

Performance Analysis of a Hybrid SEC/MRC Diversity Scheme over Rayleigh Fading

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Abstract – Diversity is an effective technique to improve wireless communication performance. In this paper, we propose a dual hybrid diversity scheme in which connected branches are switched in order to determine whether a dual branch should be combined via maximal-ratio combining (MRC) in multi-branch. This scheme provides improved performance along additional diversity branch available, without requiring a signal power. Also, it achieves additional performance gain by adaptive switching thresholds. We find a threshold according to the transmit signal power for a switching criterion of diversity branches. This information is then used to obtain the bit error rate in multi-branch with the proposed scheme. In particular, we consider the independent and identically distributed (i.i.d.) Rayleigh fading on each diversity branch. Finally, we discuss the results through simulations.

Keywords – diversity combining, switched diversity, maximal ratio combining, hybrid diversity scheme, Rayleigh fading

I. INTRODUCTION

In wireless communication, robustness against fading is the most important issue for reliable communication. Diversity is one of the most attractive techniques to mitigate the deleterious fading effects [1]. This technique requires available resources, like frequency or time, in order to be applied a wireless communication system. It can be used as various methods, likely interleaving for time diversity, frequency hopping spread spectrum for frequency diversity, rake receiver for multipath diversity and so on. In variety diversity combining schemes, spatial diversity based on multiple-antenna is a very efficient scheme because additional resources are not required to achieve diversity gain [2].

In spatial diversity, a switched diversity scheme is the preferable scheme for its simpler design in comparison to those of other schemes since only one diversity branch is connected to the radio frequency (RF) and receiver chain [3]. A switched diversity scheme uses the current branch as long as it is acceptable until the signal power falls below a predetermined threshold, at which time the receiver switches to another diversity branch. The transmit switched diversity scheme requires similar steps but it requires channel state information through the feedback channel.

Switched diversity mainly focuses on the system design and performance analysis of dual-branch switched diversity over

fading channels. Recently, a multi-branch switched diversity system based on a fixed switching threshold was studied and discussed in [4]. It was shown that a switched-examine-combining(SEC) scheme improves the performance along additional diversity branches in [5]. On the contrary, a switched-stay-combining(SSC) does not receive any additional gain when the number of diversity branches increases.

In a subset of the available diversity branches with limited resources, the SEC scheme is adequate for the criteria of selecting branches based on the signal-to-noise ratio(SNR) with a low complexity combining system in comparison to the conventional hybrid selection/maximal ratio combining diversity system. In this paper, we present a dual hybrid switch-examine-combining/maximal ratio combining(SEC/MRC) diversity scheme for use in a multi-branch system and evaluates adaptive switching thresholds and its bit error rate by simulation.

This paper is organized as follows. Section II shows conventional diversity schemes. Section III presents the proposed system and channel models. Section IV describes adaptive switching thresholds and the bit error rate according to the fading model. Finally, conclusions are given in Section V.

II. DIVERSITY METHOD

A. Maximal Ratio Combining

MRC is an optimal combination method for multiple copies of the receive signal to maximize SNR. In MRC, the output is a weighted sum of all branches, so the weighted values are all nonzero. On the i_{th} receive antenna, the received signal y_i is expressed as

$$y_i = h_i x + n_i \quad (1)$$

where h_i , denoted by $h_i = \alpha_i e^{j\theta_i}$ where θ_i is the phase of the incoming signal on the i_{th} branch, is the channel between the transmit antenna and the i_{th} receive antenna, x is the transmitted symbol and n_i is the additive white Gaussian noise (AWGN) with two-sided spectral density of

