A Detection Scheme based on Matrix Partition for MIMO Signal with Distributed Antennas

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Abstract—**Aimming at the problem of the asynchronous receiving for distributed antenna multiple-input multiple-output system (D-MIMO), a serial detection scheme based on matrix partition is proposed. Firstly, a smaller matrix is partitioned from the equivalent channel matrix and then signal is detected. Secondly, the detected signal in the first step of is used for interference cancellation, and the remainders are used for combination. And then another small matrix is partitioned from the channel matrix cancelled the interference and signal is again detected. This process is repeated until all the signals have been detected. Compared to the exiting Distributed Antenna Ordering successive interference cancellation (DA-OSIC) algorithm, computer simulation results show that the proposed detection scheme support the successive transmission of signals under the single-path Rayleigh fading channel. Meanwhile, as the length of signal sequence being large, the proposed algorithm has the same performance as the DA-OSIC scheme and has lower computational complexity.**

Keywords- **distributed multiple input multiple output (D-MIMO); joint detection; matrix partition; asynchronous receiver; interference cancellation; successive transmission.**

I. Introduction

With the fast development of wireless communication technology, the demand for information transmission services is growing and the spectrum resources are increasingly strained. a distributed multiple-input-multiple-output (D-MIMO) technology, significantly improving the spectrum efficiency and the performance of mobile communication systems without additional signal bandwidth occupied [1], has become the key technology for the next generation of wireless communication.

Different from the traditional MIMO, the antennas in distributed MIMO system, are distributed to different geographical regions and connected to the center signal processor by fiber or optical wireless channel [2]. Therefore, the distributed MIMO system provides both micro diversity and macro diversity and has more independent channels [3]. As effectively shortening the signal access distance, the distributed MIMO system reduces the requirements of transmission power and has higher cell coverage radio [4]. In cell formation, the distributed MIMO system is more flexible. However, the distribution of transmitting and receiving antennas will cause the asynchronous receive of the signals. This situation can not be solved by presetting of the signal. Accordingly, traditional Vertical-Bell Labs layered space-time (V-BLAST) detection method can not be directly used in D-MIMO. The detection algorithm is the key to the achievement of the performance for D-MIMO system.

A coherent detection model with matched filter group was proposed in [5] for spatial multiplexing D-MIMO by Jong et al. In [6], per-filtering at transmitter and equalizer at receiver was used to restore the signals in D-MIMO. The detection model in [5] was improved and the traditional OSIC algorithm was introduced to D-MIMO system in [7]. A detection algorithm with Cholesky decomposition was proposed in [8] and this algorithm has lower complexity than that in [7]. However, both of the algorithms in [7] and [8] treat the equivalent channel with matched filter group as a whole to detect the signals, and the computational complexity will be significantly high when the length of signal sequence S is large. Meanwhile, the above detection algorithms are very sensitive to the delay scene and the performance will degrades with the increase of the length of S in the case of single receiving antenna [9]. So these algorithms don't be applied to the successive transmission of long signal sequence.

In this paper, a successive detection scheme based on matrix partition is proposed. This detection scheme supports the successive transmission of signals and has steady performance for the different delay scene. Meanwhile, as the length of signal sequence being large, the proposed algorithm has the same performance as the DA-OSIC scheme and has lower complexity. The rest of this paper is organized as follows. The system model is presented in Section II, and in Section III, a detection scheme is proposed. The simulation results and analysis are given in section IV, and the conclusions are given in section V.

