Chapter 4
Adaptive MRC for Stochastic Wireless Channels

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Abstract This work is related to design certain adaptive equalization and error correction coding and aids to maximal-ratio combining (MRC) in faded wireless channels. The performances derived are analyzed using semianalytic (SA) and Monte Carlo (MC) approaches in order to achieve improvement in bit error rates (BERs) of demodulated signals in wireless channels that have both Gaussian and multipath fading characteristics. Modulation techniques used in this work are bipolar phase shift keying (BPSK), quadrature phase shift keying (QPSK), and differential phase shift keying (DPSK). The work though considers the use of least mean square (LMS), adaptive filter blocks as part of a MRC setup and is tested under SNR variation between −10 and 10 dB. The results generated justify the use of the adaptive equalizer block as an aid to the MRC setup. The validity of the results is further confirmed by comparing to those obtained via SA approach and MC simulations.

Keywords Maximal-ratio combining (MRC) · Bit error rate (BER) · Least mean square (LMS) adaptive filter · Faded wireless channels · Bipolar phase shift keying (BPSK) · Quadrature phase shift keying (QPSK) · Differential phase shift keying (DPSK)

4.1 Introduction

Due to the rapid advancement of technology, wireless and mobile communications have seen unpredicted growth. As a result, bandwidth has become scarce and quality of service (QOS) has become a major factor in deciding the link reliability. The major

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challenges faced are due to the fluctuations and fading observed in the propagation medium. In case of fading where there is an absence of line of sight (LOS), component Rayleigh fading comes into the picture. On the other hand, with a LOS segment, Rician fading is observed. Diversity combining is one of the most widely employed techniques in wireless communications receivers for mitigating the effects of multipath fading. It contributes significantly toward improving the overall system performance. The most popular diversity techniques are equal-gain combining (EGC), maximal-ratio combining (MRC), selection combining (SC), and a combination of MRC and SC, called generalized selection combining (GSC) [1, 2]. This work is related to the design of an MRC scheme assisted by an adaptive equalization block so as to investigate the performance of the MRC adaptive equalization combination in Gaussian and multipath slow fading channels. The work uses bipolar phase shift keying (BPSK), quadrature phase shift keying (QPSK), and differential phase shift keying (DPSK) modulation in Gaussian, Rayleigh, and Rician fading channels with signal-to-noise ratio (SNR) variation in the range -10 to 10 dB range. The objective is to determine the appropriate combination of MRC and adaptive filters such that better bit error rate (BER) values are obtained for the given modulation techniques and the channel types. The work considers performance difference in terms of BER rate obtained using both MRC and MRC-equalizer combination. Here, least mean square (LMS), NLMS, and recursive least square (RLS) adaptive filters are taken as part of the setup to determine the best combination for the considered experimental framework. Though the work considers RLS filters, for practical purposes, the LMS-based adaptive filters are preferred due to their overall efficiency [3]. The performance of these approaches are evaluated using semianalytic (SA) and Monte Carlo (MC) approach. The rest of the paper is organized as follows. In Sect. 4.2 the related background is discussed. The experiential details are explained in Sect. 4.3. Results are discussed in Sect. 4.4. The work is concluded in Sect. 4.5.

4.2 Background

One of the common methods preferred for mitigating fading effects is the use of diversity. Among all diversity techniques, MRC is one of the preferred choices. MRC (Fig. 4.5) is a method of diversity combining in which the signals from each channel are added together, the gain of each channel is made proportional to the root mean square (RMS) signal level and inversely proportional to the mean square noise level in that channel different proportionality constants are used for each channel [1].

An adaptive filter self-adjusts its transfer function according to an optimization algorithm driven by an error signal. Because of the complexity of the optimization algorithms, most adaptive filters are digital [3]. Here LMS, NLMS, and RLS filters are used.

