Adaptive Transmit Diversity with Orthogonal Space-Time Block Coding for Telemedicine Application

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Abstract— **Recently an adaptive transmit eigenbeamforming with orthogonal space-time block coding (Eigen-OSTBC) has been proposed. This model was simulated over macrocell environment with a uniform linear array (ULA) at the base station (BS) for next-generation (NG) wireless/mobile network. In this paper, we introduce a telemedicine simulation framework employing the Eigen-OSTBC scheme for the investigation of communication system characteristics in the application of biological data such as electrocardiogram (ECG). The geometrical-based hyperbolically distributed scatterers (GBHDS) channel model for macrocell environments was simulated with angular spreads (AS) taken from measurement data. Simulation results showed that the performance improvement introduced by the Eigen-OSTBC scheme can be observed even without extensive numerical analysis as traditionally expected. It is also showed that the received signal is highly correlated with the original transmitted signal.**

I. INTRODUCTION

Direct transmission of biological signals such as electrocardiogram (ECG) and electroencephalogram (EEG) via mobile network provides practically unlimited movement of the patients and unlimited coverage area. Telecommunication technology is used in telemedicine in order to transfer medical information for education, diagnosis and therapy. The information may include real time two-way audio and video signals, medical images, patient records, output data from medical devices (i.e. ECG, EMG) and sound files [1]. The telemedical interaction may engage despatching patient data from home to a hospital or transmitting a patient medical file from a primary care center to a specialist hospital [2]. Telemedicine is a rapidly growing area and recently there are researches dedicated to pre-hospital care of patients in emergency cases [3], [4].

The cardiac signals, ECG, are used widely in different monitoring and diagnostic cardiology applications such as: the transmission of ECG over telephone network, ambulatory monitors, and ECG recorders in intensive care units. For the patient suffering from a cardiac disease it is very crucial to perform accurate and quick diagnosis. Therefore, a continuous monitoring of the cardiac signal and the patient's current heart activity are essential. There are two common practices to record the ECG signal, either in short time interval during the examination by a physician, or by performing a 24-hours ECG recording for off-line analysis. The disadvantage of the first practice is that it is not possible to have the complete diagnosis, and the limitation of the second is that it is not possible to intervene instantly, which sometimes could be serious [5].

The demand for telemedicine applications and services over wireless networks has grown exponentially, especially during the last two decades due to technological advances in digital signal processing, radio frequency (RF) systems, and networks. With the rapid growth in this area and the emergence of third generation (3G) wireless network, the reliable direct transmission of ECG signal in real time will be possible. The direct transmission of ECG signal can be utilized in emergency cases (for example in an ambulance, by a motorcycle paramedic, by a mountain rescue team) where the nearest medical center can be contacted and by GPS the patient can be found and saved [5].

A high speed data communication over a bandlimited channel is subject to the degradation in both communication channel performance and acceptable quality of received data. This is mainly due to the inherent characteristics of wireless communication systems- the time varying nature of wireless channel conditions and propagation environments [6]. The adaptive transmit eigenbeamforming combined with orthogonal space-time block coding (OSTBC) for OFDM systems has been studied in [7] over macrocell environment where ULA was deployed at the base station (BS). The performance of this scheme is based on uplink angle-of-arrival (AoA) information. In this paper we further investigate the behavior of this adaptive transmission scheme over macrocell environment for telemedicine application.

Notation used: $(\cdot)^*$, $(\cdot)^T$, and $(\cdot)^H$ are complex conjugate, vector transposition, and Hermitian transposition, respectively. $\|\cdot\|_F$ is the Frobenius norm; $\sqrt{\mathscr{A}}$ stands for Hermitian square root of matrix $\mathscr{A}$; Finally, capital (small) bold letters represent matrices (vectors).

