KAUNAS UNIVERSITY OF TECHNOLOGY

FACULTY OF ELECTRICAL AND ELECTRONICS ENGINEERING

Dilip Janarthanan

INVESTIGATE OF SIGNAL PATH LOSSES IN MICROCELLS FOR UMTS AND LTE – A TECHNOLOGIES

Master's Degree Final Project

Supervisor

Assoc. Prof. Dr. Saulius Japertas

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Smart Telecommunications Engineering (621H64001)

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DECLARATION OF ACADEMIC HONESTY

03 June 2016

Kaunas

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Dilip Janarthanan. Investigate of Signal Path Losses in Microcells for UMTS and LTE – A Technologies. Final project of Telecommunications engineering master degree / supervisor Assoc. Prof. Dr. Saulius Japertas; Electrical and Electronics Engineering Faculty, Kaunas University of Technology.

Telecommunication Engineering and Signal Path losses

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SUMMARY

This work concerns about the signal propagation models used for the existing 4th Generation (4G) of cellular networks known as Long Term Evolution Advanced (LTE - A) and the comparison between UMTS technology. LTE - A is recognized as ITU 4G technology that has yet been used to provide public services. Therefore, there are a sufficient number of the issues, including those relating to the path losses, which are not solved yet. The signal propagation for microcells based on building heights and distance from base station, plays a very significant role in planning of any wireless communication systems, is examined. The experiments were carried out in an urban area. The “Huawei LTE CPE Modem E5186 – 22a” was used to carry out the experiments in the urban area. There were measured the signals’ path losses from two mobile network base stations depending on buildings highs and distances to them. The “R&S®FSH4 View Version 2.20” spectrum analyzer was used for signal strength measurements. The results are compared with well-known models. Based on experiment results a new propagation model is proposed for the examined area and the results proved the new propagation model with accuracy ~97.8 %.

Results were approved in 2 conferences and 2 publications (Annex 1).

Dilip Janarthanan. Signalų skildimo prognozavimo modelių LTE ir UMTS tinkle tyrimas. Telekomunikacijų inžinerijos magistro baigiamasis projektas / vadovas dr. Saulius Japertas; Telekomunikacijų katedra, Elektros ir elektronikos fakultetas, Kauno technologijos universitetas.

Telekomunikacijų inžinerijos ir signalo kelias nuostoliai.

Reikšminiai žodžiai: *Mikrocelė, UMTS, LTE-A, signalo nuostoliai, pastatų aukštis, bazinė stotis.*

Kaunas, 2016. – 42 p.

SANTRAUKA

Šiame darbe didžiausias dėmesys yra skirtas 4 kartos mobiliojo ryšio tinklo (LTE-A) signalo sklidimo modelių įvertinimui. Taip pat lygiagrečiai yra atliekamas palyginimas su UMTS naudojamais modeliais. Signalų sklidimui mikrocelėse didelė įtaką turi namų aukščiai, atstumas nuo bazinės stoties, bei kitos bevielės sistemos. Atliekant eksperimentinius tyrimus buvo naudota Huawei LTE CPE Modem E5186 – 22a įranga, o pačio signalo stiprumo lygiai buvo matuojami mieto teritorijoje. Matavimai buvo atlikti tiriant signalo lygio priklausomybes nuo pastatų aukščio bei atstumo iki bazinės stoties. Signalo stiprumo matavimui buvo panaudotas spektro analizatorius "R&S®FSH4 View Version 2.20". Matavimo metu gauti rezultatai buvo aproksimuoti bei atliktas palyginimas (teorinių paskaičiavimų) su jau žinomais signalo sklidimo prognozavimo metodais. Remiantis eksperimento metu gautais rezultatai pasiūlytas naujas signalo sklidimo prognozavimo metodas, ir atlikus skaičiavimus nustatyta, kad jo patikimumas yra apie ~97.8 %.

Rezultatai yra pristatyti 2 konferencijose ir aprobuoti 2 publikacijos. (Priedas 1)

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1. INTRODUCTION

1.1 Organization of the Thesis

This thesis work is divided into five main chapters:

- Chapter 1 describes the introduction of LTE – A and UMTS with the background, role of the technology in the present mobile communication systems and the motivation of this master thesis;
- Chapters 2 lists literature review about LTE-A and the transmission techniques used in LTE-A and compared with UMTS technology;
- Chapter 3, explains the methodology and experiment used with the block diagram of signal propagation model in the simulation of LTE-A and UMTS technology;
- Chapter 4 presents result with the detailed description of proposed model for LTE-A compared with different other models and environments and with UMTS technology. This chapter describes the path loss difference based on outdoor parameters;
- Chapter 5 evaluates over the main points of this thesis work with concluding remarks and proposes future work that can be done with the simulator used in this thesis in order to continue investigation within LTE-A.

1.2 Cellular wireless communication

The cellular wireless communications industry witnessed tremendous growth in the past decade with over four billion wireless subscribers worldwide. The first generation (1G) analog cellular systems supported voice communication with limited roaming. The second generation (2G) digital systems promised higher capacity and better voice quality than did their analog counterparts. The two widely deployed second-generation (2G) cellular systems are GSM (global system for mobile communications) and CDMA (code division multiple access). The ITU-R initiative on IMT-2000 (international mobile telecommunications 2000) paved the way for evolution to 3G. A set of requirements such as a peak data rate of 2 Mb/s and support for vehicular mobility were published under IMT-2000 initiative. The 3G standard in 3GPPis referred to as wideband CDMA (WCDMA) because it uses a larger 5 MHz bandwidth relative to 1.25MHz bandwidth used in 3GPP2's cdma2000 system. The 3GPP2 also developed a 5MHz version supporting three 1.25MHz subcarriers referred to as cdma2000-3x. The two 3G standards namely HSPA (high speed packet access) [1] and HRPD (high rate packet data) [2] were finally able to fulfill the 3G promise and have been widely deployed. The introduction of

Mobile WiMAX led both 3GPP and 3GPP2 to develop their own version of beyond 3G systems based on the OFDMA (orthogonal frequency division multiple access) technology and network architecture similar to that in Mobile WiMAX.

The International Telecommunications Union (ITU) defined the third generation (3G) of mobile telephony standards IMT-2000 to facilitate growth, increase bandwidth, and support more diverse applications. For example, GSM could deliver not only voice but also circuit-switched data at speeds up to 14.4 Kbps. But to support mobile multimedia applications, 3G had to deliver packet-switched data with better spectral efficiency, at far greater speeds.

The 3rd Generation Partnership Project (3GPP) was formed in 1998 to foster deployment of 3G networks that descended from GSM. 3GPP technologies evolved as follows.

- General Packet Radio Service (GPRS) offered speeds up to 114 Kbps;
- Enhanced Data Rates for Global Evolution (EDGE) reached up to 384 Kbps;
- UMTS Wideband CDMA (WCDMA) offered downlink speeds up to 1.92 Mbps;
- High Speed Downlink Packet Access (HSDPA) boosted the downlink to 14 Mbps;
- LTE Evolved UMTS Terrestrial Radio Access (E-UTRA) is aiming for 100 Mbps.

Though there are many advantages with 3G technology, there are few drawbacks like

- Upgrading the base station and cellular infrastructure to 3G incurs very high costs;
- Service provider has to pay high amount for 3G licensing and agreements;
- Problem with the availability of handsets in few regions and their costs;
- High power consumption

In 3G services small conventional base stations mostly deployed in an outdoor environment providing short range coverage to both outdoor and indoor. This is also used for providing additional capacity to ease traffic congestion. Typical microcell range is in the order of 600 - 1000 meters. This small range allows household and small business users the coverage they need, without overlapping or interfering with their neighbors. A number of 3G mobile subscribers worldwide from 2008 to 2010 and also offers a forecast until 2020. In 2008, the number of 3G mobile subscribers worldwide amounted to approximately 690 million. The frequency that is generally used in Europe is 2100 MHz.

The beyond 3G system in 3GPP is called evolved universal terrestrial radio access (evolved UTRA) [3] and is also widely referred to as LTE (Long-Term Evolution) while 3GPP2's version is called UMB (ultra-mobile broadband) [4] as depicted in Figure 1.1. It should be noted that all three beyond 3G systems namely Mobile WiMAX, LTE and UMB meet IMT-2000 requirements and hence they are also part of an IMT-2000 family of standards.

The goal of LTE is to provide a high-data-rate, low-latency and packet-optimized radio access technology supporting flexible bandwidth deployments [5]. The air-interface related attributes of the LTE system are summarized in Table 1.1. The system supports flexible bandwidths thanks to OFDMA and SC-FDMA access schemes. In addition to FDD (frequency division duplexing) and TDD (time division duplexing), half duplex FDD is allowed to support low cost UEs. The goal for LTE-advanced [6] is to further enhance system spectral efficiency and data rates.

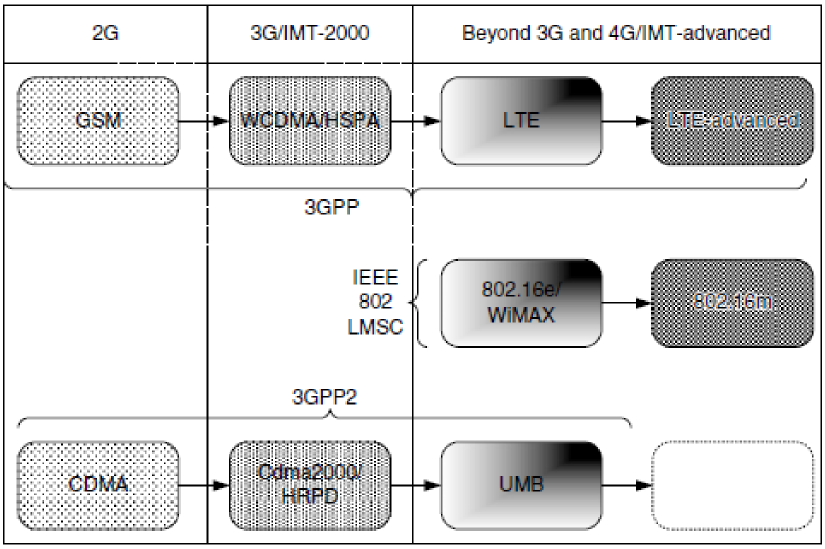
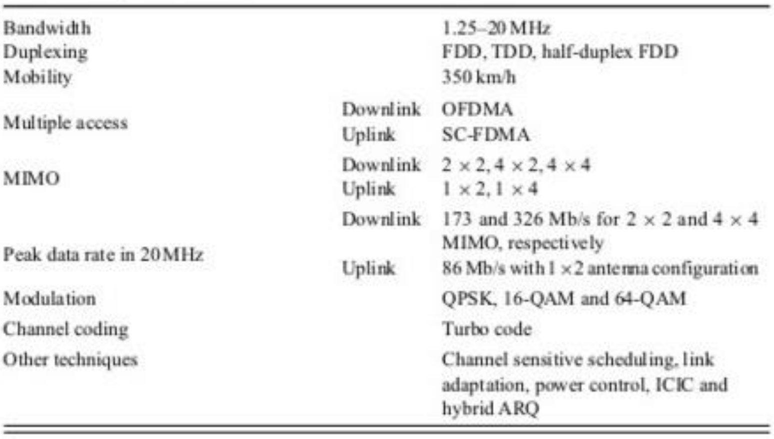


Fig. 1.1 Cellular systems evolution

Table 1.1 LTE system attributes



Bandwidth		1.25–20 MHz
Duplexing		FDD, TDD, half-duplex FDD
Mobility		350 km/h
Multiple access	Downlink	OFDMA
	Uplink	SC-FDMA
MIMO	Downlink	2 × 2, 4 × 2, 4 × 4
	Uplink	1 × 2, 1 × 4
Peak data rate in 20MHz	Downlink	173 and 326 Mb/s for 2 × 2 and 4 × 4 MIMO, respectively
	Uplink	86 Mb/s with 1 × 2 antenna configuration
Modulation		QPSK, 16-QAM and 64-QAM
Channel coding		Turbo code
Other techniques		Channel sensitive scheduling, link adaptation, power control, ICIC and hybrid ARQ

LTE (Long Term Evolution) standardization within the 3GPP (3rd Generation Partnership Project) has reached a mature state. Changes in the specification are limited to corrections and bug fixes. Since end 2009, LTE mobile communication systems are deployed as a natural evolution of GSM (Global system for mobile communications) and UMTS (Universal Mobile Telecommunications System). The ITU (International Telecommunication Union) coined the term IMT-Advanced to identify mobile systems whose capabilities go beyond those of IMT 2000 (International Mobile Telecommunications). Specifically, data rate requirements are increased. In order to support advanced services and applications 100 Mbps for high and 1 Gbps for low mobility, scenarios must be realized. Throughout 2009 3GPP worked on a study with the purpose of identifying the LTE improvements required to meet IMT-Advanced requirements. In September 2009 the 3GPP Partners made a formal submission to the ITU proposing that LTE Release 10 and beyond (LTE-Advanced) should be evaluated as a candidate for IMT-Advanced. In October 2010 LTE-Advanced successfully completed the evaluation process in ITU-R complying with or exceeding the IMT Advanced requirements and thus became an acknowledged 4G technology.

