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Phase Maximum Ratio Combining Techniques to Reduce Error Probabilityand Increase Capacity Further

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Abstract: Phase maximum ratio combining Technique is introduce as an attractive solution for providing transmission diversity, to combat the adverse effects of fading and enhancing the capacity in various applications. Typically, MRC decoding requires accurate channel state information, which is traditionally estimated through sending periodic training symbols. In this paper a subspace approach is proposed based upon phase of channel fading coefficients for MRC system, in which multiple-input multiple-output (MIMO) channels are partially uncorrelated. Capacity of an Additive White Gaussian Noise (AWGN) channel with Rayleigh fading isstudiedunder an independently identically distributedfading assumption. Indeed, the variations of the phase of the channel are taken into account in this contribution. The received signal at each receive antenna is a linear superposition of the N Received signals perturbed by noise. Maximum likelihood decoding is achieved in a simple way through decoupling of the signals transmitted from different antennas rather than joint detection technique. Simulation results demonstrate BER improvements, up to 2 dB, with different modulation schemes.

Key words: Maximum Ratio Combining (MRC) . Bit Error Rate (BER) . diversity . rayleigh flat fading . channels' capacity

INTRODUCTION

Frequency-selective time-varying fading causes a hazyform to look on a spectrogram. In wireless communications, fading is deviation of the attenuation that a signal experiences aboveconfidentbroadcast media. The fading may vary with radio frequency, topographical position ortime and is regularlydisplayed as a random process [2, 3]. A fading channel is a communication channel that experiences fading. In wireless systems, fading may either be due to multipath spread, to shadowing from obstacles affecting, referred to as multipath convinced and shadow fading, respectively [1-4].

The terms fast and slow fading denote the rate upon which the magnitude and phase change enforced by the channel on the signal modifications. The coherence time is a degree of the minimum time necessitated for the magnitude modification of the channel to become uncorrelated from its prior value. Otherwise, it may be defined as the maximum time for which the magnitude modification of channel is correlated to its prior value [2, 4].

- Slow fading stands up when the coherence time of the channel is large relative to the delay constraint of the channel. In this system, the amplitude and phase modification imposed by the channel can be cogitated coarsely constant over the period of usage. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building whichis often modeled using a log-normal distribution with a standard deviation.
- Fast fading happens when the coherence time of the channel is minor relative to the delay constraint of the channel. In this system, the amplitude and phase modification imposed by the channel varies noticeably over the period of usage.

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In a fast-fading channel, the transmitter may take advantage of the deviations in the channel conditions with time diversity to aidrobustness growth of the communication to a transitory deep fade. While a deep fade may temporarily remove some of the information transmitted, use of an error-correcting code joined with efficaciously transmitted bits during other time instances can allow for the removed bits to be recovered. In a slow-fading channel, it is not probable to utilize time diversity because the transmitter gets only a single recognition of the channel inside its delay constraint. A deep fade consequently lasts the entire duration of transmission and cannot be diminished using coding [1, 7, 9].

As the carrier frequency of a signal is varied, the magnitude of the alteration in amplitude will vary. The coherence bandwidth measures the departure in frequency after which two signals will experience uncorrelated fading [1, 2, 4].

- In flat fading, the coherence bandwidth of the channel is greater than the bandwidth of the signal. Then, all frequency components of the signal will experience the similar magnitude of fading.
- In frequency-selective fading, the coherence bandwidth of the channel is minor than the bandwidth of the signal. Different frequency components of the signal then experience decorrelated fading.

As different frequency components of the signal are disturbed independently, it is greatlyimprobable that all portions of the signal will be instantaneouslydisturbed by a deep fade. Confident modulation schemes such as CDMA and OFDM are well-costumed to using frequency diversity to afford robustness to fading. CDMA uses the Rake receiver to deal with each echo separately [11, 13]. OFDM splits the wideband signal into many slowly modulated narrowband subcarriers, each depicted to flat fading rather than frequency selective fading. This can be opposed by means of error coding, adaptive bit loading orsimple equalization. ISI is evaded by presenting a guard interval between the symbols [6].

