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WiMAX structured combat network – performance analysis

By

Jovan B. Bajčetić* Boban Z. Pavlović* Davorin L. Mikluc*

Abstract:

The elements of a battlefield nowadays are the unexhausted source of information. Modern battle environment requires extremely mobile armed systems what leads to the fact that network infrastructure needs to be more agile. The information exchange in these conditions is done mostly using the radio. The node mobility is imperative and is the beginning of all the beginnings when the network analysis is ought to be performed. Movement of the nodes is rarely measured below 60 km/h and required bit rate is mostly always above 1 Mb/s. To achieve this, the migration to new technologies, like the one described by IEEE 802.16e standard is required.
The paper gives the battle operation information exchange analysis which takes place into the flat, intercepted urban area. The information exchange is done using the cell structured network consisted of WiMAX base stations. The transceiver system described by ETSI TS 102 177 V1.5.1 (2010-05) is analyzed in detail thanks to MATLAB program package. The real battle situation simulation, coverage and interference analysis is achieved using ATDI HTZ software.
At the end, the basic assumptions review of the simulation is given. The behavior of the transmitted signal modulated using various modulation schemes in jamming environment is analyzed considering different Signal to Noise Ratios (SNR). The performance of the WiMAX base station transceiver network system doing fast handover of a given subscriber is observed. The simulated network gives the emergent data on which basis the final conclusion about network performances in rough electromagnetic environment is given.

Keywords:

WiMAX tranceiver, modulation, fading, handover, ATDI HTZ software

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* University of Defence, Military Academy, Belgrade, Serbia

1. Introduction:

WiMAX (Worldwide Interoperability for Microwave Access) is a wireless communication system specified by IEEE 802.16e standard, which has a mobility component with specifications of mobility management, authentication and protocol handover.
Within the unique access network, modern services such as a Broadband Internet access, traditional and mobile telephony and IP television can be offer to the end users at the same time. The great advantage is that these technologies can be implemented relatively quickly and economically also in areas where telecommunications infrastructure wasn't established previously [1]. Mobile WiMAX supports a mobile access in conditions without sight, and can be used for fixed and nomadic access.
The WiMAX access network designing includes a comprehensive dissection of transmission capacities and communication contingency, mutual interference of network elements analysis, and a process of finding the most optimal schedule and number of access points with the aim to reach the target territory coverage percentage. Modern software solutions gives the opportunity for a developer to efficiently plan the network requirements (territorial signal coverage demand, frequency plan for a better spectrum utilization, small interference level, the optimum positions of base stations ...).
Standard ETSI TS 102 177 V1.5.1 (2010-05) [2] provides HiperMAN (High Performance Radio Metropolitan AreaNetwork) radio interface in the physical layer for frequencies up to 11 GHz for the fixed structure, and for frequencies below 6 GHz for the occasional mobile and mobile network structure. Standard is limited to radio subsystems that comprise the Physical Layer (PHY) and Data Link Control (DLC) that are completely independent. Allocated radio resource management and connection are based on the DLC protocol that uses the DLC layer services.
This paper presents a model of the telecommunications system based on the ETSI TS 102 177 V1.5.1 (2010-05) standard that is analyzed by Matlab Simulink software package 2009. Input data are defined by the standard and represent basic parameters for the system analyze. This paper analyzes the influence of parameters on the signal characteristics for individual blocks of the telecommunications system. Simulation model is a starting point for modifications and improvements that would lead to eventual improvements in performance of the transmission system in terms of propagation through a real communication channel.
When a combat conflict or a natural disaster evolves in a certain area, it is necessary to make a detailed analysis of territory where the future activities are going to happen. The most significant part of the planning activity is finding favorable points for the possible nomadic base stations setting up. Those points must satisfy the conditions for the best possible coverage. However, the current tactical situation where the infrastructure network system will be founded has to be taken into account. Base stations mounted on combat vehicles to form nomadic (semi-mobile) network

system, as they would be on the dominant points, would be lucrative combat and electronic measure targets for an enemy. Counter measures for successful operation in this case would primarily rely on the proper masking, engineering arrangement of a station surrounding, as well as isolated antenna systems usage. Technical electronic counter measures are based on the modulation selection that are proved to be better in cases when there is a high level of noise caused by the jamming signal, whai is in detal explained in the first part of the paper. Improving media access methods and communication protocols in a term of security signal processing is required for future revisions of 802.16 sets of recommendations.

2. Telecommunication system analysis:

Block diagram of the transceiver system with propagation channel within the standard ETSI TS 102 177 V1.5.1 (2010 05) is shown in Figure 1.

