Prediction of VHF and UHF Wave Attenuation In Urban Environment

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***Abstract*—The analysis of the literature shows that there is lack of attenuation prediction models in the urban environment for frequencies the most often exploited in military communication systems and for geometries of these systems (low hanged antennas). The only model that however require additional experimental verification is the one published in [5]. Therefore the results of measurements carried out in a large urban environment proofing usability of this model have been described in presented paper.**

Keywords-propagation loss, attenuation, spectrum access.

I. INTRODUCTION

Today's military missions have shown that there have been frequent cases of disrupting of military communications systems in the theater of the military operations, especially in an urban environment. This problem arises because of growing number of networks operating in the same location area a.o. commercial systems, such as unlicensed wireless phones, pirate TV and radio broadcast stations or communication devices used by humanitarian agencies and the media [1, 2]. This dramatically decreases the efficiency of command and control systems. It may also cause the potential loss of communication with Unmanned Aerial Vehicles (UAVs) increasingly used on the battlefield.

This situation is the result of the use of current static spectrum management methods based on the prior (before action) rigid allocation of frequencies to radio networks.

Hence, the idea of dynamic spectrum access and appropriate methods of spectrum management are intensively studied and developed. Some of these methods are described in [3] and the spectrum taxonomy is illustrated on Figure 1.

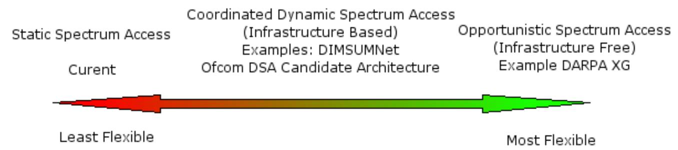

Figure 1. Spectrum Access Taxonomy

A suitable method of dynamic spectrum management for commonly exploited, modern military VHF systems is the method that will ensure so-called coordinated access to the spectrum. Here, the special infrastructure is used as, for example, a frequency broker acting in quasi-real time. The main goal of such a broker is the designing of collision-free frequency plans based on models of propagation attenuation on the path between the transmitter and receiver.

II. PROPAGATION LOSS MODEL IN MILITARY BAND

An in-depth analysis of the literature [4], shows (see TABLE I.) that there is lack of attenuation prediction models in the urban environment - in particular, inside buildings and between them appropriate for the frequency range of 30-88 MHz and geometries (antennas 1 – 3 meters above ground) used by the dominant part of military communications systems.

TABLE I.

Author	Frequency (MHz)	Distance (km)	HT (m)	HR (m)
Y. Okumura	15-1920	1-100	30-1000	
M. Hata	150-1500	≥ 1	30-200	1-10
COST 231	800-2000	0.02-5	4-50	1-3
H. Xia	900, 1900	0.001-2	3.2, 8.7, 13.4	1.6
V. Erceg	1956	0.01-0.5	3.3, 6.6	1.5
D. Har	900, 1900	0.06-2	3.2, 8.7, 13.4	1.6
A. Kanatas	1890	0.02-0.18	4	1.7
H. Masui	3350, 8450, 15750	0.02-0.5	4	2.7
Y. Oda	457-15450		≥ 20	
T. Rao	200, 400, 450	0.5-10.5	≥ 20	3
N. Blaunstein	902-928		7	2-3
W. Young	150, 450, 800, 3700	0.108-16.3	138	2

Similar extensive literature survey is presented in [5] and conclusions confirms these shown in [4]. Just for it the authors of [5] propose a new General Urban Path Loss (GUPL) model.

According this model waves propagation loss in the urban environment are described by the formula:

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$$L[dB] = -10\lg(\frac{\lambda}{4\pi d_o})^{\beta} + 10n\lg(\frac{d}{d_o}) + \alpha d + FAF$$

where: d_o – close-in-reference distance (m), d_o must be chosen in the far-field region; $d_o >> \frac{\lambda}{2\pi}$ (true when largest dimension of antenna < λ , do ≅ 30 meters); λ – wavelength (m); d – Tx - Rx distance (m); β – power component, it indicates that the received power decays with distance at a rate of 10β dB/decade; n – path loss exponent; α – attenuation constant (dB/m); *FAF* – floor attenuation factor (dB).

The factors appearing in that model take different values depending on the type of propagation environment.