The fading effects can be opposed by utilizing diversity to transmit the signal over multiple channels that experience independent fading withmerging them at the receiver. The probability of experiencing a fade in this complex channel is sorelative to the probability which are all the component channels instantaneously experience a fade, however it is unlikely event [1].

Diversity can be achieved inspace, time, orfrequency. Common methods used to overcome signal fading include [1, 4]:

- Diversity reception and transmission
- MIMO
- OFDM
- Rake receivers
- Space-time codes

Arrays of antenna can provide diversity paths to decrease the power of interfering signals at the receiver andconflictingmultipath fading of the desired signals. Thecombining methods considered in this paper is maximal ratiocombining (MRC). A less completedealing of equal-gain combining (EGC) is similarly given.In EGC, all antenna channels have equal gain, butphase variationto match the phase shift in the multipath.WithMRC, gain and phase are controlled.MRC is the optimum linear combining technique for coherentreception with independent fading at each antenna part inthe existence of spatially white Gaussian noise [13]. The complexweight at each partrecompenses for the phase shift inthe channel and is relative to the signal strength. MRC diminishesfading; however, it disregards cochannel interference (CCI) [14].

MRCdenotes a theoretically optimalcombiner over fading channels as a diversity scheme in acommunication system. Notionally, multiple copies of thesame information signal are combined so as to maximize theprompt SNR at the output [15]. But system schemesoften undertake that the fading is independent through multiple diversitychannels. Physical constraints often confine the utilization ofantennaspacingwhich is needed for independent fading throughmultiple antennas [14]. Consequently, it is essential to studyspatial correlation characteristics among antennas.Pierce and Stein have been consideredMRC of correlated fading signalswith binary phase-shift keying (BPSK) in [17] and correlated fadingsignals with PSK modulation has been further considered in [17-20] and newly in [21] where only one distributionfunction is considered for typical antenna configurations.MRC results are given forcomplex Gaussian fading channels with correlated diversityfor BPSK in bothRician and Rayleigh fading which can be usedto a diversity scenario across spacein [20].

The remainder of this paper is organized as follows: A brief introduction of space diversity with resolution methods is presented in Section II. In Section III,some preliminary notions areintroducedwhich are used in proposed scheme. Section IV describes the design of proposedscheme in detail. Simulation and results are discussed in Section V. Finally, conclusions are made in Section VI.

RELATED WORKS

Receiver diversity is a form of space diversity, where there are multiple antennas at the receiver. The presence of receiver diversity poses an exciting problemto use the information from all the antennas to demodulate the data [15-17]. Some of methods are debated like:

- Selection diversity
- Equal gain combining (EGC)
- Maximal Ratio Combining

Maximal ratio combining: In telecommunications, maximal-ratio combining is a method of diversity combining in which [15]:

- The signals from each channel are added together,
- Thegain of each channel is made proportional to the RMSsignal level and inversely proportional to the mean square noise level in that channel.
- Different proportionality constants are used for each channel. It is also known as ratio-squared combining and predetection combining. Maximal-ratio-combining is the optimum combiner for independentAWGN channels.

For the discussion, the channel state is assumed a flat fading Rayleigh multipath channel and the modulation is BPSK and the other assumptions are as follows:

- This system has N receive antennas and one transmit antenna.
- The channel is flat fading-In simple terms, it means that the multipath channel has only one tap. So, the convolution operation reduces to a simple multiplication.
- The channel experienced by each receive antenna is randomly varying in time. For the i receive antenna, each transmitted symbol gets multiplied by a randomly varying complex number . As the channel under consideration is a Rayleigh channel, the real and imaginary parts of are Gaussian distributed having mean μh_i = and variance $\sigma_{h_i}^2$ =.
- The channel experience by each receive antenna is independent from the channel experienced by other receive antennas.
- On each receive antenna, the noisen has the Gaussian probability density function with $p(n) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(n-}{2\sigma}}$ with $\mu = 0$ and σ^2 =
- The noise on each receive antenna is independent from the noise on the other receive antennas.
- At each receive antenna, the channel is known at the receiver.
- In the presence of channel , the instantaneous bit energy to noise ratio at i receive antenna is $\frac{E_b|h}{N_i}$. For notational convenience [2], let us define,$\gamma_i = \frac{E_b|h}{N_i}$