Based on the ITU requirements for IMT-Advanced systems, 3GPP created a technical report summarizing LTE-Advanced requirements. The IMT-Advanced key features delineated in the circular letter inviting candidate radio interface technologies are given below:

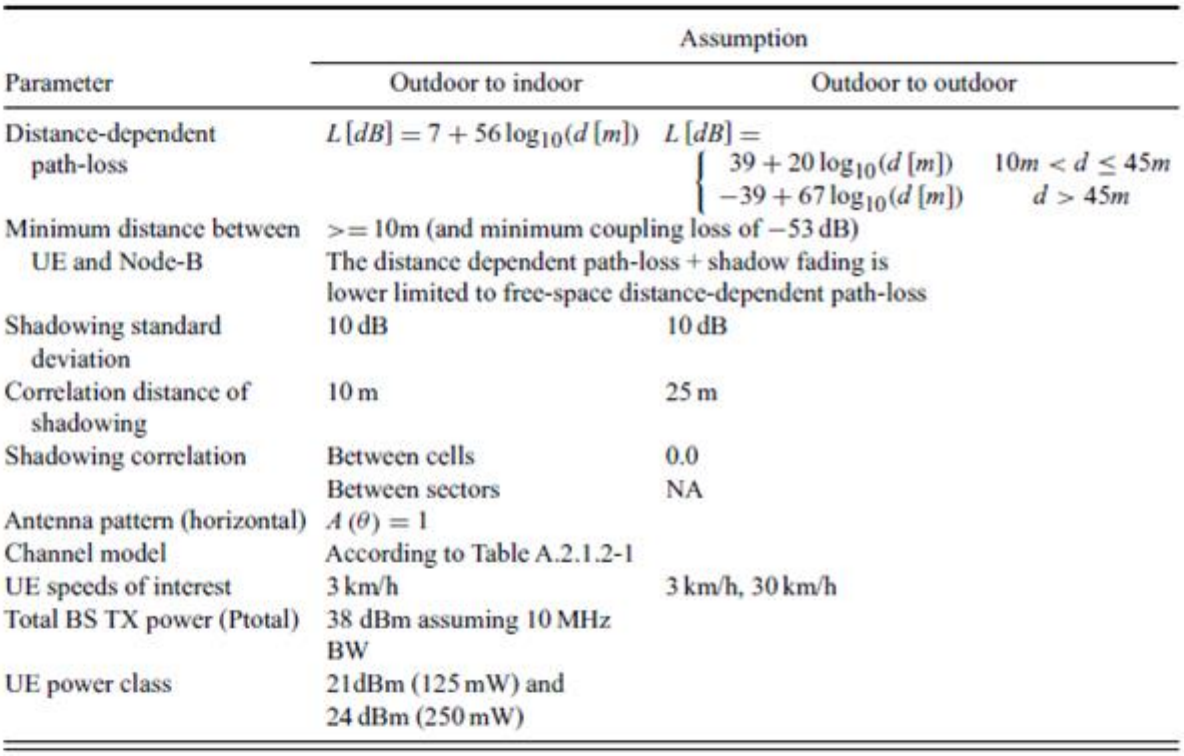
- A high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost efficient manner;
- Compatibility of services within IMT and with fixed networks;
- Capability of interworking with other radio access systems;
- High quality mobile services;
- User equipment suitable for worldwide use;
- User-friendly applications, services, and equipment;
- Worldwide roaming capability;
- Enhanced instantaneous peak data rates to support advanced services and
- Applications (100 Mbps for high and 1 Gbps for low mobility were established as targets for research).

In general, the above IMT-Advanced requirements shall be met or even exceeded. Additionally, all existing LTE requirements are equally applicable to LTE-Advanced. For several categories, concrete requirements have been set. Microcells have a range of a few hundred meters to a few kilometers, but they do not always have a self-organizing and self-management capabilities. A number of 4G mobile subscribers worldwide in 2010 and also offers a forecast until 2020. In 2010, the number of 4G mobile subscribers worldwide came to 1.18 million. The frequency used in Lithuania ranges from 800 MHz – 2600 MHz.

The specifications of Long Term Evolution (LTE) in 3rd Generation Partnership Project (3GPP) (Release 8) were finished when work began on the new Long Term Evolution Advanced (LTE-A) standard (Release 9 and beyond). LTE-A meets or exceeds the requirements imposed by International Telecommunication Union (ITU) to Fourth Generation (4G) mobile systems, also known as International Mobile Telecommunication Advanced (IMT-A). LTE-A is so appealing for operators because of peak data rates of 1 Gbps with bandwidths of 100 MHz for the downlink, very low latency, more efficient interference management and operational cost reduction.

As this work focuses on signal propagation of micro cell, the system simulation baseline parameters for the micro-cell deployment model is given in Table 1.2 [7].

Table 1.2 Microcell system simulation baseline parameters



	Assumption	
Parameter	Outdoor to indoor	Outdoor to outdoor
Distance-dependent path-loss	$L[dB] = 7 + 56\log_{10}(d[m])$	$L[dB] = \begin{cases} 39 + 20\log_{10}(d[m]) & 10m < d \le 45m \\ -39 + 67\log_{10}(d[m]) & d > 45m \end{cases}$
Minimum distance between UE and Node-B	>= 10m (and minimum coupling loss of −53 dB) The distance dependent path-loss + shadow fading is lower limited to free-space distance-dependent path-loss	
Shadowing standard deviation	10 dB	10 dB
Correlation distance of shadowing	10 m	25 m
Shadowing correlation	Between cells Between sectors	0.0 NA
Antenna pattern (horizontal)	$A(\theta) = 1$	
Channel model	According to Table A.2.1.2-1	
UE speeds of interest	3 km/h	3 km/h, 30 km/h
Total BS TX power (Ptotal)	38 dBm assuming 10 MHz BW	
UE power class	21dBm (125 mW) and 24 dBm (250 mW)	

The selection of a suitable signal propagation model for LTE is of great importance. A signal propagation model describes the behavior of the signal while it is transmitted from the transmitter towards the receiver. It gives a relation between the distance of transmitter and receiver and the path loss. From this relation, one can get an idea about the allowed path loss and the maximum cell range. Path loss depends on the condition of the environment (urban, rural, dense urban, suburban, open, forest, sea etc.), operating frequency, atmospheric conditions, indoor/outdoor and the distance between the transmitter and receiver. This work provides a new model for signal propagation with the signals' path losses from two mobile network base stations depending on different terrains.

A further example is to be found in the proposed use of radio to provide cordless access into the public switched telephone network. Such a system would provide coverage using a network of street radio distribution points, each of which would operate out to a radius of a few hundred meters. The optimum design of these systems makes considerable demands on existing radio planning methods and this, in turn, is providing the stimulus for the development of new propagation models able to provide accurate predictions in microcellular environments. Some of the typical planning issues are reviewed and the propagation modelling methodologies which are being explored as possible solutions are examined [8].

A comparison of different LOS probability models is performed for the Aalborg environment. Alpha-beta-gamma (ABG Model) and close-in reference distance path loss models are studied in depth to show their value in channel modeling. Additionally, both single-slope and dual-slope omnidirectional path loss models are investigated to analyze and contrast their root-mean-square (RMS) errors on measured path loss values. While the results show that the dual-slope large-scale path loss model can slightly reduce RMS errors compared to its single-slope counterpart in non-line-of-sight (NLOS) conditions, the improvement is not significant enough to warrant adopting the dual- slope path loss model. Furthermore, the shadow fading magnitude versus distance is explored, showing a slight increasing trend in LOS and a decreasing trend in NLOS based on the Aalborg data, but more measurements are necessary to gain a better knowledge of the UMa (Urban Macrocell) channels at centimeter- and millimeter-wave frequency bands [9].

The following items are requirements for a 5G system, which should be stressed. Different applications will place different requirements on the performance, and peak requirements that will need to be satisfied in certain configurations. For example, very-high-rate applications such as streaming high-definition video may have relaxed latency and reliability requirements compared to driverless cars or public safety applications, where latency and reliability are paramount but lower data rates can be tolerated. The Core network will also have to reach unprecedented levels of flexibility and intelligence, spectrum regulation will need to be rethought, improved and energy and cost efficiencies will become even more critical considerations in 5G System.

The Next Generation Mobile Networks Alliance explains the following requirements for 5G networks:

- Data rates of several tens of megabits per second should be supported for tens of thousands of users;
- 1 gigabit per second to be offered simultaneously to many workers on the same office floor;
- Several hundreds of thousands of simultaneous connections to be supported for massive sensor deployments;
- Spectral efficiency should be significantly enhanced compared to 4G;
- Coverage should be improved;
- Signaling efficiency should be enhanced;
- Latency should be reduced significantly compared to LTE

1.3 Objective and Tasks

The main objective of this work is to experimentally investigate the path losses in microcells for UMTS and LTE technologies, to compare these experimental data with the existing propagation prediction models and, if necessary, to propose a new path loss model.

In order to achieve this objective it is necessary to solve such tasks:

1. To study and validate different path loss (P L) models, and compute the path loss difference between the frequencies.
2. To prepare the methodology, how to investigate the path losses.
3. To carry out experiments in microcells at different heights of the building with the same base station.
4. To compare experiment results with existing PL models and if necessary to develop a new practical model for path losses.

1.4 Relevance and Novelty:

Relevance of work:

Despite the fact that UMTS and LTE technologies are widely used but the currently available Path loss (PL) models describe the actual experiments in microcells with relatively high tolerances. Those errors can reach 30 percent or more. New mobile technology 5G will operate in micro-cells of the densely populated areas, so it is necessary to have more accurate PL models and need to be more useful for the operators.

Novelty of work:

Experiments have indicated that the PL models should be taken not only to the frequency, distance from the base station, antennas heights, and building geometry, but also cellular technologies.

2. LITERATURE REVIEW

2.1 Experimental investigation of signal propagation in microcells for various frequencies range

Micro cells are low power base stations intended to cover small areas up to a 500 - 600 hundred meters, where macro cells do not provide enough network coverage or crowded areas where additional network capacity is needed. They are expected to play an important role in mobile broadband networks such as Long Term Evolution (LTE) or LTE-Advanced. Moreover, the lack of spectrum available in the lower frequency bands (e.g. 800 MHz or 2 GHz) generates a huge interest in deploying small cells at higher frequency bands. The 3.5 GHz Time-Division LTE (TD-LTE) band is considered as a good spectrum candidate [10, 11], because it allows up to 200 MHz of bandwidth with carrier-aggregation techniques, and many countries have this spectrum available.

Outdoor micro cell propagation has been covered in the literature for different frequency bands. The propagation at 900 MHz and 11 GHz for rural and urban line-of-sight (LOS) scenarios was studied in [12]. The attenuation was found to follow an inverse second power law before a breakpoint, changing to the fourth beyond that point. Similarly, [13] reported the same behavior for 800 MHz LOS micro cells in a dense-urban scenario. In [14], the authors found power decay factors close to free space path loss for both narrow and wide streets in urban scenarios for 1.8 GHz, and concluded that the changes in antenna height do not have significant effects on the path loss characteristics for below rooftop mounted antennas. However, the path loss for the specific micro cell deployment in the 3.5 GHz band has not received much attention yet.

Previous propagation studies reported in the literature for this frequency band have primarily focused on the deployment of Fixed Wireless Access (FWA) technologies such as Worldwide Interoperability for Microwave Access (WiMAX) in urban scenarios [15–18] and rural scenarios [19, 20]. These studies are performed on outdoor macro cells for a measurement distance range from a hundred meters to a few kilometers, with the base station antenna placed over the rooftop and the receive antenna at street level. In general, when addressing indoor coverage, authors do not agree on the frequency dependence of the penetration loss.

