METHOD OF ADAPTING POLARIZATION-ORTHOGONAL SIGNALS TO IMPROVE THE QUALITY OF COMMUNICATION CHANNELS WITH MIMO

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Abstract

Currently, there is considerable interest in the use of multi-antenna systems with MIMO in telecommunications, in particular - dual-polarization antennas. The use of such antennas can generally improve the quality of the channel. Polarization orthogonal antennas on both the transmitter and receiver can improve communication performance. The main disadvantage of such systems with MIMO technology is the polarization loss. The article proposes to consider the possibility of orthogonalization the components of the received signals at the receiving position. It is interesting to increase the data rate (BR) and reduce data errors (BER) in wireless communication with antennas due to the adaptive polarization of the channel.

Further development of communication systems requires the search for effective methods to ensure the quality of communication channels and electromagnetic compatibility. Using different polarizations can provide additional benefits in terms of electromagnetic compatibility [1]. The focus is on cross-polarization isolation between channels and the effect on channel quality parameters [2-5]. It is proposed to choose antennas with the minimum required values of the cross-polarization coefficient, which limit the given channel bandwidth. In wireless communications, multiple-input and multiple-output (MIMO), is a method for improving the quality, capacity, and reliability of a radio link using multiple transmission and receiving antennas to exploit multipath propagation [6-7]. The main disadvantage of systems with MIMO technology is the loss of energy due to polarization effects, and then the parameter of the receiver antenna is not equal to the signal parameter [8].

Shannon-Hartley’s channel capacity theorem is applied to provide the upper bound of the data rate given a certain bandwidth and signal to noise ratio (SNR). However, the cross-polarization discrimination (XPD) of the radio wave is not considered to resolve the capacity problem in the previous investigations. For a radio wave transmitted with a given polarization, the ratio of the power received with the expected polarization to the power received with the orthogonal polarization is called cross-polarization discrimination.

I Mathematical model of the obtained polarization-orthogonal signal for MIMO technology

MIMO technology has attracted attention in wireless communications because it offers significant increases in data throughput and link range without additional bandwidth or transmits power. It achieves this by higher spectral efficiency (more bits per second per hertz of bandwidth) and link reliability or diversity (reduced fading). The signal on the receiving party is recorded as follows:

$$X = H \cdot S + Z \,, \tag{1}$$

where S – matrix of transmitted signals; Z – matrix of a self-noise of the receiving elements of the antenna; X – matrix of the received signals; H – transformer matrix of the signals.

Most the simple and widespread matrix H is the Allamouti matrix.

The electric field vector near the transmitting antenna can be represented as a polarization vector.

$$\vec{\dot{E}}_{tr}(t) = H_\alpha^{T*} \cdot H_\beta^T \cdot \left(S_1(t) \quad 0\right)^T + H_\alpha^{T*} \cdot H_\beta^T \cdot \left(0 \quad S_2(t)\right)^T, \tag{2}$$

where

$H_\alpha = \begin{pmatrix} \cos(\alpha) & -j\sin(\alpha) \\ -j\sin(\alpha) & \cos(\alpha) \end{pmatrix}$ – Matrix ellipticity at $\alpha = -45^0 ... +45^0$;

$H_\beta = \begin{pmatrix} \cos(\beta) & -\sin(\beta) \\ \sin(\beta) & \cos(\beta) \end{pmatrix}$ – Matrix orientation at $\beta = -90^0 ... +90^0$, $\alpha = \alpha_1; \alpha_2$ and $\beta = \beta_1; \beta_2$ ellipticity and orientation angles of the first and second transmitting antenna respectively.

The vector of the received signal on the receiving antenna is displayed as

$$\begin{aligned} \vec{\dot{E}}_r(t) &= \vec{\dot{E}}_{tr}(t - \iota_0) \cdot \dot{K}_{r0}(t) + \\ &+ \sum_{i=1}^{n} \dot{R}_i(t - \iota_i) \cdot \dot{K}_{ri}(t - \iota_i) \cdot \vec{\dot{E}}_{tr}(t - \iota_i) \end{aligned}, \tag{3}$$

where n – the total number of multipath propagation; $\dot{K}_{r0}(t)$, $\dot{K}_{ri}(t-\iota_i)$ – attenuation factors of direct and multipath radio waves; ι_0 – factor of delay line and multipath radio; $\dot{R}_i(t-\iota_i)$ – coefficient matrix of reflections.

