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Experimental verification of the MIMO channel simulation model using STBC Alamouti coding

Abstract *- An experimental verification results of the MIMO channel built in Matlab was presented in this paper. An assessment of the simulation model credibility was done using determinant described in detailed in the section "The MIMO channel simulation model". It was shown that the built Matlab model can be used with acceptable error for E_b/N_0 up to about 15 dB.*

Streszczenie *– W artykule przedstawiono eksperymentalną weryfikację, zaimplementowanego w środowisku Matlab, autorskiego modelu kanału MIMO. Szczegółowy opis modelu przedstawiono w rozdziale „The MIMO channel simulation model". Poprawność wykonania modelu pozwala na prowadzenie badań dla sygnałów o wartościach E_b/N_0 mniejszych od 15 dB. (**Eksperymentalna weryfikacja zaimplementowanego w środowisku Matlab modelu kanału MIMO**)*

Keywords: Radio channel, MIMO STBC, simulation model, experiment
Słowo kluczowe: Kanał radiowy, MIMO STBC, model symulacyjny, eksperyment

Introduction

Among emerging radio technologies with the potential to push the frontiers of wireless capacity, multiple-input-multiple-output (MIMO) system stand out with the promise of many orders of magnitude improvement in spectrum efficiency relative to what is achievable today. Telatar [1] and Foshini [2] were among those who pioneered the concept of MIMO system in the early 1990s. In the mid-1990s, Foshini and his colleagues developed the Bell Labs space-time (BLAST) architecture that reports achieving spectral efficiencies in the range of 10-20 b/s/Hz for typical configurations. Since then, MIMO system have attracted a large amount of research interest.

The idea behind MIMO is that the signals on the transmit Tx antennas at one end and the receive Rx antennas at the other end are combined in such a way that quality (BER) or the data rate (bits/s) of the communication for each MIMO user will be improvee. Such an advantage can be used to increase both the network's quality of service and the operator's revenues significantly (Figure 1).

The literature proposed coding schemes can be generally split in two groups: Space Time Coding (STC) [3] and Space Division Multiplexing (SDM) [4,5,6]. STC increases the robustness/performance of the communication system by coding over the different transmitter branches, while SDM can achieve a higher data rate by transmitting independent data streams on different transmitter branches simultaneously using the same carrier frequency.

One of the most popular orthogonal space-time block codes is the Alamouti scheme for two transmit antennas [7]. In this scheme, the data is transmitted as is shown in Figure 1. At a given symbol period, two symbols s1 and s2 are transmitted simultaneously on TX 1 and TX 2, respectively. During the next symbol period, –s2* and s1* are transmitted on TX 1 and TX 2.

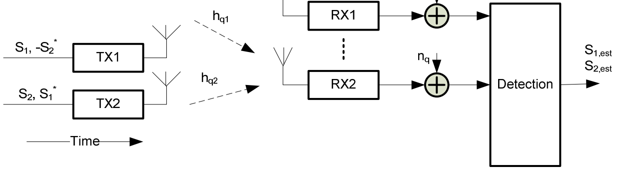

Fig. 1. The Alamouti STBC scheme [7]

To test MIMO versus SISO performance in different scenario, the MIMO (Multiple Input Multiple Output) simulation channel model was constructed on the basis of a space-time-spectrum conditions resulting from the operational analysis. These conditions are defining a range of parameters connected with probabilistic properties of received signals. The nature of simulation environment is defined by:

- carrier frequency,
- movement of subscribers,
- space structure of propagation environment,
- space structure of antenna system and its limitations.

The reliably simulation model of MIMO channel is needed to verify different concept of MIMO usage (different coding, antenna system, user mobility, environment etc.).

The Matlab model of such MIMO simulation channel with its mathematical description and verification was presented in this paper.

The MIMO channel simulation model

<u>Analytical measures of transmission quality</u>

BER (Bit Error Rate) in function of E_b/N_0 was chosen as the measure of communications quality of tested MIMO channel.