II. TELEMEDICINE SYSTEM MODEL

A general configuration of telemedicine system utilizing wireless network is shown in Fig. 1. This system consists of a real-time acquisition of cardiac data via ECG machine, personal server running on a 3G mobile phone and medical server that access through the Internet. The ECG signal can be transmitted via ZigBee wireless technology to a mobile phone and subsequently through the base station (BS) or through the Internet to a medical doctor or automatic monitoring system [12]. This system should have the capability of despatching an acknowledge message from the server to the mobile handset to indicate successful receipt of a packet or a demand for re-submission when necessary. By deploying

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the Eigen-OSTBC scheme, the communication system will be capable to minimize the transmission error. This paper focuses in the communication link between mobile station (MS) and BS where the Eigen-OSTBC scheme is located.

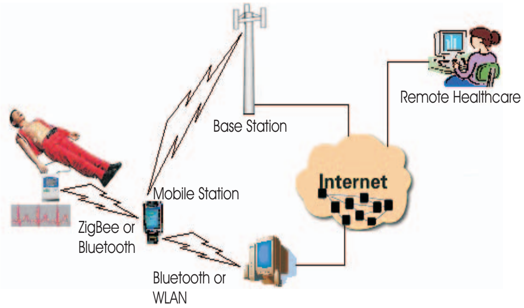

Fig. 1. General configuration of telemedicine system for Cardiac Application.

In the following subsections we will discuss the transmitted biological signal (normal-ECG), the space-time hyperbolic channel model for a macrocell environment and the space-time OFDM with adaptive beamforming.

A. Transmitted Signal

In this study we consider a normal electrocardiogram (ECG) signal (Lead-I). The ECG signal has a well-defined P, QRS, T signature that represents with each heart beat. The P-wave arises from the depolarization of the atrium. The QRS complex arises from depolarization of the ventricles and T-wave arises from repolarization of the ventricle muscles. The duration, shape and amplitude of these waves are considered as major features in time domain analysis. In this measurement, Lead-I electrodes was connected to BIOPAC systems, ECG module. The ECG module (ECG 100C) consists of instrumentation amplifier (IA) and a 50 Hz notch filter. The IA gain was set to 1000. The ECG data were recorded by using AcqKnowledge software (v.3.7.1, BIOPAC Systems, Inc., CA) in ASCII text files and processed by programs written in Matlab. The sampling rate for ECG was set to 1000 samples/second.

B. Propagation Channel Model

In this Section, we provide general descriptions for the geometrical-based hyperbolically distributed scatterers (GBHDS) channel model for macrocell environments [8], [9]. A comprehensive study of this model (at theoretical and simulation levels) as well as its validation with practical data reported in [10], [11] has been considered. They proved to be more realistic than other models in the literature when tested against practical data [8], [9].

The GBHDS for macrocell environment channel model assumes that the scatterers are arranged within a circle of radius R around the mobile. The distances r between the mobile station (MS) and the scatterers are distributed according to the hyperbolic probability density function (pdf) [8]. The geometrical scatterer density function (GSDF) for this model, $f_r(r)$, is given by

$$f_r(r) = \begin{cases} \frac{a}{\tanh(aR)\cosh^2(ar)} & \text{for } 0 \le r \le R \\ 0 & \text{elsewhere} \end{cases} \qquad (1)$$

where R is the radius of the circle enclosing the scatterers, and the applicable values of a lie in the interval (0,1) [8], [9]. The value of the parameter a controls the spread of the scatterers around the MS.

This model has been validated against measurement data reported in [10], [11]. In this paper the GBHDS model will be simulated with the same measurement angular spread (angluar spread of of 7°).

C. Orthogonal Space-Time Block Coding with Adaptive Beamforming

A general structure of the transmit scheme is shown in Fig. 2. It combines adaptive eigenbeamforming with orthogonal space-time block coding (Eigen-OSTBC) for broadband orthogonal frequency division multiplexing (OFDM). This system deploying N_t and N_r antennas at the transmitter and receiver, respectively. The OFDM system utilizes N_c frequency tones and the simulated channels are frequency-selective [8].

