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# Diversity Combiner in Adaptive Modulation over Fast and Frequency Selective Environment

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**Abstract**
Signal over fast and frequency selective channel suffers from Doppler and delay effects due to propagation mechanism such as reflection, refraction and diffraction resulting in poor quality reception. Maximal Ratio Combining (MRC) and Adaptive Modulation are some of the techniques previously used to address this problem, but each of these techniques suffers from signal fading and interference distortion as result of weak signal and delay spread respectively. Therefore, an Adaptive modulation technique which incorporates MRC is developed over fast and frequency selective Rayleigh fading channel. The system model in this study employed 10,000 bits randomly generated, gray encoded and modulated with M-ary Phase Shift Keying (M-PSK). The signals were filtered using square root raised cosine filter and then transmitted over fast and frequency selective Rayleigh fading channel. At the receiver, two paths at 100km/hr and 200km/hr were combined using MRC, the channel was estimated using Received Signal Strength Indicator (RSSI) to change the constellation size of the modulation in accordance with the severity of fading. The process was simulated using MATLAB software package. The performance of the proposed system was evaluated using Bit Error Rate (BER) at mobile speeds of 100km/hr and 200km/hr. At Signal to Noise Ratio (SNR) of 10dB, the BER values of 0.0003, 0.0013, 0.0686, and 0.3009 were obtained for conventional MRC with BPSK, QPSK, 8PSK, and 16PSK signaling scheme respectively as against 0.0011 for adaptive MPSK at a mobile speed of 100km/hr while at 200km/hr, the BER values of 0.0134, 0.0161, 0.1947, 0.4116 were obtained using MRC with BPSK, QPSK, 8PSK and 16PSK respectively as against 0.0134 for adaptive MPSK. In conclusion, adaptive modulation incorporating MRC gave the best result due to lower BER values obtained at all SNR considered. The effect of fast and frequency selective Rayleigh channel has been reduced at high speed.
**Keywords**: Adaptive Modulation, Maximal Ratio Combining , M-PSK, Rayleigh Environment, Bit Error Rate (BER), Signal to Noise Ratio (SNR).

## 1. Introduction

With the increase in demand for mobile communication system, efficient and flexible services are desired but usually not achievable due to multipath propagation caused by the channel. The mobile channel can be classified into two namely; fast and frequency non-selective in which the channel varies during the symbol period that is the symbol period is much greater than the delay spread and coherent time, and fast and frequency selective channel where the symbol period of the signaling scheme is less than the delay spread and greater than the coherent time of the channel. This is the type of channel address in this paper and it is the worst type of channel for the receiver [1, 2, 4, 5, 11, 12, 21].

The received symbol is spread over many symbol period and also the channel varies during the symbol period in this type of channel undrstudy. Reliable communication may not be possible no matter how much power is transmitted. In this case, the amplitudes, phases and time delays of anyone of the multipath components vary faster than the rate of change of the transmitted signal. Many methods have been proposed to combat fast and frequency non-selective channel but to the best of author's knowledge much has not been proposed for fast and frequency selective channel. MRC which is one of the methods previously used to improve the signal level but cannot remove ISI distortion and the Doppler Effect. Adaptive modulation method can combat ISI distortion and Doppler Effect but cannot increase the signal level [6, 8, 14, 15, 19, 22].

Therefore, this paper purposes the development of adaptive modulation technique which incorporates the MRC in fast and frequency selective Rayleigh fading channel. The system model for the purposed techniques is developed, 10000 bits randomly generated served as input data, grey encoded and modulated with M-ary PSK signaling schemes. The modulated signals are then transmitted through the raised cosine filter and then passed through the channel understudy. The faded signals through two paths were combined by MRC, demodulated, estimated using RSSI to change the constellation size of the M-ary PSK signaling scheme, where M is taken from a finite set (2, 4, 8, 16). If the Doppler and delay spreads are low, the constellation size increased, but if these spreads are high, the signal constellation size is reduced to ensure reliable transmission. The decision variable used in controlling the signal constellation sizes are the RSSI value and SNR estimate. The transmitted signals were received at mobile speed of 100km/hr and 200km/hr. The results obtained showed that reliable signal was obtained over fast and frequency selective channel when MRC was incorporated into the adaptive modulation technique because of lower BER values obtained at the two mobile speeds.