Some experiments have already been worked out for examination of above described model. The analysis and experiments carried out in [5] have enabled the preparation of a description of environment of waves propagation with the following five typical scenarios:

Scenario 1: outdoor RF propagation in an urban canyon;
Scenario 2: indoor propagation (same building, same/multiple floor(s));
Scenario 3: indoor-to-indoor propagation (between two different buildings, same/multiple floor(s));
Scenario 4: indoor-to-outdoor propagation;
Scenario 5: outdoor-in-indoor propagation.

The values of the above factors, for each of the above scenarios are presented in TABLE II.

TABLE II.

Scenario	Power component β	Path loss exponent n	Attenuation constant α (dB/m)
1	2,2	1,8	0,06
2	2,63	1,5	0,65
3	5 (if number of penetrated floors = 0), 4 (if number of penetrated floors > 0)	2	0,65
4	3,6	4	0
5	3,6	4	0

TABLE III.

Floor Attenuation Factor (dB) (FAF)			
Number of penetrated floors	30 MHz	49 MHz	87,5 MHz
1	1,5199	1,7707	2,2789
2	4,3523	4,6468	5,24355
3	13,938	14,1546	14,5935
4	16.758	16,9784	17,4250
5	9,7596	10,132	10,8866

FAF depends on the number of floors penetrated by the waves and its values are shown in TABLE III. .

According this model the propagation attenuation was calculated. An example of results for scenario 2 is presented in Figure 2.

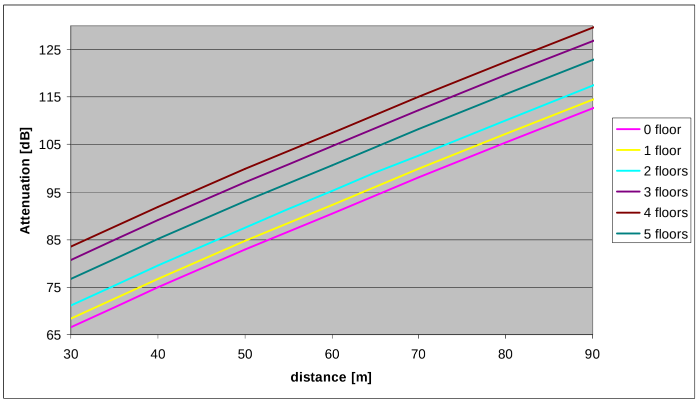

Figure 2. The changes of attenuation versus distance for various numbers of floors (49 MHz)

These results show that path loss for 5 floors are lower then for 4 and 3 floors. It seems not to be rational and possible source of this situation is assumption by authors of [5] linear extrapolation of values of FAF reported for 915 and 1900 MHz in [6].

III. DESCRIPTION OF THE EXPERIMENTS

In order to verify the GUPL model, an experiment was conducted in a large urban environment in buildings with at least five-storey's, constructed in the brick technology according to the following scenarios:

1) In scenario # 1, the attenuation was measured along the street (centre of Warsaw). During the measurement the distance between the transmitter and receiver was changed by displacing of the transmitter.

2) In scenario # 2, Experiments were carried out in two locations – campuses of Military University of Technology (MUT) and of Warsaw University of Technology (WUT).

The attenuation was measured inside the buildings. As in the case of scenario # 1 the distance between the transmitter and receiver was changed by displacing of the transmitter. In this scenario, the transmitter and receiver were located on the same floor of the buildings, as well as on different floors;

Measurements were carried out in two ranges: 30 -88 MHz and 225 – 400 MHz. In the 30 – 88 MHz frequency range the transmitter RRC 9200 with known characteristics of antennas, and SWR (Standing Wave Ratio) was used. Its parameters are presented in TABLE IV. .

TABLE IV.

Frequency Range	30 ÷ 88,975 MHz
Nominal output power	5/0,5 W
Number of channels	2320 with channel spacing of 25 kHz
Modulation	F3 STANAG 4204 (analog mode)

The Tx/Rx broadband VHF antenna was the rod antenna type of VM 3088.

In the 225 – 400 MHz R-450 C radio was used. The parameters of this radios are given in TABLE V. .

TABLE V.

Frequency Range	225 ÷ 400 MHz
Nominal output power	20 W
Number of channels	176 with channel spacing of 1MHz
Modulation	QFDM (BPSK, QPSK, 16QAM)

The transmitter and receiver used AD-18/E antennas that is a wideband monopoly mobile antenna intended for use in the frequency range from 225 to 512 MHz.