II. System Model

A. Transmitter Model

We consider a V-BLAST system with Nt transmit antennas and Nr receive antennas. The system model is shown in Figure 1. After symbol constellation mapping, the symbol vector **b,** after baseband modulating, is multiplexed into Nt substreams and transmitted by Nt antennas. We define the length of signal sequence as S. Then, the equivalent baseband signal from the kth transmit antenna is expressed as

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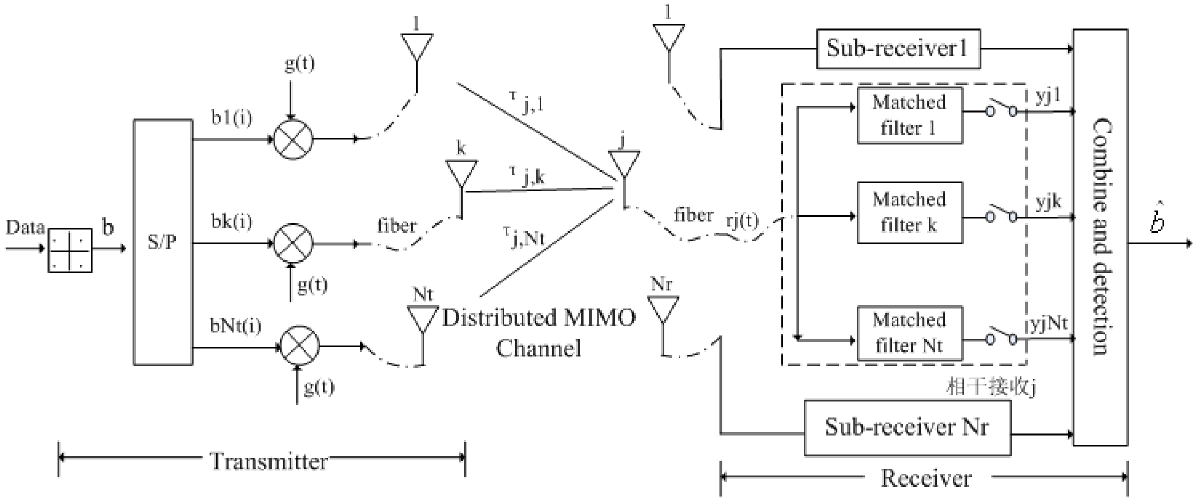

Figure 1. System model of D-MIMO

$$x_k(t)=\sqrt{\frac{E_s}{Nt}}\sum_{i=0}^{S-1}b_k(i)g(t-iT_s) \tag{1}$$

where $b_k(i)$ is the symbol transmitted on the kth transmit antenna in the ith time slot, k=1,2,…,Nt, i=0,1,…,S-1 and Es/Nt is the energy of a symbol that is radiated from each transmit. The T_s is the symbol period. The function $g(t)$ is the baseband waveform. Without loss of generality, it is assumed as

$$g(t)=\begin{cases}1, & 0\le t<T_s\\ 0, & \text{others}\end{cases} \tag{2}$$

B. *Channel Model*

As the transmitter and receiver antennas are distributed to different geographical regions, we consider an independent flat Rayleigh fading channel and the delay between different transmit and receive antennas are independent. Although the flat fading channel model does not apply in practical wireless communication system, the multiple sub-carrier channels in MIMO system can be divided into parallel independent subchannels due to using of OFDM technology. So this paper mainly considers the flat Rayleigh fading channel [10]. Then, the received signal at the jth receive antenna is written as

$$r_j(t)=\sqrt{\frac{E_s}{Nt}}\sum_{i=0}^{S-1}\sum_{k=1}^{Nt}b_k(i)a_{j,k}(i)g(t-iT_s-\tau_{j,k})+n_j(t) \tag{3}$$

where $a_{j,k}(i)$ is the complex channel coefficient from the kth transmitter antenna to the jth receiver antenna in the ith time slot and $\tau_{j,k}$ is the delay offset from the kth transmitter antenna to the jth receiver antenna. Without loss of generality, it is assumed that the delay offsets satisfy $0\leqslant\tau_{j,1}<\ldots<\tau_{j,Nt}<T_s$, where j=1,2, . . . , Nr.