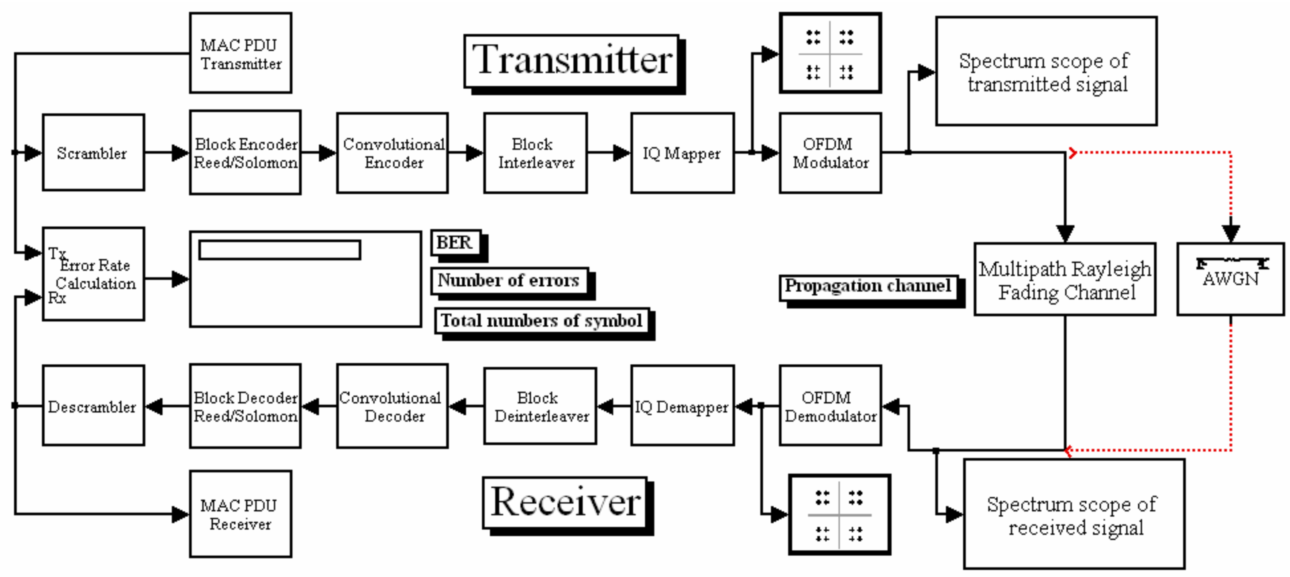


Figure (1): *Block diagram of the WiMAX transceiver according to standard ETSI TS 102 177 V1.5.1 (2010-0 5)*

This paper analyzes the impact of a modulation type and propagation channel on BER (Bit Error Rate) value in a information transfer. In particular, it is analyzed the cases when the propagation channel is represented as AWGN (Additive White Gaussian Noise), as also as Rayleigh fading channel. The results of simulation analysis are presented in the 3rd Chapter.

Description of the transceiver system

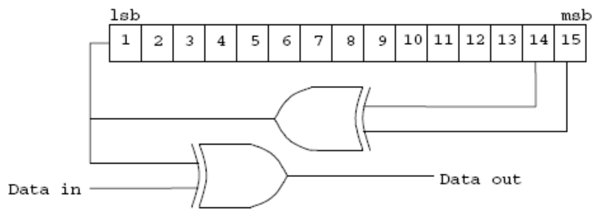
The initial analysis module – MAC PDU is a unit that consists the header that is 6 bytes in length, useful information (payload) and CRC (Cyclic Redundancy Code) field for checking errors in transmission, that is 4 bytes in length. The overall simulation structure of the MAC PDU unit is defined by the standard, and in the model it is established in the MAC PDU transmitter [3].

The next stage in a process of information creation is a channel coding information flow. The channel coding is carried out in three stages: Scrambling, Forward Error Correction (FEC) and bits interleaving. The FEC is implemented through Reed-Solomon and convolutional coding, while the convolution turbo coding (CTC) is an optional solution. At the reception module, complementary functions that involve channel decoding of information flow are performed.

Packet scrambling from the MAC layer is performed in Scrambler block. The input Signal (useful information) is fed together with the signal from the pseudorandom generator to the input of XOR logical circuit. The output signal from the XOR circuit leads to the Zero Pad block that performs padding of the transmission block with binary 1, if it is less than 288 symbols.

The Pseudorandom Binary Sequence Generator (PRBS) is represented in form $1+x^{14}+x^{15}$, as shown in Figure 2. In order to form a pseudorandom sequence, it is used the initial register value and logical operation (And/Or). The output data is then used for the FEC.

The scrambler block is formed from the elements shown in Figure 3.



F igure (2): *Data scrambling*

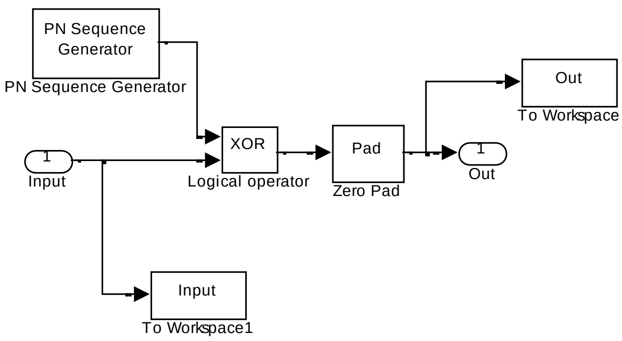


Figure (3): *The scrambler block*

The Forward Error Correction in the model is based on the Reed-Solomon's protective linear cyclic and convolutional coding, both in the UL (Uplink) and in the DL (downlink) channel. The encoding is achieved by sequentially bit stream through the RS encoder block, and then through the convolutional encoder block.

The RS coding is a form of RS (n=255, k=239, t=8) which uses GF (2^8). n is the overall number of bits after coding, k is the number of information bits before coding, and t is the number of information bits that can be corrected. For a coding process, the code generator polynomial $g(x)$ and the field generator polynomial $p(x)$, is used, as shown in formulas (1) and (2). The polynomials are defined by input data for the simulation, and prescribed by standard.

$$g(x) = (x+\lambda^0)(x+\lambda^1)(x+\lambda^2)\cdots(x+\lambda^{2t-1}) \text{ ,where } \lambda = 02_{16} \quad (1)$$

$$p(x) = x^8 + x^4 + x^3 + x^2 + 1 \quad (2)$$

Each RS block is encoded with the binary convolutional encoder whose coding quotient is 1/2 and constraint length is 7. This block uses the generating polynomials G_1 and G_2, which are $G_1=(1)_8(111)_8(001)_8=171_8$ for X and $G_2=(1)_8(011)_8(011)_8=133_8$ for Y, respectively. The convolutional code generator is shown in Figure 4.

