SOME ADVANTAGES OF MULTI-BEAM TRANSMIT DIVERSITY SCHEME IN WIRELESS COMMUNICATION SYSTEM

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Abstract
In this paper some system performance measures of multi-beam transmit diversity scheme and diversity reception technique are compared. A flat fading Rayleigh multipath channel is assumed, while the noise is supposed to have the Gaussian probability density function on each receive antenna. It is assumed that channel response is known at the receiver side, while the channel experience by each transmit antenna to receive antenna is independent from the channel experience by other transmit antennas. Simulation models are developed using MATLAB, showing BER performance improved when more antennas are present at transmitter or receiver.

Keywords: transmit diversity, receive diversity, beamforming, fading channel, multi-beam.

INTRODUCTION

In mobile wireless communications, a profound understanding and improvement of propagation channel models are very important for system design and related performance analysis. Many modern communication systems, like wireless cellular systems or satellite communication systems operate in environments that are interference and bandwidth limited, where propagation characteristics are more complicated and multipath-induced fading and shadowing are a common problem [1]. A great number of channel models have been proposed to describe the statistics of the amplitude and phase of multipath faded signals [2]. As the result of multipath reception, the mobile antenna receives a large number of reflected and scattered waves [3]. The rapid fluctuations of the instantaneous received signal power due to multipath effects are usually described with Rayleigh, Rician, Nakagami-*m*, Nakagami-*q* or Weibull model [1]. This paper discusses the case of Rayleigh distribution, which models radio transmission in urban areas [1] where the direct LoS (line-of-sight) component between transmitter and receiver doesn't exist and the random fluctuations of the instantaneous received signal power are very frequent and fast.

Several models for simulating Rayleigh fading channel for different propagation conditions have been proposed [2, 6]. Some simulation algorithms used for generation of independent and correlated Rayleigh random variables are presented in [6]. Simulation models proposed for ad hoc mobile wireless networks and mobile-to-mobile communication channels are presented in [7, 8].

In order to combat multipath fading and shadowing effects and also effects of co-channel interference, the complex receiver structures, using complicated synchronization schemes, symbol estimators and diversity and MIMO (Multiple Input Multiple Output) techniques, are often applied [9, 10]. An efficient method for mitigating fading effects by using multiple receiver antennas is called space diversity [1, 4]. The main goal of space diversity techniques is to improve transmission reliability without increasing transmission power and bandwidth while increasing channel capacity. There are several types of space combining techniques that can be generally performed depending on the amount of channel state information (CSI) available at the receiver. The most frequently used space-diversity schemes are: selection combining (SC), equal-gain combining (EGC) and maximal ratio combining (MRC) [1, 3].

MIMO (Multiple Input Multiple Output) antenna diversity systems have reached a great interest in recent years because if their possibility to increase a system performance and capacity [11, 12]. Because of these benefits, MIMO technology becomes an important part of modern wireless communication standards.

The main goal of using multiple antennas at both the transmitter and receiver is to improve communication performance, offering a significant increases in data throughput and link range, without additional bandwidth or additional transmit power [12]. It is realized by spreading the same total transmit power over antennas to achieve an array gain that improves the spectral efficiency or to achieve a diversity gain that improves the link reliability and also to reduce fading [4, 13].

MIMO technique increase either signal-to-noise ratio (SNR) or data throughput for a defined resource, or both [11]. In MIMO system, different signals are transmitted from the antennas at the same time and same frequency, using one of multiple antenna system concepts: diversity mode, spatial division multiplexing and beamforming [13, 14]. In the diversity mode, the same content is transmitted from the antennas with different coding (space-time coding), which leads to SNR increase. Spatial division multiplexing refers to system where different data streams are transmitted from the antennas. The different fading channels make it possible to distinguish between the data streams and thus increase the data rate. Beamforming is a technique where the signals are not transmitted omnidirectionally but where antenna arrays form a beam aimed toward each mobile user, which reduces interference between subscribers [13, 14].