$N_0/2$ on i_{th} receive antenna. The receiver combining scheme for the MRC is as follows:

$$\hat{x} = \frac{\mathbf{h}^H \mathbf{y}}{\mathbf{h}^H \mathbf{h}} = \frac{\mathbf{h}^H \mathbf{x}}{\mathbf{h}^H \mathbf{h}} + \frac{\mathbf{h}^H \mathbf{n}}{\mathbf{h}^H \mathbf{h}} = x + \frac{\mathbf{h}^H \mathbf{n}}{\mathbf{h}^H \mathbf{h}} \quad (2)$$

where $\mathbf{h} = [h_1 \ h_2 \ \dots \ h_N]^T$ is the channel on all of the receive antennas, $\mathbf{y} = [y_1 \ y_2 \ \dots \ y_N]^T$ is the received symbol from all of the receive antennas, $\mathbf{n} = [n_1 \ n_2 \ \dots \ n_N]^T$ is the AWGN on all the receive antenna where N is the number of receive antennas. It is intuitive to note that $\mathbf{h}^H \mathbf{h} = \sum_{i=1}^N |h_i|^2$ is the sum of the channel powers across all the receive antennas. Assuming the same noise power spectral density $N_0/2$ in each branch a total noise power spectral density of $N_{tot}/2 = \sum_{i=1}^N h_i^2 N_0/2$ is observed. Thus, the probability density function(PDF) of the output SNR is given by [7]

$$f(\gamma) = \frac{\gamma^{N-1} e^{-\gamma/\bar{\gamma}}}{\bar{\gamma}^N (N-1)!}, \quad \gamma \geq 0 \quad (3)$$

where $\bar{\gamma}$ is the average SNR of each branch.

B. Switched Diversity Combining

Switched diversity combining is a practical implementation of the selection diversity scheme. In SEC, a solution based on low/cheap complexity for fading mitigation can be achieved because the signal from only one antenna is fed to the receiver for as long as the quality of that signal remains above a predetermined threshold.

The receiver switches a branch between the available diversity branches and monitors only the currently connected branch. When the currently connected received signal power falls below the present power threshold, this branch becomes unacceptable and branch switching occurs. In the SSC scheme case, the receiver settles on the next antenna, no matter which channel states correspond to the branch. However, in the SEC scheme case, the receiver examines the switched antenna signal power to recognize the channel states corresponding to the branch. If this power is below the threshold, the receiver continues to switch until it finds an acceptable branch or all antenna branches have been examined. In the latter case, the last examined branch or the initial branch is chosen for the next transmission, both of which provide the same performance.

Let $\gamma(n)$ be the signal power at the receiver after switched diversity scheme is applied at time n , $\gamma_i(n)$ be the signal power at the i_{th} receiver antenna, and γ_T be the predeter-

mined threshold. Then, the SEC scheme process can be described as follows:

$$\gamma(n) = \gamma_i(n) \text{ iff}$$

$$\gamma(n-1) = \gamma_i(n-1) \text{ and } \gamma_i(n) \geq \gamma_T$$

or

$$\gamma(n-1) = \gamma_i(n-1) \text{ and } \gamma_k(n) < \gamma_T, k = 0, \dots, L-1$$

or

$$\gamma(n-1) = \gamma_{((i-1))_L}(n-1) \text{ and}$$

$$\gamma_{((i-1))_L}(n) \leq \gamma_T \text{ and } \gamma_i(n) \leq \gamma_T$$

or

$$\gamma(n-1) = \gamma_{((i-j))_L}(n-1) \text{ and } \gamma_{((i-j+k))_L}(n) \leq \gamma_T,$$

$$k = 0, \dots, j-1 \text{ and } \gamma_i(n) \geq \gamma_T$$

or

$$\gamma(n-1) = \gamma_{((i-1))_L}(n-1) \text{ and } \gamma_{((i-1+k))_L}(n) \leq \gamma_T,$$

$$k = 0, \dots, L-2 \text{ and } \gamma_i(n) \geq \gamma_T$$

where $i = 0, \dots, L-1$ and $((i-1))_L$ denotes the $i-1$ modulo L . For i.i.d. Rayleigh fading channels, the PDF of the output SNR for the SEC system, $f_{\sum}(\gamma)$, is given by [5]

$$f_{\sum}(\gamma) = \begin{cases} [F(\gamma_T)]^{L-1} f(\gamma), & \gamma < \gamma_T \\ \sum_{i=0}^{L-1} [F(\gamma_T)]^i f(\gamma), & \gamma \geq \gamma_T \end{cases} \quad (4)$$