Polarization parameters describe the receiving antennas with a polarization vector of each radiator in certain corners of the ellipticity and orientation angles. For the first example, we have

$$\vec{p}_{a1} = H_{\alpha 1}^{T*} \cdot H_{\beta 1}^T \cdot \vec{p}_1^{\,0}, \tag{4}$$

where

$\alpha_1 = \alpha_r = 0 \pm \Delta\alpha_{r1} = arctg\left(\frac{E_{cross\_r1}}{E_{main\_r1}}\right)$ – ellipticity angle; $\beta_1 = \beta_{r_1} = 90^0 \pm \Delta\beta_{r1}$ - orientations angle; E_{cross_r1} – cross-polarization component of the field (horizontal); E_{main_r1} – main component of the field (vertical); $\Delta\alpha_{r1}$ – ellipticity angle, determines the final denouement for real polarization antenna; $\Delta\beta_{r1}$ – non-vertical angle, the errors of installation; $\vec{p}_1^{\,0} = (1 \quad 0)^T$ – single polarization unit vector first radiator first antenna.

The signal at the output of each receiving antenna in the form

$$\dot{U}_r(t) = \vec{\dot{p}}_a^{T*} \cdot \vec{\dot{E}}_r(t) \cdot K_a + \dot{U}_n(t) = \dot{U}_s(t) + \dot{U}_n(t), \tag{5}$$

where K_a - coefficient losses and transformative capacity of the receiving antenna); $\dot{U}_n(t)$ – thermal noise of the receiver channel.

The signals from the output of the first channel of the first orthogonal polarization antenna in the form

$$\vec{\dot{z}}_{1\kappa} = \left(\dot{z}_{111} \quad \dot{z}_{121}\right)^T. \tag{6}$$

At the output of the second channel first orthogonal polarization antennas have

$$\vec{\dot{z}}_{2\kappa} = \left(\dot{z}_{211} \quad \dot{z}_{221}\right)^T. \tag{7}$$

The signal of the third and fourth channels second orthogonal polarization antenna will be correspondingly

$$\vec{\dot{z}}_{3\kappa} = \left(\dot{z}_{112} \quad \dot{z}_{122}\right)^T, \tag{8}$$

$$\vec{\dot{z}}_{4\kappa} = (\dot{z}_{212} \quad \dot{z}_{222})^T \,. \tag{9}$$

The resulting complex polarization vector signal at the output of multi-channel receiver will show in the form of components of the vectors

$$\vec{\dot{z}}_{s\_out} = \left(\vec{\dot{z}}_{1\kappa}^T \quad \vec{\dot{z}}_{2\kappa}^T \quad \vec{\dot{z}}_{3\kappa}^T \quad \vec{\dot{z}}_{4\kappa}^T\right)^T . \tag{10}$$

And in general form

$$\vec{\dot{z}}_{s\_out} = (\dot{z}_{111} \quad \dot{z}_{121} \quad \dot{z}_{211} \quad \dot{z}_{131} \quad \dot{z}_{112} \quad \dot{z}_{122} \quad \dot{z}_{212} \quad \dot{z}_{222})^T . \tag{11}$$

II The essence of the method adaptation of polarization-orthogonal signals

Resulting signal can be represented by dimensional density function ($n = 8$) with mean zero, which we consider approaching the normal law

$$P(\vec{\dot{z}}_{s\_out}) = \left((2\pi)^r \left|\dot{M}\right|\right)^{-\frac{1}{2}} \exp\left\{-\frac{1}{2}(\vec{\dot{z}}_{s\_out})^{T*} \dot{M}^{-1} (\vec{\dot{z}}_{s\_out})\right\}, \tag{12}$$

where $\dot{M}^{-1}$ – the inverse covariance matrix (CM).

CM replace its current assessment, we receive the results of a vector signal reception

$$\dot{M} \approx \dot{M}_o(t) = \frac{1}{k-1} \sum_{i=1}^{k} \vec{\dot{z}}_{is\_out}(t_i - T_0) \cdot \vec{\dot{z}}_{is\_out}^{T*}(t_i - T_0) \,. \tag{13}$$

Moreover, the value - should be sufficient in terms of estimation errors and stationary.

On the other hand, the estimate corresponds to a number of CM averaged readings, and thus a period of time averaging T_0, which is a value that depends on the correlation time signal τ_{s_corr} considering the change of polarization parameters. Note that the expression represents an adaptation to the current changes in the polarization signal $T_0 << \tau_{s\_corr}$.