Several multipath models have been suggested to explain the observed statistical nature of a wireless channel. Clarke's model based on scattering is one of the most widely preferred and discussed in the literature. Clarke suggested a model which can be used for modeling fading channels in wireless communication [1]. A signal maybe applied to a Rayleigh fading simulator to determine the performance in a wide range of channel conditions. Both flat and frequency-selective fading conditions may be simulated depending upon gain and time-delay settings. The various delayed paths overlap and cause intersymbol interference (ISI). Different frequency components of the transmitted signal experience different fading are known as frequency-selective fading. Delay spread arises from broadband transmission and leads to frequency-selective fading. When the receiver and transmitter are in relative motion with constant speed, the received signal is subjected to a constant frequency shift leading to Doppler spread and produces time-selective fading. It also creates the largest of the frequency shifts of the various paths. Coherent time is defined as the inverse of Doppler spread and uses as a measure of the signal duration at which time-selectivity becomes relevant [1–4].

4.3 System Model and Experimental Considerations

The experimental work carried out can be summarized by the flow logic shown in Fig. 4.1. Initially, the data obtained in binary form are modulated using three different techniques, namely QPSK, BPSK, and DPSK. The aim is to use coherent and noncoherent modulation schemes so as to determine combinations to nullify the effects of stochastic nature of the wireless channel. Another form of the sys-

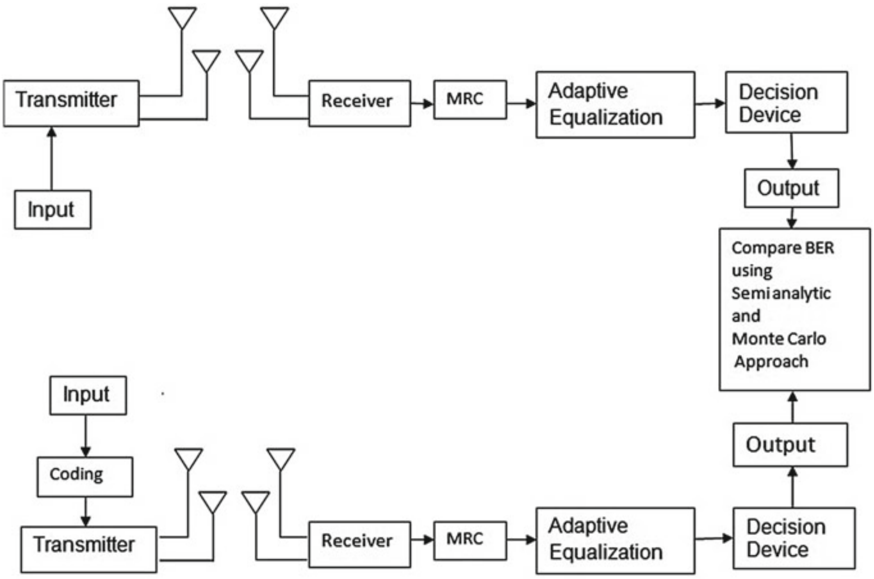

Fig. 4.1 Flow diagram of the system

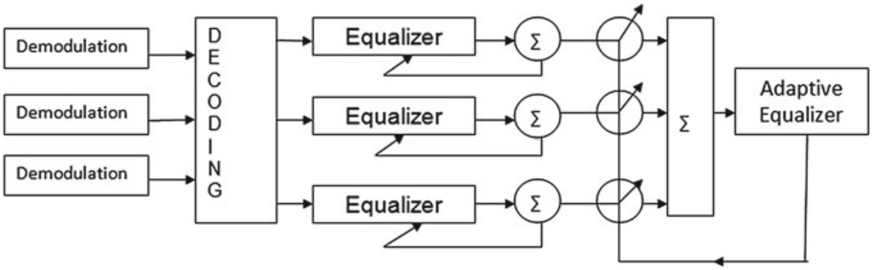

Fig. 4.2 Proposed system model of coding and adaptive equalization assisted MRC

Table 4.1 Parameters used for simulating channel using Clarke-Gans model

Sl. no	Parameter	Value
1	Freq., f_c	900 MHz
2	ω_c	$2\pi f_c$
3	Mobile speed, V	3 kmph
4	No. of paths	8
5	Wavelength, λ	$\frac{3 \times 10^8}{f_c}$
6	Doppler shift, f_m	$\frac{V}{\lambda}$
7	Sampling freq., f_s	$8 \times f_m$
8	No. of samples, N	10,000
9	Paths	16
10	Sampling period, T_s	$\frac{1}{f_s}$

