Bit Error Rate Performance of a Generalized Diversity Selection Combining Scheme in Nakagami Fading Channels

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Abstract- **The severity of fading on mobile communication channels calls for the combining of multiple diversity sources to achieve acceptable error rate performance. Traditional approaches perform the combining of the different diversity sources using either: the Conventional Selective diversity combining (CSC), Equal-Gain combining (EGC), or Maximal-Ratio combining (MRC) Schemes. CSC and MRC are the two extremes of compromise between performance quality and complexity. This paper presents a generalized diversity selection combining (GSC) scheme in which only those diversity branches whose energy levels are above a specified threshold are combined. Doing so, the proposed scheme will have a bit error (BER) performance that is upper- and lower- bounded by those of the CSC and MRC schemes respectively. Simulation results for the performances of this scheme over Nakagami Fading Channels are shown.**

I. INTRODUCTION

Diversity techniques are based on the notion that errors occur in reception when the channel is in deep fade -a phenomenon that is more pronounced in mobile communication channels. Therefore, if the receiver is supplied with several replicas, say L, of the same information signal transmitted over independently fading channels, the probability that all the L independently fading replicas fade below a critical value is p^L (where p is the probability that any one signal will fade below the critical value). The BER of the system is thus improved without increasing the transmitted power.

The most crucial issue in diversity system however is how to combine the available diversity branches to achieve optimum performance. The three traditional combiners are: **Conventional Selective combiner (CSC)** which selects the signal from that diversity branch with the largest instantaneous SNR; **Equal-Gain combiner (EGC)** which coherently combines all L diversity branches weighting each with equal gain; and **Maximal-**

Ratio combiner (MRC) which coherently combines all L diversity branches but weighs each with the respective gain of the branch. CSC gives the most inferior BER performance, MRC gives the best and the optimum performance, and EGC has a performance quality in between these two[1, 2, 3].

It is clear that CSC and MRC represent the two extremes of complexity quality trade off. CSC on one end, is extremely simple, requiring only a comparator circuit to decide on the best received branch. But the contribution from the other branches are wasted, regardless of how strong they may be. On the other end, MRC combines the outcome of all branches, regardless of how poor some of them may be, resulting in the best possible combining performance gain. The cost for this optimum performance is the extremely complicated circuitry required for phase coherence and amplitude estimation on each branch including the redundant (low SNR) ones. It should also be noted that the lower the SNR the less efficient the phase and amplitude estimation circuit will be. Hence, a combining scheme that eliminates the weak signals (in terms of energy level) prior to co-phasing and amplitude estimation will save unnecessary complications at the expense of no appreciable quality deterioration.

The author in [4] proposes a scheme which combines a fixed number of branches, say M, that have the largest instantaneous SNR out of the L available branches. As M can be chosen from the range $1 \leq M \leq L$, the scheme was called a generalized diversity selection combining (GSC) scheme. $M = 1$ corresponds to CSC, while $M = L$ corresponds to MRC. Here we refer to that scheme as M-GSC (i.e. M-based GSC).

Combining a fixed number of branches however, has obvious shortcomings. At times of deep fade, some of the M selected branches will have marginal contribution to the total energy and they could be discarded. At other times (e.g. when the channel fading level improves), some of the $L-M$ discarded branches, although inferior to the M selected branches, have significant contribution and combining them will be advantageous. When M is fixed this improvement in channel condition cannot be reflected in the system performance as the remaining $L-M$ branches will have to be discarded regardless of their energy levels. This makes the scheme in [4] not very suitable for use in a channel that improves or degrades from time to time (as is the case in mobile communication channels).

This paper proposes a generalized diversity selection combining scheme that combines diversity branches based on the energy levels received from the branches at each time instant, making it possible to reflect improvement in channel condition in the system's performance at any time. The proposed system is therefore most appropriate for use in mobile communication channels, as well as other channel types. The rest of this paper is organized as follows: In section II we present the concept of the proposed GSC scheme, Section III discusses the simulation results for the system's performance in different fading channels, and section IV draws the conclusions of this work.