In this paper the performance measures of transmit diversity system and system that uses beamforming scheme are derived and compared with receive diversity system performance measures.

SYSTEM MODEL

The Rayleigh distribution is frequently used to model multipath fading in mobile systems where no LoS path exists between transmitter and receiver antennas. It also applies to the propagation of reflected and refracted paths through the troposphere and ionosphere and ship-to-ship radio links [4].

For simulating the Rayleigh fading effect, each transmitted symbol gets multiplied by randomly varying complex number, which real and imaginary parts are Gaussian distributed variables having mean 0 and variance 0.5. It is assumed that noise on each fading path is independent from the noise on the other fading paths.

In simulation models presented in this paper MIMO systems are analyzed with one or two transmit antenna (L_t=1, 2) and one or two receive antenna (L_r=1, 2) under Rayleigh fading conditions.

When multiple antennas are available at the receiver, the transmission quality can be improved through exploiting receive beamforming, which is useful for uplink, such as from mobile transmitter to base station, as the base station is usually equipped with multiple antennas [13]. Equipping multiple antennas at the mobile terminal may not be practical due to size limitations and complexity constraint. The downlink performance is usually improved using the base station antennas creating transmit beamforming or transmit diversity [14].

When the channel state information (CSI) at the transmitter is known, transmit beamforming can be used to achieve array gain, but no diversity, and when CSI is not available, transmit diversity technique can be used to achieve diversity gain with no array gain.

In this paper the performance of transmit diversity system and transmit beamforming system are evaluated, and also compared to some other techniques used in fading propagation conditions.

It is assumed that the channel is flat fading (which means the channel has only one tap) and the channel experience by each transmit antenna to receive antenna is independent from the channel experience by other transmit antennas.

Each transmitted symbol from i-th transmit antenna to receive antenna gets multiplied by randomly varying complex number h_i. For simulating the Rayleigh fading effect, the real and imaginary parts of h_i are generated as Gaussian distributed variables, having mean 0 and variance 0.5. It is also supposed that the channel parameters h_{ji} are known at the receiver. The effect of additive white Gaussian noise (AWGN) is added at the receiver, having the Gaussian probability density function. It is assumed that noise on each fading path is independent from the noise on the other fading paths.

In transmit beamforming system, signal at the receive antenna is given by:

$$y = \begin{bmatrix} h_1 & h_2 \end{bmatrix} \begin{bmatrix} x \\ x \end{bmatrix} + n = \left(h_1 + h_2\right) x + n \quad (1)$$

where y is the received symbol, x is the transmitted symbol, h_i is the channel state on the i-th transmit antenna, and n is the noise on the receive antenna

When transmit beamforming is applied, the symbol from each transmit antenna is multiplied by a complex number corresponding to the inverse of the phase of the channel so as to ensure that the signals add constructively at the receiver. In this scenario, the received signal is given by:

$$y = \begin{bmatrix} h_1 & h_2 \end{bmatrix} \begin{bmatrix} \exp\left(-j\theta_1\right) \\ \exp\left(-j\theta_2\right) \end{bmatrix} x + n \quad (2)$$

Since $h_1=|h_1|\exp(j\theta_1)$ and $h_2=|h_2|\exp(j\theta_2)$, the received symbol is:

$$y = \left(|h_1| + |h_2|\right) x + n \quad (3)$$

For equalization, the received symbol is divided by new effective channel, and it is given by:

$$\hat{y} = \frac{y}{\left(|h_1| + |h_2|\right)} = x + \frac{n}{\left(|h_1| + |h_2|\right)} \quad (4)$$

In simulation process, the random binary sequence of +1 and -1 is generated, and the symbols are multiplied by a complex number corresponding to the inverse of the phase of the channel. After performing equalization at the receiver and hard decision decoding, the bit error are calculated and plotted for different values of E_b/N_0.

