DEVELOPMENT OF BLIND FRAME SYNCHRONIZATION FOR TRANSFER SYSTEM WITH DIFFERENTIAL SPACE-TIME BLOCK CODING

1. Introduction

This work is a continuation of research on the development of a transmission method with differential space-time block coding (DSTBC) implemented using the Multiple Input Multiple Output (MIMO) technology [1].

To implement the method of transmission from the DSTBC in the demodulator, it is necessary to provide phase synchronization of the reference carrier, as well as time synchronization of signal processing processes [2, 3]. The time synchronization task is divided into two: symbolic (clock) synchronization and frame (block) synchronization. These two types of time synchronization are completely different in purpose and implementation. The task of symbol synchronization is to synchronize the clocks of the demodulator with the input stream of demodulated channel symbols so that each input symbol is processed in an appropriate time interval. The task of synchronizing frames (blocks) is to split the sequence of characters arriving at the decoder into blocks corresponding to the blocks at the output of the encoder. If the breakdown is not carried out correctly, decoding operations will be incorrect and restoration of transmitted characters becomes impossible.

As for synchronization of the reference carrier and symbol synchronization, these types of synchronization in demodulators of digital modulation signals are solved by traditional methods [4, 5] and are not considered in this paper.

From literature it follows that in the vast majority of cases, frame synchronization is ensured by the use of pilot signals (sync words) (Reference Signal) [6, 7] – signals a priori known in the demodulator that have certain characteristics and properties. At their core, they are markers and are periodically embedded in the data stream to indicate the beginning of another new data block. It is obvious that the resources of the transmission system spent on the transmission of pilot signals are not used directly for transmitting user information, as a result of which the efficiency of using the time-frequency...
resource of the transmission system is degraded. The literature also presents, but to a lesser extent, the so-called "blind" signal processing methods that do not require the transmission of special pilot signals, but are based on the properties of the transmitted information signal, in particular, using its redundancy [6, 8]. These methods do not have the disadvantages created by the use of pilot signals, and are divided into methods for assessing the state of the communication channel, signal identification, and synchronization. Based on this, such methods are of practical interest. There are works [9, 10] that describe the methods of «blind» frame synchronization for orthogonal space-time block coding (STBC). It should be noted that these methods: — use the space-time redundancy of the transmitted signal (frames); — applicable for STBC orthogonal systems with one and two receiving antennas; — do not require knowledge of the state of the communication channel and the signal-to-noise ratio in the channel; — provide a low ability to detect the boundaries of frame intervals in the communication channel with Rayleigh fading at high signal-to-noise ratios, as the authors themselves declare.

It should also be noted that only these two blind frame synchronization methods for STBC orthogonal systems are described in the literature, and synchronization methods for STBC differential orthogonal systems are not described.

Based on the foregoing, in order to ensure frame synchronization during demodulation of the DSTBC signals, it is decided to develop an effective frame synchronization algorithm based on this coding method without using pilot signals, which is the goal of this work. Thus, the subject of this research is the methods and algorithms for frame synchronization used in multi-antenna radio communication systems (MIMO).

2. Methods of research

Below is the synchronization algorithm for the demodulator of the DSTBC signals [1] in the MIMO scheme and. Since each channel symbol is transmitted twice during the DSTBC, the signal matrix can serve as an example:

$$X_1 = \begin{bmatrix} x_1 & -x_1^* \\ x_2 & x_2^* \end{bmatrix}$$

where $x_1^*$ — complex conjugation of the symbol $x_1$, it follows that the demodulated signal has a space-time redundancy, and it is possible to find a way to synchronize the working signal.