C. *Receiver Model*

The received signals at the jth receive antenna are firstly inputted into a bank of matched filters and the matched filters process the signals from different transmit antenna by the delay offsets. Then the symbol at the jth receiver antenna in the nth time slot from the mth transmit antenna is outputted and can be written as

$$\begin{aligned}y_{j,m}(n)&=\int_{-\infty}^{\infty}r_j(t)g(t-nT_s-\tau_{j,m})dt\\&=\int_{-\infty}^{\infty}\Bigg(\sqrt{\frac{E_s}{Nt}}\sum_{i=0}^{S-1}\sum_{k=1}^{Nt}b_k(i)a_{j,k}(i)g(t-iT_s-\tau_{j,k})+\\&\qquad n_j(t)\Bigg)g(t-nT_s-\tau_{j,m})dt\end{aligned} \tag{4}$$

We define

$$n_{j,m}(n)=\int_{-\infty}^{\infty}n_j(t)g(t-nT_s-\tau_{j,m})dt \tag{5}$$

$$R_{m,k}(n-i)=\int_{-\infty}^{\infty}g(t-iT_s-\tau_{j,k})g(t-nT_s-\tau_{j,m})dt \tag{6}$$

Then (4) can be rewritten as

$$y_{j,m}(n)=\sqrt{\frac{E_s}{Nt}}\sum_{i=0}^{S-1}\sum_{k=1}^{Nt}R_{m,k}(n-i)a_{j,k}(i)b_k(i)+n_{j,k}(n) \tag{7}$$

Define the $Nt\times Nt$ cross-correlation matrix $\boldsymbol{R}(n-i)$ with entries . $\boldsymbol{R}(n-i)$ satisfies that

$$\boldsymbol{R}(n-i)=\boldsymbol{R}^T(n-i) \tag{8}$$

With the definition of $g(t)$ and $\tau_{j,k}$, so we have

$$\boldsymbol{R}(n-i)=0,\ \ \forall|n-i|>1 \tag{9}$$

Let the diagonal channel matrix of the jth receiver antenna in the nth time slot be $\boldsymbol{h}_j(n) = diag\left[a_{j,1}(n), \cdots, a_{j,Nt}(n)\right]$, The matched filter output at nth time slot can be written as

$$\boldsymbol{y}_j(n) = \sqrt{\frac{E_s}{Nt}}[\boldsymbol{R}(1)\boldsymbol{h}(n-1)\boldsymbol{b}(n-1) + \boldsymbol{R}(0)\boldsymbol{h}(n)\bullet\boldsymbol{b}(n) + \boldsymbol{R}(-1)\boldsymbol{h}(n+1)\boldsymbol{b}(n+1)] + \boldsymbol{n}_j(n) \tag{10}$$

where $\boldsymbol{y}_j(n) = \left[y_{j,1}(n), y_{j,2}(n), \cdots y_{j,Nt}(n)\right]^T$, $\boldsymbol{b}(n)=[\boldsymbol{b}_1(n), \boldsymbol{b}_2(n),...,\boldsymbol{b}_{Nt}(n)]^T$, and $\boldsymbol{n}_j(n) = \left[n_{j,1}(n), n_{j,2}(n), \cdots n_{j,Nt}(n)\right]^T$.

To simply the expression in (10), we define the $SNt \times SNt$ real symmetric matrix $\mathfrak{R}_j$ and $SNt \times SNt$ diagonal channel matrix $\boldsymbol{H}_j$ as

$$\mathfrak{R}_j = \begin{bmatrix} \boldsymbol{R}_j(0) & \boldsymbol{R}_j(-1) & 0 & \cdots & 0 & 0 \\ \boldsymbol{R}_j(1) & \boldsymbol{R}_j(0) & \boldsymbol{R}_j(-1) & \cdots & 0 & 0 \\ 0 & \boldsymbol{R}_j(1) & \boldsymbol{R}_j(0) & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & \boldsymbol{R}_j(0) & \boldsymbol{R}_j(-1) \\ 0 & 0 & 0 & \cdots & \boldsymbol{R}_j(1) & \boldsymbol{R}_j(0) \end{bmatrix} \tag{11}$$

$$\boldsymbol{H}_j = diag\left[\boldsymbol{h}_j(0)^T, \cdots, \boldsymbol{h}_j(S-1)^T\right] \tag{12}$$

