Distributed Spatial Multiplexing in MIMO Systems

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Abstract—**Communication systems with a large number of transmitting and receiving antennae are an essential part of new communication standards. However, the utilization of optimal Maximum Likelihood (ML) receivers is computationally very expensive. Therefore, linear receivers are still widely used in practical systems. This paper discusses a signal construction algorithm for the MIMO channels, which provides additional gains from spatial diversity, even with linear receivers. Analytical considerations are confirmed by the results of the simulations. Moreover, the proposed transmission method can be used efficiently with the Turbo iterative processing, which provides additional energy gains.**

I. INTRODUCTION

One of the crucial directions in the development of wireless communication systems is the use of transmitters and receivers with Many Inputs and Many Outputs (MIMO). MIMO channels significantly expand the capabilities of communication systems. The implementation of these capabilities requires appropriate algorithms for processing the transmitted information on both the transmitting and receiving sides. Currently, many algorithms efficiently use the benefit of MIMO systems [1].

At the end of the 1990s, the V-BLAST (Vertical-Bell Laboratories Layered Space-Time) spatial multiplexing system was demonstrated. It achieved a very high spectral efficiency of 24 bit/s/Hz using 8 transmitting and 12 receiving antennas in an indoor scenario without mobility [2]. Subsequent studies [3, 4] theoretically predicted a very high throughput of communication systems with MIMO channels under conditions of strong signal scattering. It was shown that the throughput grows linearly with the increase of $\min(N_T, N_R)$, where N_T and N_R is the number of receiving and transmitting antennas in the MIMO system, respectively.

Hence, communication systems with a large number of receiving and transmitting antennas (large or massive MIMO systems, mMIMO) are of great interest as an essential part of new communication standards. The implementation of an optimal maximum likelihood (ML) receivers with a large number of antennas becomes impossible due to the very high computational load. Therefore, one can use so-called linear receivers, such as MMSE (Minimum Mean Square Error), ZF (Zero-Forcing), or their modifications, for example, V-BLAST [1].

In linear receivers, the primary resource of the MIMO channel is spent on suppressing interference from signals emitted by neighboring transmitting antennas. Therefore, the

gain from diversity transmission and reception is lost. This leads to a deterioration in energy efficiency.

This paper discusses a signal construction approach for the MIMO channels, which provides additional gains from spatial diversity, even with linear receivers. The rest of the paper is arranged as follows. In the next section, we define our system model. In Section III, distributed spatial multiplexing MIMO systems are introduced in more detail. Section IV contains modeling results and their analysis. Finally, we conclude in Section V.

II. SYSTEM MODEL

Let us consider a mathematical model of a communication system with a MIMO channel and spatial multiplexing [1, 5]. A simplified block diagram of a communication system with spatial multiplexing is shown in Fig. 1. This model of a MIMO point-to-point system is used quite often. Usually, it is assumed that the system operates under conditions of slow frequency-selective fading. Channel coefficients are assumed to be constant over the transmission interval. Under these assumptions, the equivalent complex low-frequency model of the MIMO system can be formulated as

$$Y = HX + \eta, \tag{1}$$

where Y is N_R-dimensional vector of received samples at a certain point in time, H is $(N_R \times N_T)$-dimensional matrix of channel coefficient known at the receiver, X is N_T-dimensional vector of complex Quadrature Amplitude Modulation (QAM) symbols. η is N_R-dimensional complex Gaussian vector of observation noise with zero mean and
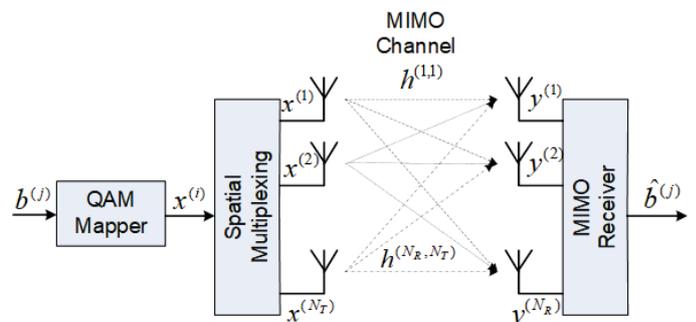

Fig. 1. System model of MIMO set-up with spatial multiplexing

correlation matrix $2\sigma_\eta^2 I_{N_R}$, where I_{N_R} is unit matrix of size $(N_R \times N_T)$. Further, we will limit our considerations to the practical scenario when $N_R = N_T$. In this case, the system of linear equations 1 with respect to the vector X is defined.

