Modeling and exploring base station characteristics of LTE mobile networks

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Abstract: This paper reports our theoretical and practical experience with fourth generation network technologies based on Long Term Evolution (LTE). For planning LTE networks there are expensive and complicated software, but it is likely that the engineers, telecommunication companies or advanced users will be interested in a simple tool to assess the capacity and range of the base station network LTE. For this purpose, we develop an expert system that is able to calculate the range and bandwidth expressed in megabits per second, which are based on the input parameters and the network equipment. In the first part we consider a model that allows estimating the range and bandwidth base station LTE network and using these data to simulate different scenarios loading base station.
In the second part, according to the experimental data, we determine dependence of the speed reception and transmission of traffic on the degree of the base station range. The information presented here will help to predict possible outcome and income in establishing new LTE network points.
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1. Introduction

With the development of mankind, the demand for services was increased in the areas of communications and the Internet, which led to the rapid development of various technologies and mobile communications. Nowadays, the internet sphere takes special and a huge role in the exchanging of data, streaming video, as well as the provision of online services to all sorts of companies.

Network that existed until now, could not combine all these possibilities. In 2008, an international association of Third Generation Partnership Project (3GPP), which develops advanced mobile communication standards, approved the LTE as the fourth generation of the network after 3G [12].

Long Term Evolution (LTE) is the next step forward in cellular 3G services. Expected in the 2008 time frame, LTE is a 3GPP standard that provides for an uplink speed of up to 50 megabits per second (Mbps) and a downlink speed of up to 100 Mbps.

LTE is the next major step in mobile radio communications, and introduced in 3rd Generation Partnership Project (3GPP) Release 8. LTE is a 3GPP standard that provides for an uplink speed of up to 50 megabits per second (Mbps) and a downlink speed of up to 100 Mbps. [1], [2]. Services that may be offered a fourth-generation network start from voice and data to video and multimedia. To implement these requirements this network must have a high speed transmission / reception signal. Ideally, LTE technology can provide transmission speed 173 Mbit / s for receiving and 58 Mbit / s for transmission. The advantage of the network is not only high speed but also the radius of coverage of a base station 5 km to 30 km. In this paper we study network architecture LTE, various technological modes and networking opportunities in real urban environments with dense buildings.

December 14, 2009, it was the launch of the first mobile network in the world, based Long Term Evolution. The network was put into operation by the operator Telia Sonera in central Stockholm. Telecommunication equipment was provided by the Swedish company Ericsson under the contract concluded in early 2009, [3].

Despite the fact that in the last years start testing LTE and pilot projects were carried out in most countries of the world, the launch of the network in commercial operation is considered as a confirmation of the results of the technology introduction. For example, according to the Global mobile Suppliers Association Equipment (Global mobile Suppliers Association, GSA) by September 2012, LTE networks in commercial operation were launched 96 operators in 46 countries. The number of operators, that have deployed LTE network, was increased by 52% in comparison with the previous year.

2. Structure and Working Principle of LTE Network

One of the main features of the LTE network is a technology, used multi-user OFDMA (Orthogonal Frequency Multiple Access), in which the user is assigned a set of channels with orthogonal frequencies. It is a digital modulation scheme that uses closely spaced apart orthogonal subcarriers in a large amount. All subcarriers are modeled after the standard modulation scheme, such as quadrature amplitude modulation at the symbol rate with the low overall compliance data rate as well as in the ordinary single carrier modulation schemes in the same bandwidth. In fact, the OFDM signals are generated due to the use of "Fast Fourier Transform".

In the LTE network as the primary method they use the method, developed by Intersil and called Orthogonal Frequency Division Multiplexing (OFDM). The principle of OFDM modulation signal is shown in Figure 1 [9].