Then (10) can be written as

$$\boldsymbol{y}_j = \sqrt{\frac{E_s}{Nt}}\mathfrak{R}_j \boldsymbol{H}_j \boldsymbol{b} + \boldsymbol{n}_j \tag{13}$$

where $\boldsymbol{y}_j = \left[\boldsymbol{y}_j(0)^T, \cdots, \boldsymbol{y}_j(S-1)^T\right]^T$, $\boldsymbol{b}=[\boldsymbol{b}(0)^T, \boldsymbol{b}(1)^T,..., \boldsymbol{b}(S\text{-}1)^T]^T$, and $\boldsymbol{n}_j = \left[\boldsymbol{n}_j(0)^T, \cdots, \boldsymbol{n}_j(S-1)^T\right]^T$.

After maximal-ratio combing of Nr receiving antennas, the received signal can be written as

$$\begin{aligned} \boldsymbol{Y} &= \sum_{j=1}^{Nr} \boldsymbol{H}_j^H \boldsymbol{y}_j \\ &= \sum_{j=1}^{Nr} \sqrt{\frac{E_s}{Nt}} \boldsymbol{H}_j^H \mathfrak{R}_j \boldsymbol{H}_j \boldsymbol{b} + \sum_{j=1}^{Nr} \boldsymbol{H}_j^H \boldsymbol{n}_j \end{aligned} \tag{14}$$

III. Detection Scheme Based On Matrix Partition

Writting (14) as

$$\boldsymbol{Y} = \boldsymbol{F}\boldsymbol{b} + \boldsymbol{N} \tag{15}$$

where $\boldsymbol{F} = \sum_{j=1}^{Nr} \sqrt{\frac{E_s}{Nt}} \boldsymbol{H}_j^H \mathfrak{R}_j \boldsymbol{H}_j$ and $\boldsymbol{N} = \sum_{j=1}^{Nr} \boldsymbol{H}_j^H \boldsymbol{n}_j$. Then $\boldsymbol{F}$ is a band matrix whose both left and right half-bandwidth are both Nt-1. If the traditional V-BLAST detection algorithms are directly used, there will be several problems. On the one hand, the $SNt \times SNt$ matrix $\boldsymbol{F}$ will be very large when the transmission of signals is successive, then the complexity of detection will be very high and the algorithm will not be used in practice. On the another hand, as a band matrix, $\boldsymbol{F}$ greatly differs from the channel matrix H in traditional MIMO system. This algorithm will has different performance with the change of S and delay offsets.

The simulation in Rayleigh fading channel shows that the performance will be sensitive to delay offsets and will degrade with the increase of S in the case of single receiver antenna when using OSIC algorithm in D-MIMO (written as DA-OSIC for short) system. The complexity of DA-OSIC scheme is $O((SNt)^4)$. So this scheme does not support the successive transmission of signals both in performance and complexity. So in this paper, a serial detection scheme based on matrix partition is proposed. The proposed detection scheme supports the successive transmission of signals and has steady performance when the delay scene changes. Meanwhile, as the length of signal sequence being large, the proposed algorithm has the same performance as the DA-OSIC scheme and has lower complexity.

Figure 2. The diagram of matrix partition

The step of matrix partition is shown in figure 2, where the number 1 is not a specific value but means the elements of matrix are not zero. Observing, the channel matrix can be partitioned after setting the former *Nt-1* columns of the matrix elements to zero. Firstly, a $M \times M$ ($M = 2Nt - 1$) matrix can be partitioned from **F**, with which signals are first detected. Then the detected signals are used for interference cancellation, and the remainder are used for combination. And then another $M \times M$ matrix can be partitioned from the equivalent channel matrix cancelled the interference. This process is repeated until all the signals have been detected.