Determinant used for verification of the mathematical channel model can be described as [9]:

$$R^2 = \frac{\sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2}, \quad (1)$$

where: $\hat{y}_i$ – a value measured from the channel mathematical model, y_i – a value measured from the real channel, $\bar{y}$ – the arithmetic mean from the real channel measures .

There is no required value of determinant but the less it differ from 1 the better it is. Basic on literature [9] we can assume that the model is good suited to reality if determinant value is bigger than 0,6.

<u>Algorithm of simulation research</u>

Consider the MIMO system consists of 2 antennas at the transmitter and 2 antennas at the receiver.

Signals at the receiver antenna array are denoted by the vector $\mathbf{y}(t) = [y_1(t), y_2(t)]^T$ where $y_i(t)$ is the signal at the *i*-th antenna port. Similarly, the signals at the transmitter are

$\mathbf{s}(t) = [s_1(t), s_2(t)]^T$. The MIMO radio channel $\mathbf{H} \in C^{2\times 2}$ which describes the connection between the transmitter and the receiver can be expressed as

(2)
$$\underline{\mathbf{H}} = \begin{bmatrix} \underline{h}_{11} & \underline{h}_{12} \\ \underline{h}_{21} & \underline{h}_{22} \end{bmatrix}$$

where $\underline{h}_{ij}$ is the complex transmission coefficient from antenna *j* at the transmitter to antenna *i* at the receiver. The relation between the vectors $\mathbf{y}(t)$ and $\mathbf{s}(t)$ can be expressed as

(3)
$$\mathbf{y}(t) = \mathbf{H}(t) \cdot \mathbf{s}(t)$$

Simulation problem: to generate of $\underline{h}_{ij}$ (channel coefficients).

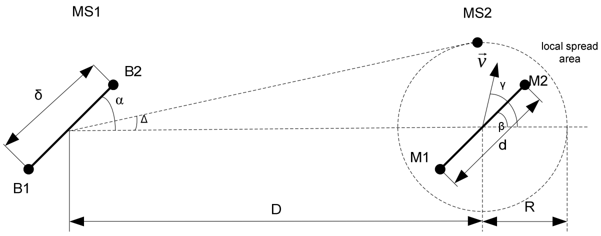

Fig.2. Graphical representation of the channel reference model [8]

Assumptions : It is assumed that all antenna elements in the two arrays have the same polarization and the same radiation pattern. The $\underline{h}_{ij}$ is complex Gaussian distributed with identical average power. The spatial complex correlation coefficient at the elements of matrix **H** is given by $\alpha_{ijkl} = E\{\underline{h}_{ij}\underline{h}^{*}_{kl}\}$. It is independent from transmitter (receiver) number.

Algorithm – step 1 – determination of matrix

Coefficients a, b, and c connected with Cartier frequency as well as with relative antenna deployment are determined at the start.

(4)
$$a = 2 \cdot \pi \cdot f_n \cdot n\,,$$

(5)
$$b = 2\pi \cdot d/\lambda \;,$$

(6)
$$c = 2\pi \cdot \delta/\lambda$$

Basing in this following parameters are calculated:

(7)
$$x_1 = \sqrt{a^2 + b^2 - 2ab\cos(\beta - \gamma)}\,,$$

(8)
$$x_2 = \sqrt{a^2 + c^2\Delta^2 - 2ac\Delta\sin\alpha \cdot \sin\gamma}$$

(9) $x_3 = \sqrt{a^2 + b^2 + c^2\Delta^2 - 2ab\cos(\beta - \gamma) - k}$

where $k = 2c\Delta\sin\alpha(a\sin\gamma - b\sin\beta)$

Different scenario assumptions

1. MIMO 1 scenario. No movement. The angle between antenna system direction (MS1, MS2) is small

$$\alpha = 0\,,\ \beta = \pi/16$$

2. MIMO 2 scenario. MS1 moves. The angle between antenna system direction (MS1, MS2) is small

$$\alpha = 0\,,\ \beta = \pi/16\,,\ \gamma = \pi/2$$

3. MIMO 3 scenario. MS1 moves. The angle between antenna system direction (MS1, MS2) is "free"

$$\alpha = \pi/4\,,\ \beta = \pi/16\,,\ \gamma = 0$$

Mentioned above parameters were used for determination of the MIMO matrix R correlation factors.