Expressing it in matrix form, the received signal is,

- y = hx+, where
- y = [$y_1 y_2 \ldots y_N$ is the received symbol from all the receive antenna

- $h = [h_1 h_2 \ldots h_N$ is the channel on all the receive antenna
- x is the transmitted symbol and
- $n = [n_1 n_2 \ldots n_N$ is the noise on all the receive antenna.
- The equalized symbol is,
- It is intuitive to note that the term,
- $h^H h = \sum_{i=1}^{N} |h_i$ sum of the channel powers across all the receive antennas.

Effective Eb/No with maximal ratio combining: Earlier, we noted that in the presence of channel , the instantaneous bit energy to noise ratio at i receive antenna is

$$\gamma_i = \frac{E_b |h}{N_i} \tag{1}$$

Given that we are equalizing the channel with i, with the receive antenna case, the effective bit energy to noise ratio is,

$$\gamma = \sum_{i=1}^{N} \frac{E_b |h}{N_i} = N \tag{2}$$

Bit error rate for BPSK modulation: Now the theoretical equation is derived for bit error rate (BER) with Binary Phase Shift Keying (BPSK) modulation scheme in Additive White Gaussian Noise (AWGN) channel.
The conditional probability distribution function (PDF) of y for the two cases is:

$$\{p(y|s_0) = \frac{1}{\sqrt{\pi No}} e^{\frac{-(y+\sqrt{E}}{No}}$$

$$p(y|s_1) = \frac{1}{\sqrt{\pi No}} e^{\frac{-(y+\sqrt{E}}{No}} \} \tag{3}$$

Probability of error given s_1 was transmittedwith this threshold, the probability of error given s_1 is transmitted is

$$p(e|s_1) = \frac{1}{\sqrt{\pi No}} \int_{-\infty}^{0} e^{\frac{-(y-\sqrt{E}}{No}} dy = \frac{1}{\sqrt{\pi}} \int_{\sqrt{\frac{Eb}{No}}}^{\infty} e^{-z^2} dz = erfc(\sqrt{}) \tag{4}$$

where erfc $(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-}$ dx is the complementary error function.Probability of error given s_0 was transmittedsimilarly the probability of error given s_0 is transmitted is (the area in green region):

$$p(e|s_0) = \frac{1}{\sqrt{\pi No}} \int_{0}^{\infty} e^{\frac{-(y+\sqrt{E}}{No}} dy = \frac{1}{\sqrt{\pi}} \int_{\sqrt{\frac{Eb}{No}}}^{\infty} e^{-} dz \tag{5}$$

Total probability of bit error is given by:

$$P_b = erfc(\sqrt{}) \tag{6}$$

PRELIMINARIES

It was shown that, in the presence of channel , the effective bit energy to noise ratio is $\frac{E_b |}{N}$.
The bit error probability for a given value of is

$$P_{b|h} = \frac{1}{2} erfc\left(\sqrt{\frac{E_b |h|^2}{N_0}}\right) = \frac{1}{2} erfc(\sqrt{} \tag{7}$$

The resulting BER in a communications system in the presence of a channel , for any random values of |h, must be calculated evaluating the conditional probability density function P_i over the probability density function of .

$$P_b = \int_0^{\infty} \frac{1}{2} erfc(\sqrt{\gamma}) p(\gamma) \quad (8)$$

Where,the probability density function of γ is $P(\gamma) = \frac{1}{\bar{\gamma}} e^{\frac{-\gamma}{\bar{\gamma}}}, \gamma \geq$ and = .