The channel transmission coefficients

$$h^{(i,j)}, \quad i = \overline{1, N_R}, \quad j = \overline{1, N_T}$$

are the elements of the matrix H from (1). They are Gaussian complex random variables with zero mean and unit dispersion. The coefficients can be independent or correlated depending on various factors, including the distance between the antennas, the number of scatters in the environment, and so on.

III. DISTRIBUTED SPATIAL MULTIPLEXING

One may notice that in a conventional spatial multiplexing system (Fig. 1), each symbol is emitted by one transmit antenna. Therefore, it has only N_R equivalent propagation paths. The total number of equivalent paths in the MIMO channel equals $N_T N_R$. Hence, with independent fading, the potential diversity gain of the system will also be determined by the product $N_T N_R$. In order to increase the diversity gain, it is necessary to form a signal in such a way that each symbol $x^{(i)} \in X$ is emitted by each antenna, i.e., the information contained in this symbol must be distributed across all the antennas. A version of such communication system with a MIMO channel and distributed spatial multiplexing is shown in Fig. 2.
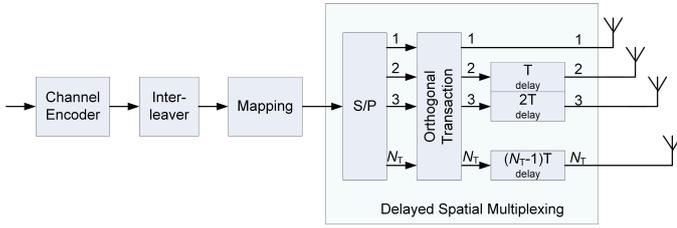

Fig. 2. Block diagram of the transmitting part of the system with a MIMO channel and distributed spatial multiplexing

The system in Fig. 2 has N_T transmit antennas and N_R receive antennas. In this system, one individual symbol will be emitted alternately by all transmitting antennas, what is true only when the matrix of orthogonal transformation does not have zero elements. This in turn leads to an increase in spatial diversity efficiency, both due to receiving and transmitting antennas. In this case, the distribution of the symbol over the antennas is carried out by orthogonal conversion and delay of the converted symbols by a different value. Therefore, such a system can be called as Delayed Spatial Multiplexing (DSM).

The signal generation model in the system above and the reception model can be described by the following expressions:

$$Z_n = F Z_{n-1} + G Z_n,$$
$$Y_n = HEX_n + \eta_n, \tag{2}$$

where F, E, G are encoding matrices, and

$$Z_n \triangleq \left[X_n^T X_{n-1}^T \ldots X_{n-N_T}^T \right]^T$$

is the extended vector of symbols.

Expressions (2) are state and observation equations of the Markov process. Therefore, a linear Kalman filter [6] can be used as one of the simplest approaches for the evaluation of the vector of symbols Z_n. In this case, the estimation algorithm will be described by the following recurrence expressions:

$$\hat{Z}_n = F\hat{Z}_{n-1} + K_n \left(Y_n - HEF\hat{Z}_{n-1} \right),$$
$$K_n = \tilde{V}_n (HE)' \left((HE) \tilde{V}_n (HE)' + 2\sigma_\eta^2 I \right),$$
$$\tilde{V}_n = FV_{n-1}F' + GG', \tag{3}$$
$$V_n = \tilde{V}_n - K_n (HE) \tilde{V}_n.$$

The estimation of the transmitted vector X_n will be the same with the first N_T components of the vector $\hat{Z}_n$, i.e., $\hat{X}_n = \hat{Z}_n^{(1,2,\ldots,N_T)}$. The estimations of the coded bits are defined by the states of the symbols in vector X_n, and can be found as a result of QAM demodulation procedure.

