

BER Evaluation of an Enhanced Maximal Ratio Combiner over Time-Varying Nakagami Fading Channel

Omotayo M. E., Lawal A. O, Ajetumobi, E. O. and Oyajide D. O.

Abstract Wireless communication system has found worldwide acceptability as a backbone of modern digital transformation, enhancing connectivity, efficiency and transformation. However, the system is characterized with severe multipath propagation effects that degrade its performance. Maximal Ratio Combiner (MRC), as one of the techniques being used to address this problem is associated with poor performance in a time-varying channel due to increase in delay time as transmission data rate increases. Hence, in this paper, enhancement of MRC is carried out to improve its performance in a time-varying channel by reducing error rate using Adaptive Coding and Modulation (ACM) transmission technique and the Bit Error Rate (BER) of the enhanced MRC scheme is analytically derived and employed as performance metric. The multiple copies of the received signals at varying paths 'L' (2, 4) are combined using Conventional MRC (CMRC). The transmitter then selects the appropriate coding rate and constellation size for another transmission slot based on the obtained channel gain through ACM transmission technique. Mathematical expressions using Probability Density Function (PDF) of a time-varying Nakagami fading channel for Bit Error Rate (BER) is also derived. The proposed technique is simulated using MATLAB R2021a. The results obtained revealed that, the enhanced MRC scheme shows a lower BER, which indicate a significant gain in sound quality. Therefore, the proposed technique suggests a practical application in improving next-generation wireless network.

Keywords: Maximal Ratio Combiner (MRC), Adaptive Transmission (AT), Adaptive Coding and Modulation (ACM), Probability Density Function (PDF) and Bit Error Rate (BER).

I. Introduction

Wireless Communication (WC) systems are constantly evolving to meet the increasing demand for reliable and high speed data transmission. Nowadays, the demand for high data rate transmission in WC increases rapidly to meet up with increase in the demand of its services. However, these systems are significantly impacted by fading, a phenomenon that causes signal degradation due to multipath propagation. Multipath propagation which occurs when a transmitted signal propagates through many paths as a result of obstructions along the propagation paths between the

transmitter and receiver places a fundamental limitation on the performance of high data rate transmission [1]; [2]; [3]. However, the channel which serves as the medium of transmission in WC varies in time and operating environment thereby placing a fundamental limitation on the performance of high data rate transmission [4]; [5].

Several space combining diversity methods have been proposed to mitigate the detrimental effects affecting the performance of WC system. Diversity Combiner (DC) in which the independent fading paths are combined to reduce the effects of signal fluctuation is one of the techniques proposed to solve the problem of

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multipath propagation. Maximal Ratio Combiner (MRC), Equal Gain Combiner (EGC) and Selection Combiner (SC) are the basic DC techniques [6]. Previous works on diversity combiner revealed that MRC showed better performance in term of error rate reduction than other combining techniques due to different path gains in time invariant channel. However, performance of MRC deteriorates in rapidly time-varying Nakagami fading channels where the signal strength fluctuates unpredictably. Since high data rate transmission is of paramount importance in WC therefore, there is a need to strike a balance between data rate transmission and error in transmission which happen to be function of channel condition at a particular time using Adaptive Transmission (AT) technique [7].

AT is a technique in which the transmission parameters such as power and constellation size or any of their combinations change in accordance with time varying channel. The technique allows high data rate when the channel is at its best state, while a low data rate which is robust but less bandwidth efficiency is transmitted when the channel degrades [8]. Adaptive Coding and Modulation (ACM) which involves selection of an optimal combination of coding and modulation scheme to maximize bandwidth efficiency is commonly used in practice for AT transmission technique. This is due to its better performance with low error rate and reduced maintenance cost when compared to Adaptive Power (AP) which involves varying the signal power based on CSI [4]. Therefore, in this paper, ACM is adopted to enhance the performance of MRC technique in a time-varying wireless fading channel.

