Andrzej ZANKIEWICZ, Maciej SADOWSKI

Bialystok University of Technology

doi:10.15199/48.2018.12.10

Evaluation of LTE downlink transmission quality in presence of selected disturbances in radio channel

Abstract*. The goal of this paper is to evaluate quality of the downlink transmission in the LTE system The main parameter of signal transmission correctness is BER value. Transmission reliability depends on many factors – the most significant are type of propagation channel and level of noise or interference from other systems. These factors were taken into consideration for performed simulation experiments in order to determine the transmission reliability indicators like BER and SNIR for selected parameters of radio channel and LTE frame configuration.*

Streszczenie. *Artykuł przedstawia symulacyjną ocenę jakości transmisji łącza "w dół" (downlink) w systemie LTE. Jako parametry jakościowe przyjęte zostały współczynnik BER określający stopę błędów transmisji oraz parametr SNIR (Signal to Noise plus Interference Ratio). Na jakość transmisji ma wpływ bardzo wiele parametrów spośród których w artykule uwzględnione zostały typ kanału propagacyjnego oraz poziom szumu i interferencji od innych systemów. (****Ocena jakości transmisji w łączu w dół w sieci LTE w obecności wybranych zakłóceń kanału radiowego****).*

Keywords: LTE downlink, BER, SNIR, radio channel model.
Słowa kluczowe: LTE łącze w dół, BER, SNIR, model kanału radiowego.

Introduction

Mobile cellular network operators are constantly facing an increasing demand for higher mobile data rates. To cope with it, several approaches are proposed such as advanced antenna techniques, reuse of frequency channel and cell densification in areas with high capacity requirement. Those techniques often lead to situation when base stations (located in the centre of cells) are placed closely to each other (even a few stations within a 50m radius). These approaches cause more co-channel interferences and more distortions in radiocommunication channels. So that a careful planning and dynamic inter-cell interference coordination techniques are needed for an efficient network operation.

Other approach involves estimation of radio channel parameters. Channel model describes the characteristics of the connection link which carries information in the form of electromagnetic waves between the transmitter and the receiver. The estimated channel characteristics commonly include scattering, attenuation, reflection, refraction and fading. Studying radio channels helps us to get an idea about rapid fluctuations of the amplitude and phase of a radio signal.

The simulation experiments described in the article allow to reproduce computationally phenomena mentioned above with different channel parameters and selected network environments with many stations that operate in the overlapped frequencies. Research was done for LTE 4G standard which is currently the most advanced mobile cellular technology in common use [1]. LTE uses multiple-input multiple-output (MIMO) technology to increase data rate or operation range. Currently the maximum number of MIMO spatial streams is 4. Typically handheld mobile devices may have one transmit antenna and up to two receive antennas (MIMO 1x2 configuration). If it comes to coverage, the base station should provide full performance at a distance of up to 5 km. LTE implements different transmission technologies in downlink (DL) and uplink (UL) transmission. For DL the orthogonal frequency-division multiple access (OFDMA) is used. For UL - single-carrier frequency-division multiple access (SC-FDMA) was chosen.

In performed simulations the downlink communication (from base station to user mobile equipment) in an LTE multi-cellular network deployment have been taken into consideration. In LTE system the available frequency spectrum is split into a trunk of subsequent N_S sub-carriers also known as resource blocks, used for transmission of N_C OFDM symbols. Time is slotted into so called transmission time intervals (TTI) of duration of 1 ms. Every time slot the base station as a central coordination point of transmissions, dynamically allocates resources to mobile terminals.

