Effects of Varying LTE Link Budget Parameters on MAPL and Cell Range

Haider Mohammed Turki Al-Hilfi[1] and Asaad S. Daghal[2]
[1] Directorate General of Vocational Education, Ministry of Education, Iraq
[2] Al-Furat Al-Awsat Technical University, Kufa, Iraq
Email: hi.1977@yahoo.com; ad466kent@atu.edu.iq

Abstract—Long-Term Evolution (LTE) planning is considered as one of the most important processes in the process of establishment mobile network. The planning process includes coverage planning and capacity planning. There are many parameters, which affect the network coverage planning, such as neighbor cell load, frequency range, bandwidth, e.t.c. By tuning these parameters, the network will provide the best performance from the view of coverage and capacity requirements. In this paper, the effect of changing different parameters on the maximum allowable path loss (MAPL) and cell range is presented. The results show that the cell limit increases when the network operates on 700 MHz range and on 20 MHz BW. Furthermore, it is shown that the load of neighbor eNB has a large effect on MAPL. Finally, it shows that there is a large difference between the cell limit in different clutter type.

Index Terms—MAPL, LTE, eNB, EPC

I. INTRODUCTION

Mobile network deployment process starts with network dimensioning, which focus on initial estimation access stations numbers that support the coverage and capacity requirements. Long-Term Evolution (LTE) network represents fourth generation (4G) mobile network which can provide 300/150 Mbps data rate in Downlink (DL)/Uplink (UL) directions assuming 20 MHz bandwidth. The most vital step in establishment of 4G LTE mobile network is the planning stage, where the planning stage start with network dimensioning which focus on getting the estimated number of radio base stations (eNodeB) in the network. Two things must be fulfilled to get the estimated number of eNBs, coverage and capacity requirements. Link budget is the process of getting the MAPL, which used to get the estimated eNB cell range by using different clutter types. The main clutter types used in mobile environments are Dense Urban, Urban, Suburban, and Rural or open area. The remaining parts of this study is presented as follows: Section II provides a brief technical overview regarding LTE systems. The parameters that used in planning process are presented in Section III. The results are discussed in Section IV, while the paper is concluded in Section V.

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II. LTE NETWORK STRUCTURE

Long-Term Evolution (LTE) is leading the Orthogonal Frequency-Division Multiple-Access (OFDMA) of wireless mobile broadband technology. LTE delivers good spectral efficiency, low latency, and high peak rates [1]. The first release of LTE specifications, which is LTE Release-8, has been launched by the end of 2008. While Release-9 was introduced in 2009, which involved many new features compared to Release-8. In 2010, Release 10 has been launched as a huge step in LTE evolution. These new features involve carrier aggregation (CA), Multiple-Input Multiple-Output (MIMO) techniques, Coordinated Multipoint (CoMP) Transmission/Reception [2], Heterogeneous Networks (HetNets), and Relay nodes. Release 10 is called LTE-Advanced (LTE-A), which is treated as a 4G mobile technology by the International Telecommunications Union (ITU). The current work is now ongoing for Release 16 [3]. LTE network involves two parts; namely, the radio and network core parts. The core side is called System Architecture Evolution (SAE) or Evolved-Packet Core (EPC), while the radio part is known as LTE or called Evolved-Universal Terrestrial Access Network (E-UTRAN). The main function of EPC is to deliver access to other networks based on Internet Protocol (IP). Further, it provides different functions for idle and active equipment. The functions of EPC are performed using the following elements, Packet-Data Network (PDN), Packet Gateway (P-GW), Serving Gateway (SGW) and Mobility-Management Entity (MME) [4]. E-UTRAN includes a network of several inter-connected eNBs, where eNBs are connected each to other through an interface called X2 interface, and connected to EPC using an S1 interface. 4G-LTE network components are shown in Fig. 1