(10)
$$\mathbf{R}_{MIMO} = \begin{bmatrix} \alpha_{1111} & \alpha_{1112} & \alpha_{1121} & \alpha_{1122} \\ \alpha_{1211} & \alpha_{1212} & \alpha_{1221} & \alpha_{1222} \\ \alpha_{2111} & \alpha_{2112} & \alpha_{2121} & \alpha_{2122} \\ \alpha_{2211} & \alpha_{2212} & \alpha_{2221} & \alpha_{2222} \end{bmatrix}$$

where $\alpha_{1111} = \alpha_{1212} = \alpha_{2121} = \alpha_{2222} = 1$,

$$\alpha_{1121} = \alpha_{1222} = \alpha_{2111} = \alpha_{2212} = J_0(x_1)$$
$$\alpha_{1112} = \alpha_{1211} = \alpha_{2122} = \alpha_{2221} = J_0(x_2)$$
$$\alpha_{1122} = \alpha_{2211} = \alpha_{1221} = \alpha_{2112} = J_0(x_3)$$

Algorithm – step 2 – determination of channel matrix coefficients

1. Lower triangular matrix C as factorization effect of matrix using Cholesky decomposition.

(11)
$$\mathbf{C} = \begin{pmatrix} c_{11} & 0 & 0 & 0 \\ c_{21} & c_{22} & 0 & 0 \\ c_{31} & c_{32} & c_{33} & 0 \\ c_{41} & c_{42} & c_{43} & c_{44} \end{pmatrix}$$

2. Generation of 4-element complex vector with Normal distribution.

(12)
$$\underline{\mathbf{a}} = [\underline{a}_1, \underline{a}_2, \underline{a}_3, \underline{a}_4]^T$$

3. Vector of elements of channel matrix:

(13)
$$\underline{\mathbf{H}} = \mathbf{C}\underline{\mathbf{a}}$$

where $\underline{\mathbf{H}} = (\underline{h}_{11}, \underline{h}_{12}, \underline{h}_{21}, \underline{h}_{22})^T$.

4. Mentioned above step I and step II were iterated to have better final accuracy.

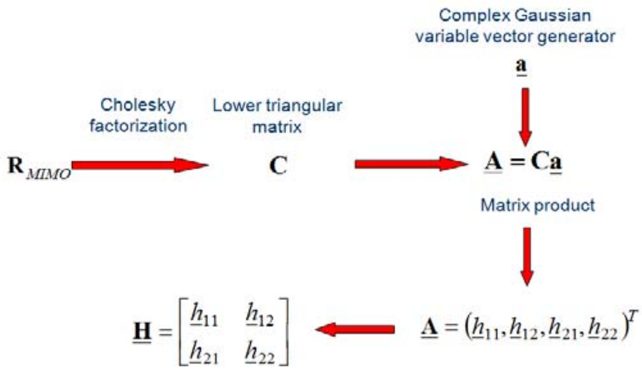

Fig.3. MIMO channel simulation algorithm [10]

Remark: In static circumstances, only 2-nd step of algorithm is used.

<u>Description of simulation tests</u>

Simulation set was built in Matlab using transmittance matrix generation algorithm described in detailed in p. Analytical measures of transmission quality. Transmittance matrix parameters for real channel were determined basing on measures from real channel according to procedure described in par.