Simulation results are presented in Fig.1, and compared with simulation results presented in [16, 17].

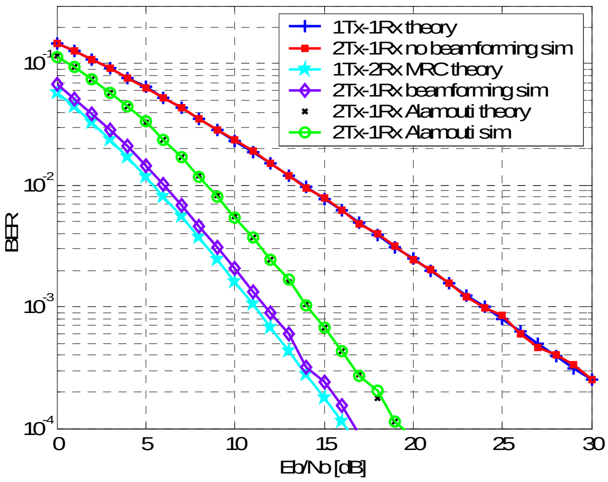

Fig. 1. *BER performance of transmit diversity, transmit beamforming and receive diversity reception with MRC, in Rayleigh fading channel*

Alamouti transmit diversity scheme based on Space Time Block Coding (STBC) is analyzed in [10], while some simulation results are presented in [17]. In Alamouti based transmit system, symbols are grouped (into groups of two), so two time slots are required to send two symbols. Hence, there is no change in the data rate in Alamouti scheme.

In Alamouti STBC, the total transmit power is twice of that used in MRC, since symbols are transmitted from two antennas. In order to make a good comparison, the total transmits power from two antennas in STBC case are scaled to be equal to the power transmitted from a single antenna in the MRC case. With this scaling, BER performance of Alamouti STBC scheme with two transmit and one receive antennas, has a roughly 3 dB poorer performance [17] than MRC diversity system with one transmit and two receive antennas, as it is illustrated in Fig.1.

DISCUSSION OF RESULTS

Simulation results show that sending the same information on two transmit antenna does not provide diversity gain, as it is expected. Due to the fact the effective channel h_1+h_2 in two transmit antenna system without beamforming is again a Rayleigh channel, BER performance is identical to one transmit-one receive antenna system in Rayleigh fading conditions.

In the case when beamforming is applied, the transmit symbols are multiplied by a complex number corresponding to the inverse of the phase of the channel so as to ensure that the signals add constructively at the receiver, and diversity gain is achieved. BER performance is slightly poorer than in one transmit-two receive antenna system with MRC, because the noise is scaled by $|h_1|+|h_2|$ in transmit beamforming system, while the noise is scaled different in receive diversity system using MRC.

The beamforming system uses closely spaced antennas, while transmit diversity uses widely spaced antennas. It is well known that the fading correlation between two antennas decreases as the separation and the angular spread increase. It can be concluded that using closely spaced antennas, the beamformer will achieve most of available array gain, but spacing the antennas relatively far apart will enable the transmit diversity system to operate with uncorrelated fading in significant angular spread conditions. When angular spread is small, the fading will be partially correlated.

CONCLUSION

The objective of this paper is to examine the difference between performance of transmit diversity system and transmit multi-beam scheme, which uses beamforming to point a relatively narrow beam at the mobile station. Both systems are assumed to use the same number of transmit antennas and same transmit power. Simulation results show that beamforming scheme leads to considerable performance improvements, but still inferior to ideal receive diversity system that uses MRC, which offers both diversity and array gain.

The beamforming system is assumed to be designed so that the fading at the antennas is highly correlated for a wide range of angular spreads, and transmit diversity system is designed so that the fading is uncorrelated for all angular spreads in small range. For a given number of antennas and transmitters and for a given fading channel conditions, the system designer may choose to put the antenna close together and form a beam, or to put them far apart and use transmit diversity.

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