Improved Root-Mean-Square-Gain-Combining for SIMO Channels

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Abstract—The major problem that wireless communication systems undergo is multipath fading caused by scattering of the transmitted signal. However, we can treat multipath propagation as multiple channels between the transmitter and receiver to improve the signal-to-scattering-noise ratio. While using Single Input Multiple Output (SIMO) systems, the diversity receivers extract multiple signal branches or copies of the same signal received from different channels and apply gain combining schemes such as Root Mean Square Gain Combining (RMSGC). RMSGC asymptotically yields an identical performance to that of the theoretically optimal Maximum Ratio Combining (MRC) for values of mean Signal-to-Noise-Ratio (SNR) above a certain threshold value without the need for SNR estimation. This paper introduces an improvement of RMSGC using two different issues. We found that post-detection and de-noising the received signals improve the performance of RMSGC and lower the threshold SNR.

Keywords—Bit error rate, de-noising, pre-detection, root-mean-square gain combining, single-input multiple-output channels.

I. INTRODUCTION

THE major problem that wireless communication systems undergo is multipath fading caused by scattering of the transmitted signal. To reduce the effect of multipath, adaptive equalization is used by subtracting the reflected multipath signals from the received signal through the use of digital filters that dynamically change their characteristics in response to different situations [1]. This technique is expensive and results a high latency which is undesired in real-time communication.

However, we can treat multipath propagation as multiple channels between the transmitter and receiver to improve the signal-to-scattering-noise ratio. Diversity techniques generate multiple signal branches between the transmitter and the receiver (Multiple Input Multiple Output (MIMO) system). Maximum Ratio Combining (MRC) and Equal Gain Combining (EGC) use the multiple signal branches to improve the performance of wireless systems [2]. As for Single Input Multiple Output (SIMO) systems, the diversity receivers extract multiple signal branches or copies of the same signal received from different channels and apply gain combining schemes such as Root Mean Square Gain Combining [3].

MRC gives better performance than EGC however it is a complex technique since it requires Signal-to-Noise-Ratio (SNR) estimation. RMSGC asymptotically yields an identical performance to that of the theoretically optimal MRC for values of mean SNR above a certain threshold value. In addition, RMSGC is a cost effective technique. It was implemented using FPGA and was proven to be efficient both in terms of speed and area [4].

In our work, we study an improvement of RMSGC diversity technique in SIMO systems (a sub-component of MIMO).

II. RECEIVER DIVERSITY GAIN COMBINING

Diversity combining techniques can be used in both pre- and post-detection, except for MRC which is pre-detection based.

In pre-detection, diversity gain combining is applied to the diversity signal path arriving at the L receiver. In post-detection, each diversity signal path arriving at the L receiver antenna is detected and then the gain combining scheme is applied to the detectors output. Thus, post-detection combining techniques require detectors as much as antennas. This becomes a disadvantage when a complex detector is used.

A. Root-Mean-Square Gain Combining Post-Detection
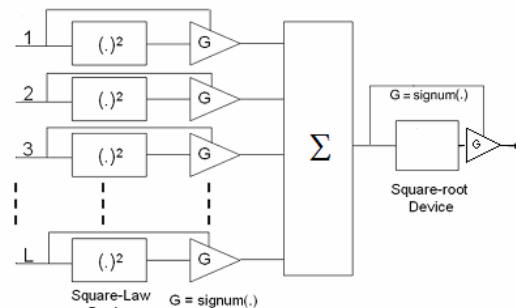

Fig. 1 RMSGC diagram

In this section, we introduce the receiver diversity gain combining technique: RMSGC post-detection (illustrated in Fig. 1). In RMSGC Post-Detection technique, each diversity signal path arriving at the L receiver is detected. The output of each detector is squared using a square law device. Depending

on the original polarity of the detector output, the result of the square law device is inverted (if originally negative), which is achieved by a signum filter. The L resulting values are summed and then the inverted output (if originally negative) of square-root (of the absolute value) becomes the decision value.

B. Root-Mean-Square Gain Combining With De-noised Signals

Assume that the original transmitted signal is $x(t)$, the output signal after applying MRC is

$$r_{MRC}(t) = x(t)\sqrt{\sum_{i=1}^{L}\gamma_i^2} + \frac{\sum_{i=1}^{L}\gamma_i n_i(t)}{\sqrt{\sum_{i=1}^{L}\gamma_i^2}} \qquad (1)$$

where γ_i and $n_i(t)$ are respectively the fading envelope and the additive noise of the ith path [2].