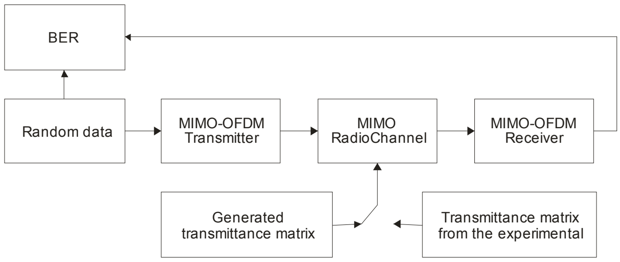

Fig.4. Block diagram of the MIMO link Matlab simulation model

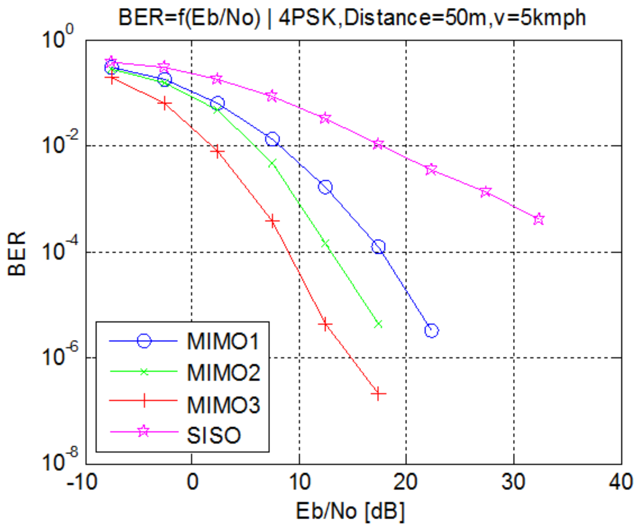

Fig. 5. MIMO in comparison to SISO for 4PSK (simulation in Matlab)

Real testbed description

The real measures were done to verify the simulation MIMO model reliability.

Simulation and measurement results have been compared and presented on one plot.

One of the urban measurements was done campaigns in Warsaw (Gibalskiego Str.), Poland, which is an area characterized as a typical urban environment (Figure 6).

The presented results were obtained by measurements in the line-of-sight (LOS) area with local scattering.

The structure of a test bed consists of an immobile transmitter station and a mobile receiver station (Figure 7).

The role of an immobile transmitter station is:
- to emit the beginning of a measurement route - 5 one-second-long synchronisation impulses (PPS) which mark the beginning of the measurement process,
- to emit a testing signal all along the measurement route,
- to emit (ones again) 5 one-second-long synchronisation impulses (PPS) which mark the end of the measurement process.

The position of a transmitter antenna of an immobile transmitter station is localised by a geodesic GPS (RTK).

The structure of the transmitter**:**
- the transmitter F=1634 MHz and F=1832 MHz antenna hanged 1,5 m overground,
- the power amplifier, model 5S1G4 5 W (0.8-4.2 GHz),
- the signal generator E4438C (it modulates and emits the PPS and the testing signal; the testing signal is recorded by the generator using the LAN interface,
- the GPS Thunderbold working as a source of PPS signals and as a source of the10 MHz external synchronising signal (this signal synchronises the generator),
- the GPS (RTK) which defines the position of the transmitting antenna,
- the 80Ah/12V battery and the DC/AC (12V/230V) converter as a power supply,
- the laptop connected with the generator (E4438C) by the LAN interface; the computer receives PPS signals and transfers them to the generator in order to mark the beginning and the end of the measurement route.