First, we are going to derive the result for the definite integral using a different notation and then we will apply the result to the concrete expression obtained for the BER [24, 25, 27]. With the above demonstration, we can easily derive the BER for a Rayleigh channel using BPSK modulation:

$$P_b = \frac{1}{2\bar{\gamma}} \int_0^{\infty} erfc(\sqrt{\gamma}) e^{-\frac{\gamma}{\bar{\gamma}}} = \frac{1}{2}(1 - \sqrt{\frac{\bar{\gamma}}{\bar{\gamma}+}} = \frac{1}{2}(1 - \sqrt{\frac{(E_b/N_0)}{(E_b/N_0)+}} \quad (9)$$

In continue this formula is used to evaluate the performance of proposed scheme. The discrete-time channel with Additive White Gaussian noise (AWGN) model is expressed by

$$V_t = U_t + N_t, \quad (10)$$

where U_t is the channel input, V_t is the channel output and N_t is an AWGN random variable with mean zero and variance N_0 at time t. Then the channel capacity, which is defined to be an upper bound for the data rate that can be attained with anrandomly small error probability in an AWGN channel, is given by [8]:

$$C = B\log_a(1 + ?) \quad (11)$$

where a is a positive real number and C is the channel capacity defined in bits per second (bps) when a = 2or nats per second where a = e. In the next discussion, nats per second isused as the unit of channel capacity.A radio channel achieves an enormously random characteristic, which does not permit to use the simple AWGN channel model referenced above to consider the channel capacity.Radio signals broadcast oftenhave large-scale shadowing, small-scale fading andattenuation. Large-scale shadowing of a signal is essentially caused by multiple reflections and diffractions of the signal while propagating, whose characteristics can be taken with a log-normal distribution. Small scale fading of a signal is caused by multiple versions of a transmitted signal with different delay times like that it has both time and location varying property. It was evidenced that these three effects are independent. Signal attenuation is mostlyannounced by the distance between the transmitter and the receiver, which can be calculated by a deterministic model. One type of channels with the fading effect caused by the mu lti-path time delay spread is flat fading channels in which the period of the transmitted signal is larger than the multi-path delay spread. Since the received signal power varies considerably in a flat fading channel, it is critical to exactly capture the distribution of the channel gain for designing a radio communication system [9]. The most common used signal amplitude distribution in flat fading channels is the Rayleigh distribution, which is the focus of this paper.

PROPOSED SCHEME

In this method, the main focus is on the channel components to reach better response with fewer errors. The idea of multi antenna network is originally investigated by MRC. The proposed method is a diversity combining is designed in a matrix form. For optimal design of code matrix, it is necessary to present a suitable technique for decreasing the probability of errors. In all manuscripts in the relevant literature, all code matrixes present the channel parameters, but none has ever considered diversity combining for phase manipulation phenomenon. In this context the output matrix is totally discarded which causes the reduction in complexity further.

Accordingly, by using channel coefficient matrix with symbol matrix and employing the MRC detector, the transmitted symbols are smeared out at the receiver. Therefore, the actual phase coded symbols for the two transmitting antennas are defined as:

$$\begin{bmatrix}\tilde{y_1}\\ \tilde{y_2}\end{bmatrix} = \begin{bmatrix}h1^* & 0\\ 0 & h2^*\end{bmatrix} \times \begin{bmatrix} \\ \end{bmatrix} \quad (12)$$

At this point, it should be noted that the difference between this scheme and MRC scheme is; in MRC, any received signals are Combined with conjugated channel coefficient by every antennas, but in this scheme any received signals are Combined with the phase of conjugated channel coefficient by every antennas. Therefore, the transmission rate in both cases is unity. Indeed, in the proposed scheme at the receiver, a large amount of power for every antenna can be observed causing the reduction of errors for every receiver antennas in the system, i.e.:

$$\tilde{s_i} = \sum_{i=1}^{M}(s_i h_i + n_i)e^{-j} \quad (13)$$

Now to add further antennas the following precoder is designed as:

$$\hat{H} = \begin{bmatrix} e^{-j\theta_{h1}} & \cdots & 0\\ \vdots & \ddots & \vdots\\ 0 & \cdots & e^{-j\theta_{hM}} \end{bmatrix} \quad (14)$$

$$\begin{bmatrix}\tilde{y_1}\\ \vdots\\ \tilde{y_{M_R}}\end{bmatrix} = \begin{bmatrix} e^{-j\theta_{h1}} & \cdots & 0\\ \vdots & \ddots & \vdots\\ 0 & \cdots & e^{-j\theta_{hM_R}} \end{bmatrix} \times \begin{bmatrix} y_1\\ \vdots\\ y_{M_R}\end{bmatrix} \quad (15)$$

It was shown that, in the presence of channel , the effective bit energy to noise ratio is $\frac{E_b|}{N}$.