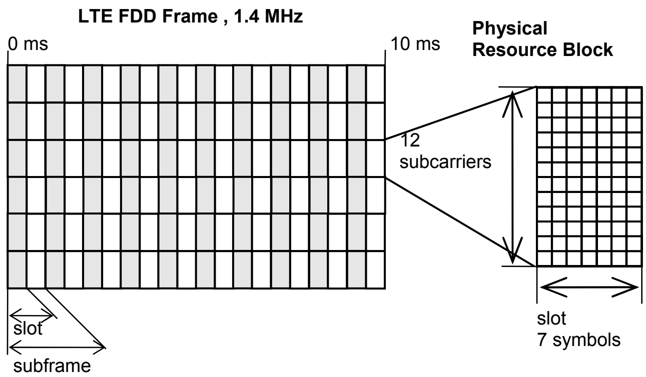

Fig.1. Structure of the frame in LTE, type 1 (FDD)

A physical resource block (PRB) is the smallest unit of resources that can be allocated to a UE (User Equipment). The resource block is 180 kHz wide in frequency and 1 slot long in time domain. In frequency domain every resource block includes 12 x 15 kHz subcarriers. The number of subcarriers used per resource block for most logical channels is 12. LTE system uses radio channels with width 1.4, 3, 5, 10, 15, and 20 MHz. Some number of PRBs (dependent on bandwidth) is combined into subframe and then in LTE frame (Fig. 1).

The main goal of the paper is to determine the transmission reliability indicators like BER and SNIR for selected parameters of radio channel and LTE frame configuration. This work is a continuation and extension of the previous one [2]. Simulations described in the paper have been done using 5G Experimental Toolset by IS-Wireless [3].

Reliability of the LTE Downlink in Multipath Propagation Environment

In the real environment usually there is a phenomenon of multipath radio waves propagation. It happens because of many surrounding objects like buildings, vehicles, trees, mountains and many others. In order to design a radio communication system we need to assume a channel model that is close to the real channel as much as possible and must consider many physical phenomena and factors where multipath propagation is only the one among many other like terrain type, mobility of transmitter and/or receiver, etc. [4].

Multipath propagation is an effect of radio signal reflection from the buildings and other objects (Fig.2). As a result the signal at the input of receiver is a superposition of direct signal and many reflected signals. The phases of reflected signals depend on delays of the particular paths and in the worst case the input signal can be even completely faded.

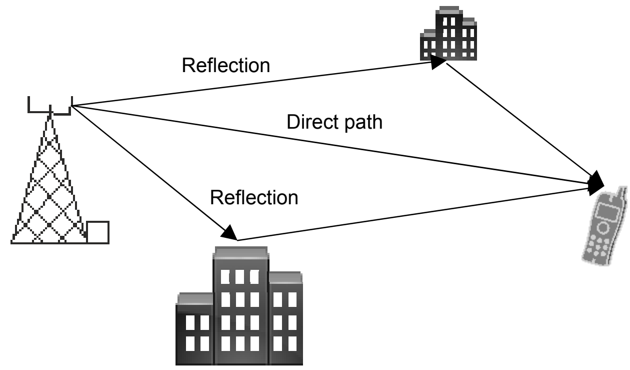

Fig.2. The example of a multipath propagation

A received signal *y(t)* can be described as a convolution of the transmitted signal *x(t)* and the channel impulse response (CIR) *h(t)*. In the frequency domain the received signal can be determined by the formula (1).

$$y(f)=H(f)\cdot x(f)+n(f) \tag{1}$$

where *H(f)* and *n(f)* are channel response and noise in the frequency domain.

There are many different channel models that can be used to design an LTE radiocommunication systems. Among them the E-UTRA (developed by 3GPP) and SUI (Stanford University Interim) belong to the most popular ones [4, 5].

There are 3 E-UTRA channel profiles with different number of paths and delays. They are listed in table 1.

