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Extended Golden Code for Digital Transmission Channels through Low Voltage Three Phase Power Lines

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***Abstract*— In this paper the performance of an extended golden code for transmission channels through low voltage three-phase power lines is analyzed and determined. According to the results obtained, the bit error probability is reduced in the order of magnitude of at least 1x10^{-3} only when the space-time technique is used.**

***Index Terms*— Golden code; transmission channels for low voltage three phase power line.**

I. INTRODUCTION

This paper analyzes and determines the performance of an extended golden code for digital data transmission channel, set up with low voltage three-phase power lines.

A complex space-time code for four full diversity antennas is given [1]. A golden code for space-time of two by two is constructed [2]. The generator array for the code has a determinant that does not vanish. A basic introduction about the golden code is provided and we discuss how to use the code in a practical concatenation for a coding scheme [3]. A golden code decoder with low implementation complexity and maximum likelihood decoding is given [4]. A family of full diversity for rotated constellations based on algebraic number theory in Z^n is provided. [5]. The golden space-time combination with Trellis codification is provided for a Rayleigh fading channel and a two inputs/outputs MIMO channel [6]. A basic introduction about golden codes is provided and we discuss how to use the golden code for MIMO systems [7]. A new pre-processing to decode by using algebraic reduction is introduced, which exploits the multiplicative structure of the code. Also the simulation results for golden codes are shown [8].

All previous work is lead at wireless channels, which has a fast Rayleigh fading and Gaussian white noise. Furthermore, there are no references for low voltage three-phase power line channels.

References [9]-[10], the low voltage power line channel has five different types of noise: Background white noise, narrow band noise, impulsive periodic-asynchronous noise with the network frequency, impulsive periodic-synchronous noise with the network frequency and asynchronous impulsive noise.

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Middleton in 1977 presented a model of impulsive noise, consisting of the sum of white noise plus impulse noise. According to the noise bandwidth, he classified it into three general classes: class A, class B and class C, [11]-[12].

We consider that the noise in the low voltage power lines consists of background noise and impulsive noise. As the background noise is stationary and behaves as additive, white Gaussian noise, is modeled as a Gaussian process, and the impulsive noise is modeled as a Poisson process. Therefore, the probability density function for noise in the low voltage power lines (1), references [13]-[14]:

$$p_N(n) = (1-\varepsilon)\ \aleph(0,\sigma^2) + \varepsilon\,\aleph(0,k\sigma^2) \qquad (1)$$

Where:

ε : Number of occurrence of impulsive noise.

$\aleph(0,\sigma^2)$: Gaussian distribution with zero mean value and variance σ^2 representing the background noise.

$\aleph(0,k\sigma^2)$: Impulsive noise component, with Gaussian distribution with a variance k times the background noise.

This paper proposes to extend the golden code of an array of two by two to another of four by four because it shows that this code has full diversity and codes gain in fast fading Rayleigh channels [2]. In Chile the medium voltage power line has three lines and a neutral.

The organization of this paper is as follows: In Section II the extended gold code is built and the performance of the transmission/reception system with the bit error rate (BER) parameters versus signal to noise ratio (SNR) is obtained. In Section III, the results obtained are shown in graphs and then these results are analyzed. In Section IV, work conclusions are given.

II. ANALYSIS OF THE PROPOSED TRANSMISSION/RECEPTION SYSTEM

The low voltage power line channel has the same features as a wireless channel with fast fading Rayleigh channel [14]. As the structure of the low voltage network and the propagation signal differs from the coupled lines; numerous reflections are caused by the attachment of plugs. Besides, the series connection of cables with different characteristic impedances and the propagation signal is not "line of sight" between transmitter and receiver. Furthermore, the echoes and the result of all this is a multipath propagation signal with a fast fading must be considered.

To apply the space-time technique it is necessary to have diversity, both in the transmitter and the receiver. For the MIMO channel (multiple input and multiple output), namely, using multiple transmit antennas and multiple receive antennas, where there should be no correlation between them. To achieve this, there should be at least a separation between the antennas half wavelength.