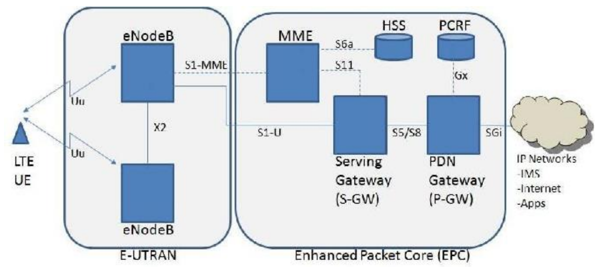

Fig. 1. LTE network

OFDMA and Single Carrier-FDMA are the multiple access methods specified for LTE DL and UL, respectively. OFDMA has been chosen due to their a good performance in fading channels (mainly frequency-selective fading channels), good spectral efficiency, bandwidth flexibility, scheduling in time/frequency domain, and support of enhanced antenna technologies, e.g., MIMO. OFDMA signal involves many subcarriers with orthogonally feature, i.e. the peak of any subcarrier intersect with zero of the other subcarriers. The sub-carriers are spaced by 15 kHz, which eliminates Intra Cell or Adjacent Channel Interference. Regarding the multiple access of OFDMA, 12 adjacent sub-carriers, that together occupy 180 kHz, form a unit of assigned resources. This unit named Resource Block (RB), which is the minimum bandwidth allocation possible. It is also form a time view of this 12 subcarrier of 0.5 millisecond (ms), which called time slot. The network bandwidth divided into different groups of RBs as listed in Table I [5].

TABLE I: RESOURCE BLOCKS VS. BW

BW- MHz	1.4	3	5	10	15	20
RB	6	15	25	50	75	100

In eNB, the MAC layer performs scheduling functions, which aim to assign RBs to different service in UP and DL directions. This scheduler makes assignment decisions every Transmission Time Interval (TTI), which has 1 ms duration, by assigning RBs to mobile subscribers, in addition to transmission parameters like Modulation/Coding Scheme (MCS), which pointed to as radio link adaptation. The allocated RBs and the MCS are signaled to the scheduled equipment on a control channel called Physical DL Control Channel (PDCCH). The dynamic scheduler also interacts with a retransmission technique called hybrid automatic repeat request (HARQ) which support scheduling retransmissions and support QoS guarantee [6].

In Release 8, the estimation of DL channel is performed based on a specific signal called Cell Reference Signals (CRS). The term CRS stems from that all user equipment in a given cell can employ the CRS for the wireless channel conditions estimation from the eNB to their location. CRS is used for feedback calculation and demodulation [7].

III. PLANNING PARAMETERS

The dimensioning step considers the first process in network planning. This process involves sequential steps of calculations that served different requirements, such as antenna radiation pattern, coverage estimation, and capacity estimations [8]. Dimensioning process output is the estimated numbers of eNBs, which meet the capacity/coverage requirements (sometimes called initial planning phase). To make a details planning, communication engineers use planning tools for this purpose like U-net or Atoll software [9], [10]. By using the link budget calculations, different losses and gains, the margins are analyzed at receiver and transmitter. Link budget output is MAPL, which achieve the required receiver signal strength. Link budget equations comprise many parameters like:

1) Transmitted power by the transmitter
2) Antenna Gain of transmitter/receiver.
3) Losses in antenna feeder.
4) Receiver sensitivity [11].

The essential output is MAPL, which used to estimate cell range and consequently Inter-Site Distance (ISD). Radio propagation environments include dense urban, sub-urban, urban, rural environments. Various objects like buildings, trees, hills, and people within these environments affect the propagation of signals in constructive or destructive manners. This situation introduces a phenomenon called fading, where fading is a term that points to received power changes caused by variations in the paths of the signals [12]. There are multiple parameters, which affects the dimensioning and planning of LTE network. Table II show the parameters used in the estimation of the results.

TABLE II: LTE DIMENSIONING PARAMETERS

Operating frequency	2600 MHz
BW	10 MHz
Downlink/Uplink rate	4096/384 Kb/s
eNB power	20 W (43 dBi)
Antenna gain	18 dBi
Noise figure (DL/UL)	7 dB/2.2dB
BLER	10%
Default load	50%

The dimensioning step starts by getting Effective Isotropic Radiated Power (EIRP) by adding the gain of the antenna (GAnt) plus transmitted power (PTX), then subtract it from different losses. EIRP is the product of transmitter power and transmitting antenna gains w.r.t isotropic antenna of a radio transmitter.