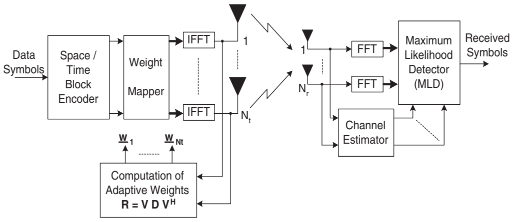

Fig. 2. General structure of the adaptive transmission scheme with OSTBC and eigenbeamforming.

At the BS, OSTBC is performed by formatting a sequence of baseband modulated data symbols into N_c codeword matrices before the linear transformation process of eigen weight mapping. Let us denote OSTBC output codeword for the k^{th} subcarrier as $\mathbf{C}_k \in \mathbb{C}^{N_t \times N}$, which spans across N OFDM-symbol intervals and N_t transmit antennas. Since the number of baseband constellation points is finite, there is a limited number of possible OSTBC codeword matrices that can be generated per subcarrier and we denote this finite set as $\boldsymbol{\Upsilon}_k \ni \mathbf{C}_k$. In this paper, the specific details of OSTBC construction are not described as we consider only the performance of the proposed transmission structure in telemedicicne application. We refer readers to [13], [14] for detailed description of formatting and decoding procedures of OSTBC.

We consider a base station (transmit antennas) equipped with an N_t identical and omnidirectional elements. The steering vector for uniform linear array (ULA) to an incoming signal from a DOA θ has the form:

$$\mathbf{a}(\theta) = [1,\, a_2(\theta),\, ...,\, a_{N_t}(\theta)]^T \qquad (2)$$

where $a_{n_t}(\theta)$ is a complex number denoting the amplitude and the phase shift of the signal at the nth antenna relative to that at the first antenna. For a ULA, $a_{n_t}(\theta) = e^{[j2\pi(n_t-1)\,d\,\sin(\theta)/\lambda]}$, where d is the space between adjacent antennas, $n_t = 1,2,\cdots,N_t$, and λ is the wavelength of the carrier.

The normalized transmit spatial covariance matrix that specifies the spatial correlation between antenna elements is defined as [15]

$$\mathbf{R}_t = \frac{1}{L}\sum_{\ell=1}^{L}\mathbf{a}(\theta_\ell)\mathbf{a}^H(\theta_\ell) \ , \tag{3}$$

where L denotes the number of dominant resolvable paths (i.e., arriving signal paths that are more than one symbol length apart with significant received power). The spatial correlation at the receiver side is assumed to be zero (single antenna), hence, only the transmitter side will be considered. This means that $\mathbf{R}_r = \mathbf{I}_{N_r}$, where $\mathbf{I}_b$ is an identity matrix of size $b \times b$.

In general, $\mathbf{R}_t$ is a nonnegative-definite Hermitian matrix and its eigenvalue-decomposition (EVD) can be expressed as $\mathbf{R}_t = \mathbf{V}\mathbf{D}\mathbf{V}^H$, where $\mathbf{V} = [\boldsymbol{\upsilon}_1,\cdots,\boldsymbol{\upsilon}_{N_t}]$ is a unitary matrix with columns that are the eigenvectors of $\mathbf{R}_t$ and $\mathbf{D} = \mathrm{diag}\{\mu_1,\mu_2,\cdots,\mu_{N_t}\}$ contains the corresponding eigenvalues. Define $\mathbf{g}_{i,j} = [g_{i,j}(0),\cdots,g_{i,j}(L-1)]$ as the L-tap channel impulse response vector for the $(i,j)^{\mathrm{th}}$ receive-transmit antenna pair. The channel frequency response matrix can be expressed as $\mathbf{H}_k \in \mathbb{C}^{N_r\times N_t}$ with its $(i,j)^{\mathrm{th}}$ entry $h_{i,j,k} = \mathbf{g}_{i,j}\mathbf{f}_k$ where $\mathbf{f}_k = [1, e^{-j2\pi(k-1)/N_c},\cdots,e^{-j2\pi(k-1)\tau_{L-1}/N_c}]^T$ is the corresponding discrete Fourier transform coefficients and τ_ℓ is the integer delay of the ℓ^{th} tap. The correlated channel frequency response can then be given as $\mathbf{H}_k\sqrt{\mathbf{R}_t}$. We assume that the spatial correlation is the same for all subcarriers.