Table 1. Profiles of E-UTRA channel models

Model profile	Number of channel taps	Delay spread	Maximum excess tap delay (span)
Extended Pedestrian A model (EPA)	7	45 ns	410 ns
Extended Vehicular A model (EVA)	9	357 ns	2510 ns
Extended Typical Urban model (ETU)	9	991 ns	5000 ns

SUI is a set of 6 channel models which represent different terrain types, Doppler spreads, delay spreads and line-of-sight (LOS) conditions [4, 5]. Table 2 summarizes the parameters for each SUI model. The terrains are classified in the three different categories. Category A is a hilly terrain with moderate-to-heavy tree density and has a high path loss. Category B is a hilly terrain with light tree density or a flat terrain with moderate-to-heavy tree density. Category C is a mostly flat terrain with light tree density and has a low path loss. The multipath fading is modelled as a delay line with 3 taps with non-uniform delays. The gain associated with each tap is described by a Rician Distribution function and the maximum Doppler frequency.

Table 2. Parameters of different SUI models

Channel model	Terrain Type	Doppler Spread	Delay Spread	LOS
SUI-1	C	Low	Low	High
SUI-2	C	Low	Low	High
SUI-3	B	Low	Low	Low
SUI-4	B	High	Moderate	Low
SUI-5	A	Low	High	Low
SUI-6	A	High	High	Low

Physical downlink channel (from base station to mobile station) in the LTE technology uses OFDM method of encoding digital data on multiple carrier frequencies and different types of modulation like QPSK, 16QAM, 64QAM. The reliability of LTE downlink transmission under condition of multipath propagation has been determined by calculation of the BER (Bit Error Ratio) parameter using LTE PHY Lab library included in the 5G Experimental Toolset [3]. It is system-level simulator that allows to configure LTE radio interface, choose traffic model, type of radio channel and different radio resource management (RRM) functionalities. The block diagram of the simulation model is presented in Fig. 3.

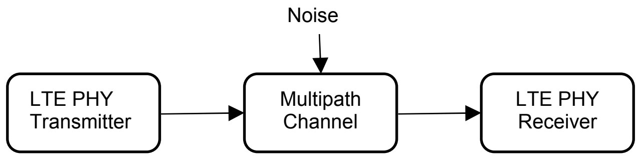

Fig.3. The block diagram of the simulation model

Simulations have been done with the following parameters:
- system bandwidth: 5 MHz (25 PRBs),
- modulation order: 16 (16QAM),
- FFT size: 512,
- tested channel: user data stream with 200 bits in each subframe.

In order to determine BER characteristic of pure radio link, the BER values were calculated without system retransmissions. In a typical operation, LTE system retransmits frames received with errors what significantly increases transmission reliability. Fig. 4 shows BER values calculated for three E-UTRA profiles (EPA, EVA and ETU).

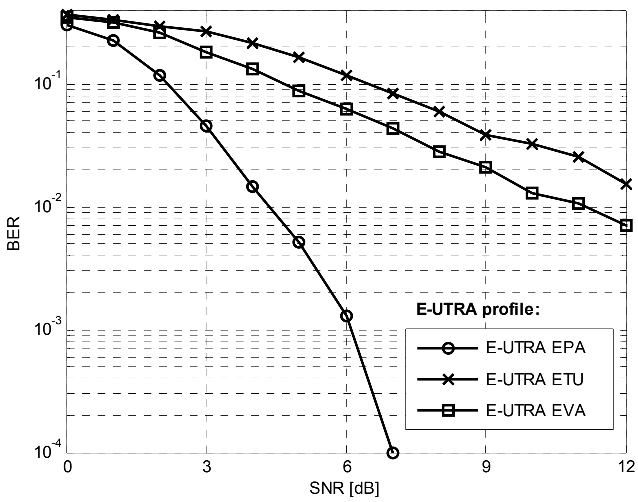

Fig.4. BER values for different profiles of E-UTRA model

BER values obtained for E-UTRA models indicate that the urban environment is the worst case for LTE downlink transmission since the high values and high spread of delays of particular signal paths.

BER values determined for six SUI models (table 2) are presented in Fig.5.