In reality, CM is ill-conditioned, and hence the expression will be incorrect. Therefore, it is appropriate to transfer the polarization vector of the signal to the vector of its independent principal components. To do this, we note that the CM is Hermitian, and hence positive definite. Therefore, it belongs to a class of diagonalizable matrices. We have

$$\dot{M} = \vec{\dot{B}} \cdot \Lambda \cdot \vec{\dot{B}}^{T*}, \tag{14}$$

where $\dot{B} = \left(\vec{\dot{b}}_1 \quad \vec{\dot{b}}_2 \quad \vec{\dot{b}}_3 \quad \vec{\dot{b}}_4 \quad \vec{\dot{b}}_5 \quad \vec{\dot{b}}_6 \quad \vec{\dot{b}}_7 \quad \vec{\dot{b}}_8\right)^T$ – eigenvector matrix;

$\Lambda = diag(\lambda_1 \quad \lambda_2 \quad \lambda_3 \quad \lambda_4 \quad \lambda_5 \quad \lambda_6 \quad \lambda_7 \quad \lambda_8)$ – matrix of eigenvalues or spectrum of CM, and, $\lambda_1 \geq \lambda_8$.

Therefore, the vector of the principal components found as

$$\vec{\dot{z}}_{s\_out_r}(t_i) = \dot{B}^{T*} \cdot \vec{\dot{z}}_{s\_out} . \tag{15}$$

Now the probability density can be r - dimensional $(r \leq n)$ density distribution with mean zero

$$P(\vec{\dot{z}}_{s\_out_r}) = \left((2\pi)^r \left|\dot{M}_r\right|\right)^{-\frac{1}{2}} \exp\left\{-\frac{1}{2}(\vec{\dot{z}}_{s\_out_r})^{T*} \dot{M}_r^{-1} (\vec{\dot{z}}_{s\_out_r})\right\}. \tag{16}$$

Note that the true rank of CM signals, excluding the effect of noise and the degree of polarization is already known and is equal to two, as the flow of information $S(t)$ the encoder transmitter has been divided into two orthogonal and thus independent sub streams $S(t) = (S_1(t) \quad S_2(t))^T$. Therefore, the use of principal component will find the transforming matrix to highlight the components of the information flow in the form

$$S(t) \Rightarrow \begin{pmatrix} S_1(t) \\ S_2(t) \end{pmatrix} = \vec{z}_{s\_out_r}(t_i) = \begin{pmatrix} \vec{b}_1 & \vec{b}_2 \end{pmatrix}^{T*} \cdot \vec{z}_{s\_out}(t) \cdot \qquad (17)$$

III Modelling Results

For comparison, we define the capacity of channels and the probability of error. Encoding - a simple binary phase. The possibility of errors was evaluated by the statistical method using the developed model and the functioning of the program channel MIMO antennas with orthogonal polarization and polarization with the distortion in the emission, distribution and reception.

Depends on BR to SNR at QPSK and polarization loss 3dB and cross-polarization discrimination XPD=20dB are shown in Figure 1. These graphs are solved by formula

$$C = F \cdot \log_2(1 + \frac{P_s}{P_n}), \qquad (18)$$

where C – Bit Rate; F – band of frequency; P_s –power of signal; P_n – power of noise.

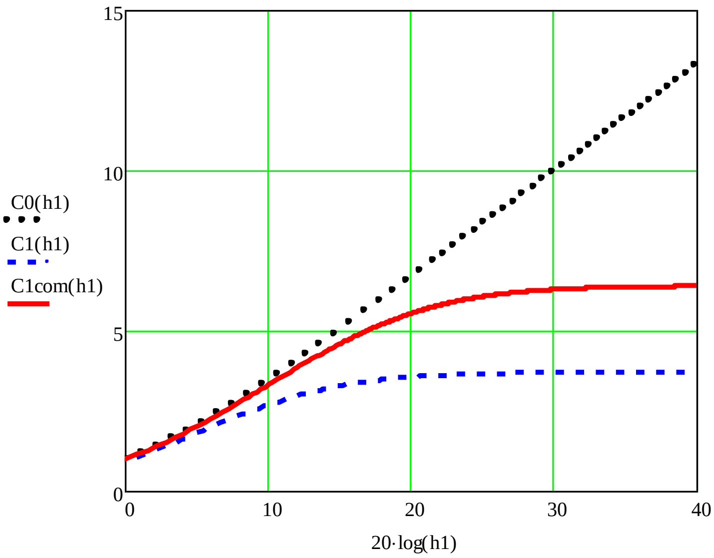

Fig. 1 Channel capacity of SISO.

