MIMO Systems with Distributed Transmit Antennas Analysis

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***Abstract* — This paper analyzes a differential en/decoding scheme for multiple input multiple-output for usage in communication links with two distributed transmit antennas and one receive antenna, in which neither the transmitter nor the receiver know channel characteristics. Analyzed scheme is simulated and results are presents for the scenario of two transmit antennas one receive antenna. It will be shown that the bit error rate is dependant on delay. Also, we will show that the optimum delay time for two transmit antennas and one receive antenna system is about $0.6T_s$ (where T_s denotes symbol period)**

***Keywords* — Channel propagation delay, differential modulation, distributed antenna system, multiple-input multiple output**.

I. Introduction

A higher demand in wireless communications calls for higher systems capacities. The capacity of a communications system can be increased directly by enlarging the bandwidth of the existing communications channels or by allocating new frequencies to the service [1]. Multiple antenna arrays in wireless communication system is known to achieve high performance in gains [2], [3] and suppression of interference. Multiple-input multiple-output (MIMO) technique was widely researched in these years to address the huge capacity gain [3], [4]. It was assumed that the transmit antennas and receive antennas are co-located. Current studies of co-located technique seldom consider the shadow fading issue which severely diminishes link quality when unfavorable shadowing is experienced. Multiple transmit antennas located in the same sites experience the same shadowing, thus it can not improve the situation.

Technique based on distributed antennas system (DAS) has many advantages [5]-[9] over co-located antenna technique: more independent channel fading, larger system capacity, lower transmission power, and enhanced coverage. Majority of nowadays mobile units have one antenna and idea of this paper is to use differential modulation scheme for DAS-MIMO [2] in system with two transmit antennas and a mobile unit with one receive antenna. The analyzed transmitter and receiver do not have the knowledge about the channel.

In this paper, like in [2], a DAS-MIMO wireless system with M transmit antennas which are geographically distributed in different locations, while L receive antennas are co-located. It was assumed that amplitude/phase-shift keying (APSK) signals are transmitted by M antennas. The paper is organized as follows: Section II describes considered modulation scheme; Section III presents results of simulation, and concluding remarks are given is Section IV.

II. Differential Modulation

A. Differential Encoding

The channel state is unknown at the receiver, and, as previously mentioned, the transmitted signals are differentially encoded before transmission. To initialize transmission the transmitter sends code matrix $\mathbf{S}^0$.

$$\mathbf{S}^0 = \begin{pmatrix} 1 & 1 & \cdots & 1 \\ 1 & 1 & \cdots & 1 \\ \vdots & \vdots & \cdots & \vdots \\ 1 & 1 & \cdots & 1 \end{pmatrix}_{M\times N} \tag{1}$$

Any element in matrix $\mathbf{S}^0$ is 1 and does not convey any information. Rests of the data are encoded in an inductive manner. Suppose than code matrix $\mathbf{S}^{l-1}$ is sent corresponding to data block $l-1$.

$$\mathbf{S}^{l-1} = \begin{pmatrix} s_{1,1}^{l-1} & s_{1,2}^{l-1} & \cdots & s_{1,N}^{l-1} \\ s_{2,1}^{l-1} & s_{2,1}^{l-1} & \cdots & s_{2,N}^{l-1} \\ \vdots & \vdots & \cdots & \vdots \\ s_{M,1}^{l-1} & s_{M,2}^{l-1} & \cdots & s_{M,N}^{l-1} \end{pmatrix}_{M\times N} \tag{2}$$