Analysis of theoretical bit error probability: The bit error probability for a given value of is,

$$P_{b|h} = \frac{1}{2}erfc\left(\sqrt{\frac{E_b|h|^2}{N_0}}\right) = \frac{1}{2}erfc(\sqrt{} \quad (16)$$

Where in this scheme is

$$\gamma = \frac{E_b|}{N} \quad (17)$$

The resulting BER in a communications system in the presence of a channel , for any random values of |h, must be calculated appraising the conditional probability density function P over the probability density function of .

$$P_b = \int_0^\infty \frac{1}{2}erfc(\sqrt{\gamma})p(\gamma) \quad (18)$$

Where,the probability density function of γ is

$$P(\gamma) = \frac{1}{(N-1)!(E_b/N_0)^N} e^{\frac{-\gamma}{\bar{\gamma}}}, \ \gamma \geq \text{ and } = .$$

First, the result will bederivedfor the definite integral using a different notation and then will be employed the result to the concrete expression obtained for the BER. With the above demonstration, the BER for a Rayleigh channel using BPSK modulation is given by:

$$= \text{erfc}(\sqrt{}) \quad (19)$$

$$P_e = \frac{1}{2\bar{\gamma}}\int_0^\infty erfc(\sqrt{\gamma})\frac{1}{(N-1)!(E_b/N_0)^N}\gamma^{N-1}e^{-\frac{\gamma}{\bar{\gamma}}} \quad (20)$$

$$P_s = p^N \sum_0^{\infty} \binom{N+k-1}{k} (1-p)^k \quad (21)$$

Given that the effective bit energy to noise ratio with maximal ratio combining is , the total bit error rate is the integral of the conditional BER integrated over all possible values of [26, 27].

Analysis of theoretical channels' capacity

$$V_t = \sqrt{A_t}\exp(j\varphi)\,U_t + \quad (22)$$

where V_t, U_t and N_t are the same as defined in Eq.(22) $\sqrt{A_t}\exp(j$ is a complex channel gain with amplitude A_t and ? at time t. The phase ? is uniformly distributed in [0, 2p) and the signal amplitude is a random variable with a flat static Rayleigh probability density function. At is mentioned as the channel power gain with the time -varying property, which is independent of the channel input U_t and could be both independent or correlated over period of time.

A_t is constant over T = 1 symbol period time units and after T time units, A_t is changed to an independent value along with some density function. The channel bandwidth and the power spectral density of the noise are B and N_0, respectively. The instantaneous SNR at time t is given by Eq.(17).

Notionally, $?_t$ is larger than or equal to zero and does not have an upper bound since the range of the signal amplitude A_t is between zero and infinity.

The distributions of A_t and $?_t$ are both determined and the mean ? of SNR is given byEq.(17) where A is the mean of the channel power gain A_t.The channel capacity is considered for the case that channel distribution information (CDI) is known by the receiver and temporarily, the instantaneous signal amplitude is known at the receiver at time t. So is $?_t$. There can be assumed the Shannon capacity. Shannon capacity is the maximum data rate that can be transmitted over the radio channel with small error probability, thus is also appealed the ergodic capacity. The maximum data rate can be attained after the channel has experienced all possible fading states throughadequately long sending time, which can be said as follows in the unit of nats per second [9].

$$C_s = \int_0^{+\infty} B\,log_e(1+\gamma)p(\gamma) \quad (23)$$

where p(?) is the pdf of the channel SNR $?_t$, which is determined by the channel power gain A_t. The time t can be ignored since the channel is noticed in steady state. The logarithmic function curve gives rise to

$$C_s \le Blog_e(1+ \quad (24)$$

By smearing the Jensen's Inequality [6]. Eq. (23) leads to the conclusion that the Shannon capacity of a fading channel with CSI known by the receiver is less than the Shannon capacity of an AWGN channel with the SNR ? [29].

