, the aggregate bit rate increases when the offered load is increased but when the offered load becomes 8.4 Mbit/s, the aggregate bit rate drops and continues to decrease even at higher offered bit rate. This behavior can be explained as: Firstly, most cell resources are shared at the cell border (i.e. zone 3). Therefore, not many users can have enough resources to achieve the required service.

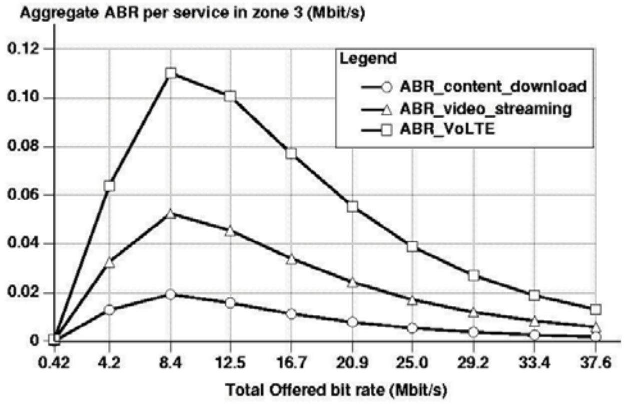


Figure 10: aggregate ABR/service in zone 3 against total offered bit rate.

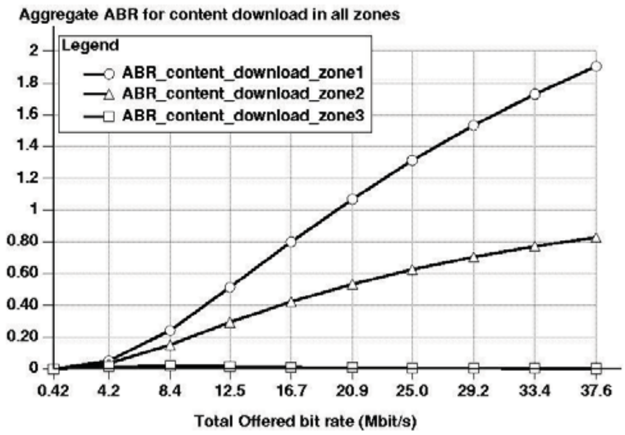


Figure 11: aggregate ABR for content download service in all zones against total offered bit rate

Secondly, most of the available resources in the border zone will be given to the high priority service (i.e. VoLTE). Therefore, some portion of the requests will be blocked, and some other portion will make handover to the border cells. Figures 11, 12 and 13 demonstrate the aggregate bit rate for each type of service in all zones. Content download service is shown in Figure 11, video streaming in Figure 12 and VoLTE is shown in Figure 13. It is shown from Figure 11 that higher aggregate bit rate is achieved for the content download service or video streaming service or VoLTE service only at zone 1 and the lowest aggregate bit rate is at zone 3. The same behavior is shown in Figure 12 where the video streaming is given. Again, the video streaming service has high quality at zone 1 (i.e. inner zone). Besides, VoLTE has the same situation at Figure 13.This behavior can be explained by the fact that the people who are close to the base station are happy, and they can enjoy the QoS of the cell or even the network. As people move away from the base station, the quality of the service becomes bad and even worse at the cell border.

5. CONCLUSIONS AND FUTURE WORK

Performance evaluation of one LTE cell with three types of service (i.e. content download, video streaming, and VoLTE) has been investigated in this paper, and the