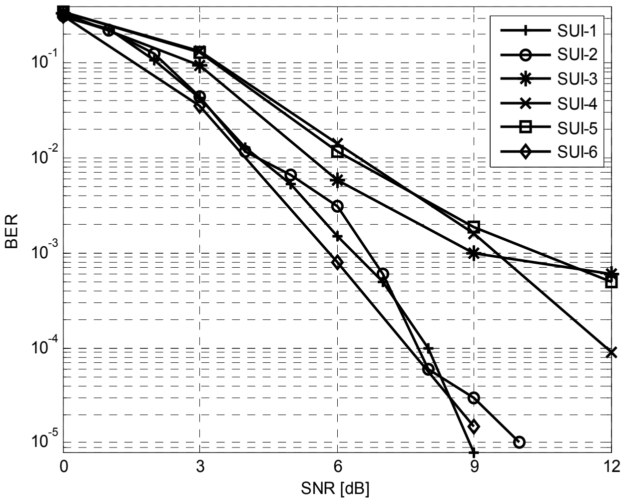

Fig.5. BER values determined using SUI models

As it can be seen it possible to distinguish two groups of BER characteristics. The first group, with the lower values of BER, have been obtained for SUI-1, SUI-2 and SUI-6 models. In the second group (with SUI-3, SUI-4 and SUI 5 models) BER has higher values because of a difficult terrain or high propagation delays.

Calculation of SNIR Coefficient for LTE Downlink

One of the main parameters that describe transmission quality is SNIR (Signal to Noise plus Interference Ratio, sometimes referred as SINR – Signal to Interference and Noise Ratio). In practice the SNIR level is more useful than SNR (Signal to Noise Ratio). Interference are all unwanted signals – noise and signals from another station. Interference cannot be avoided, but can be reduced by using different methods such as adaptive algorithms [6].

The estimation and control of the SNIR is an important problem in LTE networks as well as in many previous systems such as GSM and UMTS [7].

SNIR parameter is defined by equation (2).

$$SNIR = \frac{P_w G}{N} \tag{2}$$

where P_w is a power of required signal, G is a path loss and N is a power of noise. The power P_w depends on parameters of base station antennas and propagation model. For noise we can distinguish two components: own-cell noise and other-cell (external) noise. The last one depends on location of the nearby station and typically is the largest near the cell boundary. Path loss G is a stochastic parameter and depends on distance between UE and transmitter and on environment parameters like rapid and slow fading in the channel. SNIR level is related to the number of TTI (Transmission Time Intervals) and the number of PRB (Physical Resource Block) in data stream. TTI number determines how frequently MAC layer can schedule a transport block to transmit to an UE. TTI base value is 1 ms (duration of subframe) and each 1ms TTI consists of two slots. For calculations the LTE MAC Lab library from 5G Experimental Toolset was used [3]. The block diagram of the network used in experiments is presented in Fig. 6.

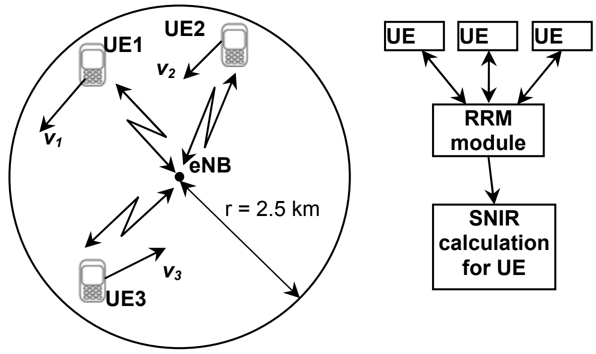

Fig.6. Block diagram of the network used for SNIR level calculation

The calculations of SNIR level were carried out with the following assumptions:

- Cell with radius 2.5 km, eNB inside the center of the cell, base station power equals 46 dBm.
- Three-sectors antenna on the tower with 30 m height, antenna gain equals 18 dBi.
- 800/900 MHz frequency band.
- 3GPP multipath channel model with and without random fluctuations.
- Number of TTI equals 3.
- Number of UEs equals 3, the various speed of UEs (100km/h, 45 km/h and 2 km/h).