Most of the existing in-building radio propagation studies that are reported in the literature are referred to the macro cell case. In [21] both building penetration loss and in-building attenuation are for the frequency range from 800 MHz to 8 GHz. The measurement results showed a constant penetration loss around 9.5 dB and an indoor attenuation based on the penetration distance of 0.6 dB/m, while [22] reports an average penetration loss of 17 dB in the frequency range from 900 MHz to 2.3 GHz. On the other hand, [23] found that penetration loss increases at the higher cellular frequencies (above 3 GHz).

Generally, the authors remark the difficulty of estimating the penetration loss in the macro cell case due to the different illumination conditions and propagation mechanisms. For micro cells (Fig. 2.1), the often cited Berg model [24] suggests a small variation of the penetration loss from 900 MHz to 1800 MHz, while [25] reported increasing penetration loss with frequency.

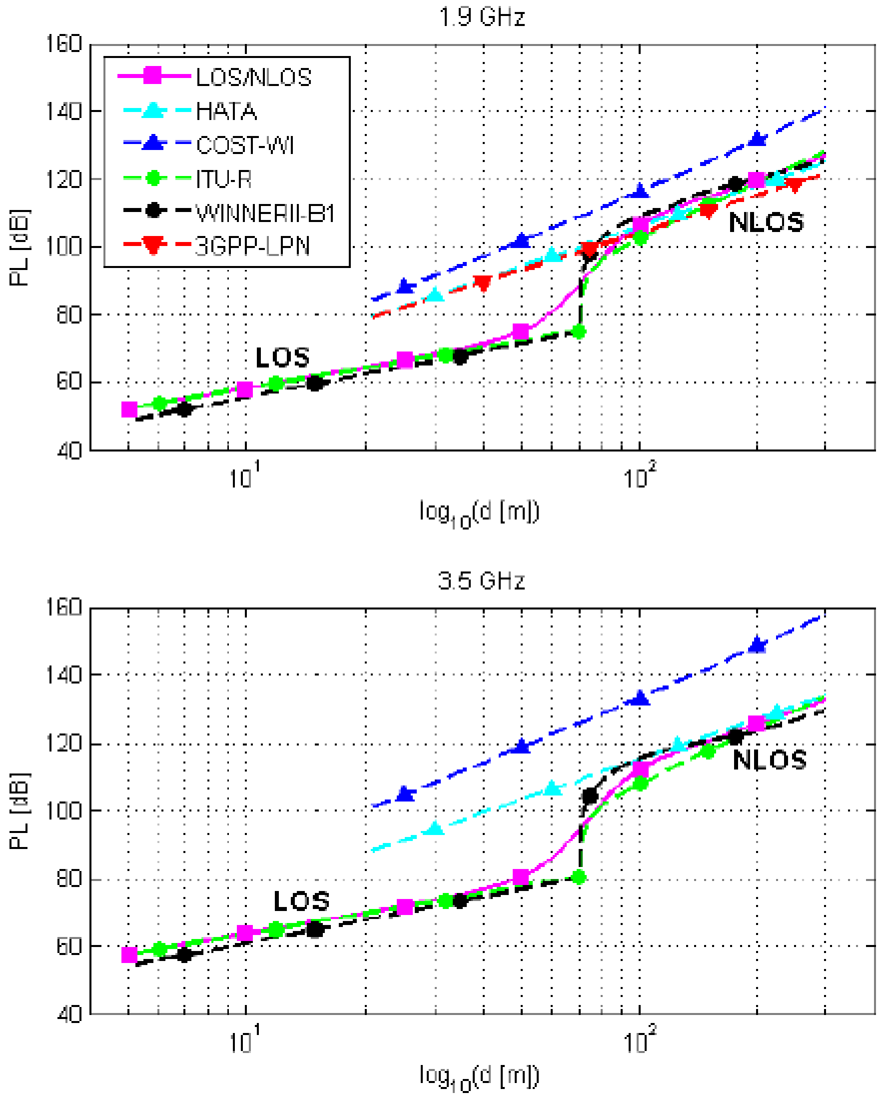


Fig 2.1 Comparison between path loss models

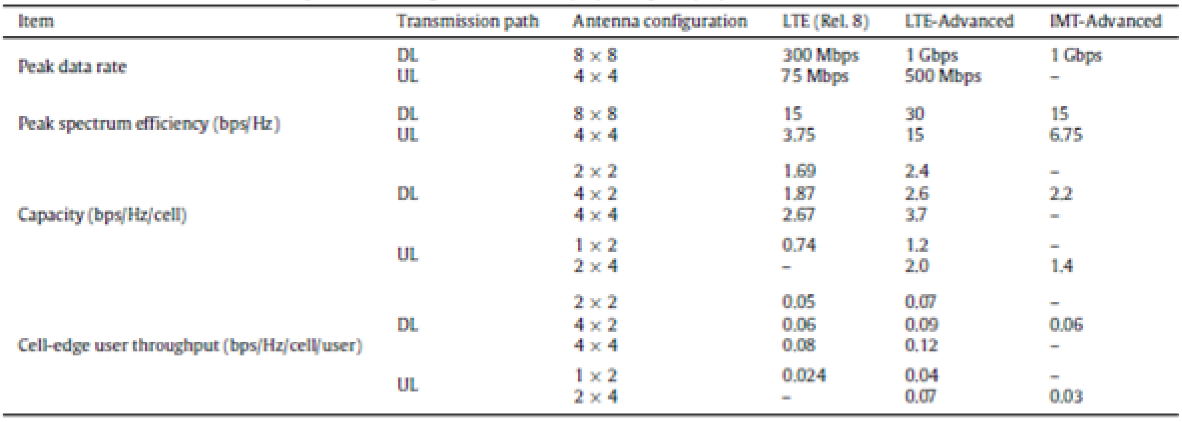
The main disadvantages of existing path loss model Okumura – Hata is the slow response to the rapid changes in the terrain. Hence, the model gives the good result in urban and sub-urban areas but not in rural areas. The common standard deviation between the predicted and the measured path loss values are around 10 dB to 40 dB [26].

Cost 231 Hata model is applicable for the frequency range of 1500 MHz to 2000 MHz. Walfisch model considers the impact of roof-top and building heights by using diffraction to predict the average signal strength at the street levels [27].

The feature usage of LTE in multiple bands of the spectrum has been explored over a period of time. Studies have been conducted for evaluating the performance of the system in various frequency bands. In [28] a thorough comparison of system performance in 800 MHz band has been made with 1800 MHz band and UMTS 900 MHz band, considering few of the primary measurement parameters such as Referenced signal received power (RSRP), Referenced signal received quality (RSRQ), Signal to Interference-noise ratio (SINR) and throughput. It emphasized the fact that 800 MHz bands provided twice the coverage than the 1800 MHz band with less number of base stations. The throughput for LTE 800 is more than UMTS 900 but with degradation towards the cell edges.

The article by ZTE discusses the inherent features of the 700 MHz band for LTE technology. It reveals the fact that using a 700 MHz band (in various scenarios) the coverage provided by a single site is about 7-8 times that offered by the 2.6 GHz band, thereby requiring very few sites operating at 700 MHz frequency. But the cost of having more number of sites operating at higher frequencies is compensated by getting an increase in the capacity of such high frequency operation networks. Thus, operators building their networks on a higher frequency of 1.7 GHz, 1.9 GHz, and 2.5 GHz would have higher capacity as compared to those using the 700 MHz band. The relationship among the requirements of LTE, LTE-Advanced, and IMT Advanced are shown in Table 1 [29].

Table 2.1 LTE, LTE – A and IMT – A performance targets



Item	Transmission path	Antenna configuration	LTE (Rel. 8)	LTE-Advanced	IMT-Advanced
Peak data rate	DL	8 × 8	300 Mbps	1 Gbps	1 Gbps
	UL	4 × 4	75 Mbps	500 Mbps	–
Peak spectrum efficiency (bps/Hz)	DL	8 × 8	15	30	15
	UL	4 × 4	3.75	15	6.75
Capacity (bps/Hz/cell)	DL	2 × 2	1.69	2.4	–
		4 × 2	1.87	2.6	2.2
		4 × 4	2.67	3.7	–
	UL	1 × 2	0.74	1.2	–
		2 × 4	–	2.0	1.4
Cell-edge user throughput (bps/Hz/cell/user)	DL	2 × 2	0.05	0.07	–
		4 × 2	0.06	0.09	0.06
		4 × 4	0.08	0.12	–
	UL	1 × 2	0.024	0.04	–
		2 × 4	–	0.07	0.03

In just a decade, the amount of IP data handled by wireless networks will have increased by well over a factor of 100: from under 3 Exabyte’s in 2010 to over 190 Exabyte by 2018, on pace to exceed 500 Exabytes by 2020. This deluge of data has been driven chiefly by video thus far, but new unforeseen applications can reasonably be expected to materialize by 2020.

In addition to the sheer volume of data, the number of devices and the data rates will continue to grow exponentially. This work complements the previous work by specifically addressing the urban micro cell scenario by focusing on various frequency bands. The propagation is investigated from different measurements for outdoor and outdoor-to-indoor conditions with the aim of developing models which are useful for standardization work and rudimentary planning purposes. Although some existing models predict the observations with good accuracy, this work proposes a model based on the line-of-sight probability that is simpler and easier to apply.

2.2 Mobile signal path loss models

There is a number of propagation models created. Existing models are not directly developed for LTE-A. All models consist of frequency, height of building and distance from the base station and could be universal for different technologies.

A comprehensive propagation prediction models for LTE Advanced is presented in paper [30]. This model was tested for path loss in different areas, such as terrains rural, dense urban, suburban, open terrain and it has been carried using MATLAB has been shown in Fig. 2.2. Simulations were for various prediction techniques: COST-231 Hata model, COST Walfisch-Ikegami method, SUI model, Egli model and mobile services. These simulations were done in wideband channels at 2.3 GHz, 2.6 GHz and 3.5 GHz for the LTE Advanced Network. By comparing prediction methods we can see that COST-231 Hata's prediction method gave minimum path losses. The advantage of this method is that it can be adapted for various environments by incorporating correction factors for different environments. The prediction errors of the COST-231 Hata and COST Walfisch-Ikegami models are considerably lower than those of the SUI and Egli models.

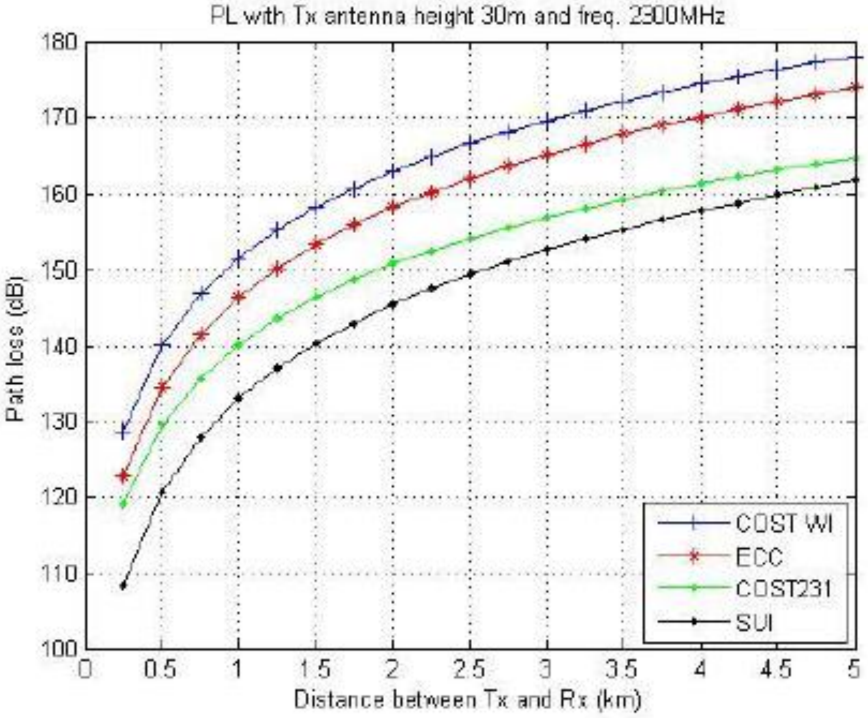


Fig. 2.2 Comparison of path losses for different propagation model

In paper [31] the research analyzed simulations for the LTE network using Hata-Okumara and COST-231 Hata path loss model has been in Fig 2.3 and Fig 2.4. Two of the most common radio propagation models was used to determine the radio coverage for LTE technology. For both models, a comparative analysis through MATLAB simulations was carried with different frequencies. The simulations frequencies were of 1000 MHz, 1500 MHz, 2000 MHz range and the link distances of 30 m, 100 m, and 200 m. As we can see, results show that for both Hata-Okumara and COST-231 Hata, the path loss is lowest when the mobile device is nearest to the base station. Also, path loss graphs evidently look similar, especially for frequencies of 1000 MHz and 1500 MHz. However, on a closer inspection it is noticed that for an antenna height of 200 m, the path loss for a COST-231 Hata model is lower than Okumura-Hata model in an urban environment than in the other environment. From the plot, it can be seen that the higher the antenna base station height is, the better the path loss is in both COST-231 Hata and Hata - Okumara models.