Table 1 shows four consecutive frames transmitted over a communication channel. Here $x_i$ — the channel symbols of the L-PSK signal.

| Moment of time | $t$ | $t+1$ | $t+2$ | $t+3$ | $t+4$ | $t+5$ | $t+6$ | $t+7$ |
|---------------|-----|-------|-------|-------|-------|-------|-------|-------|
| Antenna No. 1 | $x_1$ | $-x_1^*$ | $x_3$ | $-x_3^*$ | $x_5$ | $-x_5^*$ | $x_7$ | $-x_7^*$ |
| Antenna No. 2 | $x_2$ | $x_2^*$ | $x_4$ | $x_4^*$ | $x_6$ | $x_6^*$ | $x_8$ | $x_8^*$ |
| Frame number  | frame 1 | frame 2 | frame 3 | frame 4 |

If it is necessary to demodulate the information transmitted by frame 3 —

$$X_3 = \begin{bmatrix} x_3 & -x_3^* \\ x_5 & x_5^* \end{bmatrix}$$

then frame 2

$$X_2 = \begin{bmatrix} x_2 & -x_2^* \\ x_4 & x_4^* \end{bmatrix}$$

is required, which will be the reference. This happens when the frame synchronization is correct. Having analyzed the Table 1, two immediate cases can be assumed in which frame synchronization is not set correctly.

In the first case, let’s have the following values of the reference and signal matrices:

$$X_{orr,1} = \begin{bmatrix} -x_2^* & x_3 \\ x_1 & x_4 \end{bmatrix}, \quad X_{orr,1} = \begin{bmatrix} x_2 & x_3 \\ -x_4 & -x_3 \end{bmatrix}$$

In the second case, respectively:

$$X_{orr,2} = \begin{bmatrix} x_2^* & x_3 \\ x_1 & x_4 \end{bmatrix}, \quad X_{orr,2} = \begin{bmatrix} -x_2 & x_3 \\ x_1 & x_4 \end{bmatrix}$$

Thus, let’s obtain three possible states, in one of which the frame synchronization is set correctly, and in the other two it is not true. Hypotheses on these conditions can be respectively arbitrarily called: «early», «right» and «late».

Let’s consider the demodulation of characters in the case of a hypothesis — «right». The samples of the signals received by the receiving antennas (frame 2 and frame 3), at the corresponding time points, can be written as:

$$\begin{bmatrix} y_1(t+2) \\ y_2(t+2) \\ y_1(t+3) \\ y_2(t+3) \end{bmatrix} = X_3^T \begin{bmatrix} h_{11} \\ h_{21} \\ h_{12} \\ h_{22} \end{bmatrix} + \begin{bmatrix} w_1(t+2) \\ w_2(t+2) \\ w_1(t+3) \\ w_2(t+3) \end{bmatrix} \rightarrow Y_3 = X_3^T H + W_3$$

(1)

$$\begin{bmatrix} y_1(t+4) \\ y_2(t+4) \\ y_1(t+5) \\ y_2(t+5) \end{bmatrix} = X_3^T \begin{bmatrix} h_{11} \\ h_{21} \\ h_{12} \\ h_{22} \end{bmatrix} + \begin{bmatrix} w_1(t+4) \\ w_2(t+4) \\ w_1(t+5) \\ w_2(t+5) \end{bmatrix} \rightarrow Y_3 = X_3^T H + W_3$$

(2)

where, for example, $y_1(t+2)$ — the count taken at the time $t+2$ (upper index) by the first antenna (lower index); $h_{mn}$ — complex transmission channel transmission coefficients from the $m$-th transmitting antenna to the $n$-th receiving antenna, which are uncorrelated complex Gaussian random variables at $h_{mn} \sim CN(0,1)$; $w_1(t)$ — complex coefficients of additive white Gaussian noise with $w_1(t) \sim CN(0, \sigma^2)$ and dispersion $\sigma^2$.