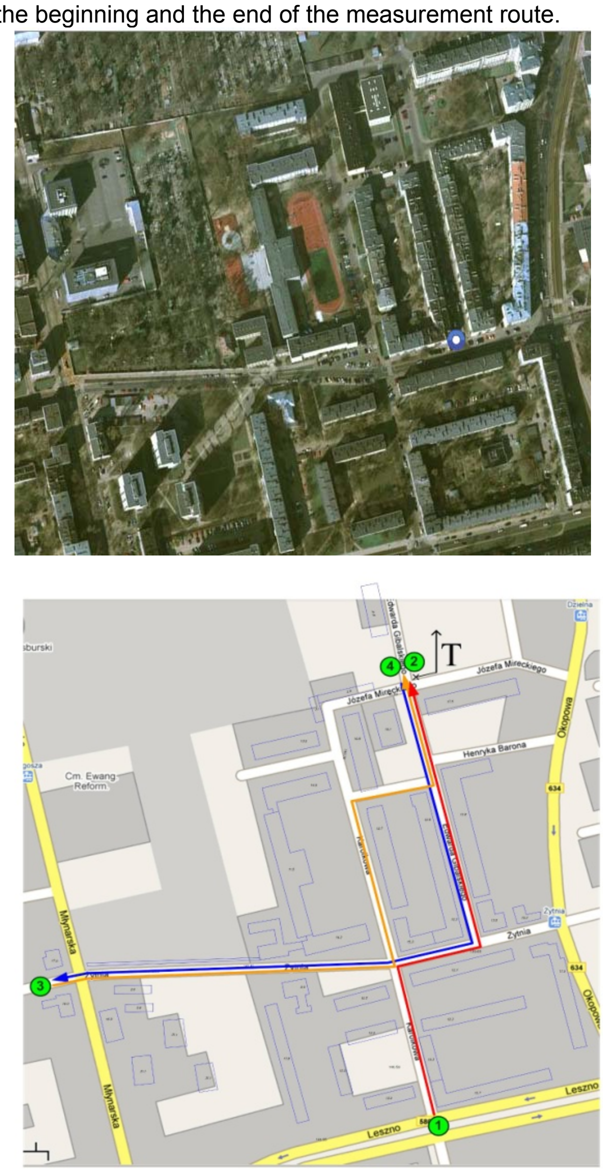

Fig.6. Plan for measuring training ground

The role of the receiving station is to receive and register signals from the transmitter in the move (5 km/h) on the defined measurement route.

The structure of the receiver:
- the receiver F=1634 MHz and F=1832 MHz antenna hanged 1,5 m overground,
- the receiver Rochde&Schwarz EM 550,
- the signal recorder connected with the receiver (Rohde&Schwarz EM 550) with the LAN interface,
- the GPS Thunderbold working as a source of unified time and as a source of the external 10 MHz synchronising signal; the signal synchronises the receiver,
- the laptop connected with a GPS with the RS232 interface which triggers the software used to synchronise both the

transmitter and receiver's time; the laptop also triggers the software to read impulses from a measurement wheel,
- the IO Tech card – as a measuring card connecting the measuring wheel and the laptop using a parallel port; it is connected to the laptop by USB interface.
- the GPS (RTK) which defines the position of the receiver,
- the 80Ah/12V battery and the DC/AC (12V/230V) converter as a power supply,
- the DC/DC 12V/27V converter as the power supply for recorder.

The measuring wheel was used to precisely define the route of the receiver station as a support for GPS.