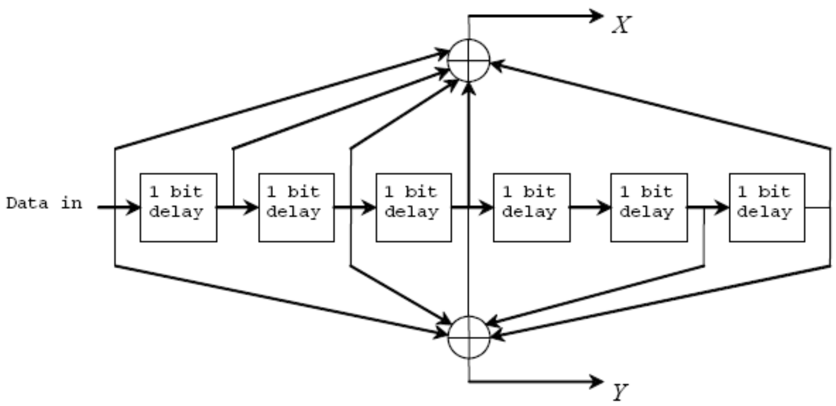


Figure (4): *The convolutional code generator with code quotient 1/2 [bits/symbol]*

Increasing of the communication speed is done by deleting some bits from the codeword (puncturing) [4]. This can be done, for example, by eliminating the odd parity bit from the first RSC (Recursive Systematic Convolutional) and the even parity bits from the second RSC.

Block diagram of simulation RS block encoder is shown in Figure 5.

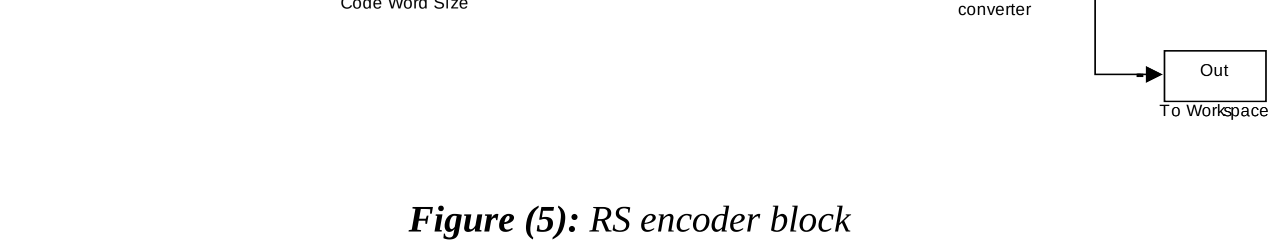


Figure (5): *RS encoder block*

First of all, conversion of the sequentially symbol stream from the binary to integer format is done. After conversion, padding with zeros is performed at the beginning of the symbol sequence, if the output block of symbols is less than 239. The integer form of information is brought to the RS encoder, and then to the selector whose function is described in Figure 5. After conversion to binary form, formed RS encoded signal is led to the convolutional encoder as shown in Figure 6.

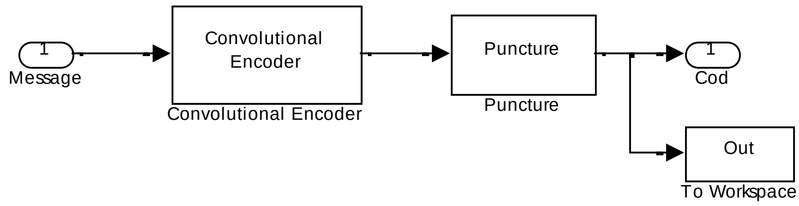


Figure (6): *Convolution encoder block*

In Table 1, block sizes for different levels of modulation and code rate are defined. To use 64-QAM modulation, it is necessary to implement the codes later.
The Interleaver block performs insertion of a protective blocks of bits in the coded information flow depending on the number of coded bits per subchannel assigned for the OFDM symbol, N_{cbps}. The Interliver block function is defined by a two-stage permutation. The first stage is defined by the formula (3), which allows adjacent bits to be mapped into nonadjacent subcarriers. The second permutation, defined by the formula (4) allow adjacent encoded bits to be alternatively mapped into a constellation bits, smaller or higher importance. In this way, a long string of less reliable bits is avoided, thereby reducing the likelihood of transmission error.
N_{cpc} is the number of encoded bits per subcarrier, which can be 1,2,4 or 6 for the BPSK, QPSK, 16-QAM or 64-QAM, respectively.

Table (1): *Block sizes for different levels of modulation*

Modulation	Uncoded block size (B)	Coded block size (B)	Overall coding rate (efficiency)	RS code	CC code rate
BPSK	12	24	1/2	(12,12,0)	1/2
QPSK	24	48	1/2	(32,24,4)	2/3
QPSK	36	48	3/4	(40,36,2)	5/6
16-QAM	48	96	1/2	(64,48,8)	2/3
16-QAM	72	96	3/4	(80,72,4)	5/6
64-QAM	96	144	2/3	(108,96,6)	3/4
64-QAM	108	144	3/4	(120,108,6)	5/6

Let's put $s=ceil(N_{cpc}/2)$. Within a block of N_{cbps} transmitting bits, let k be the index of encoded bit before the first permutation, m_k be the index of same bit after the first, and before the second permutation , while the index j_k be the index of encoded bit after the second permutation and before proceeding modulation mapping.

The first permutation is described by the formula:

$$m_k = (N_{cbps}/12)k \bmod(12) + floor(k/12), \text{ for } k = 0,1,...,N_{cpbs}-1 \quad (3)$$

The second permutation is described by the formula:

$$j_k = s \times floor(m_k/s) + (m_k + N_{cpbs} - floor(12 \times m_k / N_{cpbs})) \bmod(s),$$
$$\text{for } k = 0,1,...,N_{cpbs}-1 \quad (4)$$

Block De-Interleaver performs the inverse operation and is also defined by two permutations. After receiving a block of bits N_{cbps}, let j be the index of bit before the first permutation, m_j be the index of the same bit after the first and before the second permutation, defined by the formula (5), and the k_j represents index after the second permutation, and just before delivering a series of information to the convolutional decoder block, defined by formula (6).

The first permutation is described by the formula:

$$m_j = s \times floor(j/s) + (j + floor(12 \times j / N_{cbps})) \bmod(s), \text{ for } j = 0,1,...,N_{cpbs}-1 \quad (5)$$

The second permutation is described by the formula:

$$k_j = 12m_j - (N_{cbps}-1)\, floor(12m_j / N_{cbps}), \text{ for } j = 0,1,...,N_{cpbs}-1 \quad (6)$$

Table 2 shows the size of the inserted blocks depending on the type of modulation and coding. The first bit that arrives at interliver is mapping in the MSB constellation bit.