Let’s believe that the condition $T_0 \gg T_i$ is satisfied, where $T_0$ — the coherence time, and $T_i$ — the duration of the channel symbol — hence, the matrix of channel coefficients $H$ during $T_0$ is relatively constant [1]. In this case, the restored values of the differential coefficients transmitted by frame 3 are determined as:

$$w_1(t) \sim CN(0, \sigma^2)$$

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MIMO scheme, then formulas (1)–(3) respectively will take the following form:

\[
\begin{align*}
\mathbf{R}_{\text{true}} & = \begin{bmatrix} y_1^{(i+2)} y_1^{(i+2)} y_2^{(i+2)} y_2^{(i+2)} \\ y_1^{(i+2)} y_1^{(i+2)} y_2^{(i+2)} y_2^{(i+2)} \end{bmatrix} \\
\mathbf{R}_{\text{false}} & = \begin{bmatrix} y_1^{(i+2)} y_1^{(i+2)} y_2^{(i+2)} y_2^{(i+2)} \\ y_1^{(i+2)} y_1^{(i+2)} y_2^{(i+2)} y_2^{(i+2)} \end{bmatrix}
\end{align*}
\]

If to consider the 2×4 MIMO scheme, then formulas (1)–(3) respectively will take the following form:

\[
\begin{align*}
\begin{bmatrix} y_1^{(i+2)} y_1^{(i+2)} y_2^{(i+2)} y_2^{(i+2)} \\ y_1^{(i+2)} y_1^{(i+2)} y_2^{(i+2)} y_2^{(i+2)} \end{bmatrix} &= \mathbf{X}^*_{\text{true}} + \begin{bmatrix} w_1^{(i+2)} w_1^{(i+2)} w_1^{(i+2)} w_1^{(i+2)} \\ w_2^{(i+2)} w_2^{(i+2)} w_2^{(i+2)} w_2^{(i+2)} \end{bmatrix} \\
\begin{bmatrix} y_1^{(i+2)} y_1^{(i+2)} y_2^{(i+2)} y_2^{(i+2)} \\ y_1^{(i+2)} y_1^{(i+2)} y_2^{(i+2)} y_2^{(i+2)} \end{bmatrix} &= \mathbf{X}^*_{\text{false}} + \begin{bmatrix} w_1^{(i+2)} w_1^{(i+2)} w_1^{(i+2)} w_1^{(i+2)} \\ w_2^{(i+2)} w_2^{(i+2)} w_2^{(i+2)} w_2^{(i+2)} \end{bmatrix}
\end{align*}
\]

where \( \mathbf{H} = \begin{bmatrix} h_1 & h_2 & h_3 & h_4 \\ h_5 & h_6 & h_7 & h_8 \end{bmatrix} \) and

\[
\begin{align}
\mathbf{R}_{\text{false}} &= \sum_{i=1}^{N} \begin{bmatrix} y_1^{(i+2)} y_1^{(i+2)} y_2^{(i+2)} y_2^{(i+2)} \\ y_1^{(i+2)} y_1^{(i+2)} y_2^{(i+2)} y_2^{(i+2)} \end{bmatrix} + \begin{bmatrix} y_1^{(i+2)} y_1^{(i+2)} y_2^{(i+2)} y_2^{(i+2)} \\ y_1^{(i+2)} y_1^{(i+2)} y_2^{(i+2)} y_2^{(i+2)} \end{bmatrix}
\end{align}
\]

After restoring the differential coefficients, by assessing the maximum likelihood, the minimum distance between the possible values of the vectors \( \mathbf{R}_{\text{true}}, \mathbf{R}_{\text{false}} \) (from the set \( \mathbf{R}_{\text{all}} \) [1]) and the reconstructed vector \( \hat{\mathbf{R}}_{\text{true}}, \hat{\mathbf{R}}_{\text{false}} \) is determined:

\[
b_{\text{true}}^{(i)} = \arg \min_{j \neq \text{true}} \left( \| \mathbf{R}_{\text{true}} - \hat{\mathbf{R}}_{j} \|^2 + \| \mathbf{R}_{\text{false}} - \hat{\mathbf{R}}_{j} \|^2 \right)
\]
Fig. 1. Dependencies of $P_{e_{\text{sinch}}}$ on SNR for various amounts of $N$ at QPSK: $a$ – at $K=10$, $b$ – at $K=20$, $c$ – at $K=30$, $d$ – at $K=40$