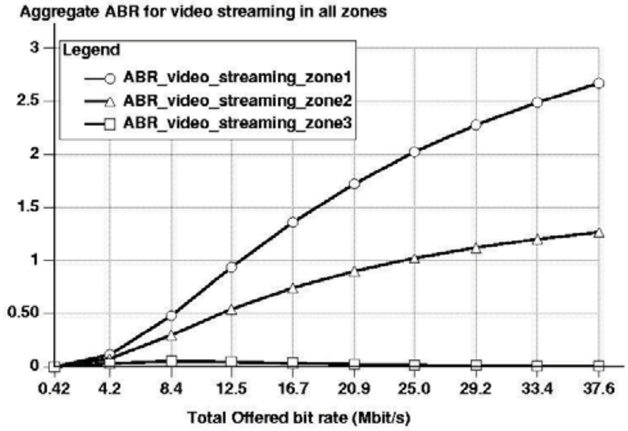


Figure 12: aggregate ABR for video streaming service in all zones against total offered bit rate

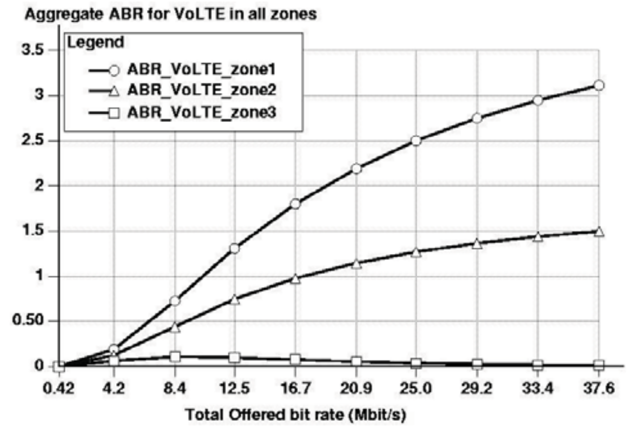


Figure 13: aggregate ABR for VoLTE service in all zones against total offered bit rate

suggested model is solved numerically using MOSEL-2 language. The LTE cell is divided into three zones according to LTE-Advanced modulation scheme; quadrature phase-shift keying (QPSK), 16-phase quadrature amplitude modulation (16QAM) or 64-state quadrature amplitude modulation (64QAM) depending on the speed needs. Interesting performance measures are investigated in the analysis such as: blocking of the cell, utilization, the average bit rate per cell, Throughput, Aggregate average bit rate per cell to all zones as well as the aggregate average bit rate per service in each zone. The outcome of this research work is useful for the planning department of mobile operators because it provides them with a methodology and tools that allow fast first prediction of key performance measures that give easy way of comparing service deployment scenarios and allow the best utilization of the existing and new technologies anywhere and on move. This work can be extended in the future to multi-cell scenario in different propagation environments. Moreover, no mobility is considered in the analysis. Therefore, it is possible to introduce a mobility model in an extended research work.

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AUTHOR BIOGRAPHIES

AYMEN I. ZREIKAT is a full professor at the Information Technology Department, Mu'tah University, Jordan. He has obtained his B.Sc. in Computer Science from Yarmouk University, Jordan in 1990 and MSc. in Science of Computational Engineering from University of Erlangen, Germany in 2000. Afterwards, he has obtained his Ph.D. from Bradford University, UK in 2003. In January, 2001, he has joined the Performance Modeling and Engineering Research Group at the Computing Department of Bradford University, UK. His area of research is in Performance Evaluation and Resource Management of Wireless Mobile Networks. He has published two books, set of Journal and Conference papers in this field and he is responsible for reviewing a set of papers in this area of research in a very reputable Journals and Proceedings. Prof. Zreikat is teaching some important courses for both undergraduate and graduate students. Furthermore, he has obtained many grants for research projects nationally and internationally. Additionally, he is supervising research students in Jordan and abroad. Prof. Zreikat is a member of some national and international coordinating committees; such as: the coordinating committee for the management of Queen Rania Al-Abdullah center for Educational Technology, Jordan, April 2009. Since May, 2009, He is a member of committee for Higher Education Accreditation Commission, Jordan. He is also member of the editorial board of the international Journal of software engineering and its applications (IJSEIA), Korea, 2012. Besides, he is a member of international organizations; such as MOSEL team. His e-mail address is: siayzrei@yahoo.com.