## 2. System Model

The simulation model for the adaptive modulation incorporating MRC is shown in Figure 1, the randomly generated signals were mapped onto a constellation size, gray encoded, modulated, filtered and transmitted through the fast and frequency selective channels in frames to include pilot symbol for channel estimation. At the receiver, the signal strength is calculated at the output of MRC, the fast and frequency selective channel was estimated with SNR. In MRC, the individual branches are co-phased, weighted proportionately to their channel gain and then summed up. Each of the L$^{th}$ received signal $r_l(t)$ from the two paths is first delayed by $\tau_L$ and coherently demodulated through multiplication by the un-modulated carrier '$\exp(2\pi f_c(t-\tau_L)+\theta_c)$'. This is equivalent to weighing each branch by the complex conjugate of its channel gain $h(t,\tau)$ [10, 13, 17, 18, 20]. The estimator selects the appropriate constellation size of the M-PSK that suites the channel condition and sends the information to the transmitter to use the appropriate constellation size for modulation based on the received SNR which is equal to the mean of RSSI value and SNR estimate. It is assumed that the feedback of the system used detection codes, the size of the feedback information is minimal and the portion with detected errors is re-transmitted. The amount of information to be fedback is minimized by feeding back only the sum of the squares of the channel gains.

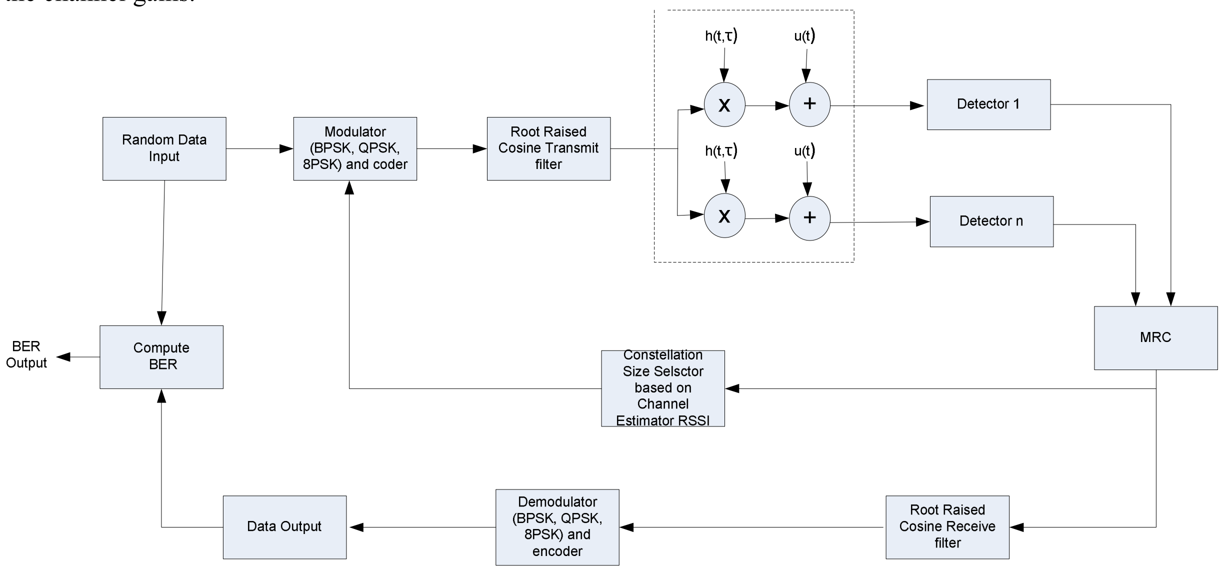


Figure 1: System simulation model for the proposed adaptive modulation incorporating MRC technique

### 2.1 Fast and Frequency Selective Fading

The fading channel is characterized as fast and frequency selective if the symbol period of the signaling scheme is greater than coherent time of the channel and less than the maximum excess delay. Alternatively, if the signal bandwidth is greater than channel coherence bandwidth and less than the Doppler spread.