The l-th data block which consisting of ($qMN + MN$) bits arrives at the encoder. The encoder maps the first qMN bits to symbols $\alpha_{m,n}^l = \Omega$ ($1 \le m \le M$, $1 \le n \le N$), where Ω is a 2^q-PSK constellation set. The second group of MN information bits $I_{m,n}^l$, $\alpha_{m,n}^l$ are mapped to symbols $\beta_{m,n}^l \in \Theta$, where $\Theta = \{1, a, 1/a\}$, and $a = r_{\max} / r_{\min}$ represents ratio between high and lower magnitudes of APSK signals. Finally signal $s_{m,n}^l$ in the l-th code matrix is obtained by differential encoding with $\alpha_{m,n}^l$ and $\beta_{m,n}^l$ from equation:

$$s_{m,n}^l = \alpha_{m,n}^l \beta_{m,n}^l s_{m,n}^{l-1} \tag{3}$$

where

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$$\beta_{m,n}^{l}=\begin{cases}1, & if \quad I_{m,n}=0\\ \mathrm{r_{max}}/\mathrm{r_{min}} & if \quad I_{m,n}=1 \quad and \quad s_{m,n}^{l-1}=r_{\min}\\ \mathrm{r_{min}}/\mathrm{r_{max}} & if \quad I_{m,n}=1 \quad and \quad s_{m,n}^{l}=r_{\max}\end{cases} \tag{4}$$

From (3) it is obvious that $s_{m,n}^{l}$ is APSK signal. In fact, bit $I_{m,n}^{l}$ determines the magnitude of $s_{m,n}^{l}$. The magnitude can be the same as $s_{m,n}^{l-1}$ or changes between r_{max} and r_{min}. The l-th code matrix $\mathbf{S}^{l}$ is obtained with $s_{m,n}^{l}$ from (2).

After encoding, the code matrix $\mathbf{S}^{l}$ is demultiplexed into M sub-streams by rows. Each sub-stream is modulated and forwarded to the corresponding transmit antenna by coaxial line or fiber optic cable. Signals are sent to the receiver with distributed transmit antennas. The equivalent complex baseband signal from k-th transmit antenna is:

$$s_k(t)=\sum_{i=0}^{N-1}s_{k,i}^{l}g(t-iT_s) \tag{5}$$

where $k=1,\ldots,M$, $s_{k,i}^{l}$ is the symbol transmitted on the k–th transmit antenna in the i–th time slot, $i=0,\ldots,N-1$. T_s is the symbol period and $g(t)$ is the baseband waveform function. Function $g(t)$ satisfies the foolowing conditions $g(t)=0, t\notin[0,T_s]$, and $\int_0^{T_s}g(t)g^{*}(t)dt=1$.

B. Differential Decoding

The received signal at the jth receive antenna is given by:

$$r_j(t)=\sum_{k=1}^{M}h_{j,k}(t)s_k(t-\tau_k)+n_j(t) \tag{6}$$

where $h_{j,k}$ is the complex channel coefficient from the k–th transmit antenna to the j–th receive antenna. $n_j(t)$ is the additive complex Gaussian noise with mean 0 and variance σ^2; τ_k denotes the channel propagation delay from k–th transmit antenna to receive antennas. Since the transmit antennas are distributed in different locations, each sub-stream from different transmit antennas may not be received synchronously at the receiver. Without loss of generality, it is assumed that the channel propagation delays satisfy $0<\tau_1<\tau_2<\ldots<\tau_M<T_s$.

The received signals at j–th receive antenna are first passed through the matched filter bank. The sampled matched filters output from time slot 0 to $N-1$ can be written as [7], [8]:

$$\mathbf{Y}_j=\mathbf{R}\,\mathbf{H}_j\mathbf{b}+\mathbf{n}_j \tag{7}$$

$\mathbf{Y}_j$ is $MN\times1$ sampled output vector, $\mathbf{R}$ is $MN\times MN$ symmetric matrix. $\mathbf{H}_j$ $MN\times MN$ diagonal channel matrix, $\mathbf{b}$ is $MN\times1$ signal vector, and $\mathbf{n}_j$ is $MN\times1$ noise vector. We will consider one receive antenna at the receiver. For more than one antenna the sum of receiving signals at each antenna is used for decoding. From [4, (8) and (9)] the $\mathbf{b}^{l}$ is obtained with following relationship

$$\mathbf{b}^{l}=\mathbf{A}^{l}\mathbf{B}^{l}\mathbf{b}^{l-1} \tag{8}$$

where superscript l denotes transmitted code matrix,

$\mathbf{A}^{l}=\mathrm{diag}\{\alpha_{1,1}^{l},\alpha_{2,1}^{l},\ldots,\alpha_{M,1}^{l},\ldots,\alpha_{1,N}^{l},\alpha_{2,N}^{l},\ldots,\alpha_{M,N}^{l}\}$