$$\mathrm{EIRP} = \mathrm{PTX} + \mathrm{G_{Ant}} + \mathrm{G_{MIMO}} - \mathrm{L_{feeder}} - \mathrm{L_{body}} \quad (1)$$

where **G_{MIMO}** is the gain due to transmit diversity techniques, and **L_{body}** is the losses due to adherence of the transceiver to the body. The next step is to get receiver sensitivity, which is the minimum amplitude of required input signal to get a specific signal with a specific SINR, or other specified criteria.

$$\mathrm{SRX} = -174\,\frac{\mathrm{dBm}}{\mathrm{Hz}} + 10\log(15\mathrm{KHz} * 12\ \mathrm{RB}) + \mathrm{NF} + \mathrm{SINR} \quad (2)$$

where -174 dBm/Hz is the thermal noise, SINR is the signal strength to interference power plus noise power ratio, and RB is the resource block numbers. NF is the device noise figure, which depends on the hardware design of receiver equipment. NF represents an additive noise generated by various hardware components.

Note that we suppose that eNBs does not use Top Mounted Amplifier (TMA), and there is not copper feeder between antenna and Base Band Unit (BBU). After getting MAPL, it is used in propagation model equations to get cell range. The evaluation was done using COST HATA-231 model, this model is used for 4G-LTE in different environments [13].

IV. RESULTS AND DISCUTION

Fig. 2 depicts the effect of changing the network operating frequency on the cell radius in all environments. It is seen from Fig. 2 that the cell limit decreases with the increase of the operating frequency. This reduction in the cell range is due to the losses which face the higher operating frequency range are greater than it with the lower frequency range.

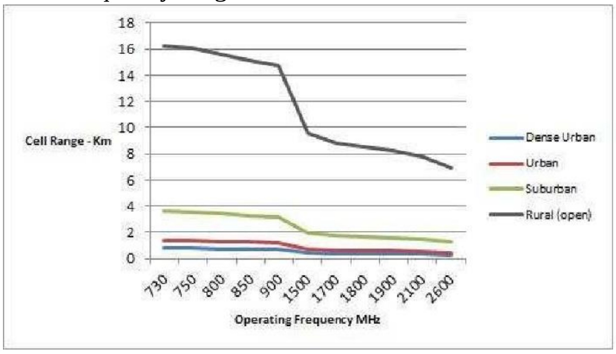

Fig. 2. eNB cell range vs. operating frequencies.

Table III shows the numerical results of both frequency, 730 MHz and 2600 MHz for all clutters.

TABLE III: TYPE SIZES FOR CAMERA-READY PAPERS

Frequency MHz	Dense Urban (km)	Urban (km)	Suburban (km)	Rural (km)
730	0.803	1.405	3.606	16.265
2600	0.295	0.471	1.281	6.899

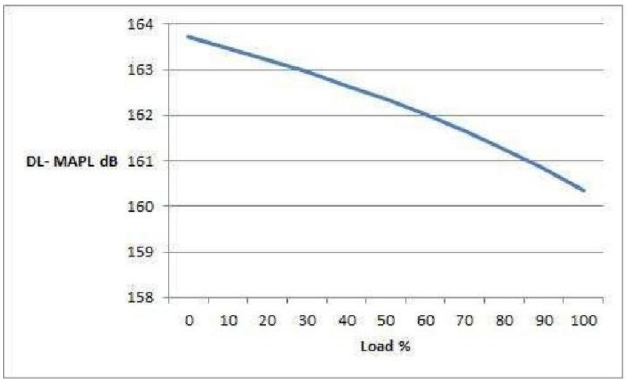

Fig. 3. Neighbor eNB load vs. MAPL in downlink direction.

Fig. 3 presents the calculation results of increasing a load of neighbor cells on MAPL in download direction. With increasing the percentage of load the interference level increases, which decrease the MAPL, hence the cell limit decreases. In addition, high neighbor cell load limits the possibility of selecting high MCS.

TABLE IV: VALUES OF MAPL AGAINST LOCATION PROBABILITY

Location Probability%	75	80	85	90	95	100
MAPL dB	136.5	134.81	133.31	131.71	128.48	122.79

Table IV lists the MAPL values against the location probability, where location probability (%) is the percentage probability of an equipment to be existing in the specific cell area. Location probability affects Slow-Fading Margin (SFM), which added to the losses at the receiving-station to get the receiver sensitivity [14]. It is clear that from Table IV, MAPL decreases as the location probability increase. This means the cell limit decreases when the location probability increases.