### 2.2 Fading Distribution

Multipath propagation which causes fast and frequency selective fading channel can be modeled mathematically using different distribution such as Rayleigh, Rician, Nakagami. This paper only addressed Rayleigh distribution where there was no line of sight components (LOS) component despite multiple reflective paths that in large number. In this channel under consideration, the received signal is characterized by a complete obstruction of the direct wave. The probability density function (PDF) $P_R(r)$ of the Rayleigh distribution is given by [12, 17] as

$$P_R(r) = \frac{r}{\sigma^2} exp - \left(\frac{r^2}{2\sigma^2}\right) \qquad 0 \le r \le \infty \qquad (1)$$

where r is the amplitude of the envelope of the received signal

$\sigma$ is the root mean square (rms) value of the received signal

 

$\sigma^2$ is the time-averaged power of the received signal

$2\sigma^2$ is the pre-detection mean power of the received signal.

**2.3 Frequency-Selective Fading Channel Model**

A linear time-varying system with a complex low pass-equivalent response is used to model frequency selective channel. The multipath channel signal $x(t)$ may be modeled as a simple low-pass equivalent characterization [11] as

$$x(t) = \sum_n a_n(t)s(t - \tau_n(t)) \quad (2)$$

where $a_n(t)$ is the attenuation factor for the signal received through n[th] path.

$\tau_n(t)$ is the corresponding propagation delay

$s(.)$ is the input signal

Therefore, the input signal s(t) can be expressed as

$$s(t) = \mathrm{Re}\{s(t)\exp(j2\pi f_c t)\} \quad (3)$$

Therefore, Equation (2) becomes

$$x(t) = \sum_n a_n(t)\,\mathrm{Re}\{s(t - \tau_n(t))\exp(-j2\pi f_c \tau_n(t))\exp j2\pi f_c t\} \quad (4)$$

Equation (4) can be rewritten as

$$x(t) = \mathrm{Re}\left\{\sum_n a_n(t)\exp(j2\pi f_c t).\exp(-j2\pi f_c \tau_n(t))s(t - \tau_n(t))\right\} \quad (5)$$

The complex envelope of the output is

$$\bar{x}(t) = \sum_n s(t - \tau_n(t))\exp(j2\pi f_c t).\exp(-j2\pi f_c \tau_n(t)) \quad (6)$$

Therefore, $h(t,\tau) = \sum_n a_n(t)\exp(-j2\pi f_c \tau_n(t))$ is the time-varying impulse response

Equation (6) becomes

$$\bar{x}(t) = \sum_n h(t,\tau)\exp(j2\pi f_c t) \quad (7)$$

**2.4 Analysis of the MPSK Scheme**

In this study the proposed M-ary PSK modulator and demodulator change within a set of 2, 4, 8, 16 constellation, representing BPSK, QPSK, 8PSK and 16QPSK respectively. From the set of 'M' values, each constellation is expressed [7, 9] as

$$M = 2^k \quad (8)$$

where $k$ is the number of bits representing an MPSK symbol

Taking logarithm to base 10 of both sides of equation (8) gives

$$\log_{10} M = k \log_{10} 2 \quad (9)$$

$$k = \frac{\log_{10} M}{\log_{10} 2} \quad (10)$$

Therefore,

$$k = \log_2 M \quad (11)$$

Bits for different constellations of MPSK signaling scheme are shown in Table 1

Table 1: Bit representation of MPSK scheme

| ***M*** | ***k=log₂M*** | Constellation (bits) |
|---|---|---|
| 2 | 1 | [0.1] |
| 4 | 2 | [00,01,11,10] |
| 8 | 3 | [000,001,011,010,110,111,101,100] |
| 16 | 4 | [0000,0001,0010,0100,1000,1001,1010,1100,1101,1110,1111] |

## 3. Adaptive Modulation

Adaptive transmission involves estimating the power gain or received SNR at time'$t$' and adapting the modulation parameters accordingly. The most common parameters to adapt are the data rate R(t), transmit power P(t), coding parameters C(t) and modulation constellations.