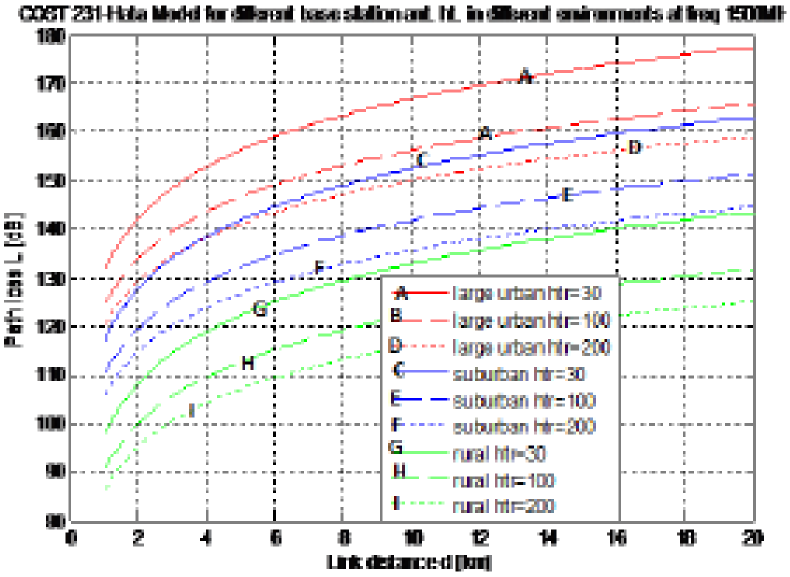


Fig. 2.3 COST – 231 Hata model for frequency 1500MHz

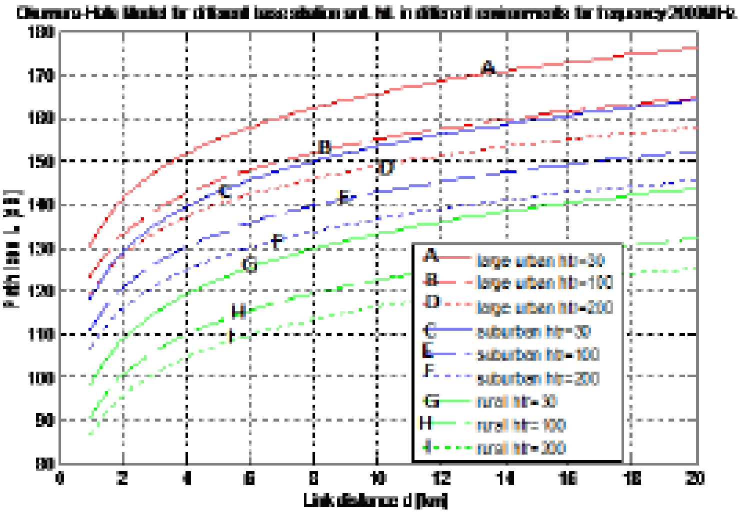


Fig. 2.4 Okumura model for frequency 2000MHz

These results derived from simulations may differ from the situation of real-world. Path loss can be influenced by real-world parameters such as building height or type. It is necessary to compare the simulations to the experiments with real data.

Other research [32] examined a large scale received signal prediction model for different types of propagation environment from field measured signal data. The results were determined based on the obtained experimental data, path loss exponent and standard deviation of strength variability. It can be seen that the values of these parameters differ from study location to location in the coverage area. The results demonstrate that different empirical models for mean signal strength should be used in different regions of the operational zone for cellular network planning.

The field measurement of received signal power conducted at a frequency of 2100 MHz for UMTS network. The path loss exponents for separate areas are gained by using the least squares method. Derived path loss exponents lie in the range from 1.6 to 3.3. The results are utilized as a reference in the system level simulation for network planning and optimizing the design parameters of handover initiation algorithms. However, the experiment was done using drive-testing and measurements could have been taken only on the roads.

The purpose of research investigation [33] was to compare measured data to optimized path loss of three different propagation models for Long Term Evolution from 2 GHz to 3 GHz bands in urban and suburban areas shown in Fig 2.5 - 2.7. The eligibility of these models was compared with actual field measurement at 2.6 GHz in Erbil city-Iraq. It was suggested to use models tuning to fit the experimental results of path loss with the propagation models. The models tuning was executed to fit empirical path loss models to actual field measurements. In conclusion, both analytical and measured results showed that the performance of tuned COST-231 Hata model is the best model among the other discussed models. The mean error of the COST-231 Hata model for an urban area is reduced to zero, the mean standard deviation value is reduced to 7.8 dB and the root mean square error reduced to 7.85 dB. Therefore, in Erbil city, the COST-231 Hata model is recommended to be used for propagation prediction.

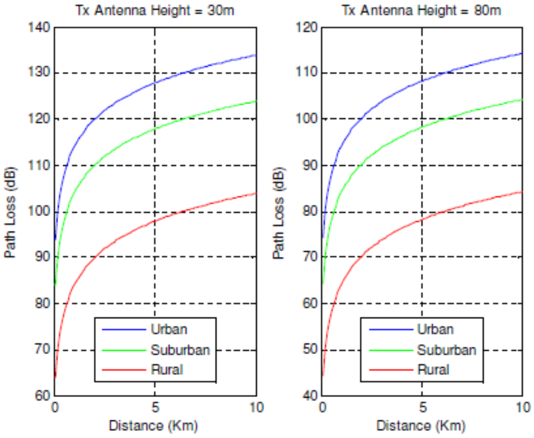


Fig. 2.5 Okumura model for 2100 MHz

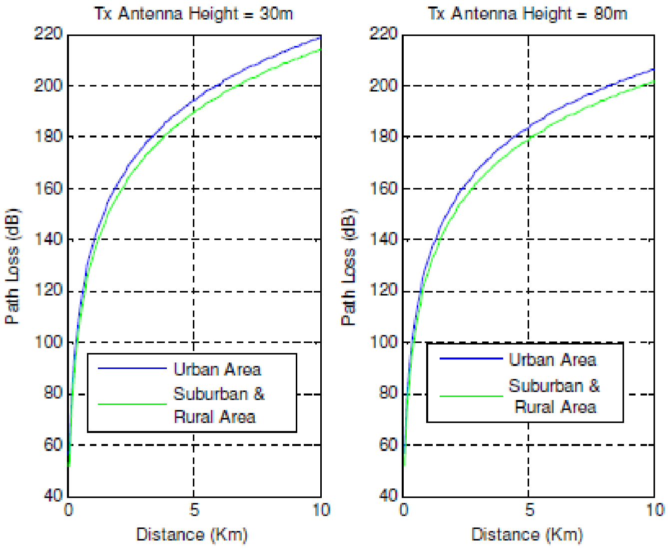


Fig. 2.6 COST – 231 model for 1900 MHz

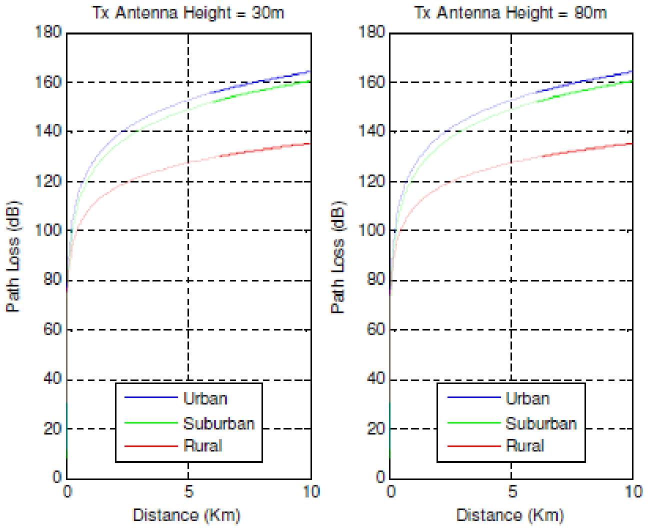


Fig. 2.7 Walfisch – Ikegami model for 2100 MHz

In article [34] propagation model for 4G mobile communication systems is proposed. It uses multiple regression formulae for Path Loss prediction model.

The cumulative distribution function (CDF) for Path Loss (PL) is presented in the Fig. 2.8. CDF is used here to evaluate the simulation results of PL from different distances between transmitter and receiver.

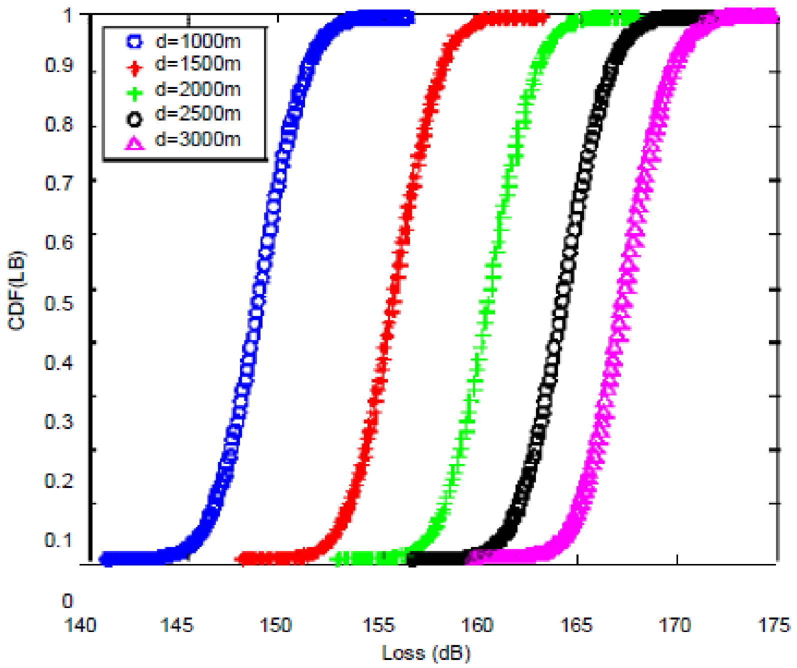


Fig. 2.8 Cumulative distribution function for Path Loss

In addition, when pulsed the additional parameter: the occupation of buildings, it can be used for suburban areas. However, the circumstances of the regression formula are the buildings height and the street width is fairly uniform and is built in rows with a small separation between neighboring buildings. This hypothesis is not corresponding with the real environment.

3. Experimental Methodology

3.1 Object description and equipment's description

The base station (BS) near Kaunas University of Technology student campus was selected. This base station supports GSM, UMTS, and the newest LTE-A technology.

The base station is located near residential buildings of different heights. All the buildings are quite close to each other and no more than 50 meters between each other.

The base station is on top of students' dormitory building. The height of base station is 40 m. The measurements of signal strength were reported for UMTS and LTE-A technologies. The operating frequency band for both UMTS and LTE-A is in the 2100 MHz band. The height of receiver antenna is 1.3 m.

In experimental part, the signal has been measured from the base station with the help of Huawei LTE CPE modem and the model is E5186s – 22a.

A spectrum analyzer is used to check the signal strength from the base station.

GPS BU-353 model is used to find the correct node of the base station.