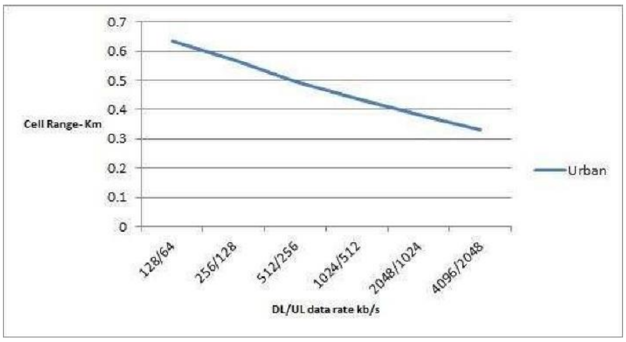

Fig. 4. Cell range vs. required DL/UL data rate.

Fig. 4 shows the link between the required data rate at the cell edge in both DL, and UL directions and the cell limit to meet this rate. The calculation is evaluated assuming urban clutter. From the figure, note that when it needed to guarantee high data rates at the cell edge, it has to decrease the cell size, this is because to deliver high data rate UE and eNB must deploy high order MCS which need high SNIR. So, if the network operator needs to guarantee high rate for its customers, it must decrease the cell size, this means that operators need to increase the numbers of eNB regardless the coverage area on these eNBs.

Table V lists cell range for different clutters to meet certain cell edge throughput. It shows huge difference among the different clutters. The previous results are obtained with 2048/1024 kb/s required DL/UL throughput at the cell edge.

TABLE IV: VALUES OF CELL RANGE IN DIFFERENT CLUTTERS

Clutter	Dense urban	Urban	Suburban	Rural
Cell range km	0.238	0.381	0.9848	5.281

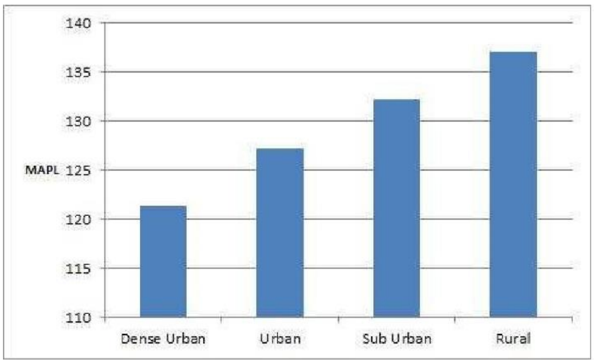

Fig. 5. Cell range vs. required DL/UL data rate.

Fig. 5 and Fig. 6 shows MAPL and limit of the cells against the different clutters. The figures are calculated for 4096/384 Kb/s DL/UL data rate and the system bandwidth is 20 MHz. The figures declare that the cell limit increases in the rural environment compared with the other clutters. This huge difference is related to the existence of surrounding obstacles in the other clutters, which increase the shadowing margin and penetration loss.

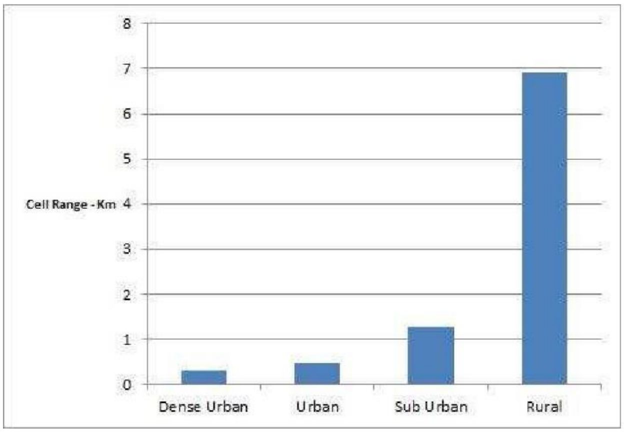

Fig. 6. Cell range in different clutters.