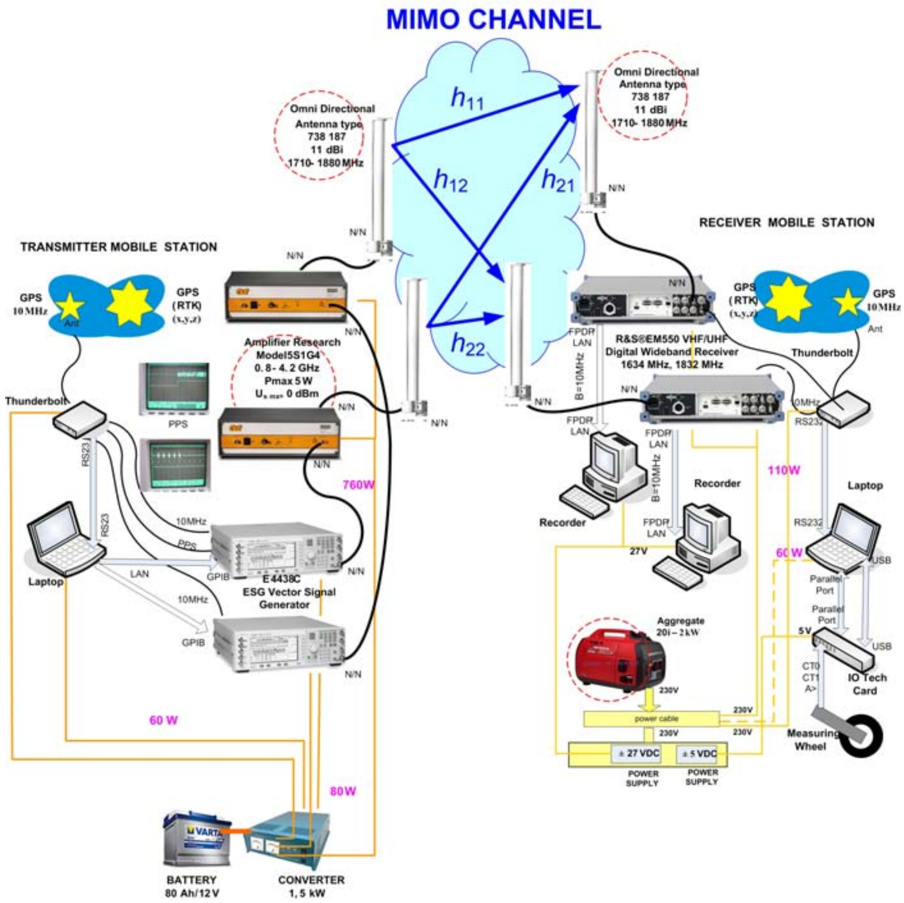

Fig.7. Structure of the test-bed for quality assessment of MIMO system

Results ANALYSIS

Results from test bench

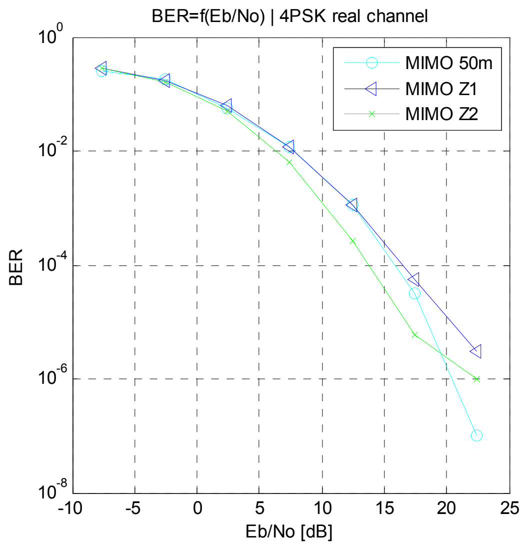

Fig.8. MIMI channel with real parameters of transmittance matrix for 3 different user locations (50m – LOS; Z1, Z2 – NLOS)

On figures 8 and 9 you can see noise characteristics as the result of simulations according to par. The MIMO channel simulation model.

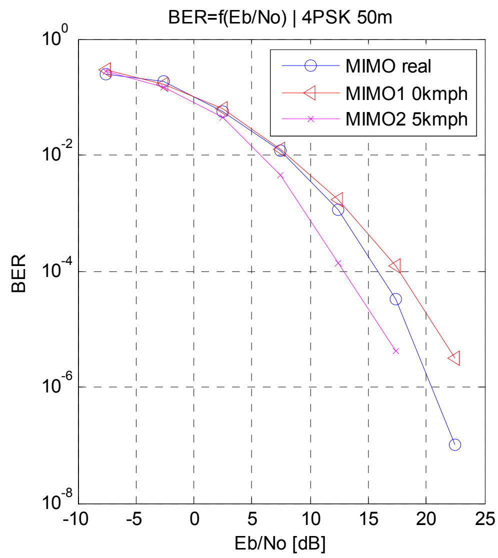

Fig.9. Comparison of MIMO channel simulation results (for user speed: MIMO1 v=0kmph, MIMO2 v=5kmph) with real environment (MIMO real, v≈2÷3kmph)

As you can see for E_b/N_0 less than 15dB mathematical model of the MIMO channel is the reflection of real MIMO channel with determinant value less than 0,6 (Figure 10). However for bigger values of E_b/N_0 the model can be treated as less adequate.