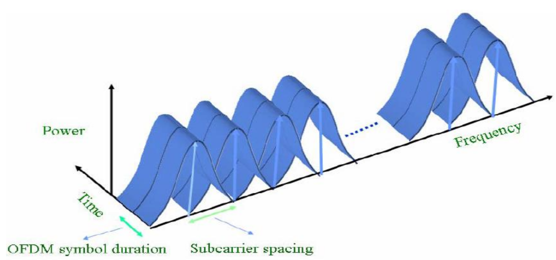

Figure 1. Principle of OFDM modulation signal

The entire frequency band is partitioned into subcarriers. They are even partially overlap, but are in an orthogonal position relative to each other. The orthogonality of the carrier signals is provided in the case, when for the duration of one symbol carrier signal will perform integer number of oscillations. To implement the method of transmitting devices an inverse fast Fourier transform (IFFT) is used, which translates signal multiplexed previously in one of the channels from the time-domain representation to the frequency. Thus, when one of a subcarrier has maximum amplitude, adjacent subcarrier has a null value. The information in this method is transmitted in the form called OFDM-symbols.

Using orthogonal frequency allows us to reduce interference between the channels with adjacent frequencies, and thereby, to improve the efficiency of frequency spectrum use. In the LTE technology the spectral efficiency is 2-4 times better than in 3G. Also in LTE networks it is possible to use multi-antenna technology called Multiple Input Multiple Output (MIMO). Application technology MIMO solves two problems:

- Increase communication quality due to spatial time / frequency coding and (or) beamforming;
- Increase the transmission rate when spatial multiplexing is applying.

Depending on the class of user equipments, in LTE it is possible to use 4x4 MIMO, i.e. a combination of four transmits and four receive antennas. Using four independent streams one can significantly increase the speed of data transmission. However, it should be noted that the use of four possible antennas is possible at a user equipment of the fifth category. Due to extremely high demand of this category, meeting the requirements of this category on the market of equipment is unlikely in the near future.

Next hallmark of networks LTE is the use of variable frequency band (1.4, 3, 5, 10, 15 and 20 MHz). This means that any of pointed out frequency bands can be allocated as a base station.

3. Mathematical Model

The main object of cardinality budget should include a base station transmitter power and antenna gain, as the dependence of its orientation. It should be noted that in the LTE network the adaptive array antenna is used with the possibility of focusing the beam on the user equipment. Such antennas are able to determine the direction of arrival of the signal and to generate a narrow beam in this direction, which will greatly reduce the interference, and hence, to obtain a significant gain. Sum of transmitter power and antenna gain, from which we deducted the loss in cables and connectors, is called the effective isotropic radiated power (Effective Isotropic Radiated Power, EIRP). From this figure, it is necessary to subtract the receiver sensitivity in the user equipment, which is formed from the receiver noise figure, the thermal noise and signal / noise ratio, as well as take into account all other losses, such as losses due to signal penetration into a car or a building. The resultant number means the maximum loss that can undergo signal propagation from the base station to the user equipment and still be recognized by the mobile device. This number will be used in the model to forecast radio attenuation for different conditions. Consequently, the model Hata is used to define the forecast range of the base station in the small cities and suburban areas.

The mathematical formula of this model is written as follows:

$$L_H = 69.55 + 26.26\log(f) - 13.87\log(h_b) - a(h_m) + [44.9 - 6.55\log(h_b)]\log R \quad (1)$$

Where L_H - loss in dB

f - the operating frequency in MHz

h_b - a base station antenna height in meters,

$a(h_m)$ - coefficient depending on the height of mobile device's antenna

R - radius in kilometers

Expressing R from this formula, and substituting the greatest possible losses in the LH, it is possible to get the maximum range of the base station.

COST231-Walfish/Ikegami model was used to predict the radius of action in the center. This model consists of three components: the loss of open space, roof-street diffraction and scattering losses and multi-screen loss. This model is more complicated than Hata model, and it is a combination of empirical and deterministic models. It takes into account not only the height of the transmitter and receiver antennas, but also the height of buildings, the distance between the buildings and the width of the street. Thus, this model can predict the range of the base station located in the city center with sufficient precision.