For UMTS, the signal frequency is used as 2127 MHz

For LTE, the signal frequency is used as 1818.7 MHz

For the measurements of signal strength, "R&S FSH8" spectrum analyzer was chosen. The measuring frequency interval for this spectrum analyzer is from 9 kHz to 8 GHz. The results were processed using "R&S®FSH4 View Version 2.20" software. For further data analysis recorded data could be exported to .txt format.

In 500 m radius around the BS, four residential buildings were selected. The height of those buildings ranged from 14 meters to 32 meters. The maximum of 7 measurement points was selected behind each of the building. The distance for the experiment was limited because of the nearby buildings. Signal strength was measured for UMTS and LTE-A technologies at the same time and with non-line of sight (NLOS) conditions. The first measuring point was 1 meter from the buildings to minimize the scattering effect. The measuring step was 5 meters.

Signal strength measurements for each technology were taken 10 times at each point few days in a row to minimize the error of the results.

Based on experiment results two signal propagation models for UMTS and LTE-A technologies are proposed.

The below Fig. 3.1 shows the place where the signal has been measurement and experiment part has been taken.

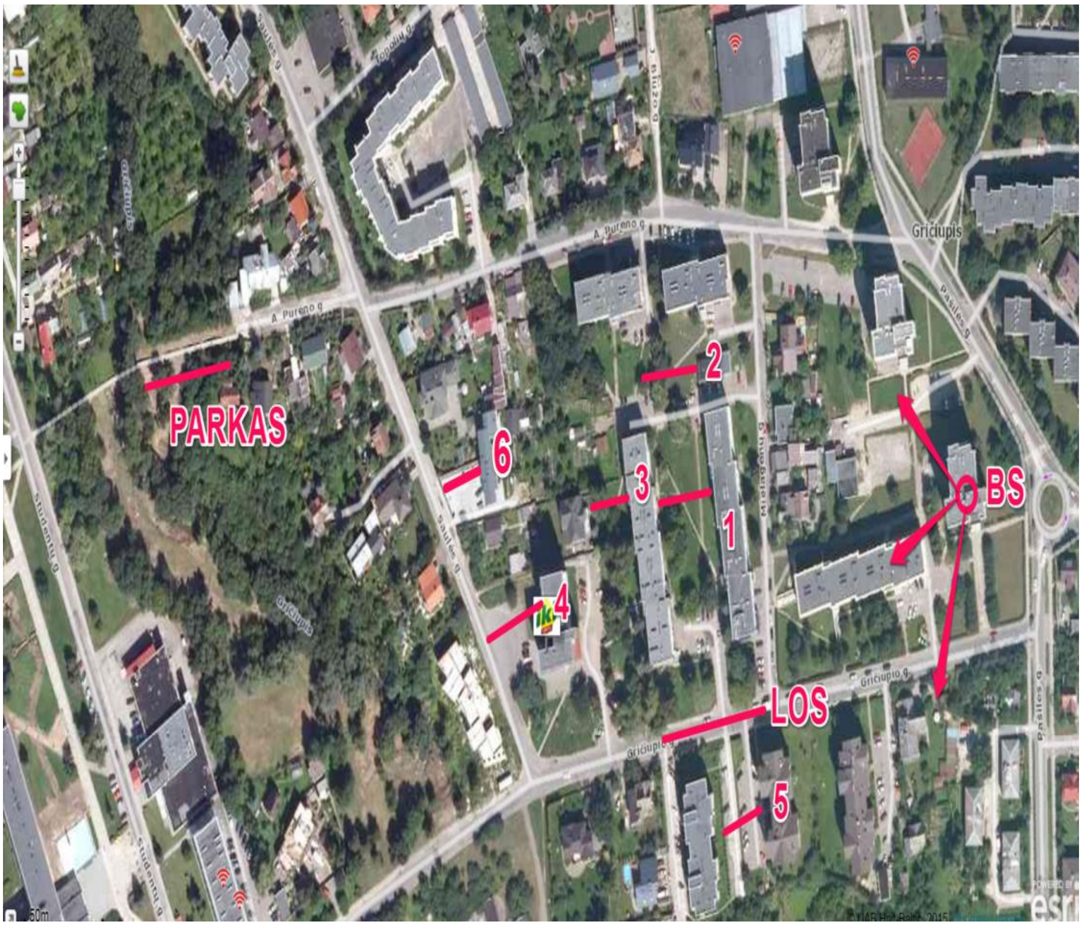
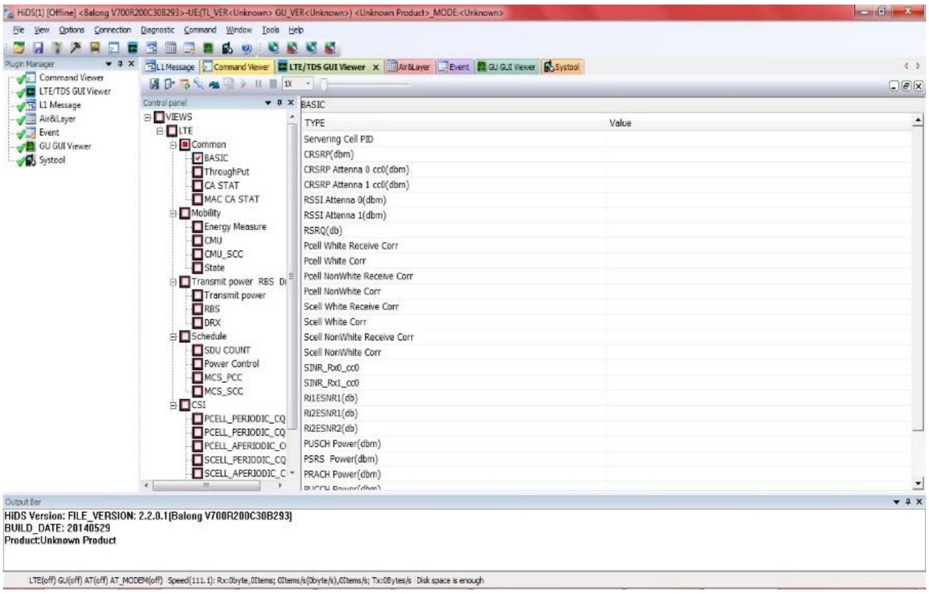


Fig. 3.1 Signal measured near these building from the base station

The HiDS and Wfetch 1.4 software used to calculate the measurement of LTE signal and UMTS signal with the base station (Fig. 3.2 and Fig. 3.3).

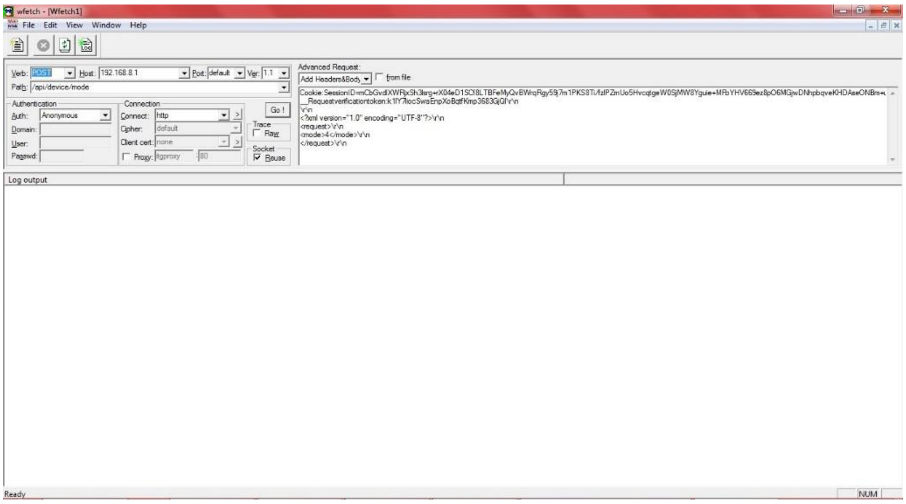


TYPE	Value
Servering Cell PID	
CRSRP(dbm)	
CRSRP Attenna 0 cc0(dbm)	
CRSRP Attenna 1 cc0(dbm)	
RSSI Attenna 0(dbm)	
RSSI Attenna 1(dbm)	
RSRQ(db)	
Pcell White Receive Corr	
Pcell White Corr	
Pcell NonWhite Receive Corr	
Pcell NonWhite Corr	
Scell White Receive Corr	
Scell White Corr	
Scell NonWhite Receive Corr	
Scell NonWhite Corr	
SINR_Rx0_cc0	
SINR_Rx1_cc0	
Ri1ESNR1(db)	
Ri2ESNR1(db)	
Ri2ESNR2(db)	
PUSCH Power(dbm)	
PSRS Power(dbm)	
PRACH Power(dbm)	

```
HiDS Version: FILE_VERSION: 2.2.0.1(Balong V700R200C30B293)
BUILD_DATE: 20140529
Product:Unknown Product
```

```
LTE(off) GU(off) AT(off) AT_MODEM(off)  Speed(111.1): Rx:0byte,0Items; 0Items/s(0byte/s),0Items/s; Tx:0Bytes/s  Disk space is enough
```

Fig. 3.2 HiDS software



Verb: POST
Host: 192.168.8.1
Port: default
Ver: 1.1
Path: /api/device/mode
Auth: Anonymous
Domain:
User:
Passwd:
Connect: http
Cipher: default
Client cert: none
☐ Proxy: itgproxy 80
☐ Raw
☑ Reuse
Advanced Request: Add Headers&Body ☐ from file

```
Cookie:SessionID=mCbGvdlXWRjxSh3lsrg+rX04eD1SCf8LTBFeMyQvBWrqRgy59j7m1PKS8Ti/fzlPZmUo5HvcqtgeW0SjMW8Yguie+MFbYHV669ez8pO6MGjwDNhpbqveKHDAseONBm+
__Requestverificationtoken:k1lY7locSwaEnpXoBqtfKmp3683GjQl\r\n
\r\n
<?xml version="1.0" encoding="UTF-8"?>\r\n
<request>\r\n
<mode>4</mode>\r\n
</request>\r\n
```

Fig. 3.3 Wfetch 1.4 software

These are the two main software used to measure the signal. By using all the needed equipment’s the signal strength is measured from the base station to the user equipment. These experiments are carried out behind the building far away from the base station. For each and every 5m distance the results have been taken in a text file.

The (Fig. 3.4 – 3.9) shown in Annex - 2 is the main scheme of the measurement.

3.2 Error evaluation

The various errors were calculated in order to evaluate the results accuracy (3): the relative error δ, the root-mean-square of the measurement result S_{RSL}, the root-mean-square of the measurements mathematical expectation and skewness γ:

$$\begin{cases} \delta = \dfrac{\frac{1}{n}\left|RSL_i - \langle RSL\rangle\right|}{\left|\langle RSL\rangle\right|} \times 100\%, \\ S_{RSL} = \sqrt{\dfrac{\sum\limits_{i=1}^{n}\left(RSL_i - \langle RSL\rangle\right)^2}{n-1}}, \\ S_{\langle RSL\rangle} = \dfrac{S_{RSL}}{n}, \\ \gamma = \dfrac{\frac{1}{n}\sum\limits_{i=1}^{n}\left(RSL_i - \langle RSL\rangle\right)^3}{\left(S_{RSL}\right)^3}. \end{cases} \qquad (1)$$

where RSL_i is the signal strength of the separate measuring, [dBm]; $\langle RSL\rangle$ is the mathematical expectation, [dBm]; *n* is the number of measurements.

Summarizing all received errors it was found that $\delta \approx 4\%$ is for all measurements of the average relative error, $S_{RSL} \approx 1{,}63 dBm$ is the root-mean-square of the measurement result is, $S_{\langle RSL\rangle} \approx 0{,}47 dBm$ is the root-mean-square of the measurements mathematical expectation.

4. Results and its Analysis

4.1 Results

In telecommunication, received signal strength indicator (RSSI) is a measurement of the power present in a received radio level.

The summary of LTE signal measurement all building has been mentioned below in tables 4.1 – 4.3.