To facilitate OSTBC codeword transmission in the eigenmodes of the correlation matrix, eigen weight mapping is performed across the space dimension of the OSTBC codeword $\{\mathbf{C}_k\}_{k=1}^{N_c}$ prior to transmission. Mathematically, it can be expressed as $\mathbf{W}^H\mathbf{C}_k$, where $\mathbf{W} = [\mathbf{w}_1,\cdots,\mathbf{w}_{N_t}]$ is the eigen weight mapping matrix and $\mathbf{w}_j = \boldsymbol{\upsilon}_j$. Then signal transmission on different eigenvectors of $\mathbf{R}_t$ amounts for transmitting N_t orthonormal beams in the direction of the dominant multipaths seen by the BS. In the case when $\mathbf{R}_t$ is not the same for all subcarriers, beamforming should be performed individually for groups of subcarriers with one coherent bandwidth apart.

At the receiver, discrete Fourier transformation (DFT) is applied to the received signals from N_r antennas. The discrete time baseband equivalent expression of the received signal has the form

$$\mathbf{Y}_k = \mathbf{H}_k\sqrt{\mathbf{R}_t}\mathbf{W}^H\mathbf{C}_k + \mathbf{E}_k \ , \tag{4}$$

where $\mathbf{E}_k$ is the receiver noise matrix and its elements are modelled as uncorrelated white Gaussian random variables having $\mathscr{N}(0,\sigma_n^2)$. At the receiver, channel estimation is performed by correlating pilot tones embedded in the transmitted signal. The result is then fed into the MLD for OSTBC codeword decoding of data symbols by evaluating the decision matrix as follows

$$\widehat{\mathbf{C}}_k = \arg\min_{\mathbf{C}_k\in\boldsymbol{\Upsilon}_k}\|\mathbf{Y}_k - \mathbf{H}_k\sqrt{\mathbf{R}_t}\mathbf{W}^H\mathbf{C}_k\|_F^2 \ . \tag{5}$$

The received ECG information bits are then recovered through baseband demodulation of the estimated space time (ST) codeword $\widehat{\mathbf{C}}_k$. Thus, the resulting quality of the ECG data and the system performance depends on the estimation accuracy of the decision matrix (5)

In Fig. 3 we demonstrated the performance improvement of using the Eigen-OSTBC systems over systems using only OSTBC in a correlated channel environment. It is clearly shown that there is a significant performance difference between these two transmission schemes in the same channel condition (macrocell environment with AS = 7°), where the difference gets larger as the SNR increases.

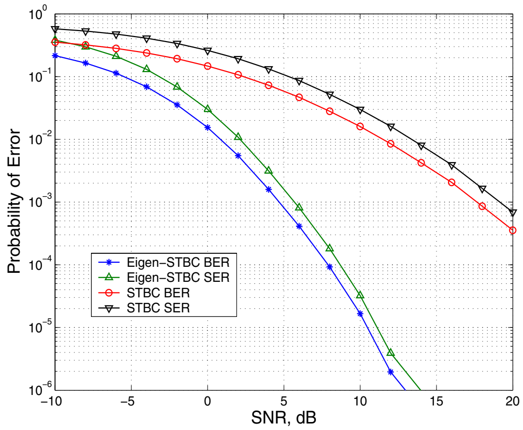

Fig. 3. Simulated error rate performance of the OSTBC and OSTBC-Eigen OFDM systems over GBHDS macrocell channel model deploying ULA antenna at the transmitter with $d = 0.5\lambda$.