$\mathbf{B}^{l}=\mathrm{diag}\{\beta_{1,1}^{l},\beta_{2,1}^{l},\ldots,\beta_{M,1}^{l},\ldots,\beta_{1,N}^{l},\beta_{2,N}^{l},\ldots,\beta_{M,N}^{l}\}$

It is assumed that the channel is unchanged for the duration of two consecutive code matrices reception. Based on (8), the received sampled input vector can be written as

$$\tilde{\mathbf{Y}}^{l}=\mathbf{A}^{l}\mathbf{B}^{l}\tilde{\mathbf{Y}}^{l-1}+\bar{\mathbf{n}}^{l} \tag{9}$$

where

$\tilde{\mathbf{Y}}^{l}=\mathbf{R}^{-1}\mathbf{Y}^{l}=(\tilde{y}_1,\tilde{y}_2,\ldots,\tilde{y}_{MN})^{T}$, $\bar{\mathbf{n}}^{l}=(\bar{n}_1,\bar{n}_2,\ldots,\bar{n}_{MN})^{T}$,

and $(\bullet)^{-1}$ denotes inverse matrix, diag{} denotes diagonal matrix, and $(\bullet)^{T}$ denotes transpose operation.

Differential decoding has two steps. The first step is to detect symbol $\beta_{m,n}^{l}$. From [4, (12)] the symbol $\beta_{m,n}^{l}$ can be detected by:

$$\begin{aligned}\hat{\beta}_{m,n}^{l}&=\arg\min_{\beta_{m,n}^{l}\in\Theta}\left\{\left\|\tilde{y}_{m(n-1)+m}^{l}\right|-\beta_{m,n}^{l}\left|\tilde{y}_{m(n-1)+m}^{l-1}\right\|\right\}\\&=\arg\min_{\beta_{m,n}^{l}\in\Theta}\{z(\beta_{m,n}^{l})\}\end{aligned} \tag{10}$$

Here "arg" denotes any argument that achieves the maximum (or minimum). After detection of $\beta_{m,n}^{l}$ symbol, we calculate $I_{m,n}^{l}$ in the following way $I_{m,n}^{l}=0$ if $\beta_{m,n}^{l}=1$, and $I_{m,n}^{l}=1$ if $\beta_{m,n}^{l}=a$ or $1/a$.

Symbol $\alpha_{m,n}^{l}$ is independent and can be detected by

$$\begin{aligned}\hat{\alpha}_{m,n}^{l}&=\arg\max_{\alpha_{m,n}^{l}\in\Omega}\left\{f_{m,n}(\alpha_{m,n}^{l})\right\}\\f_{m,n}(\alpha_{m,n}^{l})&=\mathrm{Re}\left\{\left(\tilde{y}_{m(n-1)+m}^{l}\right)^{*}\left(\tilde{y}_{m(n-1)+m}^{l-1}\right)\alpha_{m,n}^{l}\right\}\end{aligned} \tag{11}$$

$\alpha_{m,n}^{l}$ and $\beta_{m,n}^{l}$ can be detected in a parallel manner. The block diagram of differential decoder is shown in Fig.1.