The 3GPP multipath model was described in document 3GPP TS 36.101: UE Radio Transmission and Reception. For this model software calculates delay profile depending on the E-UTRA channel model described previously (table 1) and determines maximum Doppler frequency (caused by moving UEs in the mobile radio channel). For the case of multi-antenna systems, a correlation between the UE and eNodeB antennas may be set.

The Rice-Rayleigh model of multipath propagation and 3GPP multipath model was used. The Rayleigh method assumes that exists a non-direct path between base station and mobile terminal, there are many signal paths and no one of them is the main (with a significantly higher power than other). In the Rice model the direct path was added. The software itself determines if there are direct visibility conditions (LOS - Line of sight) and chooses the appropriate model (Rice or Rayleigh).

The results of simulation for 3GPP channel with random fluctuation are presented in Fig.7. For each UE we have different values of SNIR level. For 1st and 2nd UE the SNIR value in downlink is near constant, and it does not show dependencies on number of PRB and number of TTI. For 1st user, which is moving near edge of the cell, SNIR value is very low, about -14 dB, what indicates the significant amount of interferences from nearby cells. For 3rd user (moving at the slowest speed to the center of the cell) the SNIR level in the downlink changes between 5 dB and 18 dB and especially depends on number of TTI. The results showed that SNIR level inside the cell is clearly higher than near edge of the cell. Within the cell, the SNIR level depends on number of PRB and number of TTI, and near edge it rather does not show such dependence. The SNIR level is weakly dependent on the velocity of the mobile terminal too. For comparison, the results of simulation for 3GPP model without fluctuation for UE3 is showed in Fig.8. The characteristic is similar to channel's model with fluctuations, but SNIR value is smaller (2 to 10 dB).

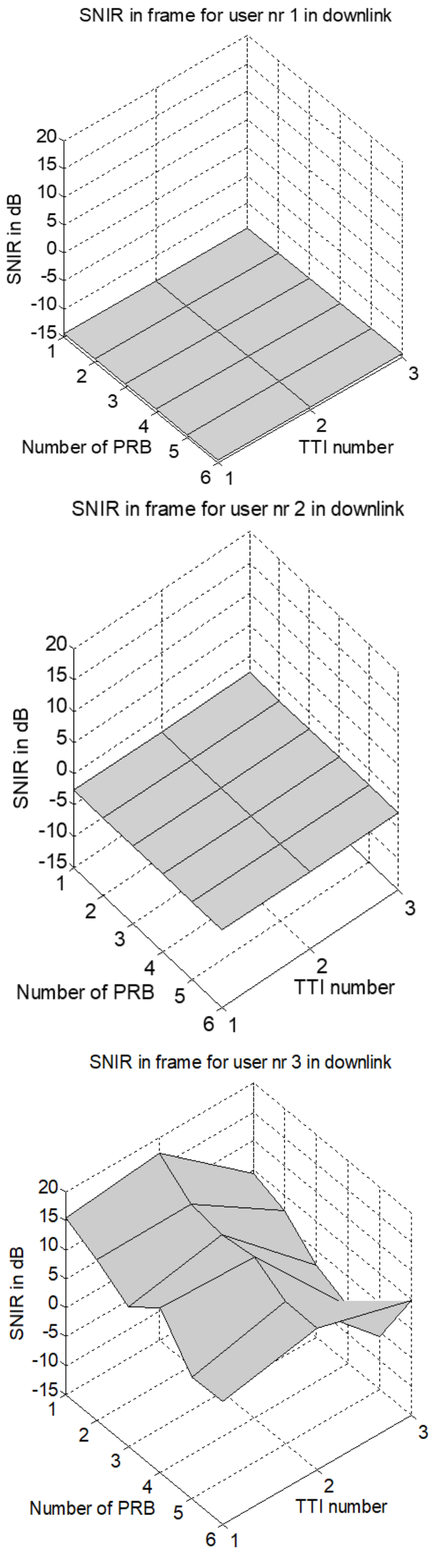

Fig.7. SNIR level for users in the downlink versus number of PRB and TTI number for frequency band 800/900 MHz, urban environment, and 3GPP multipath channel model with random fluctuations