Digital Modulation (DM) is often used in WC as a result of its robustness to channel impairments

and resistance to noise and interference. DM schemes include Quadrature Amplitude Modulation (QAM), Phase Shift Keying (PSK) and Frequency Shift Keying (FSK) [9]; [1]. The QAM scheme used in this paper is due to its ability to modify the phase and amplitude of the signal simultaneously in accordance with the carrier signal [10]. The distribution of signal propagated in multiple copies in time-varying channel follows different fading distributions such as Nakagami-m, Rayleigh and Rician distributions. In this paper Nakagami-m distribution is adopted due to its ability to model both Rayleigh and Rician distribution that make it suitable in modelling terrestrial environment [11]; [12].

Several works have been carried out on diversity combining technique in order to improve the performance of wireless communication. In Abolade et al, [13], enhancement of MRC over log-normal fading channel using Firefly Algorithm (FA) was carried out to improve the performance of conventional MRC. In this paper, FA algorithm was used to select the strong path among the multiple copies of the received signals and ignore the weak paths. The results obtained revealed that, the technique had a better performance with low BER than the conventional MRC. However, the technique suffers from poor performance in a time varying channel due to increase in delay time as transmission data rate increases.

Furthermore, [14] proposed a new hybrid diversity combining scheme over Nakagami fading channel to solve the problem of signal fluctuation at the receiver in a wireless communication system. In the paper, the multiple copies of the transmitted signal were received using multiple antennas were then made to pass through MRC to improve the signal

quality before passing through a single RF chain and MF. The results obtained revealed that, the new hybrid combining technique has a better performance in a time invariant channel with low OP and ST values when compared with conventional MRC and EGC. However, the proposed technique suffers from poor performance in a time varying channel due to increase in delay time as transmission data rate increases. However, past researches on diversity combining technique revealed that MRC has a better performance only in a time invariant channel but poor performance in a time varying channel due to increase in delay time as transmission data rate increases. Therefore, this paper present an enhanced MRC scheme that improves BER in a time varying Nakagami fading channel. The proposed approach optimally adapts to changing channel conditions, offering a more robust signal reception strategy compared to conventional MRC

II. Materials and Method

A. Maximal Ratio Combiner

Maximal Ratio Combiner (MRC) is one of the most effective techniques for combating fading and improving signal reception. It is a diversity reception method that optimally weights and sums multiple received signal copies to maximize the Signal to Noise Ratio (SNR). MRC gives an output SNR equivalent to the sum of individual SNRs. The combiner therefore has the ability to produce an output signal with a strong SNR even when all the available branches are below the acceptable quality [15]; [2]. The block diagram of MRC technique is shown in Figure 1

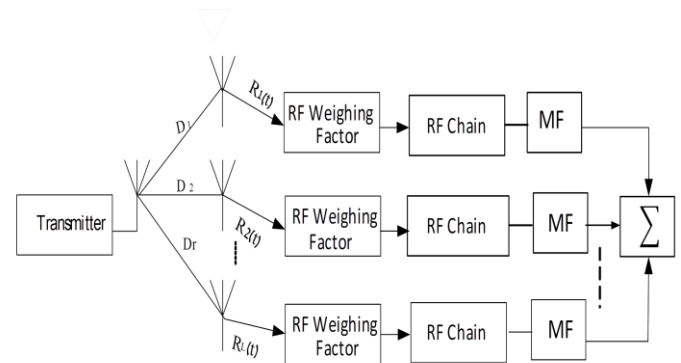


Figure 1: Block Diagram of Maximal Ratio Combining Technique

B. Proposed Enhanced Maximal Ratio Combiner Using ACM Transmission Technique

The multiple copies of the transmitted signal are received using multiple antennas. The received signals are co-phased and weighted with different weights before summing. The signal output is made to pass through the CSI unit to obtain the channel gain. The output of CSI is used as input at the decision device to determine the channel condition based on the value of channel gain obtained as shown in Figure 2. Transmitter then selects the appropriate coding rate and constellation size for another transmission slot through feedback loop using ACM algorithm. If the channel gain is high, decision device instructs the transmitter through a feedback path to increase coding rate as well as constellation size, and reduce it, if the gain is low as shown in algorithm 1. The RF chains are used to down convert the received signals from higher frequencies to lower frequencies, while MFs are used to remove the unwanted signal before summing.