For M-ary signaling scheme, the data rate is given by [23] as

$$R(t) = \log_2 \frac{M}{T_s} = B_s \log_2 M \quad (12)$$

where $B_s$ is the received signal bandwidth

$T_s$ is the symbol period

The SNR estimate is denoted as

$$\bar{\gamma}(t) = \frac{\bar{p}\,\bar{g}(t)}{N_o B_s} \quad (13)$$

where $\bar{p}$ is the average transmit signal power

$\bar{g}(t)$ is the channel power gain estimate

$N_o$ is the power spectral density of the AWGN

### 3.1 Received Signal Strength Indicator (RSSI)

The received signal strength indicator used in changing the constellations of the modulation orders is calculated as follows:

*The transmitted signal 'T' and Received signals 'R' are added together to give 'S'*
*Variance of 'S' is calculated to give 'V'*
*Mean of the variance 'M' is computed from 'V'*
*Reciprocal of the mean 'M' gives RSSI*
*RSSI is converted to decibel to give R (dB)*

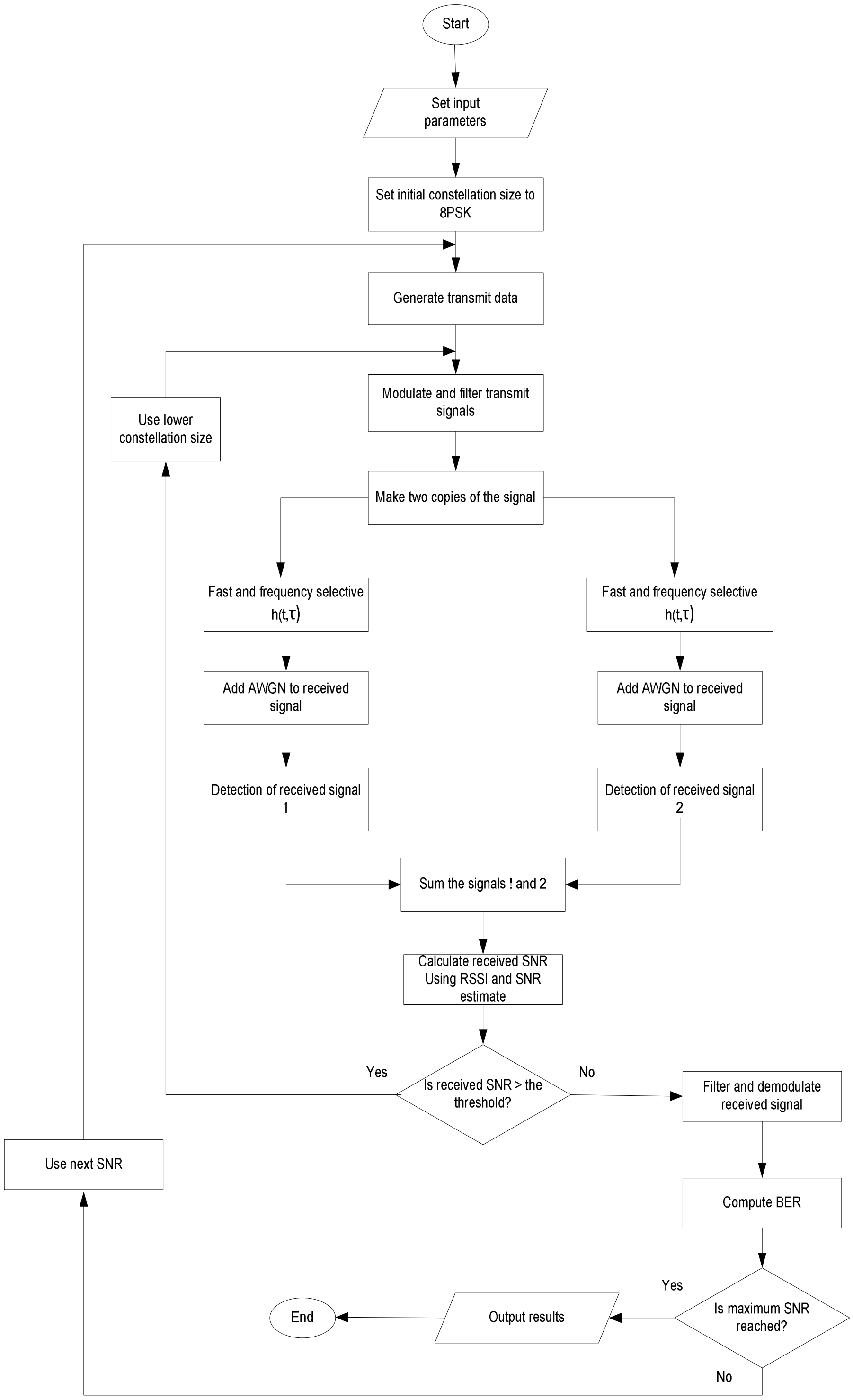


Figure 2: Flowchart of the proposed technique

## 3.2 Bit Error Rate (BER) of M-PSK scheme

In digital modulation system, the baseband signals are represented as a time sequence of symbol where each symbol has 'M' finite states and represented by 'k' bits of information.

The symbol error probability $P_s$ of M-PSK for 'k' bits in Equation (11) is expressed [7, 9, 11, 12, 13, 23] as

$$P_s = 2Q\left(\sqrt{2\gamma_s}\sin\left(\frac{\pi}{M}\right)\right) \quad (14)$$

where M=2,4,8,16

$P_s$ is related to $P_b$ by the relation $P_s = kp_b$

$$P_b = \frac{p_s}{k} = \frac{2}{\log_2 M} Q(\sqrt{2\gamma_b \log_2 M} \ \sin\left(\frac{\pi}{M}\right)) \qquad (15)$$

where 'Q' is the Marcum Q-function given as

$$Q = \frac{1}{2} erfc(\frac{x}{\sqrt{2}})$$

$erfc$ is the complimentary error function

$P_s$ is the symbol error probability for coherent modulation

$p_b$ is the bit error probability (bit error rate) for coherent modulation