tem model is depicted in Fig. 4.2. The signal at the receiver is captured by several diversity branches and passed onto the demodulation blocks. Before demodulation and reconstruction, there is an equalizer block which is combined with the MRC to make improvement in the SNR of the received signal. The equalizer is designed using the LMS algorithm and is provided a mean square error (MSE) convergence goal of 10^{-3}. The equalizer takes around 150 iterations on an average to reach this goal for about 50 sets of data. Four path Rayleigh and Rician channels are generated using the considerations described above. The set of characteristics for multipath fading generated using the parameters given in Table 4.1. Similarly, the Rician channel generated using corresponding considerations yields a set of plots as shown in Fig. 4.3. After the channels are generated, the modulated signals are convolved to provide the transmission effect. Additive Gaussian noise is mixed with values of −3, 1, and 3 dB for three separate channel sets each of size 20. A coded form of the above approach is also proposed. The block diagram is shown in Fig. 4.4. The data before modulation is coded using linear block code (Hamming code) in (7, 4) format which help to improve the quality of the received signal.

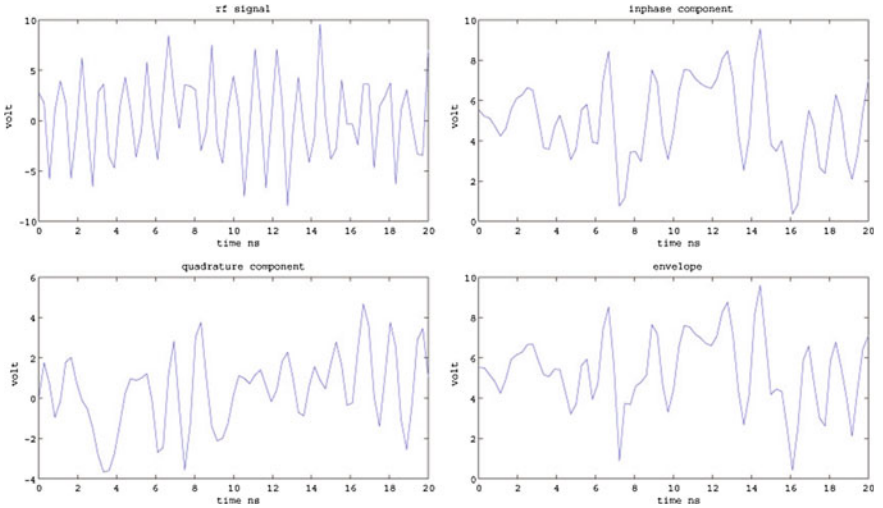

Fig. 4.3 Rician channel path gains

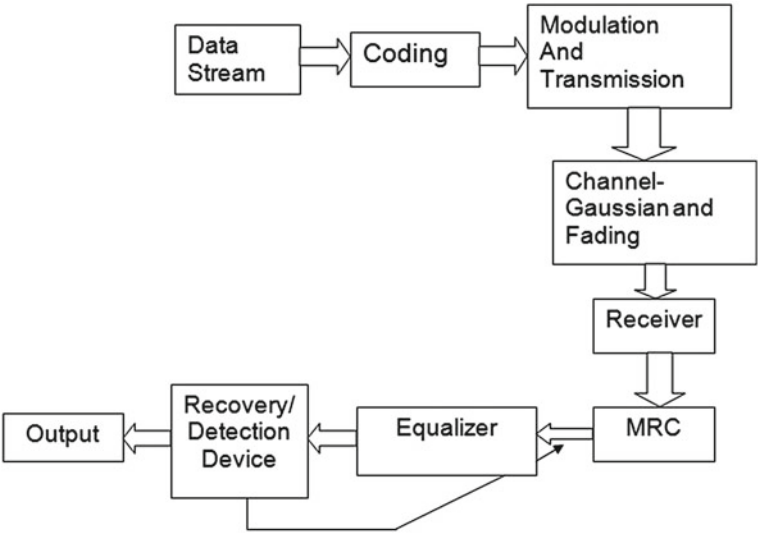

Fig. 4.4 System block diagram showing use of coding

4.4 Results and Discussion

At the receiver end, the MRC process is carried out with two- and three-branch configurations. The three-branch configuration provides better results but at the cost of greater computational constraints. The updating process of the weights of the MRC