To emulate the MIMO system in low voltage power lines, the three-phase electrical system in Chile is considered, which has three 380 Volt lines plus the neutral, with a frequency of 50 Hz. The equivalent MIMO channel has four transmit antennas and four receiving antennas. The separation between three-phase cables allows inferring that no correlation exists between them.

The transmission system consists of the low voltage three-phase electrical systems and the following differences from the wireless channel should be considered: In the space-time wireless channel with *n* transmit antennas and *m* receiving antennas, the signal received in the *j* antenna (*j* = 1, 2, ... *m*), at any time *t* is the combination of the signal emitted by the *n* transmitting antennas, which is not the case for the three-phase system, because each phase is isolated from one another, thus isolating the path of the transmitted signal. This gives a natural decoupling between any of the three remaining signals corresponding to different transmitted symbols. The signal received is (2).

$$\sum_{i=1}^{4} y_i(t) = \sum_{j=1}^{4} h_{i,j}(t)s_j(t) + n_j(t) \quad (2)$$

Where:

$y_i(t)$: Signal received by the line *i*, at time *t*.

$h_{i,j}(t)$: Signal fading at time *t*, due to the path *i*.

$n_j(t)$: Low voltage power line noise at time *t*, due to the route *i*.

The extended golden code is discussed as follows: If *n* is not a quadratic integer, then $Z(\sqrt{n})$ is an integral domain, therefore, $Z(\sqrt{n})$ is a subset of the field $Q(\sqrt{n})$, called quadratic domain in $Q(\sqrt{n})$.

The quadratic norm $N : Q(\sqrt{n}) \to Q$ is defined as (3):

$$N(a+b\sqrt{n}) = (a+b\sqrt{n})(a-b\sqrt{n}) = a^2 - nb^2 \in Q \quad (3)$$

The field of quadratic extension $Q(i)$ is considered, which is a set of (4):

$$L = \{x = a + b\sqrt{d} \quad a, b \in Q(i)\} \quad (4)$$

Denoted as:

$$L = \frac{Q(i, \sqrt{d})}{Q(i)} \quad (5)$$

Where:

d: Positive and quadratic integer.

As: $Q(i) \cap Q(\sqrt{d}) = Q$

The Galois group is given by (6):

$$\sigma : \sqrt{d} \to -\sqrt{d} \quad (6)$$

Let O_L the ring of integers of L and $B = \{1, v\}$ is denoted as the base $Z(i)$. A subset of L is given by (7):

$$O_L = \{x = a + bv \quad con\ a, b \in Z(i)\} \quad (7)$$

In the case of golden codes, it is given (8):

$$L = \frac{Q(i, \sqrt{5})}{Q(i)} \quad (8)$$

Where:

v: Number of gold (9).

$$v = \frac{1+\sqrt{5}}{2} \quad (9)$$

The golden code is constructed using a particular family of algebra division which is called cyclic division algebra. It is constructed from a quadratic extension of the base field $Q(i)$, where $i^2 = -1$. The base field $Q(i)$ also gives the determinant characteristic that does not fade, which is a property of golden codes.

To ensure a good performance of the code, it must have complete diversity. For this purpose, it must be met (10):

$$\det(X_i - X_j) \neq 0 \quad X_i \neq X_j \in C \quad (10)$$

Where:

det: Determinant.

C: Set of code words.

As golden codes are linear and constructed with cyclic algebra [16], diversity is simplified to (11):

$$\det(X) \neq 0 \quad 0 \notin C \quad (11)$$

In order to obtain coding gain, it should be found the minimum determinant (12):

$$\delta_{\min}(C) = Min_{x \neq 0} |\det(X)|^2 \quad (12)$$

The proof is in [16]. The golden code has the shape of (13):

$$\begin{bmatrix} s_1 + s_2\theta & s_3 + s_4\theta \\ i(s_3 + s_4\hat{\theta}) & s_1 + s_2\hat{\theta} \end{bmatrix} \quad (13)$$

Where:

$s_1, s_2, s_3\ y\ s_4$: Constellation symbols.