Table 4.1 Signal measured at 18 m and 20 m distance from the building

18 m		20 m	
d_{BS}, m	P_{Rx}, dBm	d_{BS}, m	P_{Rx}, dBm
156	-69.15	212	-77.8
160	-67.45	216	-72.8
165	-68.5	221	-71.85
170	-71.1	226	-76.85
175	-66.15		
180	-65.3		
185	-70.95		

Table 4.2 Signal measured at 23 m and 32 m distance from the building

23 m		32 m	
d_{BS}, m	P_{Rx}, dBm	d_{BS}, m	P_{Rx}, dBm
169	-73.35	268	-73.65
173	-73.35	272	-66.2
178	-70.45	277	-62.55
183	-68.05	282	-69.45
188	-69.4	287	-67.85
193	-66.4	292	-69.8
		297	-69.85

Table 4.3 Signal measured at 14m distance from the building

d_{BS}, m	P_{Rx}, dBm
303	-72.5
307	-73.4
312	-71.5
317	-73
322	-72.6
327	-64.1

The summary of UMTS signal measurement all building has been mentioned in the below Table (4.4 – 4.6).

Table 4.4 Signal measured at 18 m and 20 m distance from the building

18 m		20 m	
d_{BS}, m	P_{Rx}, dBm	d_{BS}, m	P_{Rx}, dBm
156	-55.067	212	-78.58
160	-53.1	216	-56.47
165	-50.775	221	-54.29
170	-55.44	226	-56.011
175	-47.037		
180	-48.822		
185	-48.38		

Table 4.5 Signal measured at 23 m and 32 m distance from the building

23 m		32 m	
d_{BS}, m	P_{Rx}, dBm	d_{BS}, m	P_{Rx}, dBm
169	-61.144	268	-53.5
173	-53.66	272	-47.2

178	-49.256	277	-45.7
183	-48.133	282	-46.3
188	-55.22	287	-51.22
193	-54.48	292	-46.69
		297	-52.89

Table 4.6 Signal measured at 14m distance from the building

d_{BS}, m	P_{Rx}, dBm
303	-39.59
307	-38.73
312	-43.52
317	-39.5
322	-47.629
327	-42.14

The results of signal path losses for LTE and UMTS technologies compared with 4 propagation models are presented in Fig. 4.1 – 4.2.

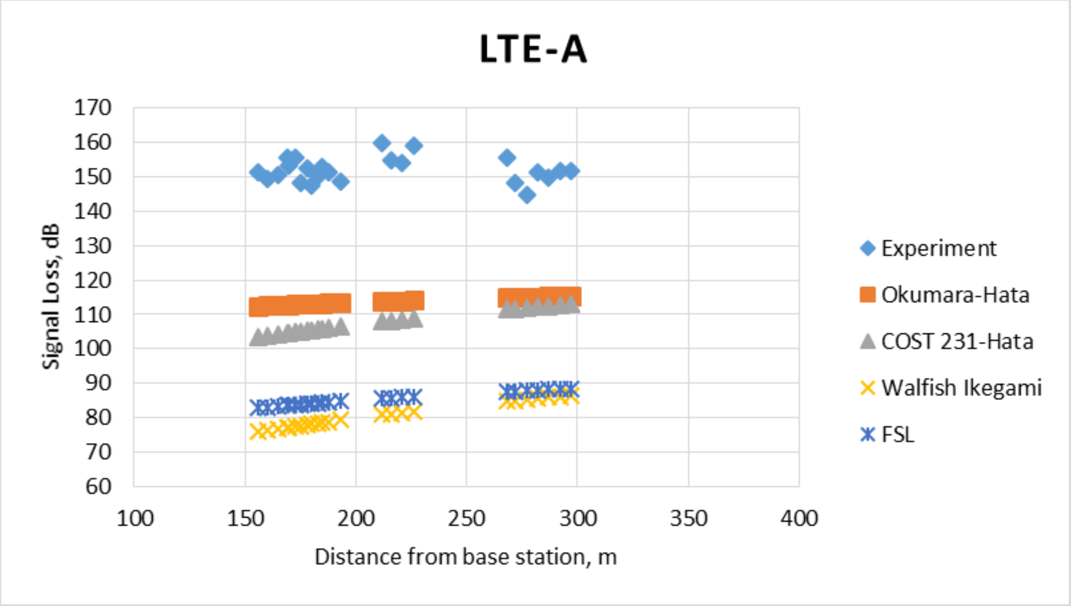


Fig. 4.1. Comparison of LTE-A experiment results and propagation models.

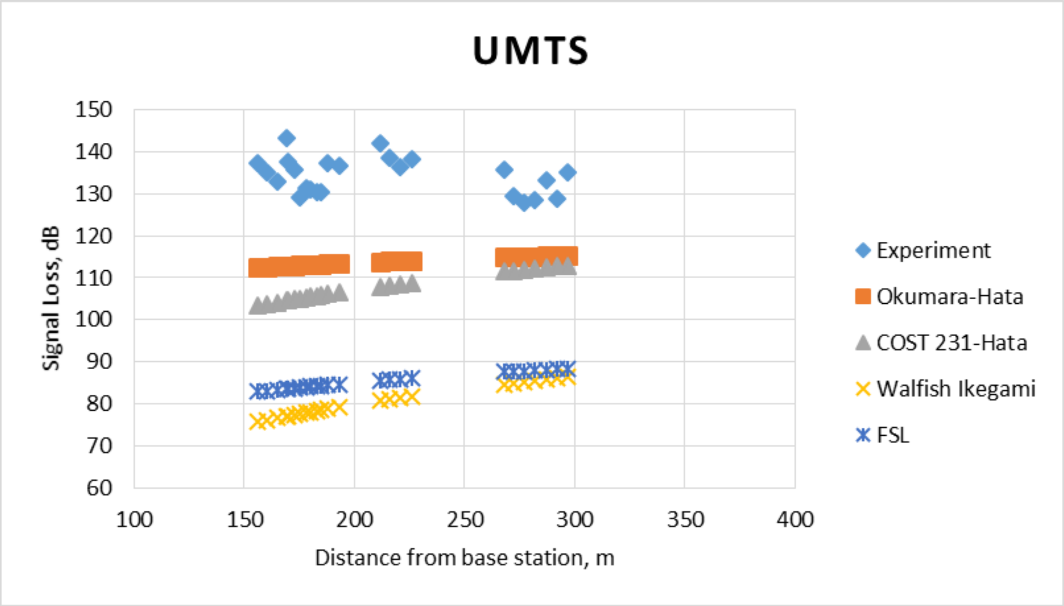


Fig. 4.2. Comparison of UMTS experiment results and propagation models.

Based on Fig. 4.1 and 4.2 it is clear that no propagation models are suitable for evaluating path losses in selected environment. The path losses for propagation models are much smaller than from the experiment results. LTE and UMTS results also are quite different. It is evident that current models do not fit the selected environment, therefore, two propagation models for different technologies has to be proposed.

The impact of different building heights for signal strength is presented in Fig. 4.3 and 4.4.

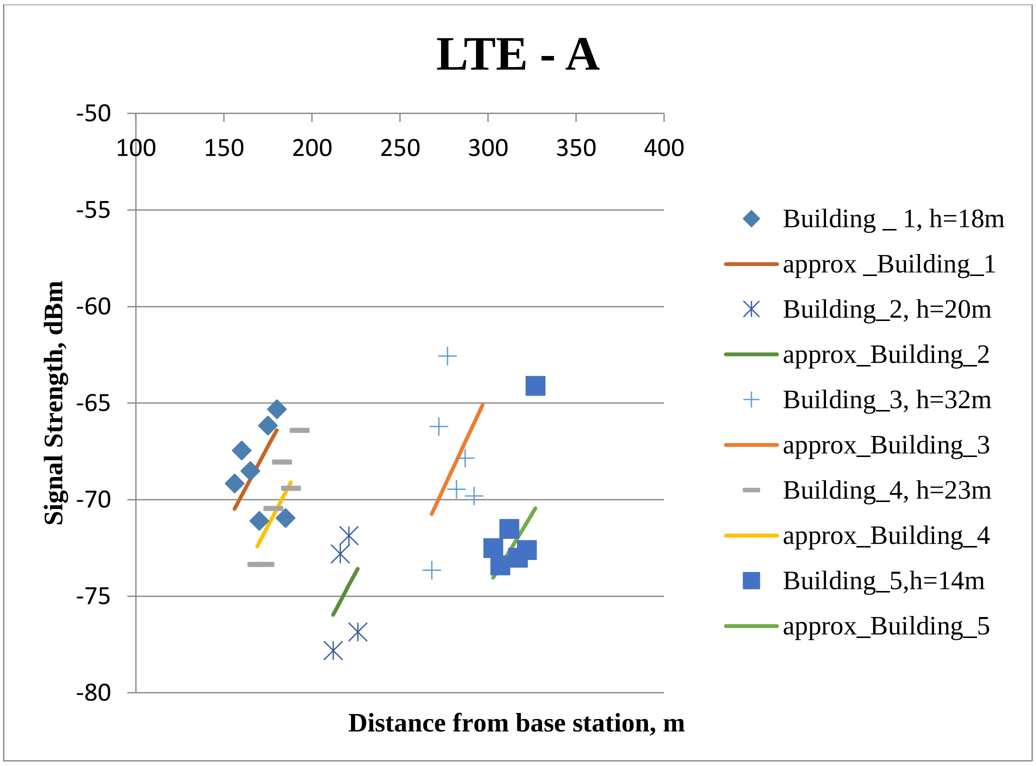


Fig. 4.3 The impact of different building heights for signal strength (LTE-A).

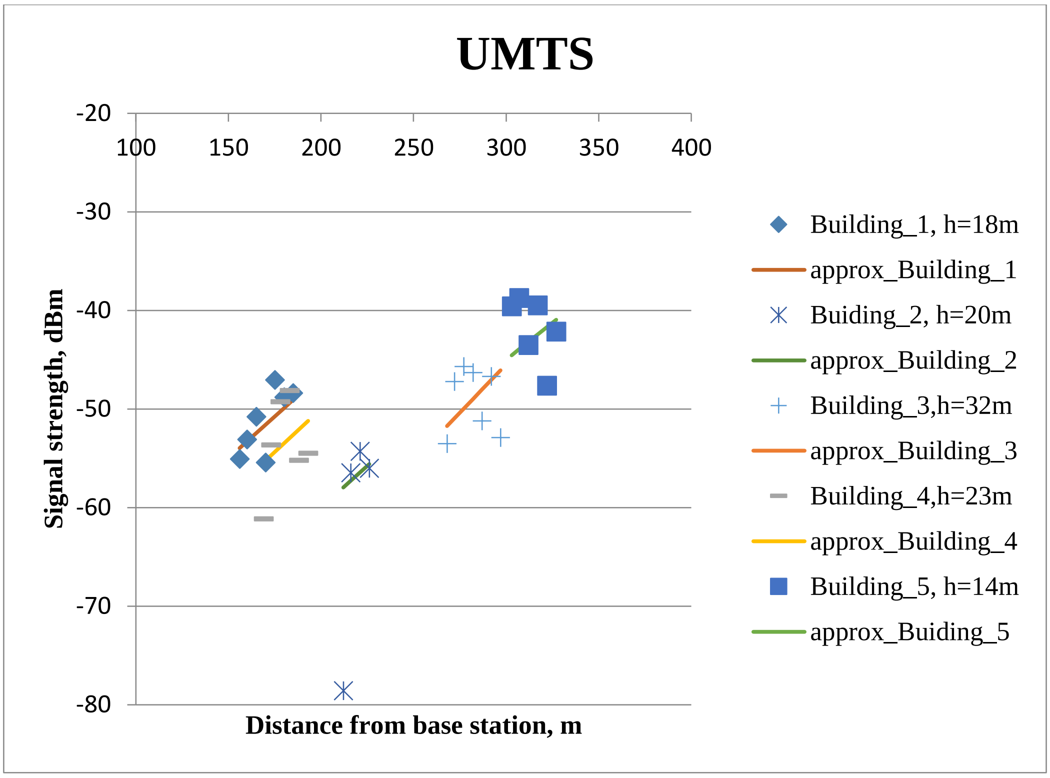


Fig. 4.4 The impact of different building heights for signal strength (UMTS).

It is seen that all changes could be described by the straight line law y=ax+b with the approximately the same angle for each technology.

4.2 Analysis of the experiments results

The height of the buildings was ranging from 14 to 32 meters. Based on Figures 4.3 – 4.4 it is evident that the total signal strength level decreases when the distance is larger. However, the signal level behind each building increases due to diffraction effect. This dependence is the same for both LTE and UMTS technologies.

The measured signal strength values behind each building were approximated by the equation of a straight line: $y = ax + b$ and shown in Table 4.7.