IV. GUPL MODEL EXPERIMENTAL VERIFICATION FOR SCENARIO # 2

Description of results for frequency range 30 – 88 MHz

In accordance to measurement scenarios presented above the verification of FAF with the employment of a comparative method was performed. In all cases, the radio receiver was located on the top storey. The level of the signal was measured on the same storey for three frequencies of 30, 49 and 87,5 MHz in distances of 30, 40, 50, 60, 70, 80, 90 and 100 m between the transmitter and the receiver. In the next steps, the transmitter and the receiver were located on different floors, from 1 to 5, for above listed frequencies and distances.

TABLE VI. and Figure 3. Figure 4. and Figure 5. present FAF values obtained by performing our measurements at two locations as a function of frequency and number of floors. The results published in [5] (blue line) were added to the charts for comparison.

In contrast to the results taken from [5], FAF values increase with the number of stories. Differences for the two locations are mainly caused by different construction of the buildings – ceiling thickness, material and height of a storey.

TABLE VI.

Number of floors	FAF [dB]					
	Location 1 (MUT)			Location 2 (WUT)		
	30 MHz	49 MHz	87,5 MHz	30 MHz	49 MHz	87,5 MHz
1	0,71	3,76	1,68	3,03	3,11	4,84
2	3,61	9,33	5,42	8,08	6,00	5,57
3	3,08	10,8	9,52	15,1	20,6	11,0
4	9,82	15,5	10,5	21,1	22,0	17,8
5	19,7	23,3	17,8	22,8	27,0	21,8

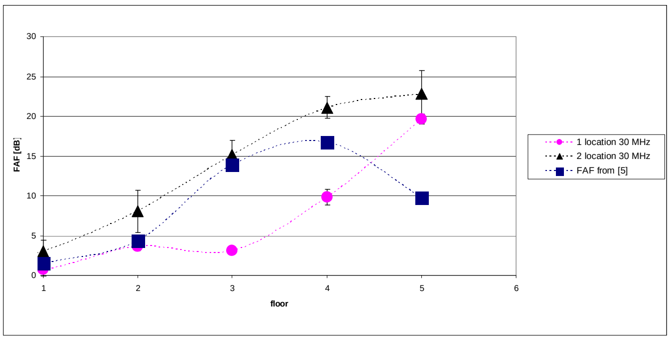

Figure 3. Comparison of measured FAF values and FAF values for 30 MHz taken from [5] (TABLE III.)

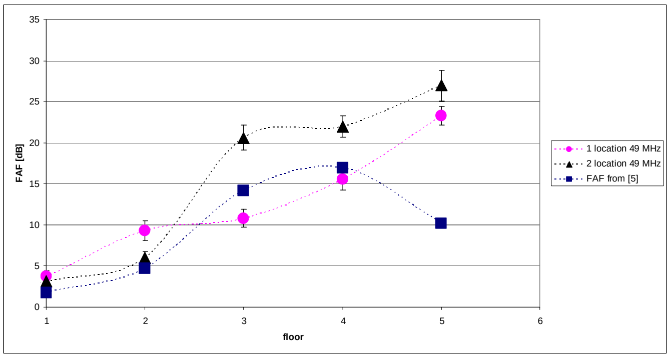

Figure 4. Comparison of measured FAF values and FAF for 49 MHz taken from [5] (TABLE III.)

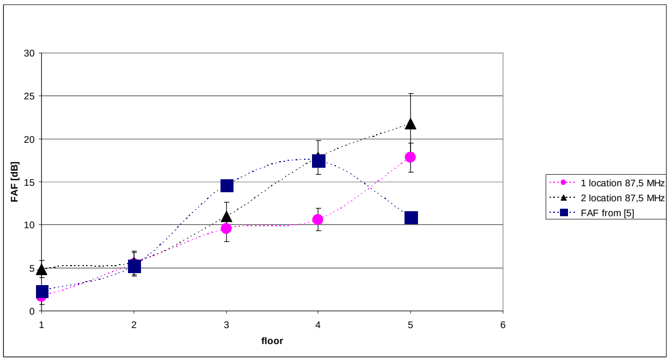

Figure 5. Comparison of measured FAF values and FAF for 87,5 MHz taken from [5] (TABLE III.)