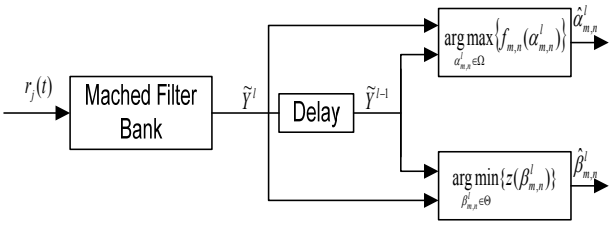

Fig. 1. Block diagram of differential encoder

III. Simulation Results

In this section, the Monte Carlo simulation results are presented for several different cases of τ for $L=1$, $N=2$, $a=2$ and BPSK set is chosen. For this simulation, the channel coefficient h is described by $h=\varepsilon_r\varepsilon_r$, where ε_r represents multipath fading (Flat Rayleigh fading). ε_r is a factor that captures the effects of large-scale pass loss and gain which causes the average received signal power decreases logarithmically with distance. The average pass loss is in dB and expressed as

$$\overline{PL}(dB)=-10\log_{10}\left(\left(\frac{\lambda}{4\pi}\right)^{2}d_0^{-2}\right)+10n\log_{10}\left(\frac{d}{d_0}\right) \tag{12}$$

where d is T-R separation distance, $n=4$ is path loss exponent, d_0=100 m is the close-in reference distance, and wavelength λ=0.14m [9].

In figure 2, the simulation results of the proposed scenario are provided when the system has two transmit antennas, one receive antenna. Delay is the propagation channel delay defined above.

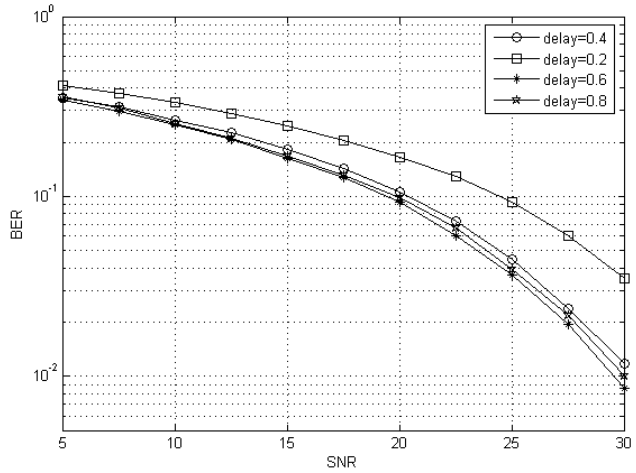

Fig. 2. Performance of analyzed scheme where delay is between 0.2 T_s and 0.6 T_s at bandwidth efficiency 4b/s/Hz

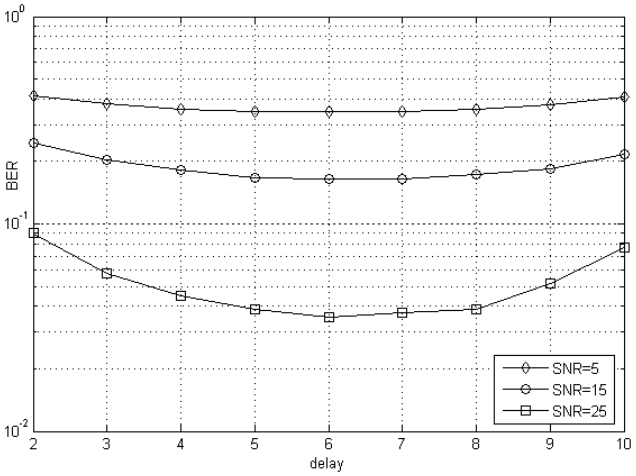

Fig. 3. BER performance versus channel propagation delays at bandwidth efficiency of 4b/s/Hz, (M,L)=(2,1) and τ_1=0, delay [number of samples]

The bit error rate depends on the delay. Therefore, it is important to find out the delay time for the optimal system performance.

In Fig. 3 the bit error probability is compared for different delay cases for (M,L)=(2,1). For the simulation, one bit is modeled as 10 samples array. The delay in Fig. 3 has the unit of the number of samples. Optimum delay time for two transmit antennas system and one receive antenna is about 6 samples, which is equal to $0.6T_s$.

IV. Conclusion

In this paper, the differential modulation scheme is analyzed in case of system with two distributed transmit antennas and one receive antenna. It was shown that there is a optimal value for the delay, which provides the lowest error probability at the receiver. The optimal value for the delay is approximately equal to $0.6T_s$, where T_s is the symbol period.

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