Table 4.7 Values of Coefficient a and b

h_b, m	LTE		UMTS	
	a	b	a	b
14	0.15	-74.2	0.15	-44.7

18	0.17	-69.7	0.17	-54.1
20	0.17	-76.1	0.17	-57.1
23	0.18	-71.8	0.18	-54.8
32	0.195	-70.9	0.195	-51.9

The coefficient *an* in linear equation estimates the influence of the height of the buildings (Fig. 4.5). From figures 4.5 – 4.6 we can see that all results approximated by the equation of straight line have almost the same *a* coefficient.

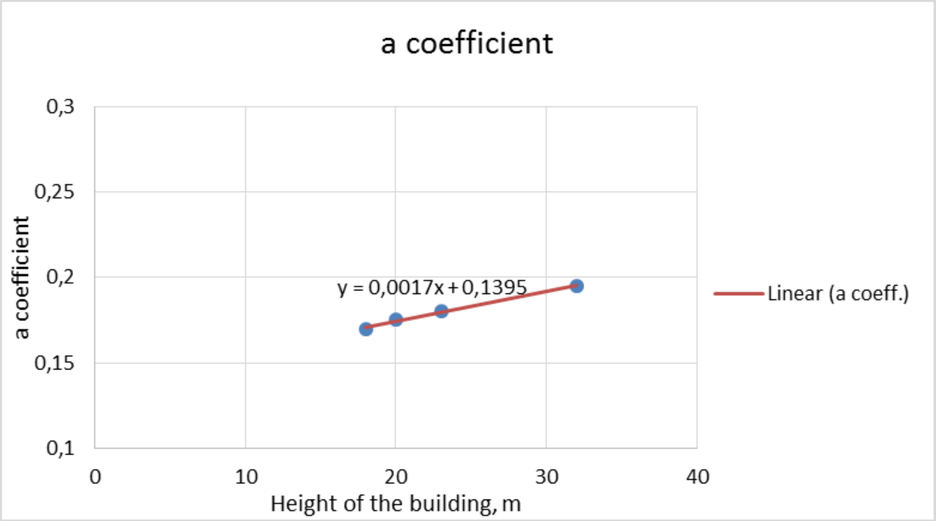


Fig. 4.5 The influence of different building heights for a coefficient.

From figure 4.5 it is clearly seen that *a* coefficient increases if the height of the building increases also. The coefficient *a* based on experiment results can be approximated by the following equation:

$$a = 0.0017h_b + 0.1395 \qquad (2)$$

where h_b is the height of the building (m).

The coefficient *b* in our particular case depends on the cellular technology and distance from the building to the base station (Fig 4.6). Coefficient b for LTE and UMTS technologies can be approximated as follows:

$$b_{LTE-A} = -0.261d_{BS-n} - 58\ , \qquad (3)$$

$$b_{UMTS} = -0.261d_{BS-n} - 38\ , \qquad (4)$$

where d_{BS-n} is the distance from the base station to the rear wall (from BS) of the building (m).

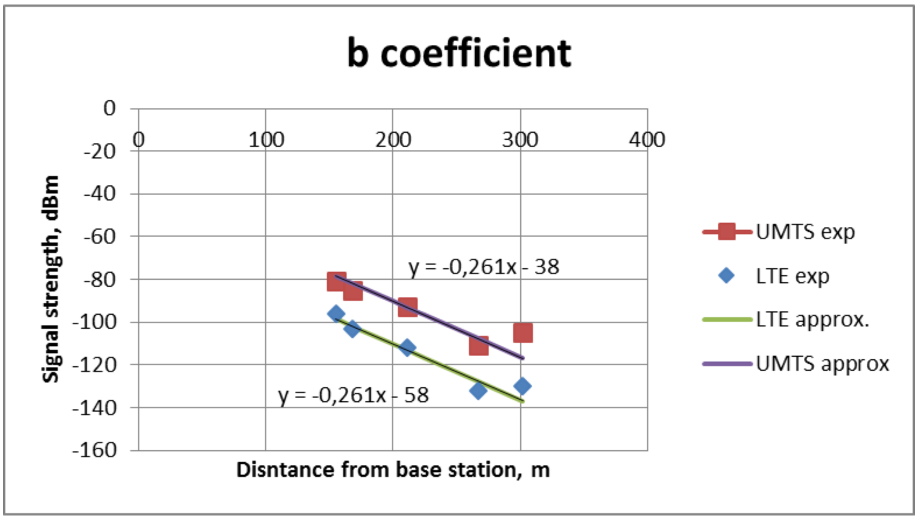


Fig. 4.6 Comparison of new propagation model and experiment results.

From Fig. 4.6 it can be seen that the type of cellular technology has an impact on the results. LTE and UMTS in our experiments operated in the same 2100 MHz frequency band, however, signal strength results are quite different for each technology. This just proves that different propagation models must be used for different technologies.

It was found that the received signal level is a linear function. The height of the building, distance from the base station and cellular technology had the biggest impact on signal strength. The signal strength differences from the experiment for LTE-A and UMTS technologies could be due to different modulation schemes. Two new models are proposed for different technologies based on functions of coefficients *a* and *b*.

The new models can be expressed by the following equations:

$$L_{LTE-A} = P_{Tx} - (0.0017h_b + 0.1395)d_{BS} - (0.261d_{BS-n} + 58), \quad (5)$$

$$L_{UMTS} = P_{Tx} - (0.0017h_b + 0.1395)d_{BS} - (0.261d_{BS-n} + 38), \quad (6)$$

where d_{BS} is the distance from the base station to the measurement point behind the building (m), d_{BS-n} is the distance from the base station to the rear wall (from BS) of the building, h_b is height of the building (m), *L* is signal loss (dB), P_{rx} is UE received signal power (dBm), P_{tx} is BS transmitting power.

From equations 4 and 5, it is evident that only last values differ for each technology. These values were experimentally determined.

The comparison of proposed models for cellular technologies and experiment results is presented in Fig. 4.7 – 4.8. The CDF of the signal strength is presented in Fig 4.8.

The proximity of new models and experiment results is high. Furthermore, the results closely correlate with outdoor environment variables: height of the building, distance from BS. Clear differences are visible between LTE-A and UMTS technologies. Signal level for LTE-A network is a bit lower. The differences between two technologies could have been because of different modulation schemes.

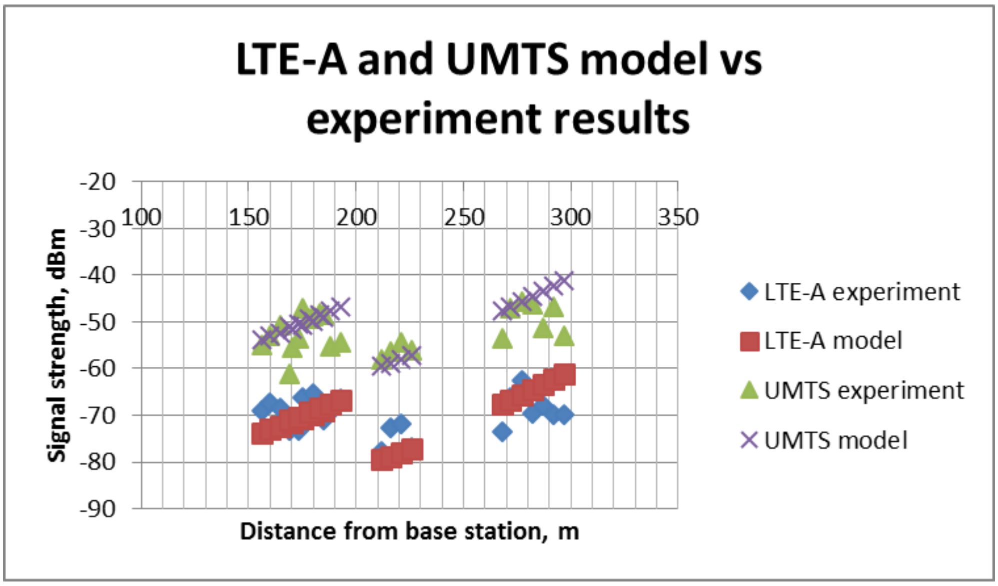


Fig. 4.7 Comparison of new propagation model and experiment results for LTE-A and UMTS.

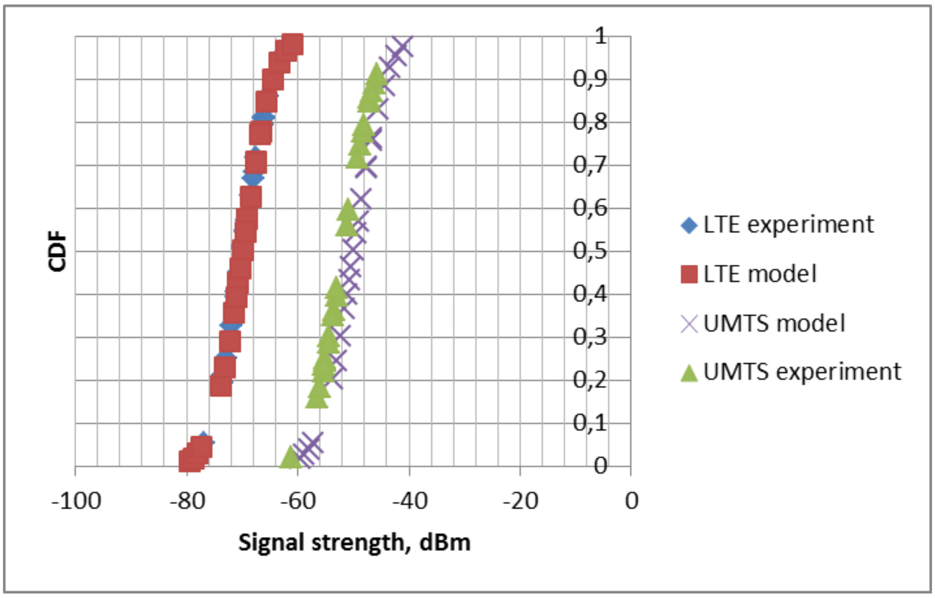


Fig. 4.8 Cumulative distribution function for signal strength.

The differences between experiment results and proposed models were 4.6 % for LTE - A only and 6.8 % for UMTS. Based on these findings, new propagation models can be used to evaluate the loss of the signals for LTE-A and UMTS networks.

The results coincide well enough and the average relative error does not exceed 6.5%. The calculated skewness γ shows that the deviation of the experimental results from the mean (mathematical expectation) is low, because $\gamma_{LTE} < 3{,}2 \cdot 10^{-7}; \gamma_{UMTS} < 7{,}2 \cdot 10^{-7}$, i.e. in all cases $\gamma \rightarrow 0$.

Model validation criteria:

1. UMTS Frequency - 2127 MHz;
2. LTE – A Frequency - 1818.7 MHz;
3. Base station antenna height – 40 m;
4. Building height – 14m to 32m.

5. Conclusions

1. It has been found that strength of the signal between LTE-A and UMTS networks is quite different from the same base station, although, the operating frequency for both technologies is in 2100 MHz band.
2. It was found that the path losses decrease behind the building when the distance from base station increases. This decreasing may be affected by such electromagnetic wave propagation mechanisms as shadowing and diffraction. Such decreasing, in our view, would take place up to position behind the house, where the line-of-sight conditions would start.
3. Two new path loss evaluation models have been proposed for LTE-A and UMTS networks with the error does not exceed 6.5%.
4. New or current propagation models for UMTS and LTE-A technologies could be improves based on the results of this work.

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Annex - 1

Conferences:

1. 19th international conference ELECTRONICS 2015;

2. 12th students scientific conference E2TA 2015.

Publications:

1. Japertas, Saulius; Pilipavičius, Karolis; Janarthanan, Dilip. Signal propagation model for microcells at 900 MHz frequency range // Elektronika ir elektrotechnika = Electronics and electrical engineering. Kaunas: KTU. ISSN 1392-1215. 2015, vol. 21, iss. 4, p. 65-68. [Science Citation Index Expanded (Web of Science); Inspec; Computers & Applied Sciences Complete; Central & Eastern European Academic Source];

2. K. Pilipavičius, D. Janarthanan, P. Dapkus. Diffraction Effect on 2.4 GHz Frequency//E2TA-2015. Kaunas:KTU. ISSN 2335–7878. 2015. p. 9-11.