SIMULATION RESULTS

In this section, the Simulations carried out for SIMO systems with a varying number of transmit/receive antennas is performed based upon different types of transmitted CSI. The transmit symbols are equally distributed based upon anBPSK constellations. The transmit power across all transmit antennas is set to one. Regarding the channel, it is a flat fading static SIMO channel and the transmitted data packets are assumed to be fixed. Hence the parameters to be analyzed for the system performance are the bit error rate and throughput. They are both discussed as follows:

BER performance: Primarily, the simulation is carried out for two receive and one transmitantennas considering the rate one MRC techniques and also it is assumed that the two received antennas are completely uncorrelated.

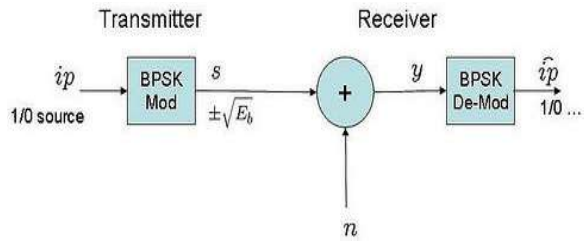

Fig. 1: Simplified block diagram with BPSK transmitter-receiver

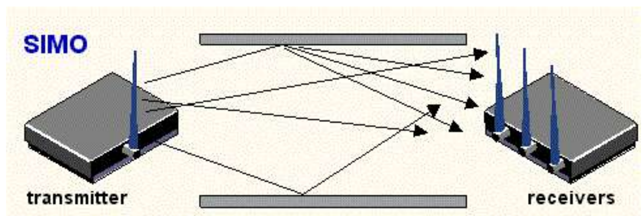

Fig. 2: Block diagram of SIMO channel

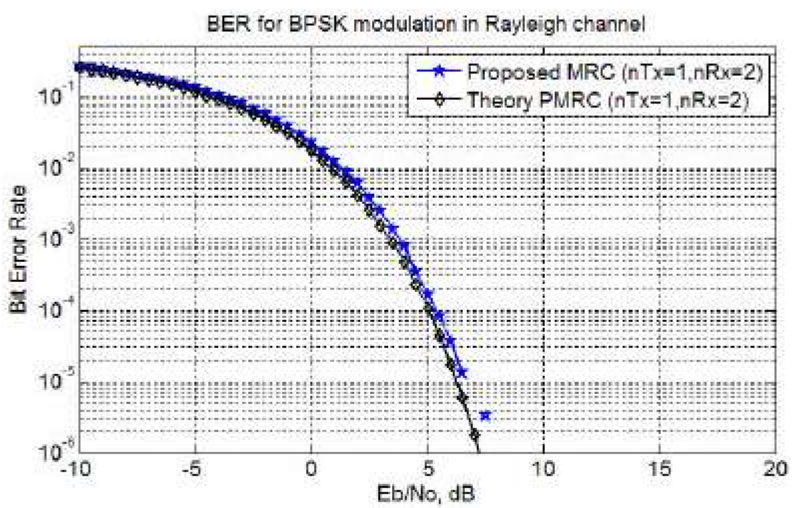

Fig. 2: BER performance comparison for simulation PMRC and theoretical MRC with bpsk modulation scheme

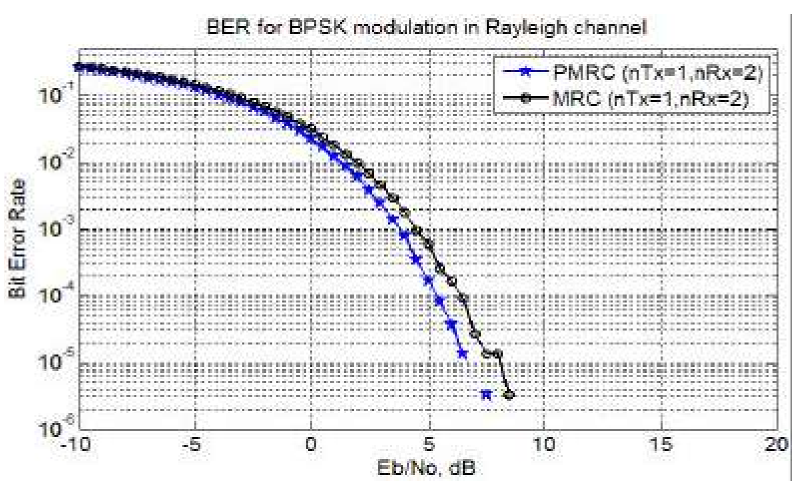

Fig. 3: BER performance comparison for PMRC and normal MRC with bpsk modulation scheme