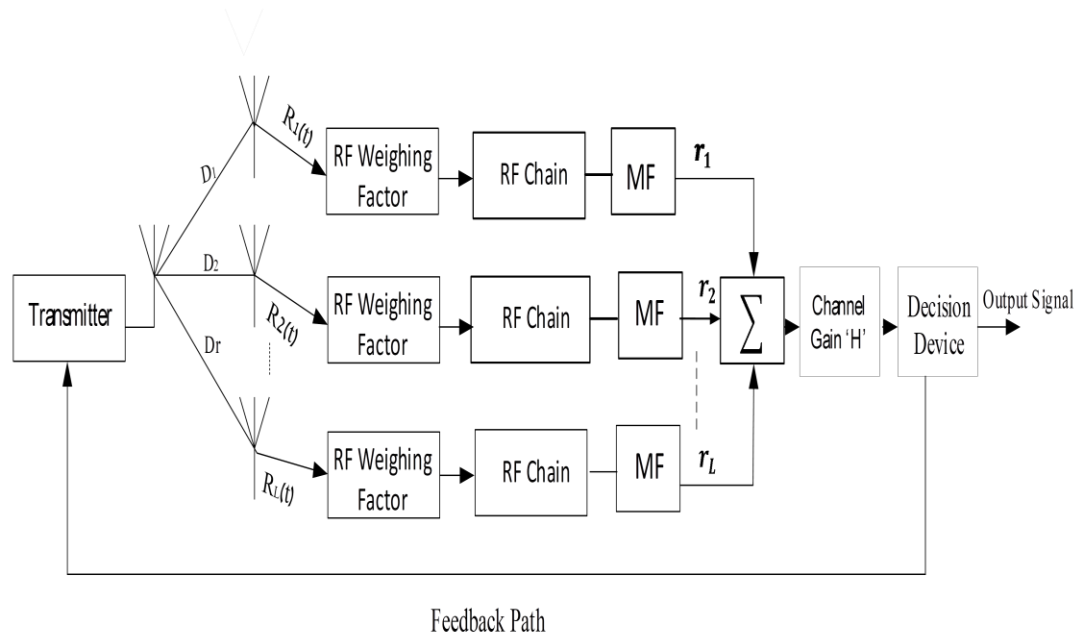


Figure 2: Proposed Enhanced Maximal Ratio Combiner (MRC).

The modulated signal was made to pass through the Square Root Raised Cosine (SRRC) filter to remove the unwanted signal for suitable transmission over a time-varying Nakagami fading channel. The proposed MRC technique is used to combine the multiple copies of the received signal at the RF stage. The instantaneous signal strength of the received signal is ' γ ' is given in [16] as

$$\gamma = \frac{P_t H}{NB} \quad (3)$$

where: P_t is the transmit power

B is the channel bandwidth

H is the channel gain

N is the noise spectral density

But code rate ' R ' is given as

$$R = B \times \log_{10} \left(\frac{1 + (P_t \times H)}{N} \right) \quad (4)$$

where: B is the Bandwidth of transmitted signal

P_t is the transmit power

H is the channel gain

N is the noise present

Using Equation (4), channel gain ' H ' is obtained as

$$H = \frac{(N \times 10^{R/B}) - 1}{P_t} \quad (5)$$

Substituting Equation (5) into (3) gives

$$\gamma = \frac{P_t \frac{(N \times 10^{R/B}) - 1}{P_t}}{NB} \quad (6)$$

$$\gamma = \frac{(N \times 10^{R/B}) - 1}{NB} \quad (7)$$

Equation (7) is the instantaneous signal strength of the received signal. However, the PDF of Nakagami- m fading channel is given in [17] as

$$P_r(r) = \frac{2}{\Gamma(m)} \left(\frac{m}{2\sigma^2} \right)^m r^{2m-1} \exp \left(\frac{-mr^2}{2\sigma^2} \right) \quad (8)$$

where: $\Gamma(\cdot)$ represents the Gamma function
 r is the strength of the received signal
 m is the shape factor

C. Bit Error Rate (BER)

The expression for Bit Error Rate ($P_b(E)$) is given in Rappaport (2002) as

$$P_b(E) = \int_0^\infty P_b(E/\gamma) P_\gamma(\gamma) d\gamma \quad (9)$$

where: $P_b(E/\gamma)$ is the conditional error probability.