The specific steps of the algorithm can be given as follows:

*1) **Set the former Nt-1 columes of the matrix elements to zero***

This can be achieved by sending only one symbol in *Nt*th transmit antenna in the former time slot. Then the $\boldsymbol{F}$ can be written as

$$F = F_{Nt,SNt}$$

*2) **Matrix Partition and signal Detection***

$$M = 2Nt - 1$$

$$for \;\; i = 1 : SNt - M + 1$$

$$y_i = Y_{i,i+M-1}$$

$$G_i = (F)_{i,i+M-1}^{i,i+M-1}$$

$$x_i = b_{i,i+M-1}$$

$$k_i = sum\left(abs\left(G_i\right).\hat{}\,2\right)$$

$$\hat{x}_i = \arg\min_x \left\| y_i - G_i x_i \right\|^2$$

$$\hat{b}_{i,i+M-1} = \hat{b}_{i,i+M-1} + \hat{x}_i \times diag(k_i)$$

$$\hat{b}_i = Q\left(\hat{b}_i\right)$$

$$Y = Y - (F)^i \hat{b}_i, \;\; F = F - (F)^i$$

$$end \;\; for$$

where $Y_{i,i+M-1}$ means the elements of $\boldsymbol{Y}$ from the i th to the $i+M-1$ th, and $(F)_{i,i+M-1}^{i,i+M-1}$ means the elements of matrix **F** from the i th row to the $i+M-1$ th row and the elements from the i th column to the $i+M-1$ th column.

*3) **Output** $\hat{b}$*

IV. Simulations And Analysis

To evaluate the performance of the proposed detection scheme, some computer simulation can be done and results are presented in this section. In the simulations, the i.i.d flat Rayleigh fading D-MIMO channels and the QPSK modulation are used.

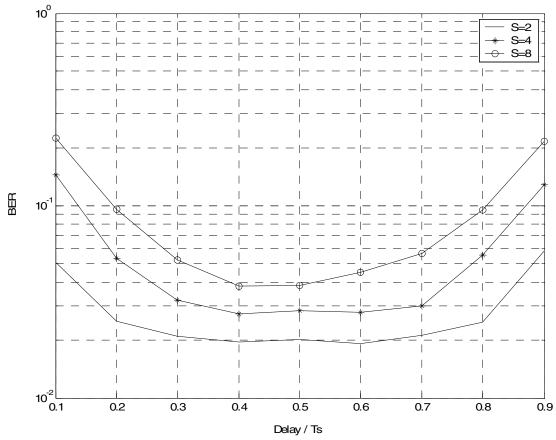

Figure 3. Influence of delay offsets in DA-OSIC

Nt=2, Nr=1,SNR=15

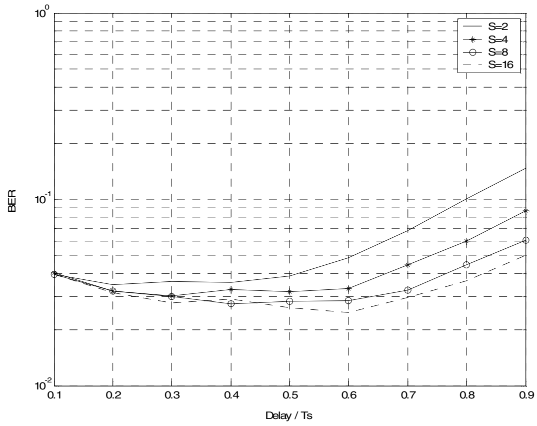

Figure 4. Influence of delay offsets in proposed scheme(DA-M)

Nt=2, Nr=1,SNR=15

Figure 3 and Figure 4 compare the BER of DA-OSIC and the proposed algorithm (DA-M) versus delay offsets when SNR=15dB, respectively. From the figures, we can see that DA-OSIC is more sensitive to the delay offsets for single receiving antenna in D-MIMO system and the performance is influenced by the channel matrix. While the inter-symbol interference is enhanced, the performance is degraded and further different versus delay offsets with the increase of *S*. Therefore, this algorithm is more suitable for a small *S* as *S*=2. To avoid interblock interference, zero is inserted in the signal blocks. So *S* =2, detection performance is retained well but the data transmitting rate is reduced. However, the proposed DA-M algorithm can be applied for every M matrix. So with the increase of *S*, the algorithm is not sensitive to the delay offsets and the performance will be increased. So the proposed scheme has good robust and can support the successive transmission of signals.