Taking into account all these measured values we assumed as a recommended FAF – average values of data obtained for both locations (see TABLE VII. and Figure 6.).

TABLE VII.

Recommended FAF			
Number of floors	30 MHz	49 MHz	87,5 MHz
1	1,9	3,44	1,76
2	5,85	7,67	5,5
3	9,1	15,7	10,26
4	15,46	18,75	14,15
5	21,25	25,15	19,8

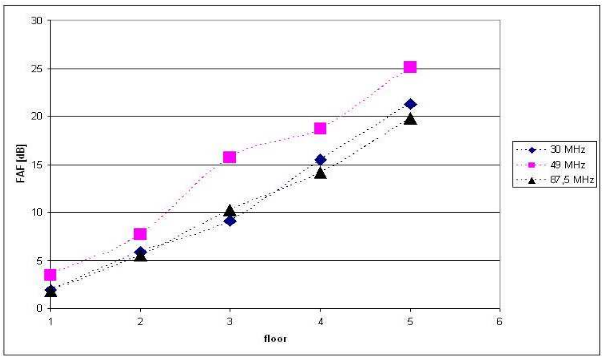

Figure 6. The plot of recommended FAF

The plot of attenuation versus distance for various number of floors according to GUPL model with recommended FAF values is illustrated in Figure 7.

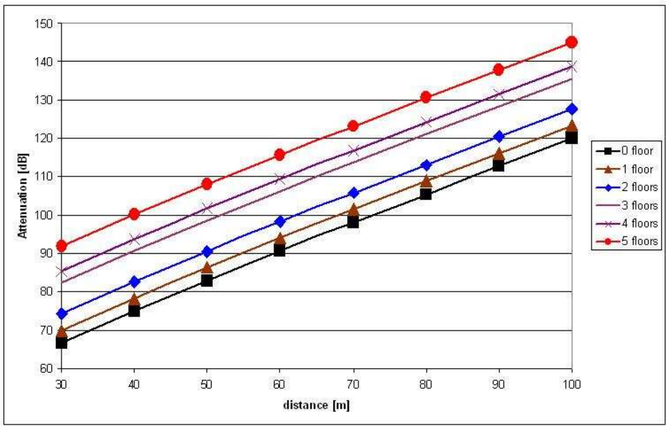

Figure 7. The changes of attenuation versus distance according to GUPL model with recommended FAF values.

In contrast to results published in [5] recommended FAF value determined from measurements at two different locations increases with increasing number of floors and similar behaviors shows attenuation of waves.

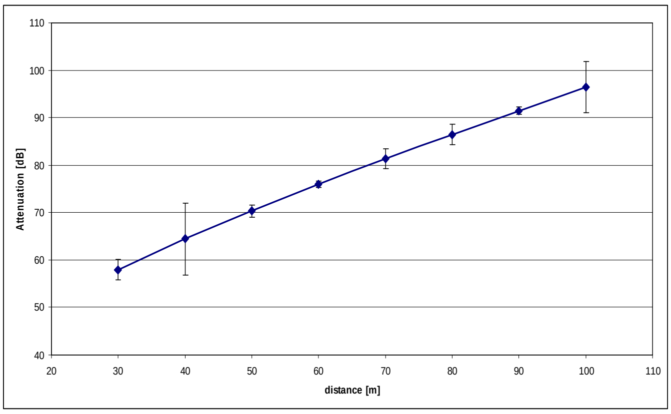

Figure 8. The calculated value of the attenuation according to the GUPL model with standard deviation of measurement results obtained for 87,5 MHz 3 floors.

Description of results for frequency range 225 – 400 MHz

Basing on information contained in [5] the estimation of the coefficient FAF for the frequency 230 MHz and 320 MHz was done using the method of linear extrapolation (TABLE VIII.).

TABLE VIII.

Floor Attenuation Factor (dB) (FAF)		
Number of penetrated floors	**230 MHz**	**320 MHz**
1	4,16	5,35
2	7,45	8,85
3	16,22	17,25
4	19,08	20,12
5	13,68	15,44

FAF coefficient obtained from measurements carried out in two places (campus of MUT and WUT) and at two frequencies 230 and 320 MHz are included in TABLE IX. .

TABLE IX.