Fig. 2. Dependence of $P_{e_{\text{sinch}}}$ on SNR at $K=10$, 20, 30, 40, 50, MIMO $2 \times 2$: $a$ – at BPSK, $b$ – at QPSK

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4) when analyzing the dependences of the probability of the exit from synchronism ($P_{\text{exit}}$) (Fig. 1, 2) and the probability of error of the received bits (BER) [1, Fig. 6] it is possible to conclude that the developed synchronization algorithm is more noise-resistant than the DSTBC method. Example: at QPSK, MIMO $2 \times 2$, $K = 10; 20; 30; 40$, $P_{\text{exit}}$ less than BER by 5; 7; 8.3 and 8.5 dB, respectively.

4. Conclusions

The blind frame synchronization algorithm proposed for this work for the DSTBC method [1] is the first consideration of the blind frame synchronization for STBC differential orthogonal systems. This algorithm has advantages over similar algorithms in the required number of frames to ensure synchronization and computational complexity, as well as being flexible for extensions. The simulation results confirm its ability to establish frame synchronization under the condition of a low signal-to-noise ratio in the system and the absence of the need for knowledge about the state of the communication channel.

References

1. Tokar, M. S. (2018). Differencialnii metod blokovogo kodirovaniia dlia primenenia v sistemakh MIMO. Sistemy sinkhronizacji, formirovaniiia i obrabotki signalov, 1, 147–159.
2. Meyr, H., Moeneclaey, M., Fechtel, S. (1998). Digital communication receivers, synchronization, channel estimation, and signal processing. John Wiley & Sons, Inc., 827. doi: http://doi.org/10.1002/0471200573
3. Rohde, U., Whitaker, J., Zain, H. (2017). Communications Receivers: Principles and Design. McGraw-Hill Education, 941.
4. Fomin, A. I. (2005). Sistemy cifrovii radiosviazi: bazovyie metody i kharakteristiki. Moscow: SAINS-PRESS, 80.
5. Blahut, R. E. (2010). Modern Theory: An Introduction to Telecommunications. Cambridge University Press, 515. doi: http://doi.org/10.1017/cbo9780511811401
6. Nasir, A. A., Durrani, S., Mehrpouyan, H., Blostein, S. D., Kennedy, R. A. (2016). Timing and carrier synchronization in wireless communication systems: a survey and classification of research in the last 5 years. EURASIP Journal on Wireless Communications and Networking, 2016 (1), 180–218. doi: http://doi.org/10.1186/s13638-016-0670-9
7. Mahmood, A., Ashraf, M. I., Gildmund, M., Torsner, J., Sachs, J. (2019). Time Synchronization in 5G Wireless Edge: Requirements and Solutions for Critical-MTC. IEEE Communications Magazine, 57 (12), 45–51. doi: http://doi.org/10.1109/mcom.001.1900379
8. Volkov, L. N., Nemirovskii, M. S., Shinakov, Iu. S. (2005). Sistemy cifrovii radiosviazi: bazovyie metody i kharakteristiki. Moscow: Eko-Trendz, 392.
9. Marcy, M., Dobre, O. A., Inkol, R. (2013). A Novel Blind Block Timing and Frequency Synchronization Algorithm for Alamouti STBC. IEEE Communications Letters, 17 (3), 569–572. doi: http://doi.org/10.1109/lcomm.2013.13.122518
10. Marcy, M., Dobre, O. A., Liao, B. (2014). Second-Order Statistics-Based Blind Synchronization Algorithm for Two Receive-Antenna Orthogonal STBC Systems. IEEE Communications Letters, 18 (7), 1115–1118. doi: http://doi.org/10.1109/lcomm.2014.2323245

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