The value de θ and $\hat{\theta}$ is [14] and [15]:

$$\theta = \frac{1+\sqrt{5}}{2} = 1.618 \quad (14)$$

$$\hat{\theta} = \frac{1-\sqrt{5}}{2} = -0.6118 \quad (15)$$

The word golden code to be independent of the size of the constellation, has the following shape (16):

$$X = \frac{1}{\sqrt{5}} \begin{bmatrix} \alpha(s_1 + s_2\theta) & \alpha(s_3 + s_4\theta) \\ i\hat{\alpha}(s_3 + s_4\hat{\theta}) & \hat{\alpha}(s_1 + s_2\hat{\theta}) \end{bmatrix} \quad (16)$$

Where:

$s_1, s_2, s_3\ y\ s_4$: Constellation symbols.

$\theta = 1.618$

$\hat{\theta} = -0.6118$.

The α (17) and $\hat{\alpha}$ (18):

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$$\alpha = 1 + i - i\theta = 1 + i2.618 \qquad (17)$$

$$\hat{\alpha} = 1 + i - i\hat{\theta} = 1 + i1.618 \qquad (18)$$

It has:

$$\alpha\hat{\alpha} = 2 + i \qquad (19)$$

It is determined the minimum determinant from (16) is (20):

$$\det(X) = \frac{2+i}{5}\left[(s_1 + s_2\theta)(s_1 + s_2\hat{\theta}) - i(s_3 + s_4\theta)(s_3 + s_4\hat{\theta})\right] \qquad (20)$$

Manipulate (20) is obtained (21):

$$\det(X) = \frac{1}{2-i}\left[(s_1^2 + s_1 s_2 - s_2^2) - i(s_3^2 + s_3 s_4 - s_4^2)\right] \qquad (21)$$

$\left[(s_1^2 + s_1 s_2 - s_2^2) - i(s_3^2 + s_3 s_4 - s_4^2)\right]$ is at least 1, therefore δ_{min} is given (22):

$$\delta_{\min}(C_\infty) = Min_{X \neq 0}\left[\det(X)\right]^2 = \left(\frac{1}{2-i}\right)\left(\frac{1}{2+i}\right) = \frac{1}{5} \qquad (22)$$

It is made the golden code length for a channel with low voltage three phase power lines, but in this case the neutral address three phase power lines, but in this case neutral addresses as another digital data transmission channel, leaving a array of four by four (24).

$$\begin{bmatrix} \alpha(s_1+s_2\theta) & \alpha(s_3+s_4\theta) & \alpha(s_5+s_6\theta) & \alpha(s_7+s_8\theta) \\ i\hat{\alpha}(s_3+s_4\hat{\theta}) & \hat{\alpha}(s_1+s_2\hat{\theta}) & i\hat{\alpha}(s_7+s_8\hat{\theta}) & \hat{\alpha}(s_5+s_6\hat{\theta}) \\ \alpha(s_9+s_{10}\theta) & \alpha(s_{11}+s_{12}\theta) & \alpha(s_{13}+s_{14}\theta) & \alpha(s_{15}+s_{16}\theta) \\ i\hat{\alpha}(s_{11}+s_{12}\hat{\theta}) & \hat{\alpha}(s_9+s_{10}\hat{\theta}) & i\hat{\alpha}(s_{15}+s_{16}\hat{\theta}) & \hat{\alpha}(s_{13}+s_{14}\hat{\theta}) \end{bmatrix} \qquad (23)$$

Where:

$s_1, s_2, \ldots\ldots, s_{15}\ y\ s_{16}$: Constellation symbols.

$\theta = 1.618$

$\hat{\theta} = -0.6118$

$\alpha = 1 + i2.618$

$\hat{\alpha} = 1 + i1.618$

$i = \sqrt{-1}$

As the three-phase power lines are isolated from one another, signals are only received from the respective line and do not coupling signals from other lines. That is why it is applicable the golden code length of the two by two dimensional array to the four by four array. In this model of four three-phase power lines (three lines plus neutral), the received signal (low voltage electrical line R) is given by (24), (25), (26) and (27):

$$y_{11} = h_{11}(\alpha s_1 + \alpha s_2\theta) \qquad (24)$$

$$y_{12} = h_{12}(i\hat{\alpha} s_3 + i\hat{\alpha} s_4\hat{\theta}) \qquad (25)$$

$$y_{13} = h_{13}(\alpha s_9 + \alpha s_{10}\theta) \qquad (26)$$

$$y_{14} = h_{14}(i\hat{\alpha} s_{11} + i\hat{\alpha} s_{12}\hat{\theta}) \qquad (27)$$