Number of floors	FAF [dB]			
	Location 1 (MUT)		Location 2 (WUT)	
	230 MHz	320 MHz	230 MHz	320 MHz
1	2,3	1,2	10,5	14,7
2	5,8	3,1	17,8	18,4
3	9,2	4,8	19,8	25,2
4	17	7,8	26,8	28,5
5	24,3	10,5	28,9	29,7

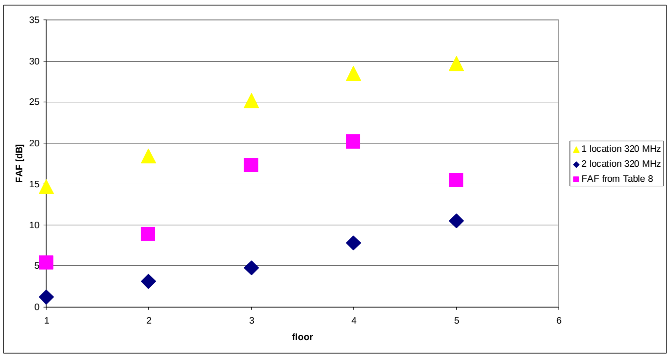

Figure 9. Comparison of measured FAF values and FAF values for 320 MHz taken from TABLE VIII. .

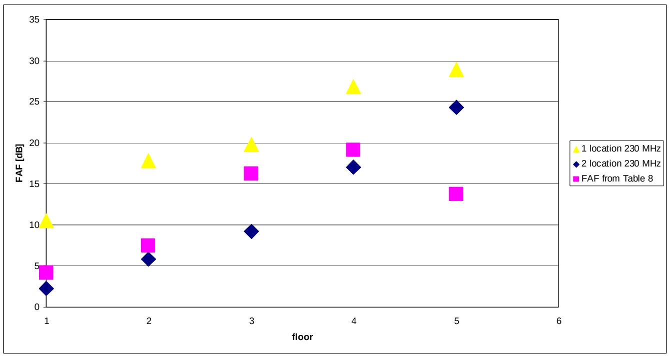

Figure 10. Comparison of measured FAF values and FAF values for 230 MHz taken from TABLE VIII. .

TABLE X.

Recommended FAF		
Number of floors	**230 MHz**	**320 MHz**
1	6,4	7,95
2	11,8	10,75
3	14,5	15
4	21,9	18,15
5	26,6	20,1

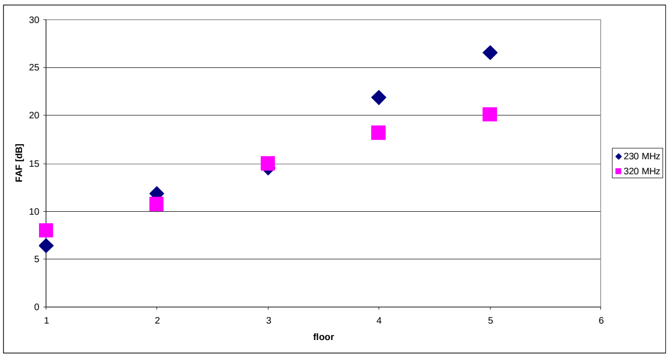

Figure 11. The plot of recommended FAF for 230 and 320 MHz

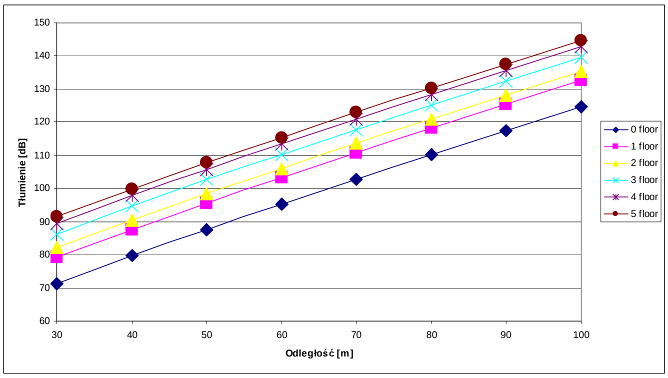

Figure 12. The changes of attenuation versus distance according to GUPL model with recommended FAF values for 320 MHz

In contrast to results published in [5] recommended FAF value determined from measurements at two different locations increases with increasing number of floors.