$\frac{N_O}{2}$ is the one sided noise power density(watts/Hz)

M is the modulated bits per symbol

Signal-to-Noise Ratio (SNR) per bit $\gamma_b = \frac{E_b}{N_o}$ also known as bit energy

For M-PSK Signal, SNR $\gamma_b = \frac{kE_b}{N_o}$ where k=2, 4, 8, and 16

**4. Results and Discussion**

The performance of adaptive modulation incorporating MRC over fast and and frequency selective environment is presented in Figures 3 to 9 using Bit Error Rate (BER) at 100km/h and 200km/h. Figure 3 shows the results of BER against SNR in fast and frequency selective Rayleigh fading channel with two paths at 100km/h with MRC using M-PSK signaling scheme. It can be observed that at SNR of 4 dB, BER values of 0.0133, 0.0379, 0.2624 and 0.4448 are obtained for BPSK, QPSK, 8PSK and 16PSK respectively with conventional MRC as against 0.0133 obtained for Adaptive modulation incorporating MRC in Figure 4. Figure 5 showed that BER values 0.1083, 0.1300, 0.3795 and 0.4802 were obtained for BPSK, QPSK, 8PSK, and 16PSK respectively with conventional MRC at 200 km/h as against 0.1083 for adaptive counterpart presented in Figure 6.

The BER values for the BPSK, QPSK, 8PSK and 16PSK with conventional MRC are higher than the Adaptive modulation incorporating MRC for all the SNR between 0 and 20dB indicating poor performance due to delay spread resulting into selective fading. Also, the BER values obtained at 200km/h are higher in values than at 100km/h, this indicates that as the speed increases the performance decreases due to Doppler and signal fading effects.

The results obtained are justifiable because of RSSI used with the channel estimator to improve the prediction accuracy of the receiver, so that their mean value give the receiver better information for decision making when the value of any of the two decision variables was inaccurate.