The low voltage electrical line S receives the signals (28), (29), (30) and (31):

$$y_{21} = h_{21}(\alpha s_3 + \alpha s_4\theta) \qquad (28)$$

$$y_{22} = h_{22}(i\hat{\alpha} s_1 + i\hat{\alpha} s_2\hat{\theta}) \qquad (29)$$

$$y_{23} = h_{23}(\alpha s_{11} + \alpha s_{12}\theta) \qquad (30)$$

$$y_{24} = h_{24}(i\hat{\alpha} s_9 + i\hat{\alpha} s_{10}\hat{\theta}) \qquad (31)$$

The low voltage electrical line T receives the signals (32), (33), (34) and (35):

$$y_{31} = h_{31}(\alpha s_5 + \alpha s_6\theta) \qquad (32)$$

$$y_{32} = h_{32}(i\hat{\alpha} s_7 + i\hat{\alpha} s_8\hat{\theta}) \qquad (33)$$

$$y_{33} = h_{33}(\alpha s_{13} + \alpha s_{14}\theta) \qquad (34)$$

$$y_{34} = h_{34}(i\hat{\alpha} s_{15} + i\hat{\alpha} s_{16}\hat{\theta}) \qquad (35)$$

The low voltage electrical line N (neutral) receives the signals (36), (37), (38) and (39):

$$y_{41} = h_{41}(\alpha s_7 + \alpha s_8\theta) \qquad (36)$$

$$y_{42} = h_{42}(i\hat{\alpha} s_5 + i\hat{\alpha} s_6\hat{\theta}) \qquad (37)$$

$$y_{43} = h_{43}(\alpha s_{15} + \alpha s_{16}\theta) \qquad (38)$$

$$y_{44} = h_{44}(i\hat{\alpha} s_{13} + i\hat{\alpha} s_{14}\hat{\theta}) \qquad (39)$$

A maximum likelihood detector is used to detect the transmitted symbols, which makes an exhaustive search of all possible values of the transmitted symbols and decides in favor of the set of symbols that minimizes the Euclidean distance. To decrease the probability of error of the detector instead of detecting simultaneously the sixteen symbols, the process is carried out in groups of four symbols at a time, as follows (40) until (43):

$$D(s_1, s_2, s_3\ y\ s_4) = \left\{ \begin{array}{l} \left|y_{11} - h_{11}(\alpha s_1 + \alpha s_2\theta)\right|^2 \\ + \left|y_{22} - h_{22}(\hat{\alpha} s_1 + \hat{\alpha} s_2\hat{\theta})\right|^2 \\ + \left|y_{12} - h_{12}(i\hat{\alpha} s_3 + i\hat{\alpha} s_4\hat{\theta})\right|^2 \\ + \left|y_{21} - h_{21}(\alpha s_3 + \alpha s_4\theta)\right|^2 \end{array} \right\} \qquad (40)$$

$$D(s_5, s_6, s_7\ y\ s_8) = \left\{ \begin{array}{l} \left|y_{31} - h_{311}(\alpha s_5 + \alpha s_6\theta)\right|^2 \\ + \left|y_{42} - h_{42}(\hat{\alpha} s_5 + \hat{\alpha} s_6\hat{\theta})\right|^2 \\ + \left|y_{32} - h_{32}(i\hat{\alpha} s_7 + i\hat{\alpha} s_8\hat{\theta})\right|^2 \\ + \left|y_{41} - h_{41}(\alpha s_7 + \alpha s_8\theta)\right|^2 \end{array} \right\} \qquad (41)$$

$$D(s_9, s_{10}, s_{11}\ y\ s_{12}) = \left\{ \begin{array}{l} \left|y_{13} - h_{13}(\alpha s_9 + \alpha s_{10}\theta)\right|^2 \\ + \left|y_{24} - h_{24}(\hat{\alpha} s_9 + \hat{\alpha} s_{10}\hat{\theta})\right|^2 \\ + \left|y_{14} - h_{14}(i\hat{\alpha} s_{11} + i\hat{\alpha} s_{12}\hat{\theta})\right|^2 \\ + \left|y_{23} - h_{23}(\alpha s_{11} + \alpha s_{12}\theta)\right|^2 \end{array} \right\} \qquad (42)$$