The received signal form the ith diversity path is

$$r_i(t) = \gamma_i x(t) + n_i(t) \qquad (2)$$

The signal at the output after applying the RMSGC technique is

$$r_{RMSGC}(t) = sign\left(\sum_{i=1}^{L} sign\left(r_i^2(t)\right)r_i^2(t)\right)$$
$$\cdot \sqrt{\left|\sum_{i=1}^{L} sign\left(r_i^2(t)\right)r_i^2(t)\right|} \qquad (3)$$

If the additive noise is small enough to be neglected, the received signal becomes

$$r_i(t) \xrightarrow[n_i(t)\ll]{} \gamma_i x(t). \qquad (4)$$

After processing the diversity signals through MRC and RMSGC, approximately the same signals are obtained for both techniques

$$r_{RMSGC} \xrightarrow[n(t)\ll]{} x(t)\sqrt{\sum_{i=1}^{L}\gamma_i^2} \qquad (5)$$

$$r_{MRC} \xrightarrow[n(t)\ll]{} x(t)\sqrt{\sum_{i=1}^{L}\gamma_i^2} \qquad (6)$$

Therefore at high SNR, when the AWGN can be neglected, both MRC and RMSGC will result the same performance with the advantage that RMSGC does not require any estimation.

From this point the need to get rid of the additive noise before processing the received signal with RMSGC to achieve the performance of MRC at lower SNR values.

To achieve this goal, a de-noising filter is used to reduce the effect of the additive noise. An existing de-noising filter that is based on wavelet decomposition is used (the de-noising filter design is not the purpose of this paper).

III. Simulated BER

Through the simulation, we consider BPSK over independent Rayleigh fading (slow and non frequency selective) diversity channels with AWGN. The average reference SNR $\overline{\rho} = E_b P_{dif} / N_0$, E_b is the energy per bit, P_{dif} is the mean diffuse power, and $N_0/2$ is the AWGN power spectral density [2].

The simulated BER curves are plotted as a function of the average SNR (dB). Fig. 2 shows that post-detection improve the performance of RMSGC compared to pre-detection; however it has no effect on the performance of EGC (Fig. 3). In addition, the BER decreases monotonically with an increase in the average SNR. It also decreases when the number of antennas increases.

From Fig. 3 and Fig. 4, we can see that the de-noise filter has no effect on the performance of EGC and MRC because they linearly filter the AWGN. On the other hand, the de-noise filter significantly improves the performance of RMSGC (Fig. 2) because the non-linear square device (a sub-component of RMSGC) yields square-noise terms, so de-noising the diversity signals before RMSGC processing them reduces the "noise-squaring" effect and hence improves the performance of RMSGC.

Both pre-detection and de-noising improved the BER of RMSGC and they both lead to the same BER. This improvement pushed down the threshold SNR where RMSGC and MRC have the same BER (Fig. 5 and Fig. 6). The performance of RMSGC is very close to that of MRC and almost identical for SNR above 18 dB. While MRC is the theoretical optimal scheme, we conclude that RMSGC is near-optimal. The threshold SNR values are obtained experimentally using Monte-Carlo simulation and are tabulated in Table I. We observe that as the average diffuse power P_{dif} increases, the cutoff SNR increases. On the other hand, the number of antennas has no noticeable effect on the value of the cutoff SNR.
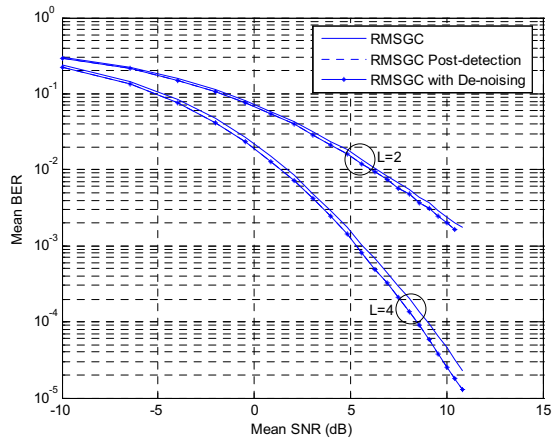