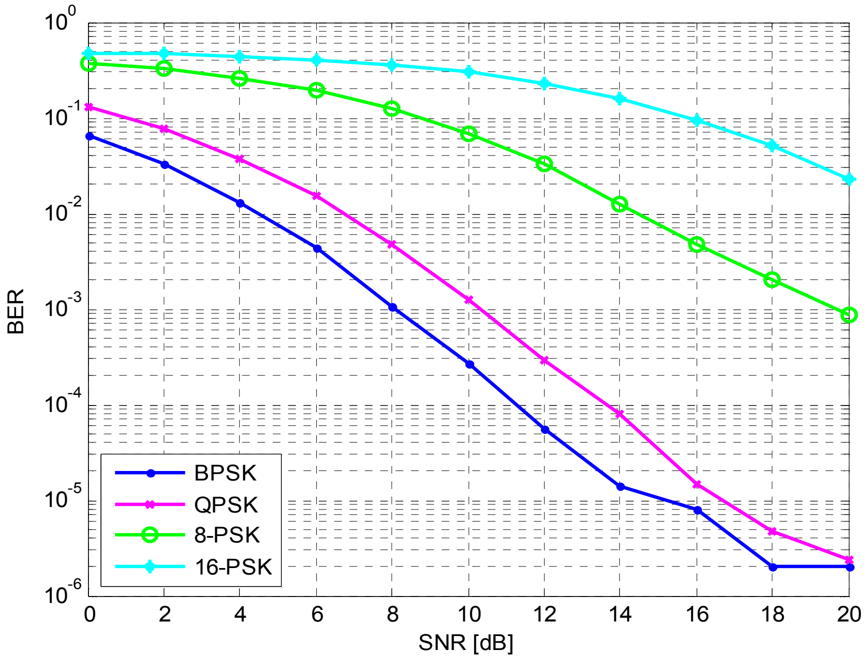


Figure 3: BER vs SNR of Conventional MRC using M-PSK with 2-path over fast and frequency selective Rayleigh fading channel at mobile speed of 100 km/h

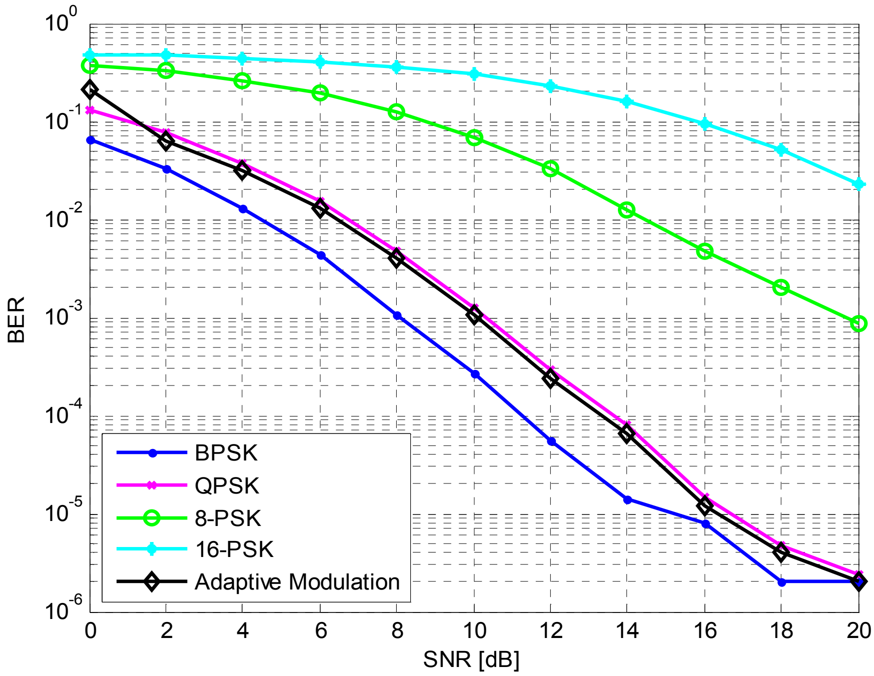


Figure 4: BER vs SNR of Adaptive M-PSK incorporating MRC with a 2-path over fast and frequency selective Rayleigh fading channel at speed of 100km/h