High speed data transmission over LTE is achieved by applying a high-order modulation. In LTE networks they use three kinds of modulation signals as quadrature-phase modulation (Quadrature Phase Shift Keying, QPSK) and two types of QAM (Quadrature Amplitude Modulation, QAM) - 16QAM and 64QAM. Modulation QPSK allows transmitting two bits in one symbol, the modulation 16QAM - 4 bits per symbol, and 64QAM - 6 bits in one symbol. However, for QAM, state radio channel should be good enough, and requirements for signal / noise ratio should be very high. If modulation order is higher, then the signal / noise ratio at the receiver should be greater, that the message was successfully decoded.

To protect the transmitted information in LTE the system error correction is provided by the method forward error correction (FEC is also called Channel Coding). In this method control bits are added to the information bits, moreover, initial message can be restored in case of loss of information bits. If condition of the radio channel is bad (the lower the signal / noise ratio), then more control bits will be added to the initial message.

Obviously, the control bits reduce travel speed data transmission. In LTE the following coding of the coefficients are used: 1/8, 1/5, 1/4, 1/3, 1/2, 2/3, 3/4 and 4/5. These ratios show the number of control bits in the message. For example, the ratio of 2/3 shows that 3-transmitted bits: two bits are informational and one - control. For each combination of the modulation technique and the ratio of FEC, there is a desired value signal / noise ratio. Obviously, if modulation order is higher and the added control bits are lower, then more signal / noise ratio at the receiver will be required, therefore the receiver must be closer to the transmitting base station.

For each combination of power and modulation coding technique one can calculate the reference sensitivity of receiver, using the following formula:

REFSENS = P + NF + SINR + IM – 3dB (2)

Here, P – thermal noise,

NF – Noise figure coefficient,

SINR – Signal to Noise and Interference Ratio

IM – Implementation Margin.

3 dB corresponds to the increase due to the use of MIMO technology.

Table 1. Signal / noise ratio plus interference techniques for different modulation and FEC, [6]

Modulation	FEC	SINR, dB	IM, dB	SINR+IM, dB
QPSK	1/8	-5,1	2,5	-2,6
	1/5	-2,9		-0,4
	¼	-1,7		0,8
	1/3	-1		1,5
	½	2		4,5
	2/3	4,3		6,8
	¾	5,5		8,0
	4/5	6,2		8,7
16QAM	½	7,9	3	10,9
	2/3	11,3		14,3
	¾	12,2		15,2
	4/5	12,8		15,8
64QAM	2/3	15,3	4	19,3
	¾	17,5		21,5
	4/5	18,6		22,6

Table 1 shows the calculation of SINR value for the relative sensitivity of the receiver. The table shows that the highest requirements on the ratio signal / noise plus interference is imposed on the high-order modulation with the least amount of control bits.

Substituting the relative sensitivity to cardinality budget, it is possible to calculate the radius in which one or the other modulation technique will still act. Obviously, the smallest radius is 64QAM modulation with a small number of control bits.

To calculate the capacity of the base station in LTE network it is first necessary to study the structure of data organization. In time domain the data is organized in ten millisecond radio cell (Radio frame). Each of these cells consists of ten one-millisecond sub-cells (Subframe), which in its turn are divided into two slots with duration 0.5ms. In the frequency domain the data is grouped into groups of 12 sub-carriers frequencies, each of them has a range of 15 kHz, which gives a total of 180 kHz per group.

A group of twelve sub-carrier frequencies lasting one slot is called a resource block. The smallest resource unit in LTE is one subcarrier frequency. Duration in a slot is called as a resource element (Resource Element). Depending on the type of the guard interval (Cyclic Prefix) - normal or extended, one resource block consists of 84 or 72 resource elements, respectively. One resource element, depending on the modulation technique, may include 2 bits for QPSK, 4 bits for 16QAM and 6 bits for 64QAM, as mentioned earlier.

Thus, due to these data it is possible to calculate a theoretical maximum throughput of a base station. If we assume that the selection of the base station of the maximum frequency range is 20 MHz, corresponding to 100 resource blocks, using 64QAM modulation and Cyclic Prefix guard interval standard, the data rate can be calculated as follows.