Fig. 2 BER using RMSGC, RMSGC post-detection and RMSGC after de-noising the received signals with two and four diversity antennas
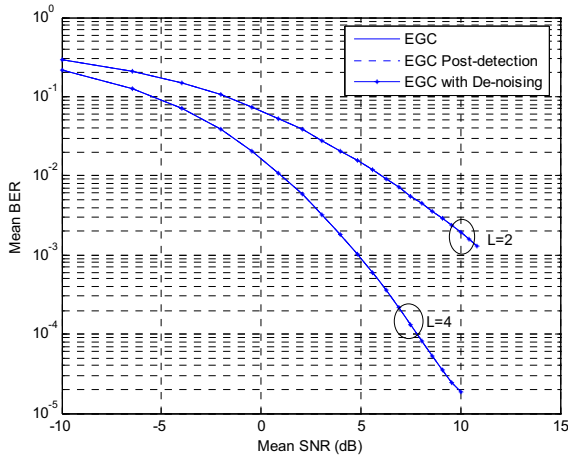
Fig. 3 BER using EGC, EGC post-detection and EGC after de-noising the received signals with two and four diversity antennas
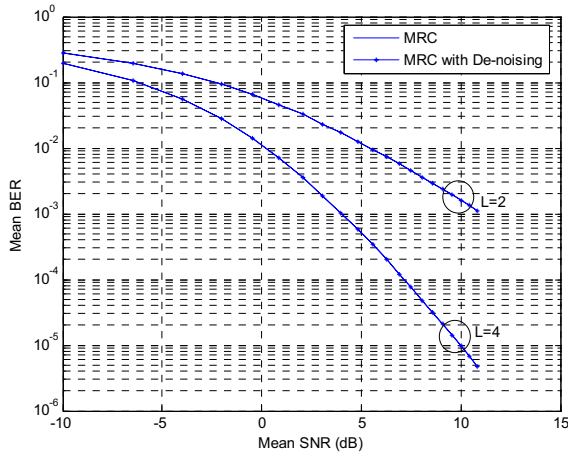

Fig. 5 BER using RMSGC post-detection and MRC with two, three and four diversity antennas

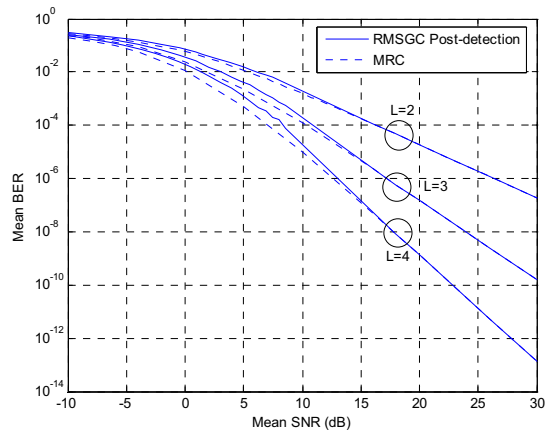Fig. 4 BER using MRC and MRC after de-noising the received signals with two and four diversity antennas
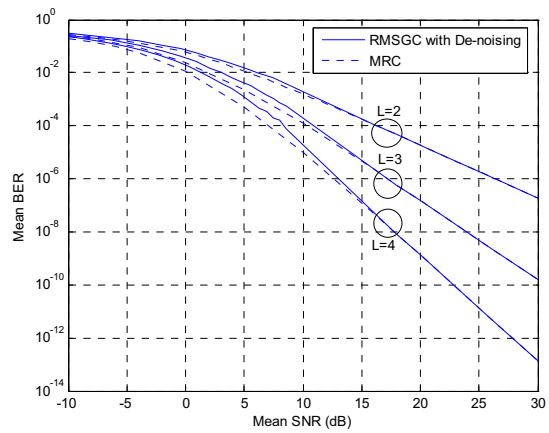

Fig. 6 BER using RMSGC after de-noising the received signal and MRC with two, three and four diversity antennas

TABLE I
CUT OFF SNR IN DB FOR RMSGC POST DETECTION AND RMSGC WITH DE-NOISING FOR VARIOUS P_{DIF} AND NUMBER OF ANTENNAS

$L \mid P_{dif}$	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
2	12.5	12.7	13.6	14	15	15.4	15.6	16.1	17.5	18
3	12.5	12.7	13.6	14	15	15.4	15.6	16.1	17.5	18
4	12.5	12.7	13.6	14	15	15.4	15.6	16.1	17.5	18

IV. CONCLUSION AND FUTURE WORKS

In this paper we developed an improvement of RMSGC technique. The BER of RMSGC was reduced using either post-detection technique or de-noising filters. RMSGC proved to be near optimal in the sense that the BER results were close to MRC and almost identical for SNR over 18 dB. In addition, we found that the BER of RMSGC decreased as the number of antennas increased.

RMSGC is relatively simple and, unlike MRC, does not require SNR estimation.

As future work, we propose to study the co-channel interference (CCI) resulting from the correlation between the receiver antennas as their number is increased. The increase of the BER resulting form CCI can be resolved using OFDM. SIMO is a sub-component of MIMO; this work can also be extended to MIMO systems simple spatial cycling techniques [5 - 8]. We can also improve the de-noising filter to achieve lower threshold SNR.

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