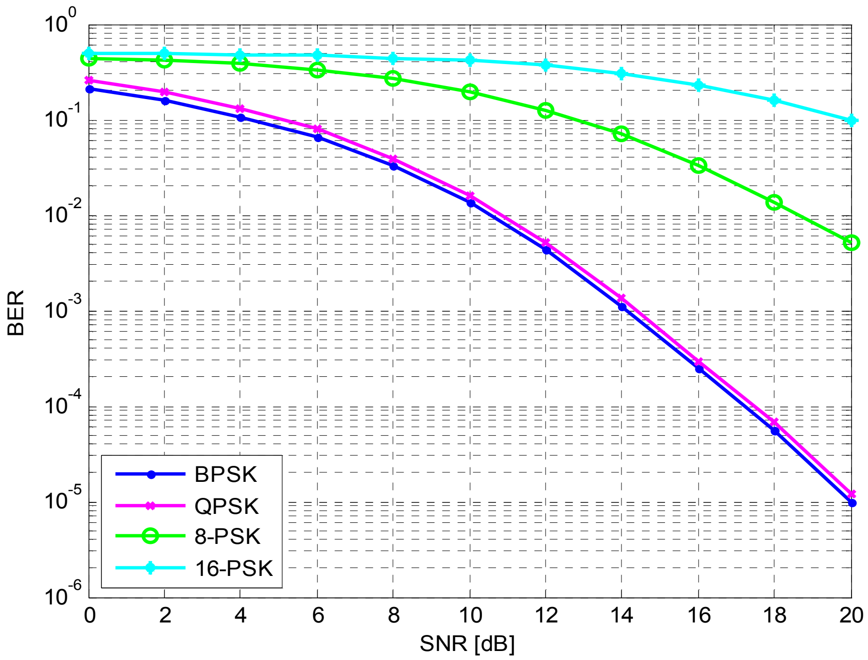


Figure 5: BER vs SNR of Conventional MRC using M-PSK with 2-path over fast and frequency selective Rayleigh fading channel at mobile speed of 200 km/h

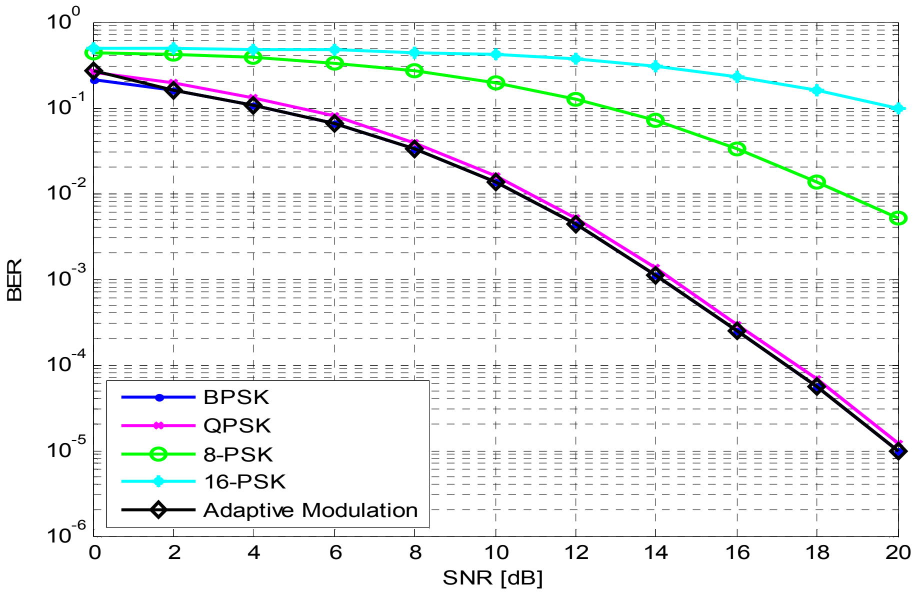


Figure 6: BER vs SNR of Adaptive M-PSK incorporating MRC with a 2-path over fast and frequency selective Rayleigh fading channel at speed of 200km/h

## 5. Conclusion

Adaptive modulation incorporating MRC using 2 paths over fast and frequency selective Rayleigh fading channel at speeds of 100km/h and 200km/h has been developed and evaluated. This is then simulated using 10,000 bits randomly generated as input signals, processed with all the signal processing techniques involved and the output signals were compared with inputs to evaluate the performance at two different speeds. This has been compared with conventional MRC without adaptive modulation. The BER values for adaptive modulation incorporating MRC were lower than the conventional MRC using M-PSK scheme at all SNR with two speeds considered due to RSSI used to adjust the constellation. Therefore, this paper has shown that the effect of fast and frequency selective fading channels which occurred in environment where delay and Doppler spreads are prominent that degrade the transmitted signals has been reduced by incorporating MRC in adaptive modulation.

