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Outage Probability of Impairments due to Combining Errors and Branch Correlation in Rayleigh Fading Channels Incorporating Diversity

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The principles of diversity combining have been known to wireless communication fraternity for decades. Diversity requires that a number of transmission paths be available, all carrying the same message but having independent fading statistics. The mean signal strengths of the paths should also be approximately the same. Proper combination of the signals from these transmission paths yields a resultant with greatly reduced severity of fading and correspondingly improved reliability of transmission. Space diversity is a historical technique that has found many applications over the years and is in wide use in a variety of present-day microwave systems. It is relatively simpler to implement and does not require additional frequency spectrum. Each of the M antennas in the diversity array provide an independent signal to an M-branch diversity combiner, which then operates on the assembly of signals to produce the most favorable result. A variety of techniques are available to perform the combining process in say, a Rayleigh fading channel. Maximal Ratio Combining (MRC) is considered as the most efficient among all techniques as it improves the average Signal-to-Noise Ratio (SNR) over that of a single branch in proportion to the number of diversity branches combined and also provides the lowest probability of deep fades.

Keywords : Branch Correlation, Combining Errors, Diversity Combining, Maximal Ratio Combining, Outage Probability, Rayleigh Fading.

1. INTRODUCTION

In theory, there are many diversity methods to improve performance of the transceiver system and to reduce the Bit Error Rate (BER) at the receiver. Diversity methods reduce the effects of fading as they deal with multiple paths carrying the same message, but with independent fading statistics [1]. Proper combination of signals from multiple transmission paths yields a resultant with greatly reduced severity of fading and correspondingly improved reliability of transmission. Over the years, a number of methods have evolved to capitalize on the uncorrelated fading exhibited by separate antennas in a space-diversity array. In general, the analysis of the mean Signal-to-Noise Ratio (SNR) of the combined signal is based on the assumption that the faded signals in the various branches are uncorrelated.

In some cases, the antennas in the diversity array could be improperly positioned or the frequency of separation between the diversity signals could be too small [1]. It is thus important to analyze performance degradation of a diversity system when the diversity branches are correlated to a certain extent. It is observed that a moderate amount of correlation between diversity branches is not too damaging. Most diversity combining schemes assume that combining mechanisms operate perfectly. Since information needed to operate a combiner is extracted in some way from the signals themselves, there is a possibility of making an error, thus not completely achieving the expected performance. This effect is studied in detail in [2].

ceiver. So, the channel with lower cutoff SNRs alone dominate in combining, and so the channel experiences lower BER which in turn leads to lower outage capacity as shown in Figure 4 through numerical results.

Figure 5 shows outage probability of branch correlation errors for various values of ρ. The graph shows that outage probability increases as ρ increases, and reaches maximum value close to 0.045 as ρ reaches 0.9 for a particular cutoff SNR value of 0.5. Thus, it can be concluded that lower the correlation between two branches in a 2 branch diversity system, lower the probability of error and outage probability.

Figure 6 shows outage probability of branch correlation errors for various values of Individual branch SNR. It is clearly observed that Pout decreases as SNR increases for a particular ρ and γ_0. This is due the fact that channel quality is good at high SNRs and so the Channel State Information (CSI) at the receiver which is used to adjust weights in the MRC combiner becomes accurate to judge channel performance. So, the message signal is sent with very low BER. Thus, outage capacity which results due to correlation between any two branches is reduced as the correlation between the two branches decreases, which is proved mathematically and graphically through numerical analysis of Eq. (17). Also, if the channel is good, even a higher correlation gives better performance than when the channel is bad.

Figure 7 shows Pout vs. the optimal cutoff SNR, γ_0. Here, outage probability increases as optimal cutoff SNR increases for a particular value of ρ and Γ. It is known that optimal cut off SNR is the level below which data transmission is suspended. In case of branch corfrelation also, optimal cutoff SNR plays an important role in sending information with lesser number of errors. From Figure 7, it is concluded that lower optimal cutoff is desired for less error prone transmission and for obtaining low outage probability.

6. CONCLUSIONS

Closed-form expressions for outage probability of MRC scheme for a) Space Combining errors and b) Branch Correlation are derived and discussed in this paper. Numerical results show that outage probability decreases with increase in diversity order, M, increase in correlation between message and pilot, ρ and/or increase in Individual branch SNR, Γ, for combining errors. Also, if cutoff SNR, γ_0 increases, outage probability increases. In case of branch correlation, the outage probability increases with increase in correlation between the branches, but decreases with increase in Individual branch SNR, and decrease in optimal cut-off SNR. To summarize, increase in correlation between the message and pilot helps to reduce impairments due to combining errors and decrease in correlation between two branches reduces impairments due to branch correlation.

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