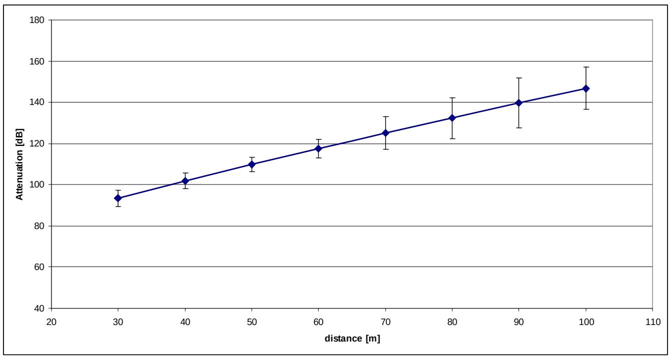

Figure 13. The calculated value of the attenuation according to the GUPL model with standard deviation of measurement results obtained for 230 MHz 3 floors.

V. GUPL MODEL EXPERIMENTAL VERIFICATION FOR SCENARIO # 1

In scenario #1 the attenuation was measured along the street (centre of Warsaw). During the measurement the distance between the transmitter and receiver (30, 40 ,50, 60, 70, 80, 90, 100 and 200 meters) was changed by displacing of the transmitter.

The level of the signal was measured for five frequencies of 30, 49, 87,5, 230 and 320 MHz.

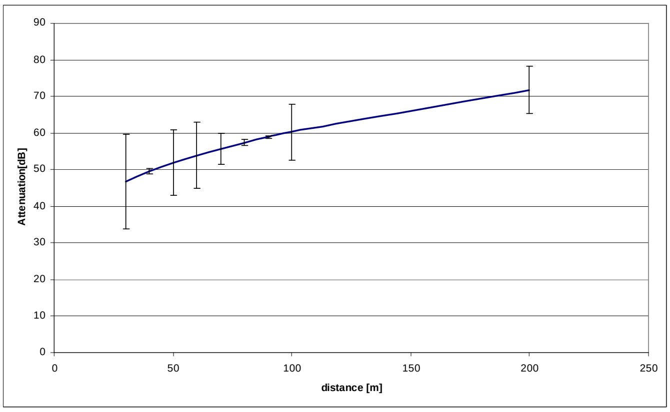

Figure 14. The calculated value of the attenuation according to the GUPL model with standard deviation of measurement results obtained for 87,5 MHz

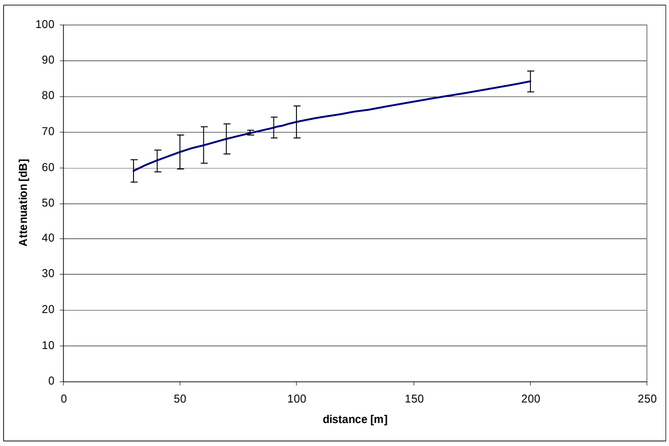

Figure 15. The calculated value of the attenuation according to the GUPL model with standard deviation of measurement results obtained for 320 MHz.

VI. CONCLUSIONS

The authors of GUPL model stated that it requires further experimental verification. That's why in presented paper the results of measurements carried out in a large urban environment (Warsaw) with a view of verifying the suitability of the above model for 30÷88 MHz frequency range were presented. Moreover during mentioned experiment measurements of path loss for frequency range 225÷400 MHz verifying the applicability of GUPL model for this frequencies were done.

In both the above frequency ranges measurements were carried out for two scenarios – outdoor and indoor environment.

Taking advantage of measured data of path losses we estimated values of FAF for 1 - 5 floors which are presented in TABLE VII. and TABLE X. . Implementation of this values to GUPL model has given more rational relation between attenuation and number of floors (Figure 7. and Figure 12.).

Figure 14. and Figure 15. shows distribution of measured attenuation around predicted values obtained from GUPL model for 87,5 and 320 MHz (for scenario 1).

Obtained results confirm usability of GUPL model for indoor and outdoor (in urban canyon) environment.

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