Table (2): *Size of the inserted blocks*

	N_{cbps}				
	16 sub-channel	8 sub-channel	4 sub-channel	2 sub-channel	1 sub-channel
BPSK	192	96	48	24	12
QPSK	384	192	96	48	24
16-QAM	768	384	192	96	48
64-QAM	1152	576	288	144	72

Figure 7 shows the Interleaver block diagram.

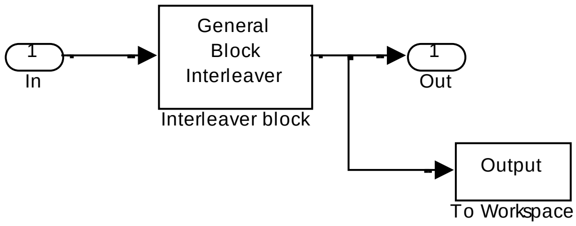


Figure (7): *Interleaver block diagram*

After the protective bits insertion, the serialized bit stream is delivered at the constellation mapper. BPSK, QPSK Greys, 16-QAM and 64-QAM mapping constellation procedures are recommended. Constellation shown in Figure 8 are normalized by multiplying constellation points with the factor *c* for balancing average power per symbol. For each modulation, b_0 indicates LSB bit. The first bit that arrives from interleaver is mapped in the MSB bit, and so on.
In the downlink, adaptive modulation and coding are enabled. In the uplink, a variety of modulation schemes for each user station are implemented, based on MAC configuration received from the base station. The data mapped in constellation structure is performing modulation to the assigned carriers to increase the index of the frequency shift (offset). The first symbol at the output from the constellation mapper perform carrier modulation with the lowest index of the frequency shift.

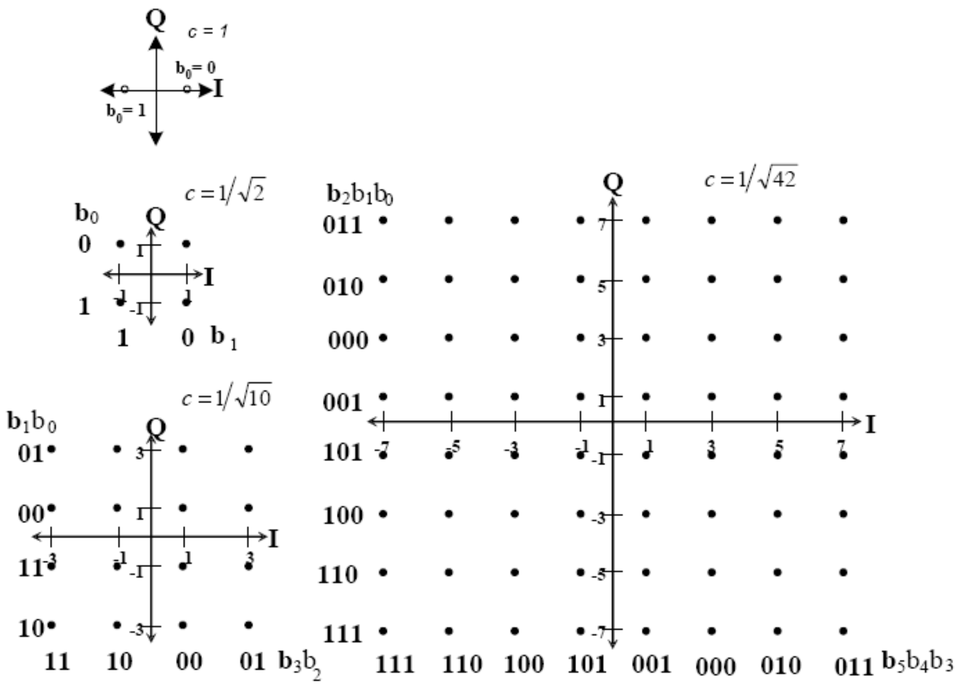


Figure (8): *Constellation diagrams for each modulation scheme*

3. Simulation results of the transceiver system:

The influence of the channel with the AWGN on signal transmission

Using previously described structures that are involved in signal transmission, transmission channel simulation with AWGN is executed [5]. According to changing the Signal/Noise ratio (1, 2, 3, 5, 7, 9, 10, 12, 15, 17, 20, 22, 25, 27 and 30 dB), it is observed how many errors occured during transmission. The performance of the system are analyzed by changing the following parameters:

• Modulation schemes and channel coding parameters

• The size of cyclic prefix (CP)