$P_\gamma(\gamma)$ is the PDF of the SNR

Therefore, substituting Equation (12) into (15) gives

$$P_b(E) = \int_0^\infty P_b(E/\gamma) \frac{2}{\Gamma(m)} \left(\frac{(10m^{R/B}) - m}{2B\sigma^2} \right)^{3m-1} \exp \left(\frac{((-BmN^2 \times 10^{R/B}) + m)^2}{2\sigma^2} \right) d\gamma \quad (10)$$

$$= \int_0^\infty P_b(E/\gamma) \left(\frac{(10m^{R/B}) - m}{\Gamma(m)B\sigma^2} \right)^{3m-1} \exp \left(\frac{((-BmN^2 \times 10^{R/B}) + m)^2}{2\sigma^2} \right) d\gamma \quad (11)$$

According to Adeyemo *et al.* (2020), conditional error probability $P_b(E/\gamma)$ is given as

$$P_b(E/\gamma) = 1/2 \exp(a\gamma) \quad (12)$$

where: $a = 0.5$ for non-coherent modulation

Therefore, for non-coherent modulation, equation (18) becomes

$$P_b(E/\gamma) = 1/2 \exp(0.5\gamma) \quad (14)$$

Substituting equation (19) into (17) gives

$$P_b(E) = \int_0^\infty \frac{1}{2} \exp(0.5\gamma) \times \left(\frac{(10m^{R/B}) - m}{\Gamma(m)B\sigma^2} \right)^{3m-1} \exp \left(\frac{((-BmN^2 \times 10^{R/B}) + m)^2}{2\sigma^2} \right) d\gamma \quad (20)$$

$$P_b(E) = 0.5 \left(\frac{(10m^{R/B}) - m}{\Gamma(m)B\sigma^2} \right)^{3m-1} \exp \left(\frac{((-BmN^2 \times 10^{R/B}) + m)^2}{2\sigma^2} \right) \times \int_0^\infty \exp(0.5\gamma) d\gamma \quad (15)$$

Integrating equation (21) with respect to γ and substituting upper and lower limit gives

$$P_b(E) = 0.5 \left(\frac{(10m^{R/B}) - m}{\Gamma(m)B\sigma^2} \right)^{3m-1} \exp \left(\frac{((-BmN^2 \times 10^{R/B}) + m)^2}{2\sigma^2} \right) \times (-0.5) \quad (16)$$

for m equal to 0.5, Equation (22) becomes

$$P_b(E) = 0.25 \left(\frac{(5^{R/B}) - m}{\Gamma(m)B\sigma^2} \right)^{0.5} \exp \left(\frac{((-BN^2 \times 5^{R/B}) + m)^2}{2\sigma^2} \right) \quad (17)$$

for m equal to 1, equation (22) becomes

$$P_b(E) = 0.25 \left(\frac{(10^{R/B}) - 1}{\Gamma(m)B\sigma^2} \right)^2 \exp \left(\frac{((-BN^2 \times 10^{R/B}) + 1)^2}{2\sigma^2} \right) \quad (18)$$

Equations (23) and (24) are the Bit Error Rate (BER) for the proposed technique for m equal to 0.5 and 1, respectively.