Annex – 2

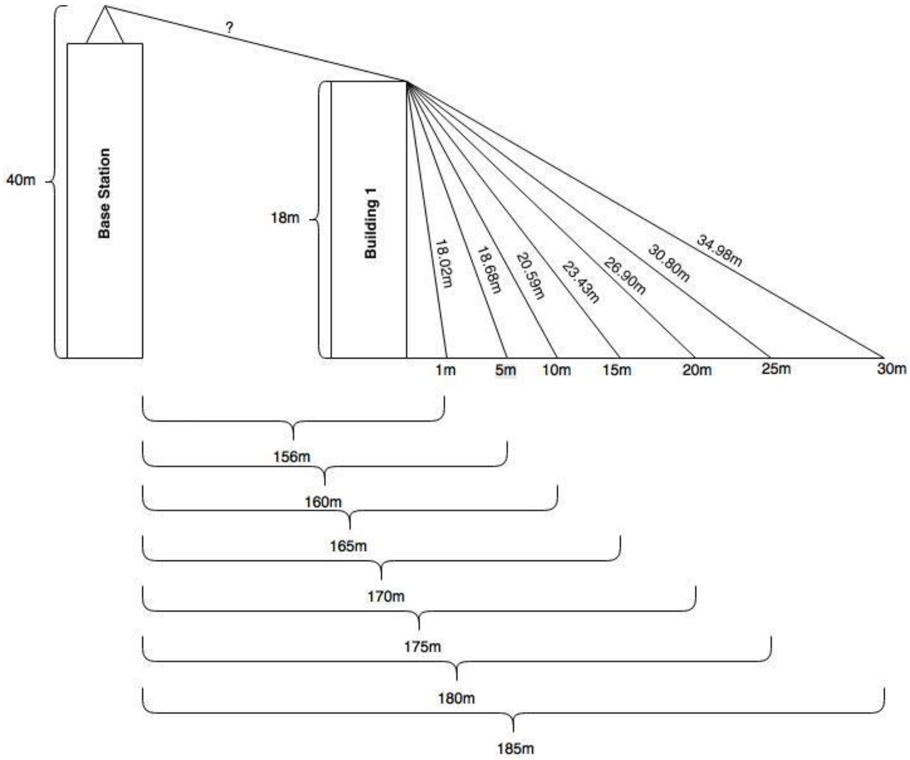

Figure 3.4 Measurement scheme for building 1

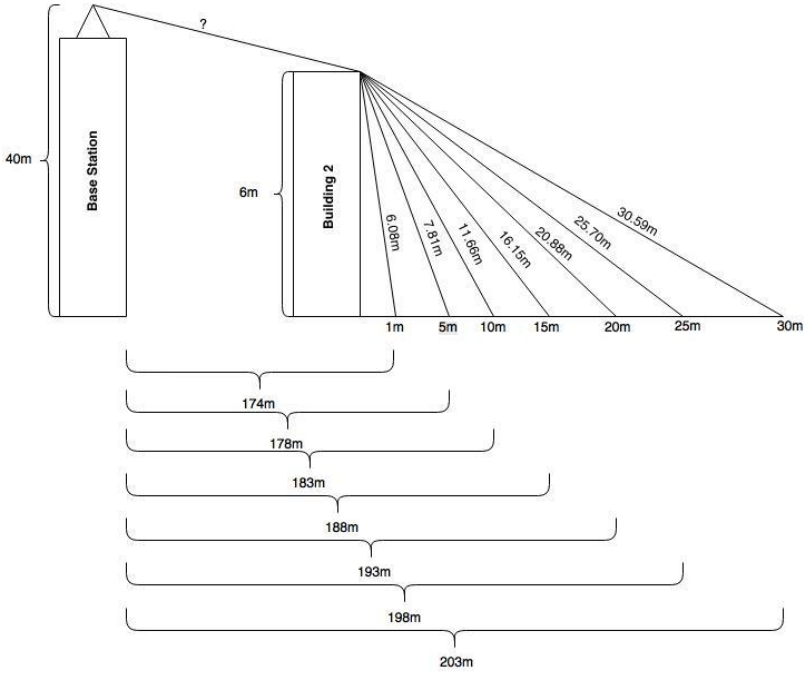

Figure 3.5 Measurement scheme for building 2

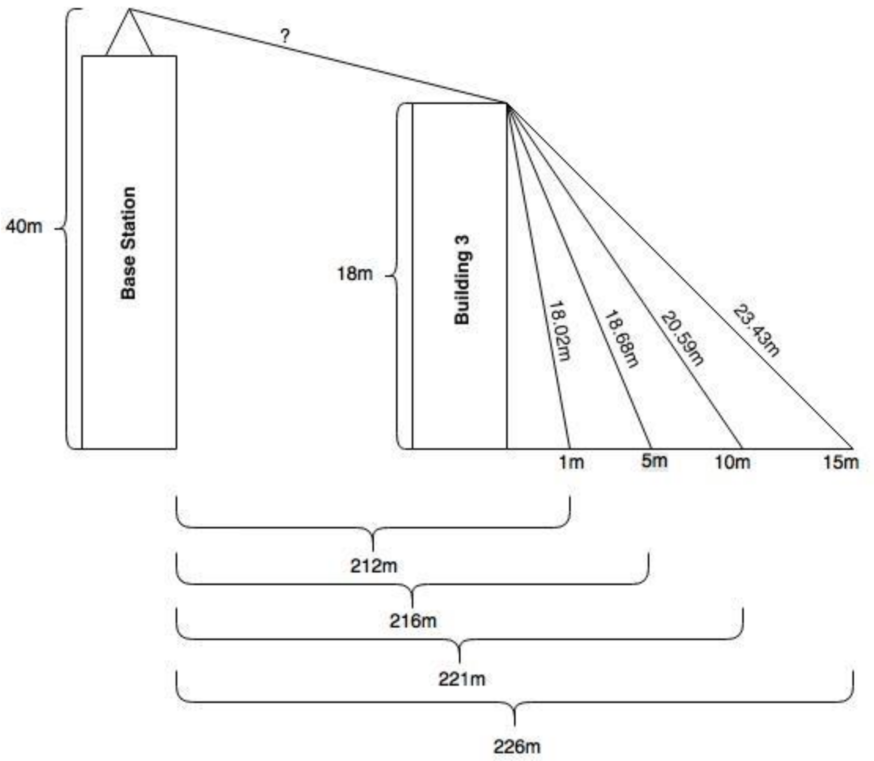

Figure 3.6 Measurement scheme for building 3

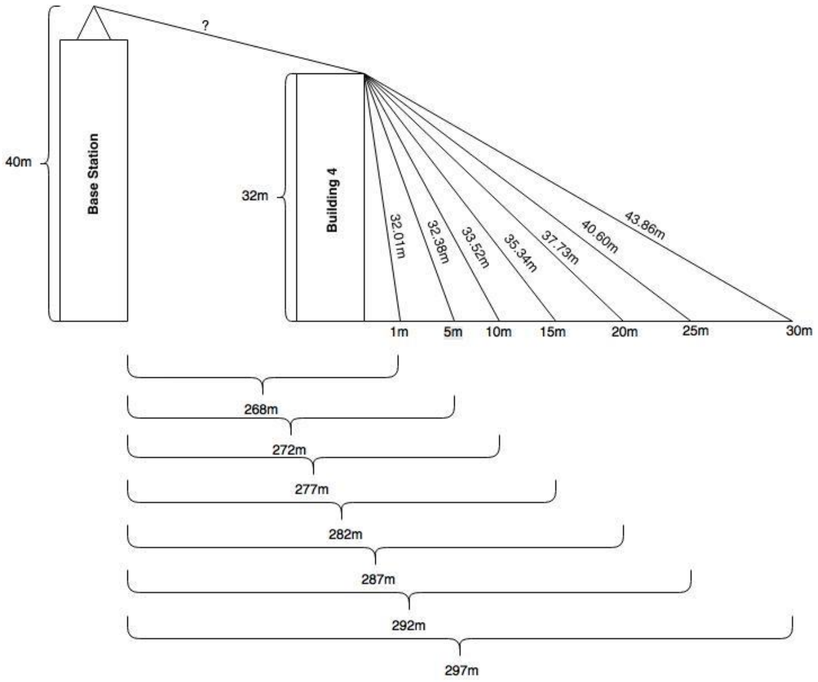

Figure 3.7 Measurement scheme for building 4

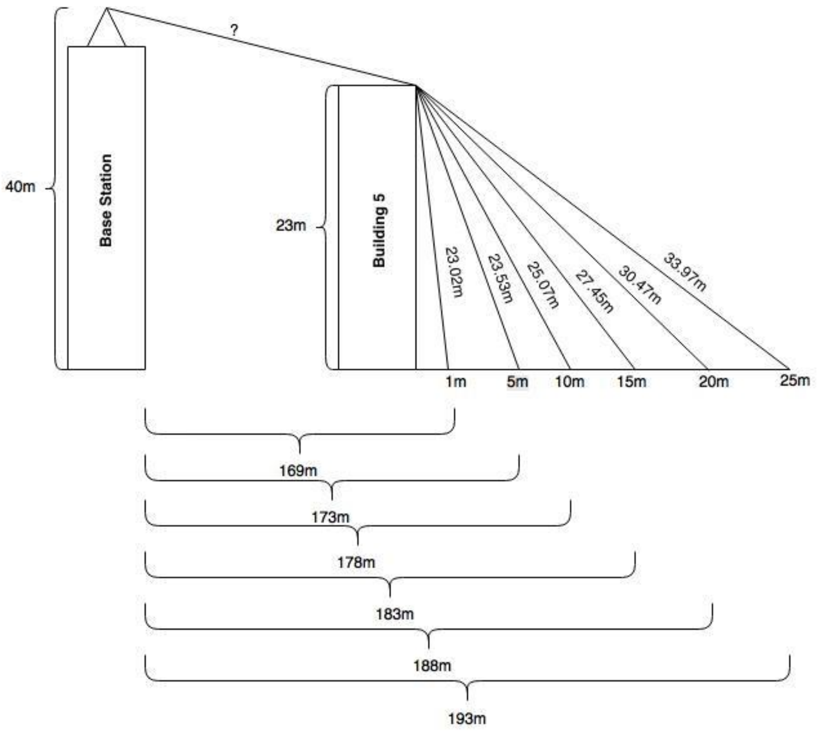

Figure 3.8 Measurement scheme for building 5

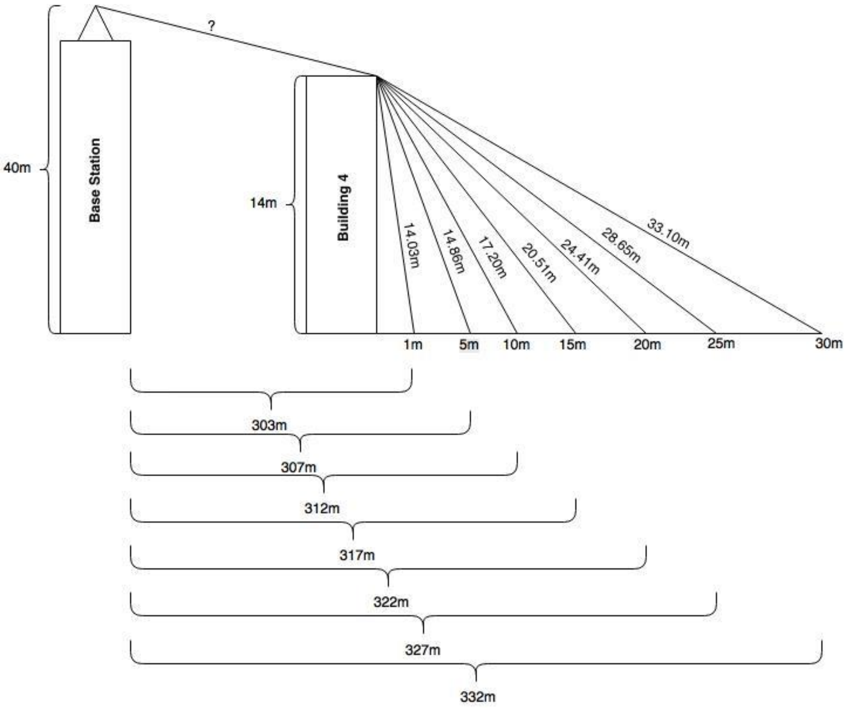

Figure 3.9 Measurement scheme for building 5