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$$D(s_{13}, s_{14}, s_{15}\ y\ s_{16}) = \left\{ \begin{aligned} &\left| y_{33} - h_{33}(\alpha\, s_{13} + \alpha\, s_{14}\theta) \right|^2 \\ &+ \left| y_{44} - h_{44}(\hat{\alpha}\, s_{13} + \hat{\alpha}\, s_{14}\hat{\theta}) \right|^2 \\ &+ \left| y_{34} - h_{34}(i\hat{\alpha}\, s_{15} + i\hat{\alpha}\, s_{16}\hat{\theta}) \right|^2 \\ &+ \left| y_{43} - h_{43}(\alpha\, s_{15} + \alpha\, s_{16}\theta) \right|^2 \end{aligned} \right\} \qquad (43)$$

The two dimensional constellation used is given [14], which has a very good performance in noisy channel class A, because it has an optimal rotation angle.

The amplitude of impulse noise and background noise is modeled by a Gaussian distribution and is defined as index $A = \lambda\Gamma$

The Middleton class A probability density is write as (44) and (45):

$$p_M(n) = \sum_{m=0}^{\infty} e^{-A} \frac{A^m}{m!\, 2\pi\, \sigma_m^2} e^{-\frac{|n|^2}{2\sigma_m^2}} \qquad (44)$$

And σ_m^2 as (45):

$$\sigma_m^2 = \sigma^2 \frac{\frac{m}{A} + \Gamma}{1 + \Gamma} \qquad (45)$$

Where:

σ^2 : Total noise power (including power over the background noise plus power over impulsive noise).

$$\Gamma = \frac{\sigma_G^2}{\sigma_I^2} \qquad (46)$$

Where:

Γ : Impulsive noise power ratio.

σ_G^2 : Gaussian noise power.

σ_I^2 : Impulsive noise power.

To study the performance of the system proposed in scheme shown fig. 1, the parameters considered are the bit error rate versus signal noise ratio.

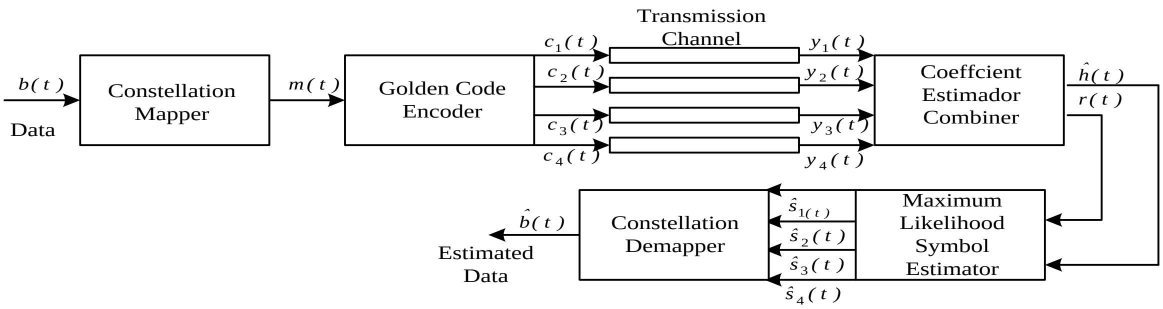

Fig. 1 shows the scheme to study the performance of the proposed system. The parameters considered are the bit error rate versus signal-to-noise ratio.

According to fig. 1, data to be transmitted $b(t)$ is obtained. These bits are converted into symbols of the circular, rectangular, and hexagonal of four and sixteen symbols constellation used in the transmission. Then, the golden code encoder converts the symbols into code words $c_i(t)$. The transmission channel adds noise and fast fading to the transmitted signal $y_i(t)$. At the receiver, there is the fading coefficient estimator $h_{ij}(t)$ and the combiner which builds golden codewords locally $r(t)$. Besides, the maximum likelihood symbol estimator determines the transmitted symbols and the constellation becomes demapper of symbols to bits.