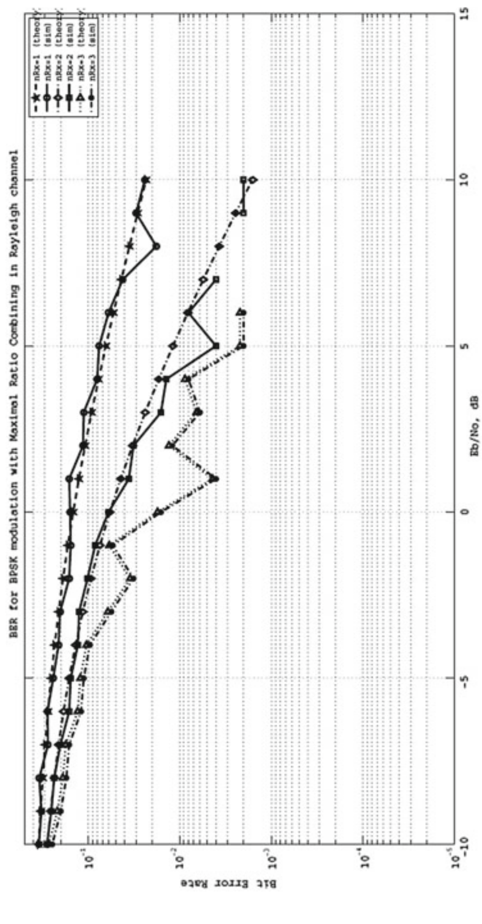

Fig. 4.5 BER plot of MRC with three branches without equalization

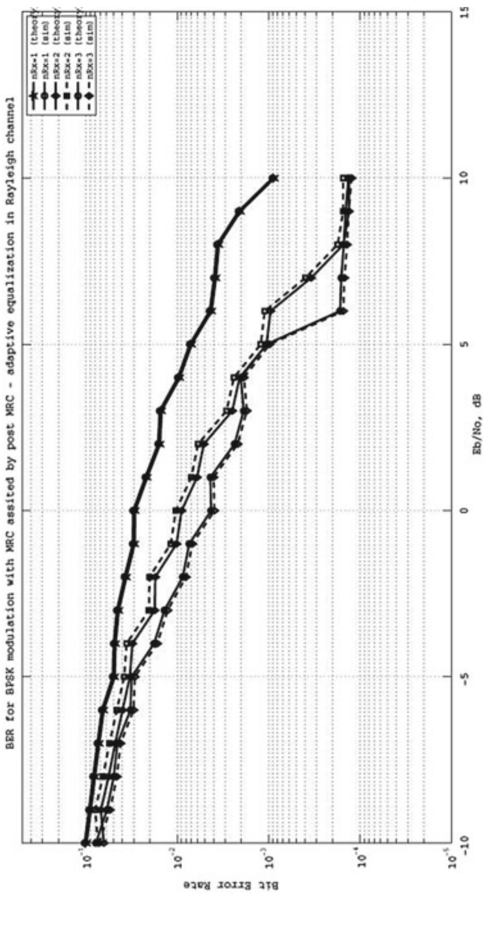

Fig. 4.6 BER plot of MRC with three branches with equalization

Table 4.2 Average MSE of signal inputs at four branches of MRC with coding and adaptive LMS equalization

Sl.no	SNR in dB	MSE for branch MRC wireless channels			
		Branch-1	Branch-2	Branch-3	Branch-4
1	0	0.000071	0.000051	0.000041	0.000049
2	1	0.0000049	0.000051	0.000032	0.000039
3	2	0.000041	0.000048	0.000030	0.000038
4	3	0.000041	0.000040	0.000016	0.000038
5	4	0.000034	0.000036	0.000014	0.000033
6	5	0.000032	0.000035	0.000013	0.000031
7	6	0.000031	0.000033	0.000012	0.000014
8	7	0.000025	0.000031	0.000012	0.000010
9	8	0.000017	0.000032	0.000009	0.000006
10	9	0.000015	0.000025	0.000009	0.000005