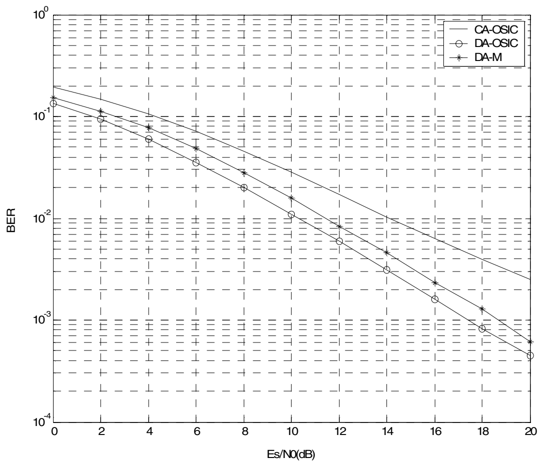

Figure 5. Performance comparison of the three algorithms

Nt=2, Nr=2, DA-OSIC: S=2, DA-M: S=32, delay offsets=0,0.2Ts

Figure 5 compares the performance of centralize antenna OSIC(CA-OSIC) algorithm, DA-OSIC algorithm and the proposed DA-M algorithm. Because CA-OSIC algorithm requires the number of receiving antennas no less than the number of transmitting antennas, we use 2 receiving antennas here. In the DA-OSIC algorithm, S=2. In the DA-M algorithm, S=32. And the delay offset is $0.2T_s$.

Simulation results show that the performance of DA-MIMO system is better than CA-MIMO system. As the length of signal sequence being large(S=32), the proposed algorithm has the nearly same performance as the DA-OSIC scheme. Assuming that 64 symbols will be transmitted, for each transmitting antenna, there are 32 symbols. When using DA-OSIC algorithm, the symbols need to be transmitted in 16 blocks while each block have 2 symbols per transmitter antenna. To avoid interblock interference, zero is inserted in the blocks. So the data transmitting rate (DTR) is $64/((2+1)\times16) \approx 1.33$. Meanwhile, the proposed DA-M algorithm only need to set the first symbol in first transmitting antennas to zero, and the DTR is $64/(32+1) \approx 1.94$. When the number of symbols transmitted being larger, the DTR will be close to 2 (equal to Nt) for DA-M algorithm but permanent in 1.33 for DA-OSIC algorithm. Besides, the algorithm complexity of DA-OSIC is $O((SNt)^4)$. Assume S=32, this algorithm's complexity will be $(32\times2)^4$=16777216. The complexity of DA-M algorithm is $O((SNt-2Nt+2)(2)^{QM})$. Here S=32, then the complexity is $(32\times2-2\times2+2)\times2^{2\times3}$=3968. So compared with DA-OSIC, DA-M algorithm has lower complexity and better DTR with a slight loss of detection performance. So it is more suitable for successive transmission of signals.

V. Conclusions

In this paper, a serial detection scheme based on matrix partition is proposed for DA-MIMO system. Firstly, a smaller matrix M is partitioned from the equivalent channel matrix, from which signals are detected. Then the first of the detected signals are used for interference cancellation, and the remainder are used for combination. And then another matrix M is partitioned from the equivalent channel matrix cancelled the interference. This process is repeated until all the signals have been detected. Computer simulation results under the single-path Rayleigh fading channel show that the proposed detection scheme support the successive transmission of signals, compared to the exiting DA-OSIC algorithm. Meanwhile, when the length of signal sequence is large, the proposed DA-M algorithm has lower complexity and better DTR with a slight loss of detection performance.

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