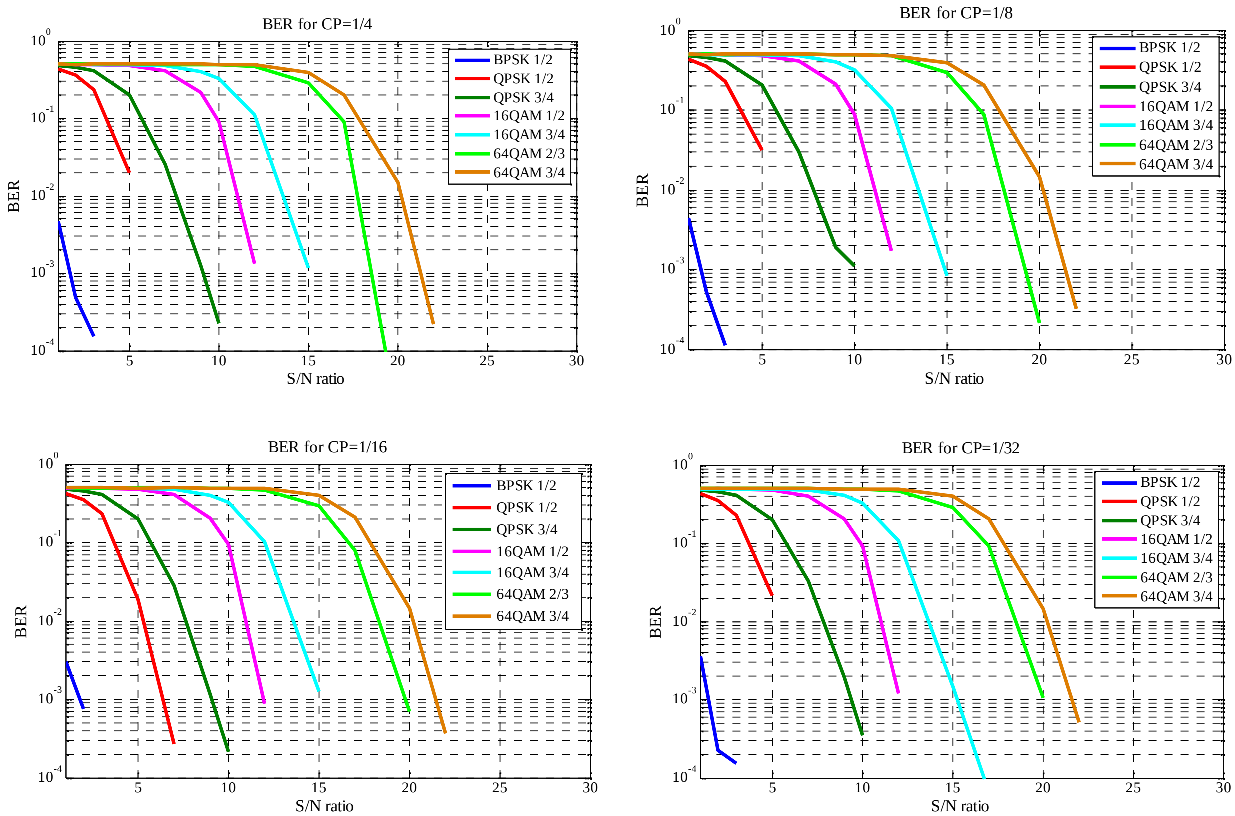
The results are shown graphically in Figure 9.

Through analysis of the obtained graphic, we made the following conclusions:

• BPSK modulation is the most resistant to a bad propagation conditions and for the value of BER=10^{-4} and less, Signal/Noise ratio needed to be 5 dB;

• Reducing the size of the cyclic prefix (CP), generally for all types of modulation, degradation in performance of transmission is observed, ie. with using greater CP value with lower Signal/Noise ratio, it is possible to achieve a better transfer of information (lower BER);

• Decrease in performance of the system is not significant by reducing the size of cyclic prefix, because in this case we didn't use fading channel.



Figure(9): *Simulation results for channel with AWGN*

The influence of channel with fading on the signal transmission

Standard that is described in this paper enables the achievement of equipment interoperability from different manufacturers for mobile users. Some client applications are more sensitive to delay, so it is therefore necessary to examine in particularly changing the quality of transmission in terms of multiple propagation that occurs when user stations moving. This situation can be presented in the most accurate way if we insert a component of the observed Doppler shift frequency signals in the simulated propagation channel, which implies the movement within each cell. Superposition of received signals at different time moments affect the transmission quality by randomly changing signal strength value. In the case when a direct and superimposed wave are in the same phase quadrant, the signal will be enhanced, while reducing the signal level at the reception lead to errors in transmission. Rician block fading channel is used in this model.