Each of 100 resource blocks consists of 84 resource elements, each of which in its turn carries 6 bits of information. Duration of resource element is 0.5 ms. Hence, the data rate of the base station is:

Data Speed = 100 [resource blocks] · 84 [Resource elements] · 6 [Bit] / 0.5 [ms] = 100.8 Mbit / s

However, the calculated data rate will be significantly greater than useful transmission rate, since in this calculation we take into account all transmitted bits, including control bits of error correction system (FEC), and bits of control information transmitted by the base station.

Instant user data rate will depend on the number of resource blocks defined by user, of used modulation and coding degree [5].

Table 2. Simulation bandwidth of base station [5]

Bandwidth (Mbit / s)	Number of resource blocks					
Modulation/ Coding Degree	6	15	25	50	75	100
QPSK 4/5	1.310	3.55	5.92	11.84	17.76	23.68
16QAM 4/5	2.61	7.10	11.84	23.68	35.52	47.36
64QAM 4/5	3.92	10.66	17.76	35.52	53.28	71.04

Table 2 shows the throughput of a base station at different frequency bands, using three modulation techniques with a fixed degree of coding. As the table shows, the maximum possible data rate is about 71 Mbit / s, which is approximately 30% lower than the stated maximum speed of 100 Mbit / s. This means that approximately one third of the resources are used to protect user information against damage during the transmission and for control information transmitted by the base station for all users within its scope.

4. Method and Experimental Settings

The purpose of this research is to identify the actual speed of transmission and reception of mobile access to the Internet, moreover, to define the dependence of speed on the distance of wireless 4G modems from LTE base stations in Almaty, Kazakhstan. Experiment can determine which speed in the Internet at what distances can give LTE network. Theoretical maximum speed of LTE network can reach 100 Mbit / s - downlink and 50 Mbit / s - uplink.

Radius installed by LTE base station may vary, depending on the used frequencies, signal power and the radio conditions in each individual case. Typically, the rate is about 5 kilometers but signal can reach 30 or even 100 kilometers by sufficient lifting power and antenna.

Actual speeds for subscribers «ALTEL 4G» will depend on factors such as proximity to a base station and channel loading. To provide the experiment, a modem and determining a location of the base stations are required.

Table 3. Values of reception and transmission speed depending on the distance of base section

N	Distance from BS (m)	Ping (ms)	download speed	transmission speed
1.1	100	32	52.03	15.06
1.2	100	35	53.25	14.23
1.3	100	33	51.35	14.81
2.1	300	32	33.48	12.26
2.2	300	34	34.05	11.42
2.3	300	33	32.38	11.93
3.1	500	30	26.07	10.30
3.1	500	29	25.09	9.94
3.3	500	32	25.44	10.36

Mathematical expectation and variance for the receipt and transmission speed:

$$M[X] = \sum_{i=1}^{\infty} x_i p_i \quad (3)$$

$$D[X] = M[|X - M[X]|^2] \quad (4)$$

Table 4. Mathematical expectation for the receipt and transmission speed

N	distance from base section (m)	Mathematical expectation for the transmission speed	Mathematical expectation for the receipt speed
1	100	52.21	14.70
2	300	33.30	11.87
3	500	25.53	10.20

Based on the data in Table 3 it can be determined that the channel loading does not exceed 35 ms, which is a good indicator. Receipt speed is not higher than 54 Mbit / s, which is two times less than the theoretical speed. A transmission rate does not exceed 16 Mbit / s, that is three times less than promised 50 Mbit / s. Note that there is a fluctuation of the reception speed between 54 Mbit / s and 20 Mbit / s, dependence of the speed on the distance is diminished up to one kilometer at times. These findings suggest a relatively good quality of the network and the possibility of mass demand in the telecommunications market.