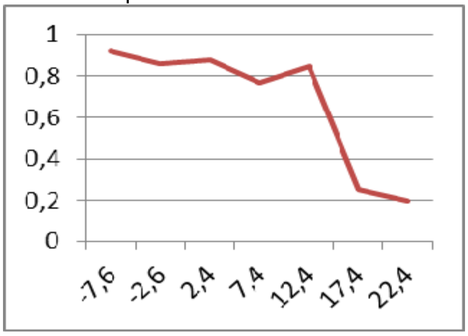

Fig.10. Value rate of the determination $R^2 = f(E_b/N_0)$

Conclusion

We verified that MIMO channel simulation model with mathematical generation of transmittance matrix parameters can be used in future experiments investigations of MIMO links but rather for E_b/N_0 less than 15dB (SNR less than 25 dB).

The reason of limitation can be additive components of the real channel transmittance (noise and interferences) of model.

REFERENCES

[1] Telatar E., Capacity of multiantenna Gaussian channels, *AT&T Bell Laboratories, Tech. Memo*., (June 1995)

[2] Foshini G. J., Layered space-time architecture for wireless communication in a fading environment when using multielement antennas, *Bell Labs. Tech. J.* Autumn, (1996)

[3] Tarokh V., Seshadri N., and Calderbank A. R., Space-time codes for high data rate wireless communication: performance criterion and code construction, *IEEE Transactions on Information Theory*, vol. 44, no. 3, (March 1998), pp. 744-756.

[4] Foschini G. J. and Gans M. J., On limits of wireless communications in a fading environment when using multiple antennas, *AT&T Bell Labs Internal Tech. Memo, Sept. 1995. Published in Wireless Personal Communications*, vol. 6, no. 3, (March 1998), pp. 311-335

[5] Raleigh G. G. and Cioffi J. M., Spatio-temporal coding for wireless communication, *IEEE Trans. on Communications*, vol. 46, no. 3, (March 1998), pp. 357-366

[6] Van Zelst A., Space division multiplexing algorithms, *in Proc. of the 10th Mediterranean Electrotechnical Conference (MELECON) 2000*, vol. 3, (May 2000), pp. 1218-1221

[7] Alamouti S. M., A simple transmit diversity technique for wireless communications, *IEEE Journal on Selected Areas in Communications*, vol. 16, no. 8, (Oct. 1998), pp. 1451-1458.Decoding (equalisation) methods

[8] Michalak J., Uljasz B., Ziółkowski C., Ocena skuteczności zakłócania techniki MIMO-OFDM wybraną klasą sygnałów zakłócających, Wybrane problemy rozpoznania i walki elektronicznej, Wojskowa Akademia Techniczna, (2011), rozdz.4, str.353-361, Warszawa

[9] Makuć W., Urbanek-Krzysztofiak D., Metody opisu statystycznego, *Wydawnictwo Uniwersytetu Gdańskiego*, Gdańsk (2004)

[10] Michalak J., Uljasz B., Ziółkowski C., MIMO versus SISO – Simulation Results, *Biuletyn Wojskowej Akademii Technicznej* no. 1/2012, (2012), pp. 223-239

[11] Michalak J., Uljasz B., Ziółkowski C., Experimental verification of the MIMO channel simulation model, *MIKON 2012*, Warszawa (2012), Vol.2, pp. 537-541

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