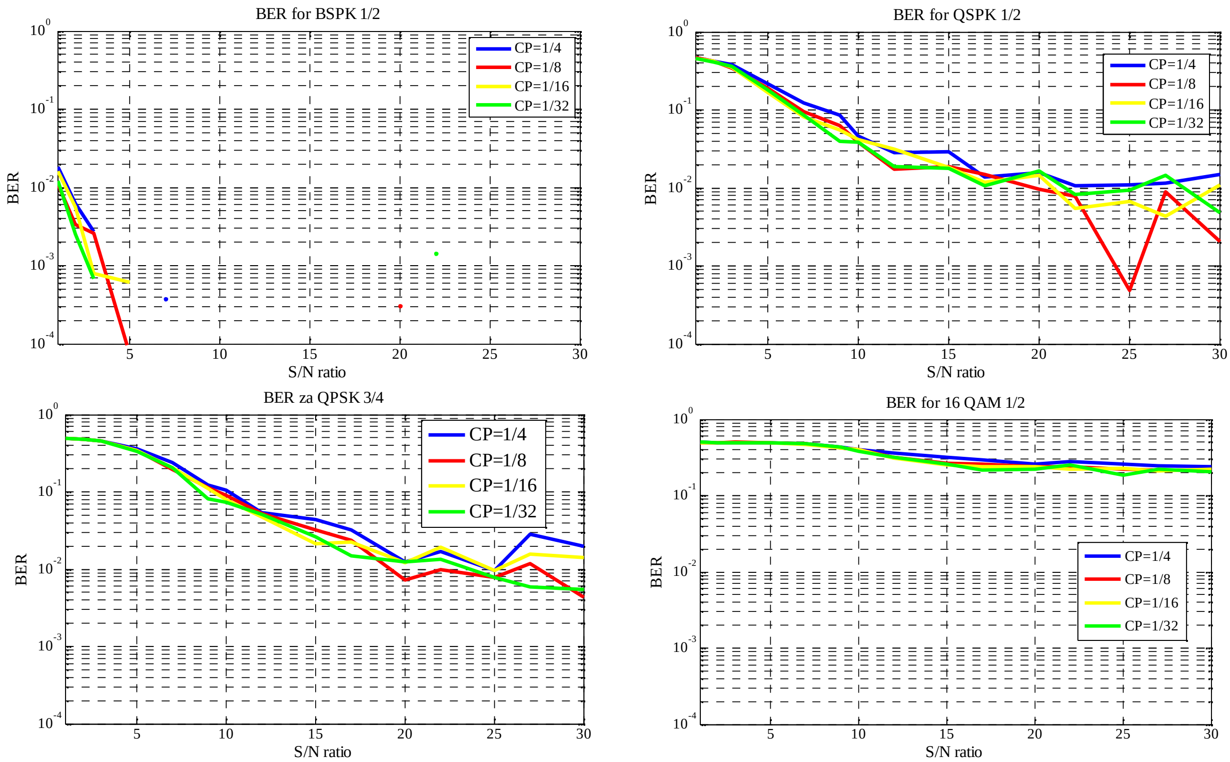


Figure (10): *The results of simulations for a channel with fading*

Characteristics of Rician fading channel with the four secondary paths through the arrival of reflected waves, are presented. The value of K fading factor (linear relationship between main and the reflected wave at point of receipt) that was used in the experiment is 10. Only the first reflected wave has the characteristics of Rician fading (four in total), while the other three components has characteristics of the Rayleigh fading. The maximum Doppler shift which is defined in the simulation was 20 Hz, while the transfer rate taken to be 500 kb/s. Discrete delay for all four reflected waves were 0, 0.04, 0.08, and 0.12 seconds, and a gain (amplification) were

0, -90, -95, and -100 dB, respectively. By changing the CP for each transfer in this established scenario, we obtained the results shown in Figure 10.
The previously figures indicate the following:
• BPSK 1/2 modulation allows the most quality transmission in the case when S/N=5 dB, especially in the case of CP=1/8. A significant deterioration in the quality of transmission is presented for the CP value of 1/16, whereas for other values of CP it can not be inferred with certainty due to insufficient number of processing OFDM symbols in the simulation.
• With other types of modulation a significant decline in the quality of a transmission for all values of cyclic prefix are generally observed.
• Using QPSK 1/2 modulation and CP value of 1/8, compared with S/N of 25 dB allows a significant reduction in BER.
• While the complexity of the constellation is increasing, for all values of cyclic prefix of OFDM symbols, the transmission quality is reducing in the same relation.

4. Planning of a nomadic access network:

The area of interest has been chosen, in this case to be mostly plain, intercepted by lot of rivers and lakes, land with few dominant high ground points, predominantly rural with few urban places. For the signal coverage analysis, the northern part of Serbia, part of Vojvodina, the territory bordered by the cities of Belgrade – Novi Sad – Zrenjanin is taken into account. The application used to perform network planning and analysis was HTZ software produced by ATDI Company [6].
The initial elements necessary to establish the project were digital 3D terrain map (.geo file), topographic or geographic map in digital format (.img file), color palette for the map (.pal file) and clutter map – ground covers (.sol file). In a graphical environment that these four elements form, one can do approximate spatial access point distribution to form the optimally deployed network. Those AP-s are meant to be located at dominant points, in areas where the need for the highest capacity network is considerable (urban and suburban areas), at the places where the lowest level of interference originating from adjacent and neighboring cells are going to obtain. During design, it is necessary to consider the potential operational directions of future combat operations (in this case, significant road communications) considered as areas of high importance that imply the existence of communication links in all conditions.
The first step in planning a network is an arbitrary arrangement of the selected cells per field. The simulated terrain of interest is determined by the size of cells in a specific surface area in a rural, suburban and urban environment at south of Vojvodina. The cells are hexagon shaped, with 10 km^2 surface, distributed evenly on the terrain of 100 km^2.

Table (3): *Base station technical characteristics*

Nominal radiated power	10 W
Tx/Rx antenna gain	17 dBi
Antenna – device connection loss	1 dB
E.I.R.P.	398,1072 W
Frequency	3,5 GHz
Antenna height	50 m
Channel bandwidth	3,5 MHz
Modulation type	QPSK ½
Minimum receiving field level	35 dBµV/m

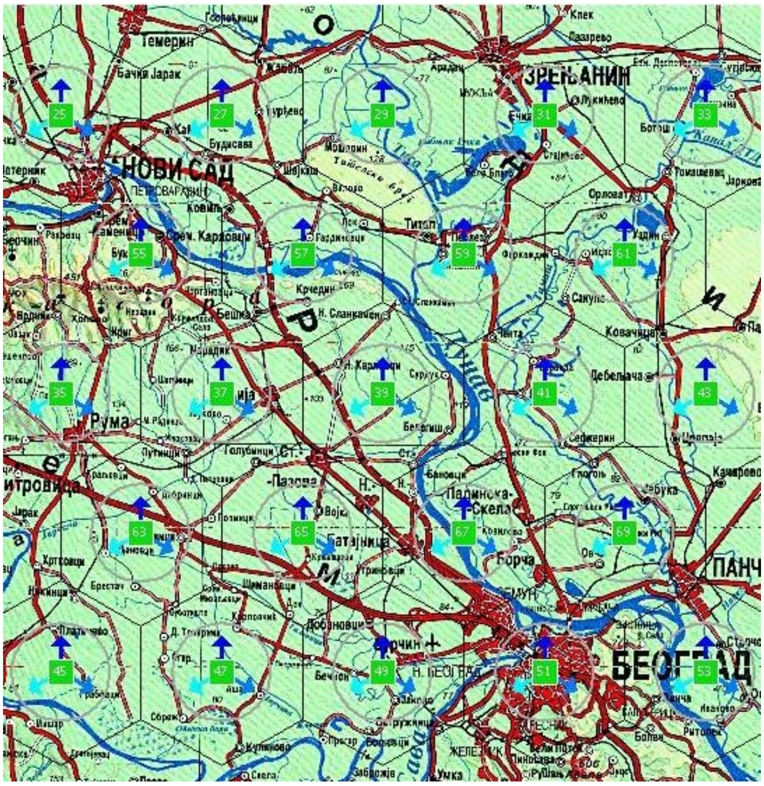


Figure (11): *The initial network structure*

Those cells form the initial network structure ready for further adaptation (Fig. 11). In the center of each cell, there is a base station with characteristics shown in Table 3.
The next step in designing a network is to determine the position of stations based on the cover codes. In defining the position of cells, it is necessary to determine cover codes (clutters) which will provide the best base station positioning (Fig. 12). In urban areas it is desirable to set the base station to the dominant point in the city (mostly buildings). For rural areas, the approximate capacity required for each cluster of base stations has to be taken into account and from that point of view to find a

dominant high land point.