5. The Calculation Part

For LTE 1800 network we define the radius of coverage, if values of the loss L, dB, height of base station H_{BS} and subscriber station H_{SS} are known. We use the following formula:

$$R = 10^{\frac{L-45,5+13,82\lg H_{BS}-\log F+(1,1\log F-0,7)H_{US}}{44,9-6,55\log H_{BS}}} \quad (5)$$

Possible loss is 149.2 dB (GSM), and 155,1 (LTE).
L = 155.1 dB H_{BS} = 17 m; H_{SS} = 1.5 m, type of coverage - the city

$$R = 10^{\frac{155,1-45,5+13,82\log 17-35,4\log 1800+(1,1\log 1800-0,7)*1,5}{44,9-6,55\log 17}} = 2,666km \quad (6)$$

Rating Allowable Transmission Rate in the Channel Network of LTE for "Close" and "Distant" Users in the domain u

Transmission speed in the channel of LTE for "close" (center cell) users (Mbit / s):

$$R1(u) = \frac{4}{7} W \log_2(1+\eta 1(u)) \quad (7)$$

for "distant" (at a cell boundary) users:

$$R2(u) = \frac{3}{7} W \log_2(1+\eta 2(u)) \quad (8)$$

where W - band for users who are located in the center and on the cell boundary for DL, when the system band W, MHz, η1 (u) - SINR for the cell center, η2 (u) - SINR for the cell boundary are known.

Calculate the transmission rate in the channel:
W = 10 MHz,
η1 (u) = 5
η2 (u) = 0.45
Transmission speed for users in the cell center:

$$R1(u) = \frac{4}{7} 10 Log_2(1+5) = \frac{4}{7} * 10 * 2,59 = 14,8 Mbit/s \quad (9)$$

and the transmission rate for the users in the cell boundary:

$$R2(u) = \frac{3}{7} 10 Log_2(1+0,34) = 2,5 Mbit/s \quad (10)$$

Calculation of the Energy Budget for the LTE Network

We give calculation the energy budget of LTE systems with time and frequency division of duplex transmission channels with 2600 MHz operating frequency. The calculation principle is illustrated in Figure 2, the MAL is calculated as the difference between the equivalent isotropic radiated 2 powers (EIRP) of the transmitter and the minimum required signal power at the receiver of the conjugate side, in which the normal signal demodulation at the receiver is provided, taking into account any losses in the communication channel.

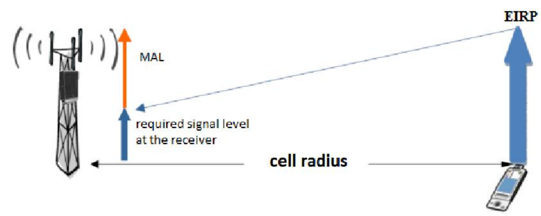

Figure 2. The calculation principle of energy budget for the LTE network

Consider a BS, in which the RF - block of each sector has two transceivers. Output power of each transmitter equals to 20 W (43 dBm). To eliminate the large losses in the feeder tract the transceiver is installed directly on the antenna. Mode of operation of the base station downlink is MIMO 2x2, using cross-polarized antenna. Calculation the energy budget is made for a subscriber station (SS), located at the edge of the cell. It receives signals from the BS with a low value of power of the useful signal, and hence, with a low signal / noise ratio (SNR) [11]. Transmission mode of the BS to the SS is a mode of the diversity transmission. Since addition of signal powers of two transmitters occurs in a space, it is possible to obtain energy gain (3 dB). As subscriber station we apply USB-modem, Class 3 - EIRP 23 dBm. Equivalent isotropic radiated power will be executed by following formula:

$$EIRP = P_{TX} + G_{TxDiv} + G_{TxA} - L_{TxF} \quad (11)$$

where PTX - output power of transmitter dBm;
GThDiv - benefit from the addition of transmitter power, dB;
GTxA - antenna gain in dB;
LTxF - loss in feeding path, dB.

Calculation the Maximum Allowable Losses of LTE Network

Maximum allowable loss:

$$L_{MARL} = P_{EIRP} - S_{RxA} - L_{RxF} - M_{Build} - M_{Int} - M_{Shade} + G_{HO} \quad (12)$$

where PEIRP - EIRP of transmitter, dB;
SRx - receiver sensitivity, dB;
GRxA - antenna gain, dBi;

LRxF - loss in feeding path, dB;
MBuild - stock penetration into the room, dB;
MInt - margin for intersystem interference, dB;
MShade - stock for shadowing, dB;
GHO - handover gain, dB.

Margin for Allowable Intra-system Interference.