II. SYSTEM CONCEPT

It is assumed that each of the L diversity branches experiences Nakagami m-fading; that the fading process on the L branches are mutually statistically independent, and that an additive white Gaussian noise process corrupts the signal on each diversity branch. It is assumed also that these additive noise processes are mutually statistically independent.

The proposed scheme will combine diversity branches based on a criterion which we call the branch relative strength (BRS) . The BRS is the ratio of the SNR of each branch to the SNR of the best branch at the same instant of time.

$$BRS_i = \frac{SNR_i}{SNR_{max}} \qquad i = 1, 2 \ldots L \qquad (1)$$

The combining rule is then stated as follows: If the BRS_i is larger than a specified threshold T (where $0 < T \leq 1$), the branch is considered for combining; otherwise it is discarded. This way, only significant branches will always be combined at any time. The user defines what is significant by choosing the proper T. If it happens that all the branches' BRS meet the specified T (i.e. significant enough) they will all be combined, otherwise only the significant branches are combined while others are discarded. It is then obvious that M, the number of branches combined at each time instant here will not be fixed, but varies in correspondence to the channel fading level. Hence, performance gain due to improvement in channel conditions will always be reflected in the system performance all the time. Since the GSC scheme here is based on the use of a threshold T, we refer to the proposed GSC scheme as T-GSC. The scheme is as illustrated in Fig. 1.

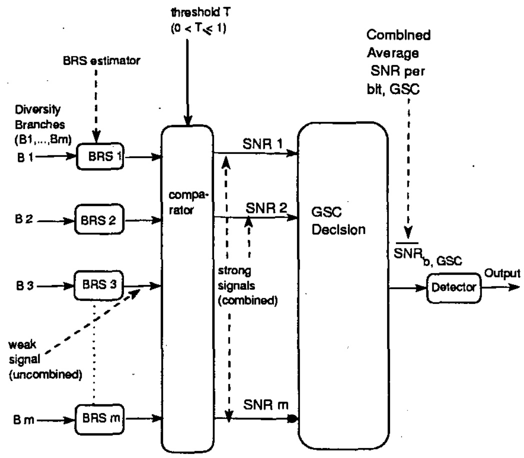

Figure 1: Block Diagram of the proposed T-GSC scheme (GSC combining diversity branches using a threshold T criterion).

III. SIMULATION RESULTS

It has been observed that from an actual point of view, it seems more reasonable to assume that fluctuations of signal carrier envelopes on the mobile receiver are approximated by the *m-distribution* proposed by Nakagami [5] when trying to investigate fading statistics for land mobile radio both in urban areas and suburban (open) areas [6]. Therefore, the Nakagami *m-fading model* was used in our simulations to model mobile environments, and the orders of diversity used is $L = 5$. Nakagami *m-fading statistics* is a general fading statistics from which other fading statistics approximating the mobile communication environments can be modeled by setting the Nakagami parameter m to an appropriate value. We recall that $m = 1$ corresponds to Rayleigh, and as m is increased (i.e. $m > 1$), the fading becomes less severe. System performances shown in Fig.s 2 and 3 were evaluated in Rayleigh (Nakagami $m = 1$) fading channel, while those shown in Fig.s 4, 5 and 6 were evaluated in Nakagami-Ricean fading channels.

Our simulation result in Fig. 2 shows that the BER of a T-GSC scheme decays roughly as $(SNR)^{-M}$, where M is the number of diversity paths that meet the specified T. This result is in agreement with the results shown in [4] on the combined average SNR of M-GSC scheme in Rayleigh fading channel. More importantly the result in Fig. 2 confirms the fact that the BER performance of the T-GSC scheme is upper- and lower- bounded by those of the CSC and MRC schemes respectively.