After determining the covering codes suitable for setting up base stations that are in the simulation presented as number 3 - 15m height of the urban area and number 4 - 30m height of the urban area, the software calculates the position of cells. Number of cells is reduced in accordance with the covering demand. Unnecessary cells become inactive, and then are deleted from further consideration. After reduction, the number of base stations remaining for deliberation is 30, where each cell consists of three separate elements that make up the different cluster at the angle of 120°. After the optimal scheduling, there should be performed signal coverage for defined locations. Determined coverage includes various parameters and values used in the simulation, which are given in Table 4.

Table (4): *Coverage calculation parameters*

Rx antenna height	2m
Circle radius around a base station in which the calculation is performed	20 km
Minimum receiving field level, by demand	26 dBμV/m² (-115 dBm)
Propagation model	ITU-R 525
Clutter loss	
Rural area	30 dB/km
Suburban area	40 dB/km
Urban area height up to 8m	50 dB/km
Urban area height up to 15m	60 dB/km
Urban area height up to 30m	70 dB/km
Forest	40 dB/km
Hydro	10 dB/km

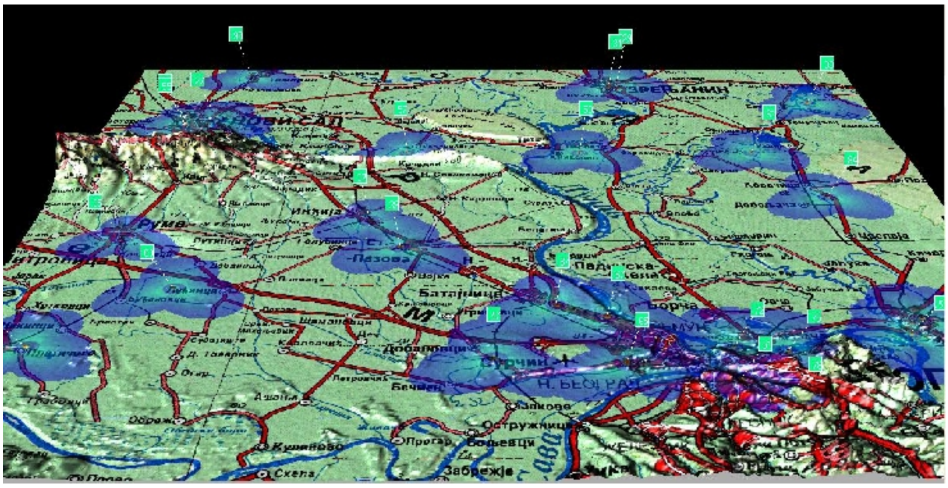


Figure (12): *WiMAX network coverage*

The same frequency usage, such in the formed scenario, leads to mutual base station interference. Figure 13 shows areas where interference problems between base stations can occur and those parts of the network are colored in pink.

Table (5): *Subscriber station technical characteristics*

Nominal radiated power	1 W
Tx/Rx antenna gain	7 dBi
Antenna – device connection loss	0 dB
Frequency	3,5 GHz
Antenna height	2 m
Channel bandwidth	3,5 MHz
Modulation type	QPSK ½
Minimum receiving field level	35 dBµV/m

Table (6): *Base station technical characteristics*

Nominal radiated power	10 W
Tx/Rx antenna gain	17 dBi
Antenna – device connection loss	1 dB
E.I.R.P.	398,1072 W
Frequency	3,5 GHz
Antenna height	50 m
Channel bandwidth	3,5 MHz
Modulation type	QPSK ½
Minimum receiving field level	35 dBµV/m

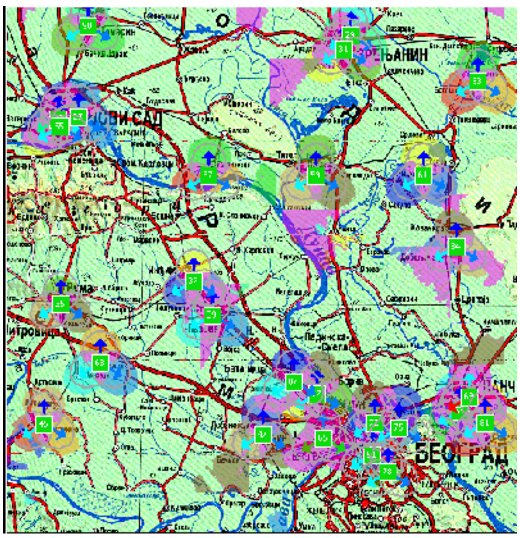


Figure (13): *Interference in the network*

Users in the network are randomly assigned to clutters: semi-urban, urban buildings with up to 30m in height, and the internal building areas in towns and populated areas. Technical characteristics of the user stations are given in Table 5, while the base station technical characteristics are given in Table 6.
Number of users per square kilometer is given for different areas as follows:
Semi-urban - 5;
Urban 8m - 7;
Urban 15m - 10;
Urban 30m - 8;
Urban 50m - 1;
Enclosed areas of up to 20 stories – 3 [7].