The number of simulated bits of information - 10^6, number of tests - 25.

Note that with the increase of the signal - noise (SNR) throughput increases. If for a signal - noise ratio of 10 dB throughput in ideal conditions up to the amount of 3.8 Mb/s, in the real media, this value drops to 2.7 Mb/s. Application of the method of compensation of polarization distortion can increase the capacity up to 3.6 Mb/s.

With respect to the signal - noise ratio of 20 dB throughput under ideal conditions has already reached the amount of 6.8 Mb/s, in real conditions - 3.2Mb/s, and the application of the proposed method makes it possible to increase the capacity from 3.2 Mb/s to 5.9Mb/s. A further increase in the signal - noise does not lead to a significant increase in capacity due to the impact of decoupling on the polarization of the antenna orthogonal polarizations. This throughput is committed to the value of 6.2 Mb/s.

It also shows the Bit Error Rate (BER) of this channel in accordance with the formula for calculation of analytical

$$P_{BER} = 1 - F\left(\sqrt{k \cdot h^2 \cdot \frac{1 + m \cdot (2\cos^2\delta - 1)}{2}}\right), \tag{19}$$

where k – coefficient associated with the type of modulation; $F(x)$ - Laplace function.

The upper and lower limits of the confidence intervals with 0.95 reliability shown by the dash - dotted line on figure 2. Statistical modelling results are in accordance (program in appendix) with the Monte Carlo method and evaluation of the likelihood of errors shows the corresponding characters.

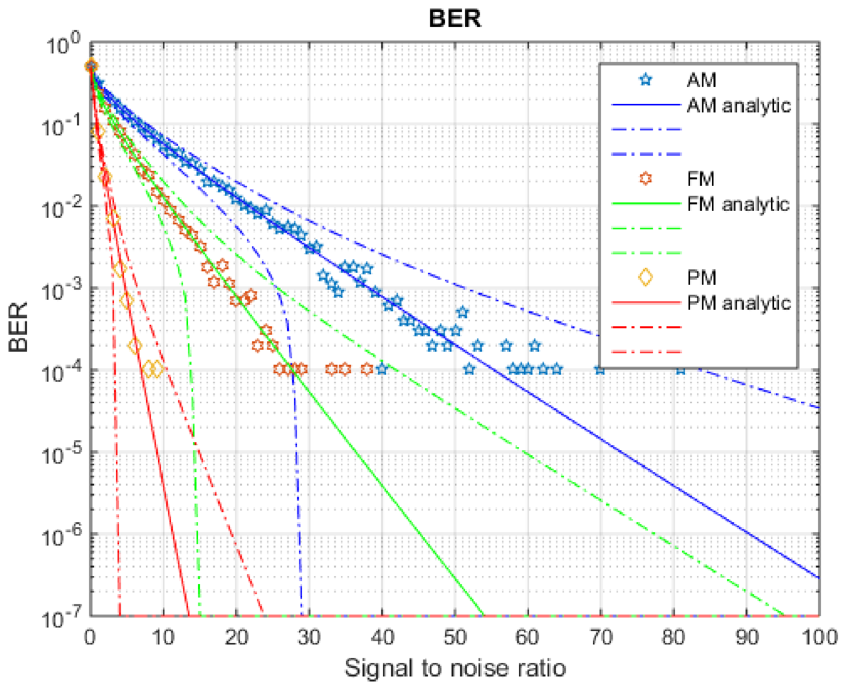

Fig. 2 – BER of channels at AM, FM and PM

The simulation results of incoherent reception at a different modulation method and Rayleigh scattering multipath propagation is shown in Fig. 3.