III. RESULTS AND DISCUSSION

A normal ECG signal (lead-I) was used to evaluate the performance of the Eigen-OSTBC scheme in telemedicine application. This signal was transmitted over the GBHDS channel model proposed in [8], [9]. The GBHDS channel model was simulated for an urban area according to the measurement data reported in [10], [11]. In this simulation, the path loss exponent n, the number of simulated multipath components L, the angle spread, the controlling parameter a, and the distance between the mobile and the base station, D, were set respectively to 4, 100, 7°, 0.004 and 2 km. The overall communication framework was configured for QPSK baseband modulation. The $\mathscr{G}_4$ encoding matrix in [13] is utilized for OSTBC codeword construction, and hence $N_t = 4$, $N_r = 1$, and $N_c = 512$ were employed for the OFDM system.

Fig. 4 shows the transmitted and the received signals. The transmitted signal was a normal ECG signal. The communication system was configured and simulated for a $SNR = 20$ dB over a GBHDS channel (path loss exponent

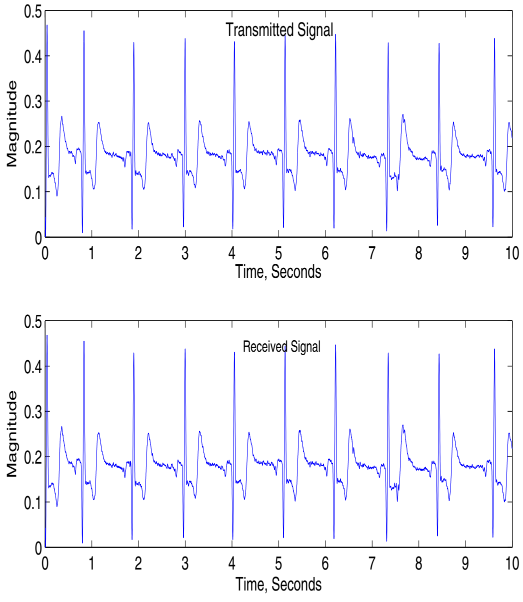

Fig. 4. Transmitted and received signals for a normal ECG Lead-I signal using the Eigen-OSTBC scheme with $SNR = 20$ dB.

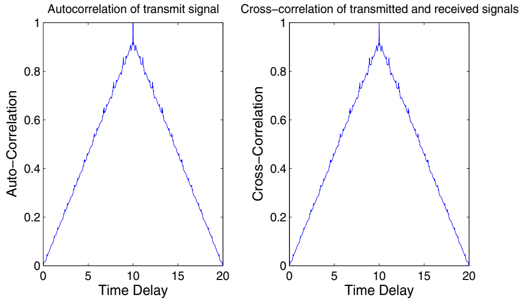

Fig. 5. The autocorrelation of the transmitted signal and the cross-correlation between the transmitted normal ECG signal and the received signal.

$n = 4$) using the Eigen-OSTBC scheme. The autocorrelation of the transmitted signal and the cross-correlation between the transmitted ECG signal and the received signal is shown in Fig. 5. This figure proves that the autocorrelation of the transmitted signal is identical with the cross-correlation of the transmitted and received signal. This confirm that the received signal is highly correlated with the original transmitted signal.

IV. CONCLUSION

In this work, we investigated the performance of the adaptive transmit eigenbeamforming with orthogonal space-time block coding (Eigen-OSTBC) for wireless ECG transmission. This scheme was tested over the GBHDS channel for macrocell environment. The GBHDS model proved to be more realistic when compared against measurement data. Error-free information (signal) at the receiver end is essential in telemedicine application. The results showed that the received signal is highly correlated with the original ECG transmitted signal. It proved that the Eigen-OSTBC scheme is practically suitable for biological signals transmission.

V. ACKNOWLEDGMENTS

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