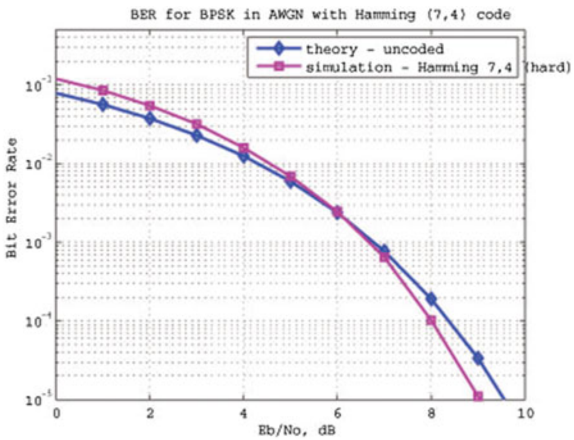

Fig. 4.7 BER calculation by using linear block codes (7, 4)

system is linked to the equalizer in a way that the process continues adaptively till the SNR crosses the fixed threshold value [5]. The use of the equalizer block with the MRC system is thus justified. During training, the MRC branches are supported by the LMS-based adaptive training of the equalizer. Some of the MSE values are shown in Table 4.2. Experiments are carried out with and without the equalizer block. Results are derived from the setup for SNR ranges between −10 and 10 dB. Figure 4.4 shows a BER plot generated for SNR ranges between −10 and 10 dB with three-branch MRC for a Rayleigh multipath fading channel. Figure 4.5 depicts BER of MRC with three branches without equalization. Similarly, a BER plot of MRC with three branches and with equalization is shown in Fig. 4.6. The use of the equalizer block with the MRC system is thus justified. The performance of the system is improved

Table 4.3 Coding gain generated with respect to adaptive equalizer-assisted MRC and coding adaptive equalization with MRC

SNR range (dB)	Uncoded MRC and equalizer (BER)	Coded MRC and equalizer (BER)	Gain
−4	$10^{-1.5}$	$10^{-1.7}$	0.01169
−2	$10^{-2.1}$	$10^{-2.3}$	0.002931
0	$10^{-2.2}$	$10^{-2.5}$	0.0031472
2	$10^{-2.7}$	$10^{-2.9}$	0.0007363
4	$10^{-3.0}$	$10^{-3.2}$	0.0003690
6	$10^{-3.5}$	$10^{-3.8}$	0.00015773
8	$10^{-3.9}$	$10^{-4.3}$	0.00007577
10	$10^{-4.9}$	$10^{-5.3}$	0.00007577

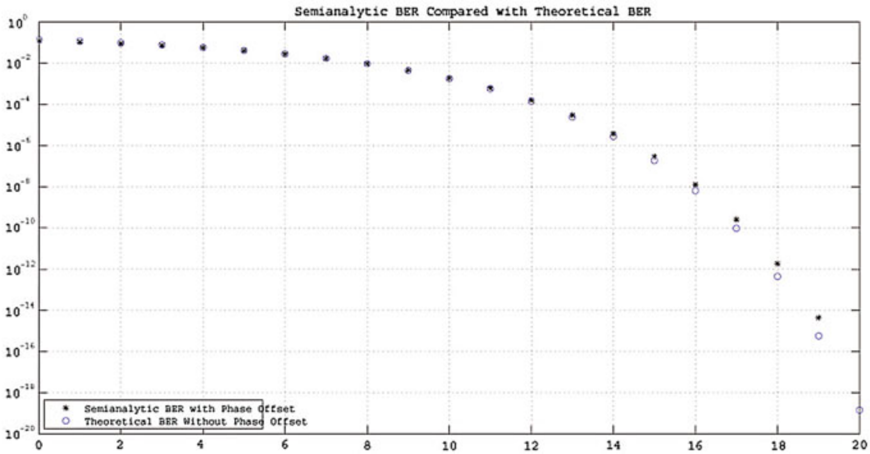

Fig. 4.8 BER calculation using Monte Carlo approach for the three-branch MRC with equalization

further by the use of coding. This is depicted by Fig. 4.7. The use of coding generates certain coding gain. This is summarized in Table 4.3.