It should be noted, that algorithm (3), like the well-known MMSE algorithm, is linear. Therefore, to improve the quality of symbol detection, it can also be used as a part of an iterative algorithm with Turbo processing [7, 8]. Turbo algorithm uses sequentially a Gaussian approximation, which is also linear. Then, the resulting estimates are refined by taking into account the non-Gaussian distribution of QAM symbols. An increment of information at each step is used at the next iteration. A similar method of iterative reception, in combination with the MMSE algorithm, is described in [9]. It can be modified easily enough to make it compatible with the algorithm (3).

The block diagram of such an iterative Turbo receiver is shown in Fig. 3.
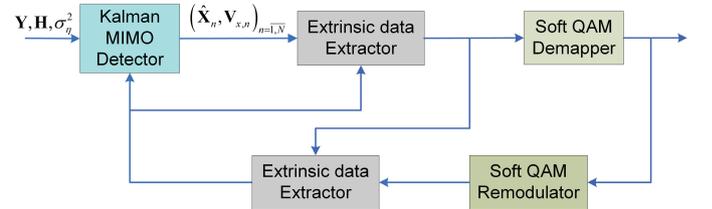

Fig. 3. Block diagram of an iterative receiver for a system with a MIMO channel and distributed spatial multiplexing

IV. MODELLING

The computer model was created in MATLAB to verify the effectiveness of the considered MIMO scheme with distributed spatial multiplexing. The simulations were carried out for a MIMO channel with 4 antenna configuration. LDPC channel code with a coding rate of $\frac{3}{4}$ was used.

Fig. 4 shows the Frame Error Rate (FER) versus the signal-to-noise ratio per bit for a system with conventional spatial multiplexing (SM) and distributed spatial multiplexing (Distr. SM) using an iterative Turbo receiver. Worse mentioning, that if only one iteration of Tubo receiver is used, then the reception algorithm becomes a conventional linear receiver: for
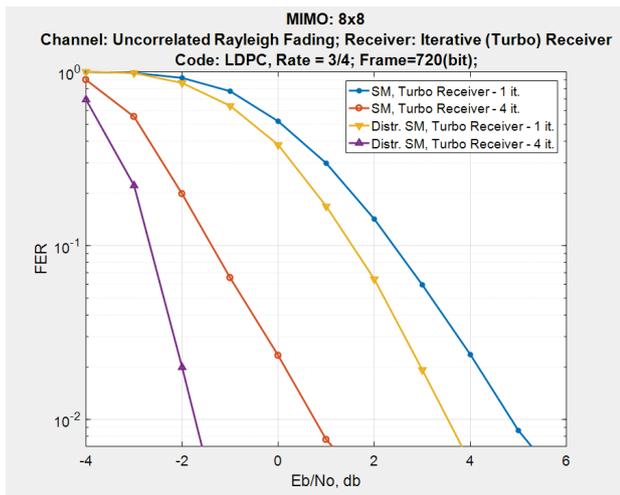
Fig. 4. FER versus signal-to-noise ratio per bit for a MIMO system with conventional spatial multiplexing and distributed spatial multiplexing

traditional spatial multiplexing it is MMSE, and for distributed - a Kalman filter.

From the results of Fig. 4, it can be concluded that the use of distributed spatial multiplexing gives us an additional energy gain of about 2 dB. Moreover, this gain holds both for a simple non-iterative receiver and for a Turbo receiver. Additionally, the use of an iterative receiver allows us to obtain a gain of about 8 dB with 3 iterations of the algorithm.

V. CONCLUSION

This paper proposed a new method of distributed spatial multiplexing for MIMO channel systems. In the algorithm, each QAM symbol after orthogonal transformation is sequentially emitted by each transmit antenna. As a result of

this approach, an energy gain is achieved due to spatial and temporal diversity. A linear Kalman filter can be used to receive a signal constructed in such a way. Moreover, this transmission method and linear receiver can be used efficiently with the Turbo iterative processing, which provides additional gains at the receiver.

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