III RESULTS AND DISCUSSION

A Results

In the low voltage three-phase power line channel, it is assumed that route gains h_{ij} are modeled as independent samples of complex Gaussian random variables with a variance 0.5 per real dimension. The transmission channel is assumed quasi-static; the routes gains are constant throughout the length of the frame p (number of rows of the transmission array) and vary from one frame to another. The class A noise samples are independent-identically-distributed (iid) complex random variables.

The parameters of the noise in the low voltage power line are: Impulsive index value $A = 0.01$ and the ratio of impulse noise $\Gamma = 0.001$. With these values the noise is highly impulsive.

Fig. 2 shows the contrast of the performance of extended golden code compared to the optimal space-time technique with four symbols constellations for three-phase power line channel and BER parameter versus SNR parameter.

Fig. 3 shows the comparison of the performance of extended golden code compared to the optimal space-time technique with sixteen symbols constellations for three-phase power line channel and BER parameter versus SNR parameter.

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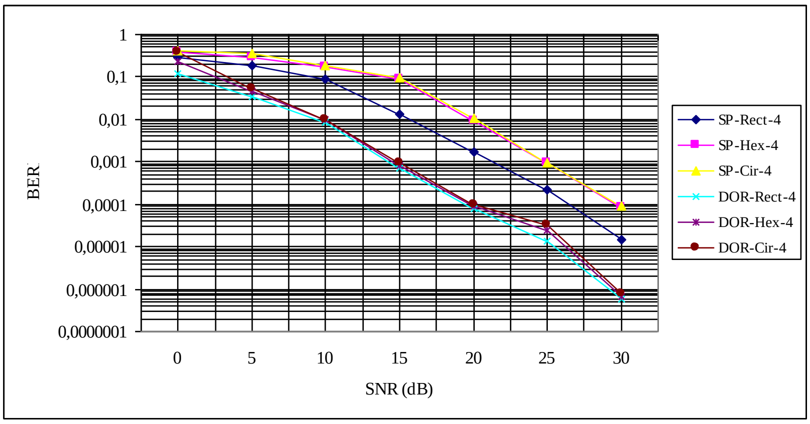

Fig. 2 shows the comparison between the performance of extended golden code and the optimal space-time technique with four symbols constellations for three phase power line channel with BER parameter versus SNR parameter.

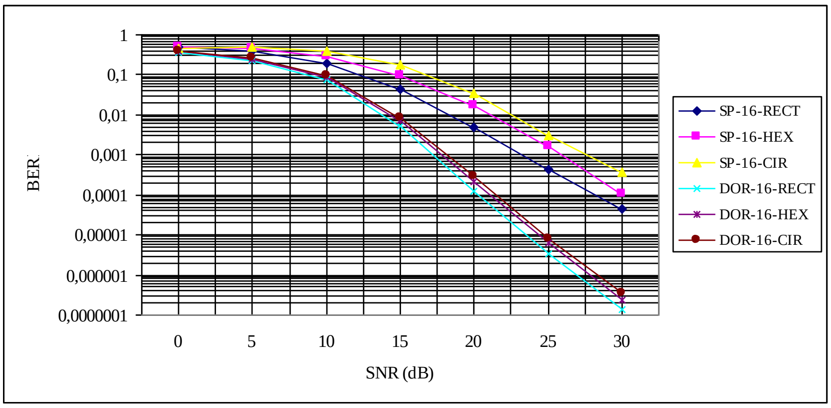

Fig. 3 shows the comparison of the performance of gold code extended compared to the optimal space-time technique with sixteen symbols constellations for three phase power line channel, with the BER versus SNR parameter.

B Discussion

From fig. 3 and 4, we infer that the extended code has better performance than its optimal space-time counterpart, for four and sixteen symbols constellations. Besides, it is proved that the performance is independent of the constellation form; this is because the extended code performance of the three constellations (rectangular, circular and hexagonal) does not get much difference together.

In the case of four symbols constellations, the extended code error decreases the probability by at least in an order of magnitude of 1×10^{-3} for a SNR of 15 dB, compared to the best optimal space-time technical performance. The same applies to the sixteen symbols constellation.