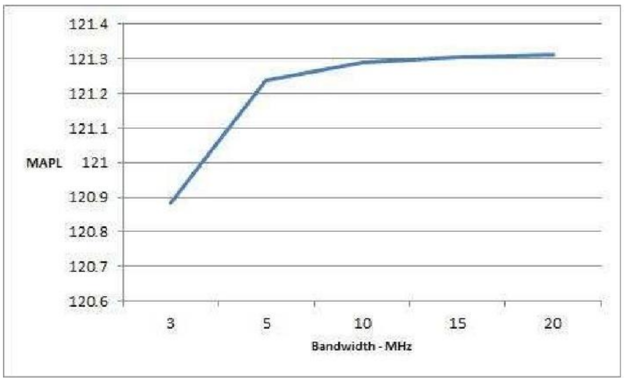

Fig. 7. MAPL vs. network bandwidth- Dens urban area.

Fig. 7 presents the link between the network bandwidth and MAPL in a dense urban environment. The figure declares that MAPL increases with increasing network BW. This is because the scheduling gain increases with increasing the network BW. This gives a great chance to select different sets of RBs to mitigate interference. The scheduling gain is added to the gains in link budget computation, which increase MAPL and consequently increase the cell limit in the network.

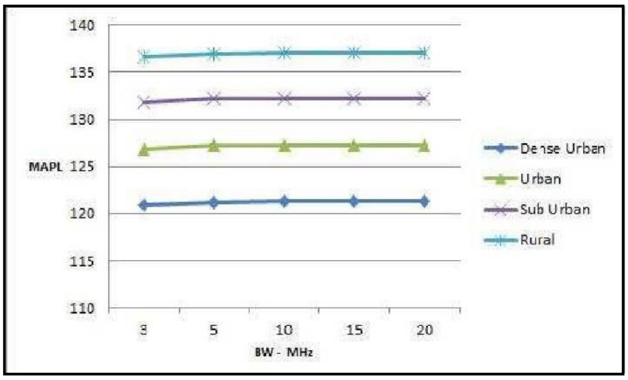

Fig. 8. MAPL vs. network bandwidth in all clutter types.

Fig. 8 shows how the changing of system BW reflect on MAPL for all clutter types. It shows that the best results from the view of MAPL are with rural areas, which gives the largest cell size.

V. CONCLUSION

The correct choice of planning parameters in wireless network planning processes has a large effect on 4G-mobile network performance from cell range and MAPL perspectives. The paper presents the changing effects of network BW, operating frequency, neighbor load, location probability, and clutter on the MAPL, and cell radius. From the output results, it is observed that the cell limit increases when the network operates on 700 MHz range and on 20 MHz BW. It is clear that the load of neighbor eNB has a large effect on MAPL (about 3 dB difference from zero loads to 100 % load). Also, the calculation results of using different clutter on LTE cell size and MAPL has been investigated. There is a large difference between the cell limit in different clutter type. For example, the cell limit is about 230 meter in dense urban and about 5280 meters in rural area.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Haider. M. T. ALHILFI conducted the research; Asaad. S. Daghal analyzed the data and wrote the paper. Both authors had approved the final version.

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Haider M. T. Alhilfi was born in Basra, Iraq, in 1977. He received the B.S. degree in communication engineering from the ’Al- Furat Al-Awsat Technical University AL Najaf, Iraq, in 2009 and the M.T. Degree in wireless communication engineering from the University (SHIATS) Science and Technology, India, 2014. Ph.D. degree in Department of Telecommunications Engineering, University “Polytechnic” of Bucharest,, Romania .2018 His research interests include wireless network, wireless sensor networks, security and key management of wireless

Asaad S. Daghal received the B.Sc. and M.Sc. degrees in electrical engineering and communication engineering from the University of Technology, Baghdad, Iraq, in 1998 and 2005, respectively, and the Ph.D. degree in communication engineering from the University of Kent, Canterbury, U.K., in 2017. He is currently a Lecturer with the Engineering Technical College of Najaf, Al-Furat Al-Awsat Technical University, Iraq. His research interests include wireless communications, covering topics such as device-to-device communications, massive MIMO, cooperative communications, heterogeneous networks, Energy harvesting, smart antenna, signal processing, coding and information theory.