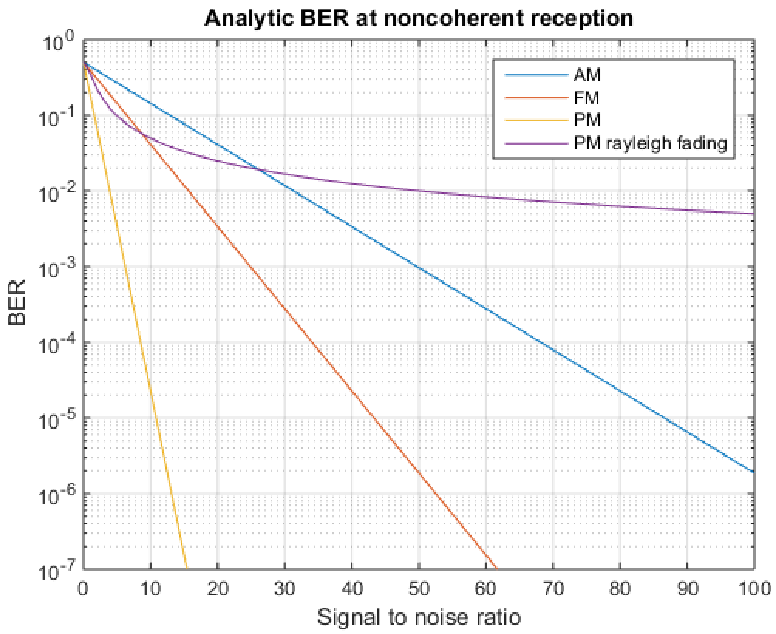

Fig. 3 – BER of channels at simulation incoherent reception

Note that if in ideal conditions, the probability of error is close to the value of 0.00001, in the real will be a worse - 0.008, and the proposed method will improve the probability of error to 0.0006 (Fig. 4).

Results of the study indicate the possibility of increasing the capacity at a lower bit error rate due to develop proposals that is practical significance. A further area of research is the development of requirements to limit instabilities specifications processing devices, to parameters and different channels different phase's polarization channels with orthogonal polarization space-time coding.

So, real antennae in MIMO technology can be represent like two input (top) and one output (bottom) antennae and this antennae can use at orthogonal polarization for better signal to noise ratio (SNR). Results of research the affectivities of the increasing capacity method are next: if in ideal conditions, the probability of error is close to the value of 0.00001, in the real will be a worse - 0.008, and the proposed method will improve the probability of error to 0.0006.

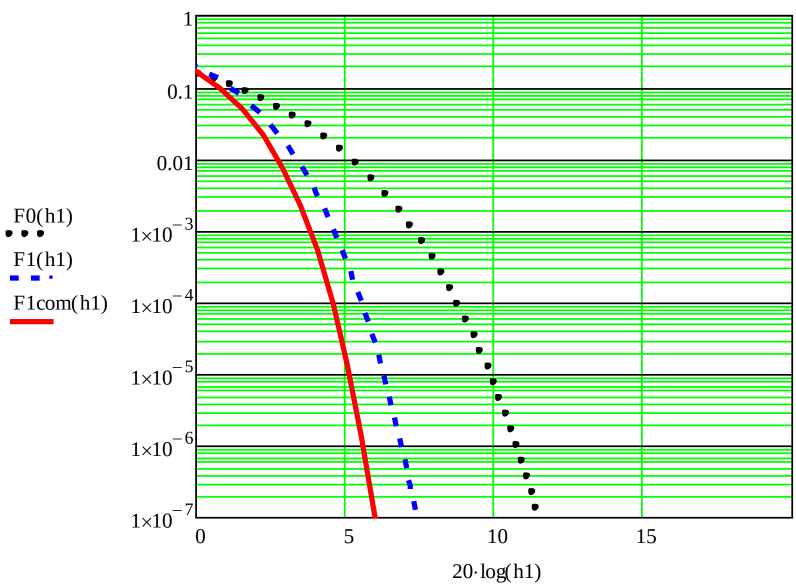

Fig. 4 – BER in ideal conditions, actual and proposed method of compensation

If for a signal - noise ratio of 10 dB throughput in ideal conditions up to the amount of 3.8 Mb/s, in the real media, this value drops to 2.7 Mb/s. Application of the method of compensation of polarization distortion can increase the capacity up to 3.6 Mb/s.

With respect to the signal - noise ratio of 20 dB throughput under ideal conditions has already reached the amount of 6.8 Mb/s, in real conditions - 3.2Mb/s, and the application of the proposed method makes it possible to increase the capacity from 3.2 Mb/s to 5.9Mb/s. A further increase in the signal - noise does not lead to a significant increase in capacity due to the impact of decoupling on the polarization of the antenna orthogonal polarizations. This throughput is committed to the value of 6.2 Mb/s.

Conclusion

Thus, the results of the study of the possibility of adapting the parameters of polarization-orthogonal signals indicate the possibility of improving the quality of communication channels.

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