Fig. 3 compares the simulation results we obtained for the BER performance of the T-GSC scheme (GSC based on threshold T), with the M-GSC scheme in [4](GSC based on

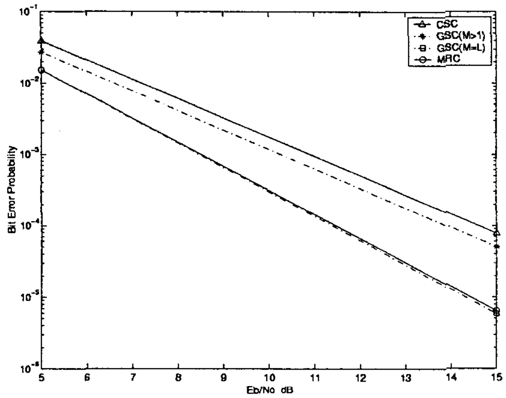

Figure 2: Comparing BER Performances of T-GSC($M > 1, \cdots, L$, where M is the number of branches having their BRS meeting the specified threshold T) with CSC,and MRC, in Rayleigh fading channel.

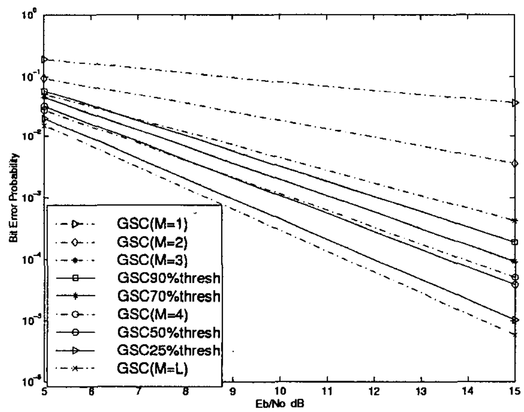

Figure 3: Comparing BER Performances of the proposed T-GSC Scheme (at $T = 0.9, 0.7, 0.5$, and 0.25) with the scheme in [4] (at $M = 1, 2, 3, 4$, and 5) in Rayleigh fading channel.

fixed M) when both operate in Rayleigh fading channel. From this figure, it can be observed that by choosing a threshold level as high as 90% of the maximum SNR received (a decision very close to CSC decision), our scheme gives a BER performance better than that of the scheme in [4] for $M = 1, 2$, and 3,when $L = 5$. This significant performance gain of T-GSC over M-GSC recorded at this high T level confirms our statement that indeed most of the time, there are actually some of the branches having their SNRs almost as strong as the ones selected by M-GSC that will still be discarded in circumstances when an envisaged channel condition improves. This, therefore, clearly represents an appreciable loss of information that could otherwise have been utilized. From this figure also, it can be observed that by setting $T = 0.25$(i.e.25%), the T-GSC shall be able to achieve a BER performance that is almost at the optimum level. This implies that at this threshold level, all the useful diversity branches that can appreciably contribute to the combined SNR without any redundancy, would have been selected and combined. Therefore other branches dropped out at this T level represents no loss of appreciable information. This point will always remain true at any time, and regardless of the type of channel involved. This is a major advantage of T-GSC over the M-GSC. Hence, T-GSC here uses a sound criterion for defining the significant/insignificant branches that will lead to no loss of appreciable information at any time instant, while operating in mobile or any other channel types.

We show next the performance of T-GSC in another frequently used fading model for mobile environment -the Ricean fading model, for different fading level. The Rice fading statistics can be closely approximated by using the following relation between the Rice factor K (where K is the ratio of power in the specular and scattered components), and the Nakagami parameter m [5]:

$$K = \frac{\sqrt{m^2 - m}}{m - \sqrt{m^2 - m}} \qquad m > 1. \quad (2)$$

Nakagami m-fading model for the parameter $m = 2$ and $m = 4$ is equivalent to the Ricean fading model for the Rice factor $K = 3.8dB$ and $K = 8.1dB$ respectively [3]. These two values of K are important practical models for mobile communication environments. The BER performance of T-GSC scheme over Ricean channel was thus simulated from the Nakagami m-fading model ($m = 2$,$m = 4$) and the results obtained for different threshold levels are as shown in Fig. 4, 5, and 6. Comparing these results with the corresponding results over the Rayleigh ($m = 1$) channel in Figure 3, it is observed that as the fading gets less severe, the BER performance of the proposed scheme improves for any particular threshold level considered. Similarly for any particular fading channel, the performance of the T-GSC improves as the threshold level is varied from 90% to 25% as would be expected.