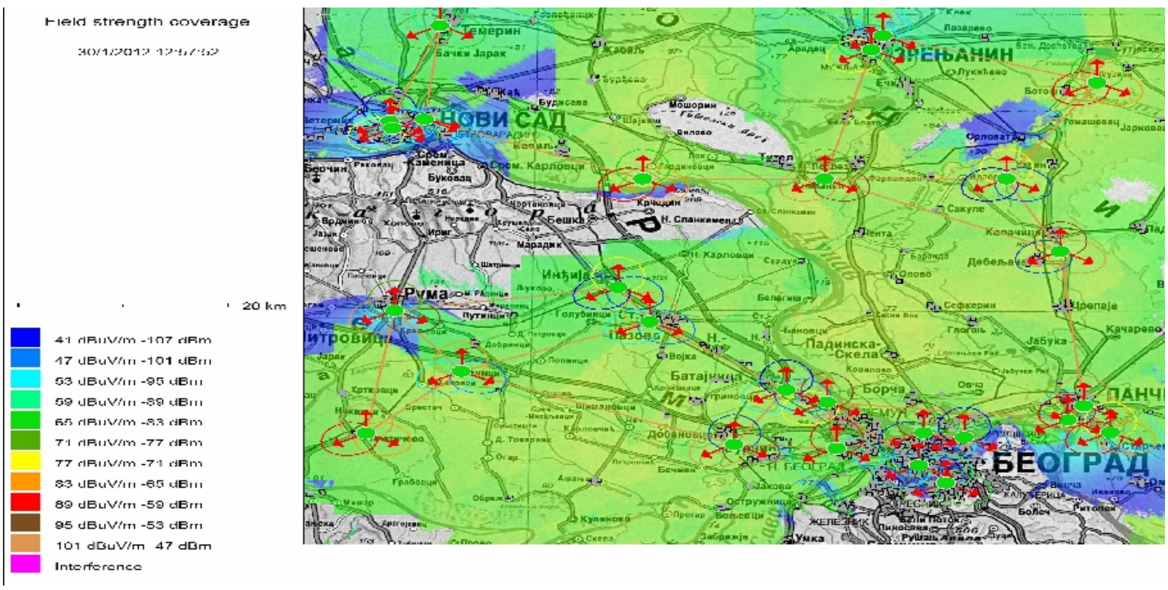


Figure (14): *2D picture of the optimized network*

Number of generated users, based on input parameters is 1584, scattered by the above criteria. Mobile stations are given a condition to meet the transport capacity of 1 Mb/s. Base stations are initially set to provide the customers with the bit rate of 20 Mb/s. Mobile stations are connected to the nearest base station using the IEEE 802.16e standard for the service flow control procedure. The minimum protective signal to noise + interference ratio on receiving signal level is set to be 14 dB.
Receiving field level analysis can be made for each user individually and according the data that HTZ software lists through the formed table, the best serving cell could be determined. Information about the level of received signals are used to find the serving station all the time simulation runs, and to make handover procedure analyzing possible while mobile users roam through the network territory [8].
After frequency adaptation accordingly the interference avoiding terms and registration procedure of mobile users to base stations in accordance with the

principle of accessing the station that provides the maximum level of received signals, the appearance of the territory and its coverage in the percentage of 66% is shown in two and three dimensions on Figures 14 and 15, respectively.

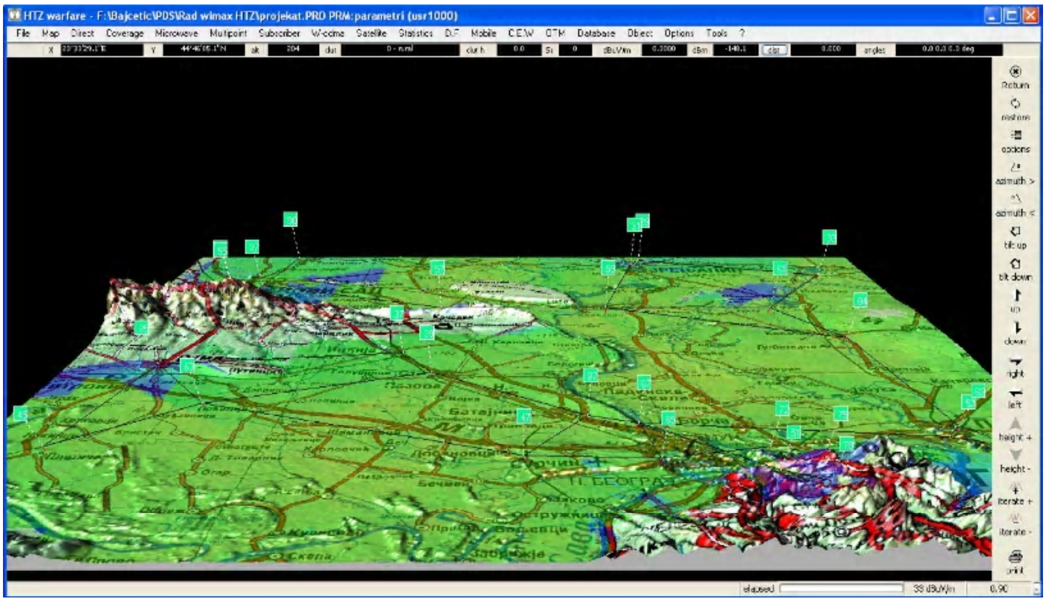


Figure (15): *3D picture of the optimized network*

5. Conclusion:

The paper represents the IEEE.802.16e physical layer analysis considering its basic block elements using MATLAB Simulink software package. The basic characteristics given by the ETSI TS 102 177 V1.5.1 (2010-05) standard which are meant to be changed due to system performance improvement are measured in many spots of transceiver model. Main attention in performance research is directed to Forward Error Correction blocks and available modulation schemes. At the end, the results of transmission performance affected by Aditive White Gaussian Noise, Rician and Rayleigh fading are given.

In order to successfully form a network which provides optimal conditions to meet user communication requirements, it is necessary to take into consideration as many relevant parameters and an empirical prediction as it is possible. In cases where the network is formed for a short period of time, where the dynamics of users is very large and we don't have time to make a deep analysis, it is necessary to use appropriate software tools to make proper screening and optimization of the network. For that kind of planning, it is conventional to have application-available solution. With a proper use of that kind of software, simulation which included a sufficient number of variables will certainly give accurate output data and results which enable the optimal use of all available resources (technical and spectral).

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