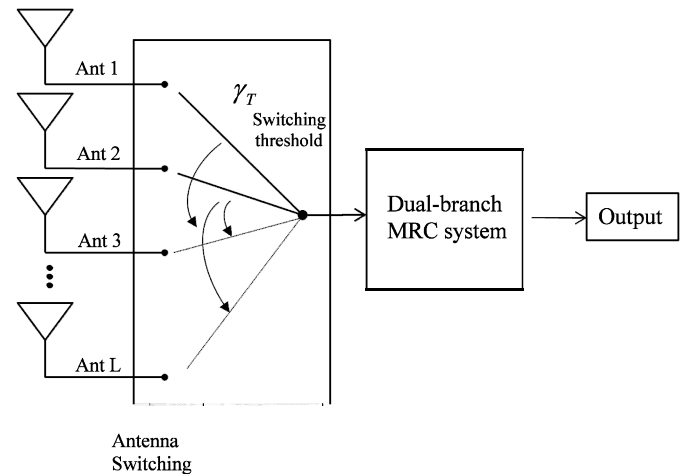


Figure 1. Dual SEC/MRC system receiver with L diversity branches.

where $f(x)$ and $F(x)$ are the PDF and the cumulative distribution function of a single branch, respectively.

III. SYSTEM AND CHANNEL MODEL

Consider a system model with L diversity branches in which i.i.d. Rayleigh fading on each branch. Let γ_n denote the instantaneous received SNR of the n th diversity branch, where $n = 1, 2, 3, \dots, L$. Conventional switched diversity schemes are switched to a single diversity branch when γ_n falls below γ_T , denoted by a fixed switching threshold.

Unlike the conventional system, the proposed scheme switches to multi-branch operation in order to decide upon a dual diversity branch to be combined by MRC, as shown in Figure 1. The instantaneous receive SNR of the n th branch is compared with a fixed switching threshold for each diversity branch but is adaptively updated according to its transmit power. Since we assume that the receiver has knowledge of the channel, the effects of imperfect channel estimates are not considered.

Branch switching is only executed during guard periods. In this time, the receiver estimates channel states corresponding to the current branch and performs a comparison with the switching threshold. It concludes a switching decision based on the comparison results and then may perhaps switch depending upon the switching decision. It is assumed that the data signal experiences approximately the same fading as its preceding guard period and that fading conditions during successive guard periods are nearly independent.

Unlike the Gaussian channel, the Rayleigh fading channel is an appropriate model within a general radio propagation environment. In order to analyze the performance of the proposed system, we consider Rayleigh fading channel. The probability density function of the Rayleigh distribution is expressed as

$$p(x) = \frac{1}{\bar{\gamma}} \exp\left(-\frac{x}{\bar{\gamma}}\right), \quad x \geq 0 \quad (5)$$

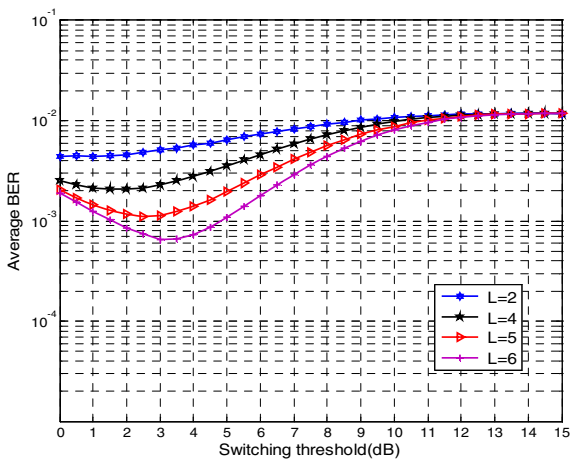


Figure 2. BER of BPSK with SEC/MRC over L multi-branch over Rayleigh fading as a function of switching threshold with $E_b/N_0=10$ dB

where $\bar{\gamma}$ is the average channel SNR [8].

IV. SIMULATION RESULTS

This section discusses the switching criteria threshold in order to enhance the bit error rate performance. The bit error rate is also evaluated according to the number of diversity branches with adaptive thresholds.