III. Results and Discussion

Figure 3 presents the BER versus SNR for the enhanced and conventional MRC at L of 2 over Nakagami- m fading channel. At SNR of 10 dB with shape factor of 1, the BER values of 8.92×10^{-7} and 4.20×10^{-4} are obtained for the enhanced and conventional MRC, respectively, while the corresponding BER

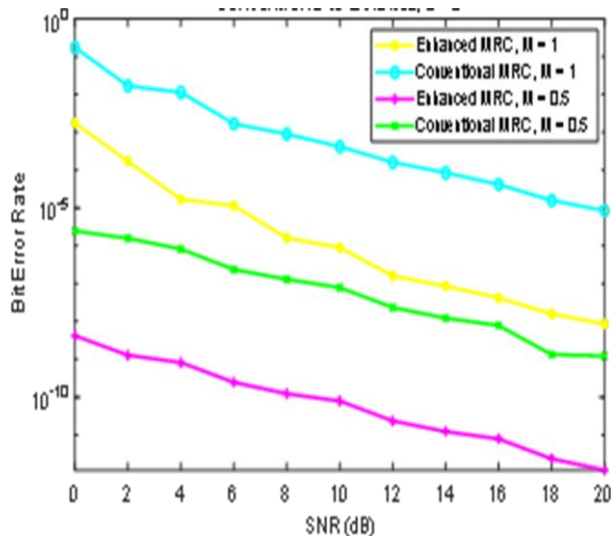


Figure 3: Bit Error Rate versus SNR for the enhanced and conventional MRC at $L = 2$ over time-varying Nakagami-m fading channel.

values obtained at shape factor of 0.5 are 7.86×10^{-11} and 7.81×10^{-8} . The results obtained revealed that, the proposed enhanced MRC gave better performance with low BER values when compared with conventional MRC and this is due to self-adjustment of the proposed technique using ACM algorithm. Also, the results obtained revealed that, both the enhanced and conventional MRC gave better performance with lower BER at shape factor of 0.5 than shape factor of 1. This is due to Nakagami-m fading channel that has no Line of Sight (LOS) component at shape factor of 1. Figure 4 depicts the BER values obtained at L of 4 with different shape factors. The BER values obtained at SNR of 10 dB with shape factor of 1 are 4.83×10^{-14} and 4.83×10^{-10} for enhanced and conventional MRC, respectively, while the corresponding BER values obtained at shape factor of 0.5 are 3.21×10^{-22} and 3.21×10^{-15} . The results obtained showed that, BER values decrease with increase in the

number of paths and this is due to increase in signal strength as number of paths increases thereby reducing error rate. However, in all the paths and shape factors considered, proposed enhanced MRC gave low BER values than conventional MRC due to self-adjustment of transmission rate used in the enhanced technique using ACM algorithm.

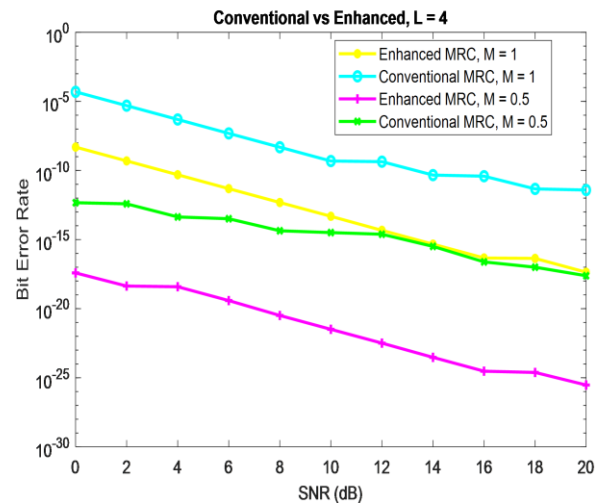


Figure 4: Bit Error Rate versus SNR for the enhanced and conventional MRC at $L = 4$ over time-varying Nakagami-m fading channel.

IV. Conclusion

An enhanced Maximal Ratio Combiner (MRC) technique has been proposed using Adaptive Coding and Modulation (ACM) transmission technique over time-varying Nakagami-m fading channel. The results obtained showed that, the proposed enhanced MRC outperforms conventional MRC by providing better error performance due to lower BER values obtained. The better performance of the enhanced MRC technique is due to adaptation of transmission rate that makes the technique to select an optimal coding and constellation size of the modulation scheme based on the channel status.

Therefore, the proposed enhanced MRC technique has been shown to have a better performance over conventional MRC technique and is particularly useful for wireless system experiencing high mobility and severe fading.

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