IV. Conclusion

According to the results obtained, we can infer that the extension of the golden code greatly improves the reliability of the proposed system for a low voltage three-phase power line channel.

The BER is reduced from 10^{-2} to 10^{-3} to SNR of 15 dB. A gain of 7 dB is obtained with extended golden code. Besides, the transmission speed (sixteen symbols) increases compared to optimal space-time (four symbols).

Future work will be focused on improving the symbols detector.

REFERENCES

[1] O. Tirkkonen and A. Hottinen, Complex Space-Time Block Codes for Four Tx Antennas, pp. 1005-1009, 2000.

[2] J. Belfiore, G. Rekaya and E. Viterbo, The Golden Code: A 2x2 Full-Rate Space-Time Code With Nonvanishing Determinants, IEEE Transactions on Information Theory, Vol. 51, Nº 4, pp, 1432-1436, April 2005.

[3] www.ita.ucsd.edu/workshop/07/files/.../paper_376.pdf

[4] M. Sinnokrot, J. Barry, Fast Maximum-Likehood Decoding of the Golden, Vol. 9, Nº 1, pp. 26-31, January 2010.

[5] E. Bayer-Fluckiger, F. Ogier and E. Viterbo, New Algebraic Constructions of Rotated Z^n Lattice Constellations for the Rayleigh Fading Channel, Vol. 50, Nº 4, pp. 702-714, April 2004.

[6] Y. Hong, E. Viterbo and J. Belfiore, Golden Space-Time Trellis Coded Modulation, International Symposium on Information Theory and its Applications, ISITA 2006, Seul Kores, October 29-November 1, pp. 848-853, 2006.

[7] http://ita.ucsd.edu/workshop/07/files/paper/paper_376.pdf

[8] G. Rekaya, B. Othman. L. Luzzi and J. Belfiore, Algebraic Reduction for the Golden Code, ICC`99 Proceedings of the 2009 IEEE International Conference on Communications, pp. 3234-3238.

[9] W. Fernández, M. Guzmán, R. Torres, "Analysis of the Performance of the Interleavers of Block, Golden and relative Golden in a of Low Voltage Power Line Channel", Ingeniare, Revista Chilena de Ingeniería, vol. 16, Nº 3, pp. 333-341, July-September 2008.

[10] W. Fernández, C. Garrido, H. Olivarez, "Analysis and Study of the Performance of the Irregular Low Density Parity Check Code in Low Voltage Powerline", Ingeniare, Revista Chilena de Ingeniería, vol. 17, Nº 1, pp. 108-119, January-April 2009.

[11] D. Middleton, Statistical Physical Models of Electromagnetic Interference ", IEEE Transactions Electromagnetic Compatibility, Vol. 19, Nº 3, pp. 106-127, August 1977.

[12] A. D. Spaulding and D. Middleton, Optimum Reception in an Impulsive Interference Environment, Part I: Coherent Detection, IEEE Transactions Communications, Vol. 25, Nº 9, pp. 910-922, September 1977.

[13] W. Fernández, P. Carrasco y L. García, Concatenación de Código LDPC Irregular de Bajo Umbral de Ruido y Constelaciones óptimas Bidimensionales, XX Congreso Asociación Chilena de Control Automático, ACCA- 2012, 12-16 de Noviembre 2012, Santiago-Chile.

[14] W. Fernández, J. Mahomar, Estudio del Desempeño de las Constelaciones Bi-Dimensionales Rectangular, Hexagonal y Circular con Rotaciones óptimas con Entrelazador Dorado para canal con ruido clase A, XX Congreso Asociación Chilena de Control Automático, ACCA- 2012, 12-16 de Noviembre,2012, Santiago-Chile.

[15] W. Fernández, Códigos Espacios Temporales con Diversidad Óptima y Velocidad Máxima para Canal de Línea Eléctrica Trifásica de Bajo Voltage, IEEE Latin America Transactions, Vol. 10, Nº 4, pp. 1901-1908, June 2012.

[16] F. Oggier, On the Optimality of the Golden Code, Proceedings of 2006, IEEE Information Theory Workshop, pp. 468-472, 2006.

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