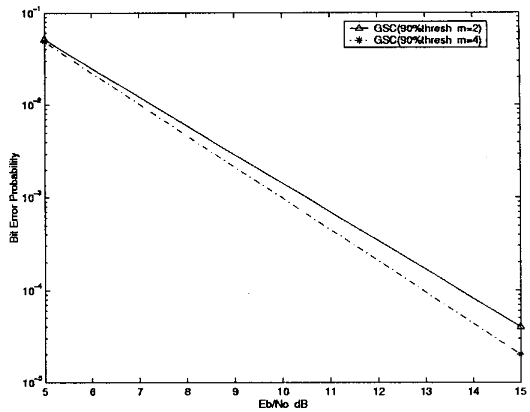

Figure 4: BER performance of the proposed T-GSC scheme (at 90% threshold level, i.e. $T = 0.9$) in Nakagami channels ($m = 2$, and $m = 4$).

IV. CONCLUSIONS

In this paper, we presented the BER performance of a T-GSC scheme which combines all significant diversity branches at any given time instant. The scheme compares a predefined T with the BRS of each branch, and thus determine the numbers of significant and insignificant branches. The BER performance of this scheme is shown to outperform that of the M-GSC scheme (which combines a fixed number of diversity branches M) presented in [4]. Our results also show that the proposed T-GSC scheme will give a BER performance close to the optimum performance at a threshold T level of about 25%. This performance is indicative of the fact that other diversity branches left uncombined at this level renders no appreciable degradation to the performance

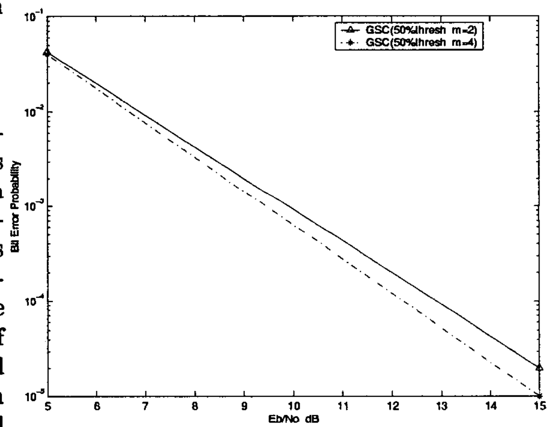

Figure 5: BER performance of the proposed T-GSC scheme (at 50% threshold level, i.e. $T = 0.5$) in Nakagami channels ($m = 2$, and $m = 4$).

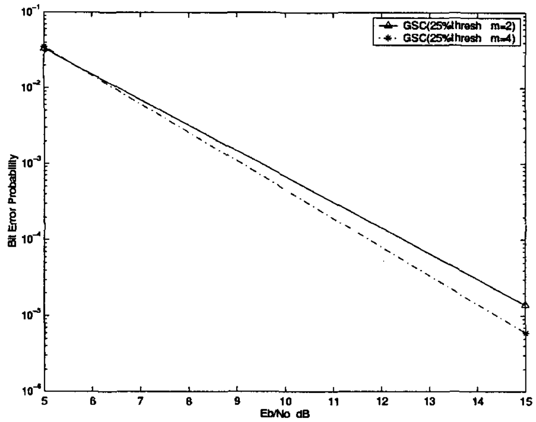

Figure 6: BER performance of the proposed T-GSC scheme (at 25% threshold level, i.e. $T = 0.25$) in Nakagami channels ($m = 2$, and $m = 4$).

of this combiner compared to the optimum performance at any time instant, and regardless of the type of channels involved. The scheme here uses a sound criterion to determine significant (combined) and insignificant (uncombined) branches that makes it more suitable for use in time varying (like the mobile communication) channels. The BER performance of the proposed scheme was compared for different fading channels and simulation results showed that as the fading gets less severe, the BER performance improves.

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