During the calculation we use the value of margin on intra-system interference, which characterizes the increase in noise power at the receiver input. To calculate it, we consider that margin for intersystem interference equals to:

$$M_{Int} = -10\log(1-\eta) \qquad (13)$$

where η - relative load cell in uplink or downlink.

As can be seen, margin on intra-system interference is a function of cell load, the greater the permissible load in the cell, the greater the value of the stock should be considered in the calculation. If loading increases to 100% then margin for noise goes to infinity and service area of the cell is reduced to zero. Dependence of these values on this load cell is shown in Figure 3.

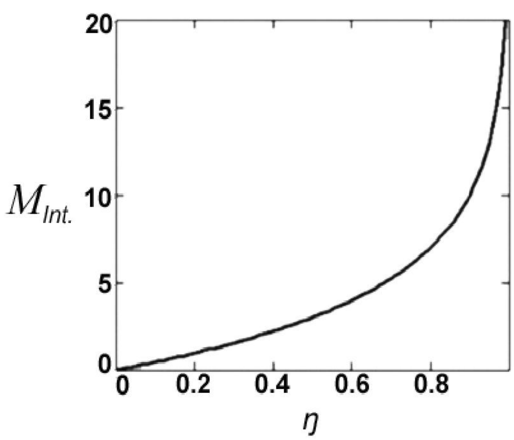

Figure 3. Dependence of the margin for intersystem interference on the relative cell load

Restriction for Managing Power or Margin on Fast Fading

Fast power control algorithm was introduced in UMTS in order to maintain a desired value of Eb/N0 at the receiver input as a constant during the fast fading, assumed as multipath. Fading depth can reach up to 30 dB. Fast power control is particularly important for the subscribers having a low speed, since they can not readily change its position to compensate deep fades. In the cell boundary, the mobile station transmitter power is the maximum; therefore, a margin does not remain for power control to compensate fast fading.

In order to take account this process in the calculation we give the value of the margin on the fast fading. Value of the margin on fast fading depends on the speed of the subscriber. Typical values of the margin, depending on the speed of the subscriber, are presented in Table 5.

Table 5. Typical values of the margin on fast fading

Type of subscriber, moving speed	The typical value of the margin on fast fading
low speed (3 km/h)	3-5 dB
average speed (50 km/h)	1-2 dB
high speed(120 km/h)	0.1 dB

Calculation the Maximum Allowable Loss

LMARL in the network LTE: if we know EIRP of Transmitter - PEIRP (dB), receiver sensitivity - SRx, (dB) gain antenna coefficient - GRxA (dBi), the loss on feeding path - LRxF, (dB), the margin for penetration into the room - MBuild, (dB), margin on shading - MShade, (dB), the gain from the handover - GHO (dB), the cell loading - η

PEIRP = 61,52дБ, *SRx* = -99,3 дБ, *GRxA* = 19 дБ, *LRxF* = 0,38 дБ, *η*.= 0,8, *MBuild*=17дБ, *MShade* = 9 дБ, *GHO* = 3дБ.

We define the margin for interference MInt, dB:

MInt =-10·log10(1-η) = -10 lg(1 - η) = -10 lg 0,2 = 6,9 дБ.

Then maximum allowable loss:

LMARL = 61,52 + 99,3m+19 -0,38 -6,9 – 17 – 9 + 3= 149,5 дБ.

Conclusion

In conclusion, we can say that the developed model allows us to estimate the range and bandwidth of a base station of LTE network and use this data to simulate different scenarios of download in the base station. This tool is affordable, and it does not require large resources of a PC, hence, it can be used for training and educational purposes.

In the experimental part, we have done several calculations as assessing allowable transmission rate in the channel of LTE network for "close" and "distant" users in the domain u, energy budget for the LTE network, maximum allowable losses in LTE network, margin for allowable intra-system interference, restriction managing power or margin on fast fading, calculation the maximum allowable loss.

The information presented here can help to predict possible outcome and income in establishing new LTE network points.

In the next step one can develop expert system that allows predict payback of telecommunication companies in establishing new networking points and chose optimal method, region and count of points, depending on input data.

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