The semianalytic (SA) technique works well for certain types of communication systems, but not for others. The SA technique is applicable if a system has all of these characteristics:

- Any effects of multipath fading, quantization, and amplifier nonlinearities must precede the effects of noise in the actual channel being modeled [6].
- The receiver is perfectly synchronized with the carrier. Because phase noise and timing jitter are slow processes, they reduce the applicability of the SA to a communication system.
- The noiseless simulation has no errors in the received signal constellation. Distortions from sources other than noise should be mild enough to keep each signal

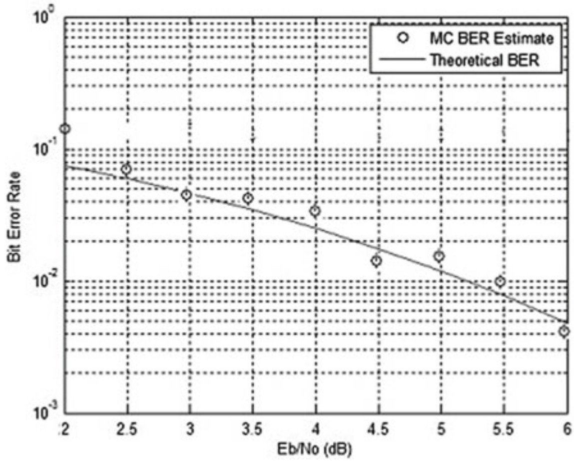

Fig. 4.9 MCS of BER estimation of MRC in Rayleigh faded channel

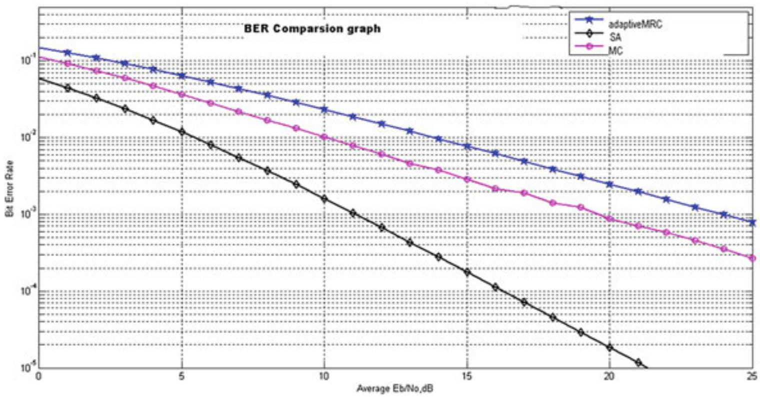

Fig. 4.10 BER comparison graph of adaptive MRC, SA, and MCS

point in its correct decision region. If this is not the case, the calculated BER is too low. For instance, if the modeled system has a phase rotation that places the received signal points outside their proper decision regions, the SA is not suitable to predict system performance.

Monte Carlo Simulation (MCS) is a class of numerical method for computer simulations or computer experiments to generate random sample data based on some known distribution for numerical experiments [7, 8]. A BER calculation by using Monte Carlo approach for the three-branch MRC with equalization is shown in Fig. 4.8. Similarly, MCS of BER estimation of MRC in Rayleigh faded channel is shown in Fig. 4.9. A comparative depiction of adaptive MRC, SA, and MCS is shown in Fig. 4.10. Thus, the use of the coding with adaptive equalization aided MRC improves the performance. This is verified using SA and MCS approaches.

4.5 Conclusion

MRC is an option to mitigate the differences of multipath fading in wireless communications. The work carried out shows that MRC becomes more effective when used in combination with adaptive equalizer. Results shows that at around 10 dB SNR with three-branch MRC, a BPSK modulated signal provides a BER of around 10^{-3} [9]. This value reaches atleast 10^{-4} when the MRC is used in combination an adaptive LMS equalizer. The improvement thus obtained is considerable. The work is further extended to include coded signals. The coding in combination with MRC and adaptive equalization provides further improvement in performance [8]. An evaluation using SA approach and MCS is carried out to obtain a comparative performance measure of MRC adaptive equalization and coding MRC adaptive equalization combinations. The later combination turns out to be superior. The work can be further extended to wireless channels showing frequency selectivity and time variations for applications in mobile networks in rapidly varying environments.

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