Obtained results show that there are specific situations when multipath propagation can increase the SNIR level. Especially it is possible in the urban environment with places without direct visibility of transmitter and receiver e.g. caused by high buildings located between them. In such situations communication can be continued through signals reflected from nearest objects.

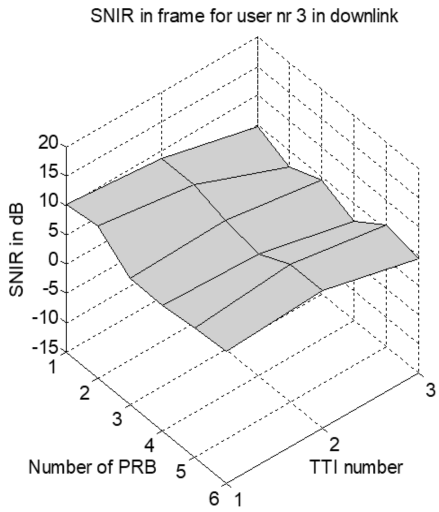

Fig.8. SNIR level for user 3 in the downlink versus number of PRB and TTI number, for frequency band 800/900 MHz, urban environment, and 3GPP channel model without fluctuations

Conclusions

The calculated BER values show that even for difficult types of channel (eg. urban environment and high-mobile users) LTE/OFDMA receiver can operate properly for SNR values less that can be practically found. In the real network its reliability is also increased by system retransmission techniques.

The SNIR level is an important parameter that determines the quality of the transmission in the system. This is a significant and convenient parameter to the quality description, since it takes into account antenna parameters, conditions of electromagnetic wave propagation, different users mobility scenarios and types of environment.

The research was conducted within the project S/WE/1/2015, financially supported by Polish Ministry of Science and Higher Education.

Authors: *dr inż. Andrzej Zankiewicz, dr inż. Maciej Sadowski, Politechnika Białostocka, Katedra Telekomunikacji i Aparatury Elektronicznej, ul. Wiejska 45d, 15-351 Białystok, E-mail:* a.zankiewicz@pb.edu.pl, m.sadowski@pb.edu.pl.

REFERENCES

[1] Cox C., *An Introduction to LTE: LTE, LTE-Advanced, SAE, VoLTE and 4G Mobile Communications*, 2nd ed.,Wiley 2014
[2] Zankiewicz A, Sadowski M.: Analysis of Transmission Reliability in LTE System for Various Channel Conditions, XXIV Int. Conf. on Electromagnetic Disturbances, Białystok, 2017, 144-146
[3] http://www.is-wireless.com/5g-toolset
[4] Shabbir N., Sadiq M.T., Kashif H., Ullah R., Comparison of Radio Propagation Models for Long Term Evolution (LTE) Network, Int. Journal of Next-Generation Networks (IJNGN) Vol.3, No.3, September 2011, 27-41
[5] Chowdhury R.H., Zinnat-Ara M., Afroz D., Performance Analysis of Channel Models of LTE in Various Transmission Modes, *Int. Journ. of Scientific & Engineering Research*, Vol.5, Is.7, 2014, 1193-1198
[6] Jańczak D., An Adaptive Algorithm of State Estimation in the Presence of Multiplicative Interferences, *Przegląd Elektrotechniczny*, vol.86, no 3, 2010, 30-31
[7] Tabia N., Gondran A., Baala O., Caminada A., Interference model and evaluation in LTE networks, WMNC 2011, 4th Joint IFIP Wireless and Mobile Networking Conf., Oct 2011, Toulouse, France, 2011, 1-6