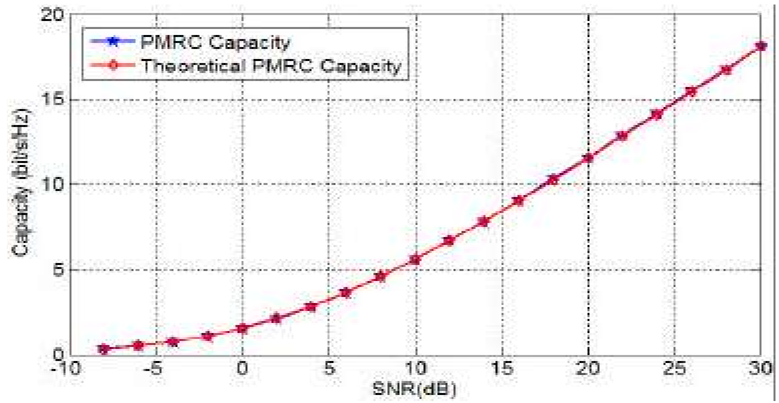

Fig. 4: Capacity performance comparison for simulationPMRC and theoretical MRC with bpsk modulation scheme

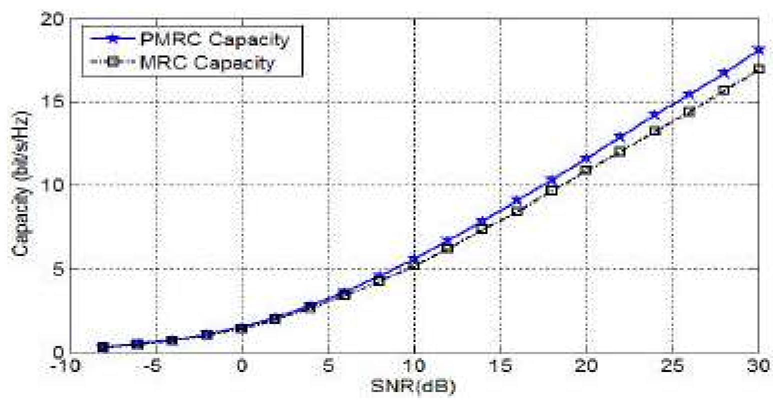

Fig. 5: Capacity performance comparison for PMRC and normal MRC with bpsk modulation scheme

Fig. 2 depicts the BER performance for the proposed, theoretical schemes considering the receiver to have the full channel CSI. And Fig. 3 depicts the BER performance for the proposed, MRC schemes.With a small diversity order, there is a gain of 2 dB for the entire available SNR.

Capacity performance: In this section, it is easy to prove the following results. Figure 4 depicts the Capacity performance for the proposed PMRC, theoretical schemes considering the receiver to have the full channel CSI. And Fig. 5 depicts the Capacity performance for the PMRC and MRC schemes.With a small diversity order, there is a gain of 2 dB for the entire available SNR.

CONCLUSIONS

This contribution improves the theory of MRC by introducing the channel coefficient phase back into the receivers. It is simple and elegant methods for transmission with multiple receive antennas for a wireless fading environment. The proposed MRC scheme can employ a very simple maximum-likelihood decoding algorithm (i.e. a linear process) for the decoding procedure part. Moreover, this scheme exploits the full diversity given by transmit and receive antennas. Furthermore, applying the proposed method, up to 2 dB better BER performance is achieved when it is compared with a normal MRC scheme. For the future research on this subject, the capacity and the power consumption relationships are the parameters to work on with a particular attention that the system requires the channel coefficient information at the transmitters.

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