Figure 2 shows the bit error rate performance of the system using BPSK modulation over the i.i.d. Rayleigh fading channel at $E_b/N_0 = 10$ dB with a linearly increasing switching threshold. The most improved bit error rate performance is presented at a threshold power lower than the signal power, and as the number of branches increase, the threshold power making the improved bit error rate performance is increased. Also, a threshold causes rapid changes in bit error rate

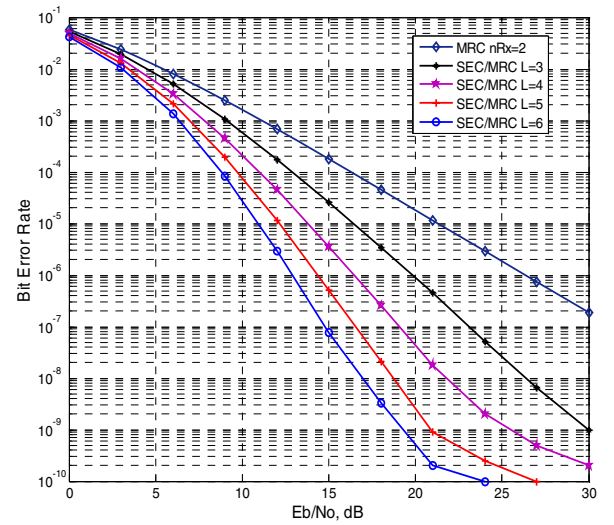


Figure 3. BER of BPSK with dual SEC/MRC with L branches over i.i.d. Rayleigh fading as a function of E_b/N_0 with $\gamma_T = 5$ dB.

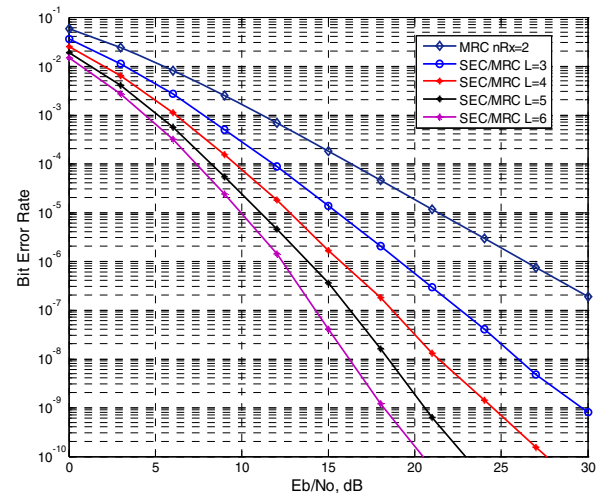


Figure 4. BER of BPSK with dual SEC/MRC with L branches over i.i.d. Rayleigh fading as function of E_b/N_0 with adaptive γ_T .

performance as the number of branches increase, which causes the additional branches to pass through the i.i.d. fading channel.

Figure 3 shows the bit error rate performance of BPSK with the proposed scheme and a switching threshold set to 5 dB over the i.i.d. Rayleigh fading channel versus that of E_b / N_0 . For a specific switching threshold, increasing the number of branches leads to a relatively significant, but reduced performance gain in the medium E_b / N_0 region. However, as the E_b / N_0 becomes very small (i.e. below 5 dB) or sufficiently large, the bit error rate improvement decreases, because all curves converge asymptotically. This causes the E_b / N_0 to be small in comparison to the switching threshold, indicating that most branches will often possess unacceptable power, and the additional branches will not be able to provide improvements. If the E_b / N_0 is very high in comparison to the switching threshold, all branches will receive acceptable power, and the combiner will typically use the first and second branches. Thus, the additional branches also do not contribute.

Figure 4 shows the bit error rate performances of the system using BPSK modulation over the i.i.d. Rayleigh fading channel with branch numbers of 2, 3, 4, 5, and 6. As shown in the figures, the adaptive switching threshold enhances the BER performance over all regions of average SNR.

V. CONCLUSIONS

This paper has proposed a hybrid SEC/MRC diversity scheme for combining a dual branch selected by using an SEC scheme. Also, bit error rate performance has been evaluated according to the number of diversity branches with a fixed and adaptive threshold in the i.i.d. Rayleigh fading channel employing BPSK. As a result, we show the effects of additional branches and switching threshold, which improves the bit error rate performance.

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