 

**References**

[1] Adeyemo, Z.K., and Raji, T. I., (2008): "Bit Error Rate Analysis for wireless links using Adaptive Combining Diversity," Journal of Theoretical and Applied Information Technology, 8(1):58-66

[2] Adeyemo, Z.K., and Raji, T.I., (2010): "Investigation of Modulation Schemes in Mobile Multipath Fading Environment with Decision Feedback Equalizer", International Journal of Biological and Physical Science, 15(1): 77-86

[3] Alouini, M., Tang, X. and Goldsmith, A.J, (1998): "An Adaptive Modulation Scheme for Simultaneous Voice Data Transmission over Fading Channels", Department of Electrical Engineering, California Institute of Technology, Pasadena, California, USA.

[4] Bernard, S., (1997): "Rayleigh fading channels in mobile digital communication system" IEEE communication magazine 35(7): 90 - 100

[5] Greenwood, D., and Hanzo, L., (1994): "Characterization of Mobile Radio Channels", 2nd edition, Pentech Press, London

[6] Kamath, K.L., and Geockel, D. L., (2004): "Adaptive Modulation Schemes for minimum outage probability in wireless systems," IEEE Transaction on communication, 52(1632-1640

[7] Krishna, S., (2008): "Bit Error Rate for 16PSK Modulation using Gray Mapping", Retrieved from http//www.google.com/search in October 2013

[8] Kowalsky, R., (2007): "The Benefits of Dynamic Adaptive Modulation for High Capacity Wireless Backhaul Solutions", White Paper, Ceragon Networks

[9] Langton C. (2005): "Modulation," Prentice Hill Incorporated, Eagle Wood Cliff, New York, pp.415.

[10] Pornchai, S., Wanaree, W., and Sawasd, T., (2009): "Performance of M-PSK in Mobile Satellite Communication over Combined Ionospheric Scintillation and Flat Fading Channels with MRC Diversity", IEEE Transactions on Wireless Communications, 8(7): 3360-3364

[11] Proakis. J.G. (2001): "Digital Communications" 3rd edition, McGraw Hill, international edition USA.

[12] Rapapport, T., S., (2002), "Wireless Communications: Principles and Practice, second edition, Prentice Hall, New Delhi.

[13] Stuber, G. L., (2002): "Principles of Mobile Communication'' second edition, Kluwer Academic Publishers, New York.

[14] Xuamming, D., (2006): "Effect of Slow Fading and Adaptive Modulation on TCP /UDP Performance of High Speed Packet Wireless Networks", Technical Report Number UCB/EEC-2006-109, University of California, Berkeley.

[15] Yumin, L. and Donald, L. (1998): "MAP selection diversity DFE for Indoor Wireless Data Communication, IEEE Journal on Selected areas in Communication, 16( )1376-1384

[16] Xiong, F., (2000): ''Digital Modulation Techniques'' second edition, Artech House Publishers, London.

[17] Gregory, D. D., Theodore, S. R., and David, A. W (2002): New Analytical Models and Probability Density Functions for Fading in Wireless Communications, IEEE Transactions on Communications, 50(6): 1005-1012.

[18] Parastoo, S. and Predrag, R. (2008): On Information Rate of Time-varying Fading Channels Modeled as Finite-State Markov Channels, IEEE Transactions on Communication, 56(8):1268-1278.

[19] Mohamed-slim., Tang and Goldsmith A. J., (1999): An Adaptive Modulation Scheme for Simultaneous Voice and Data Transmission over Fading Channels, IEEE Journal on Selected Areas in Communications, 17(5):837-847.

[20] Young, J.C. and Saewong, B., (2008): "Multichannel Wireless Scheduling under Limited Terminal Capacity" IEEE Transactions on Wireless Communications, 7(2): 611-617

[21] Zhang, Y. and Fujise, M. (2006): "performance Analysis of Wireless Networks over Rayleigh Fading Channel", IEEE Transactions on Vehicular Technology, vol. 55, no. 5, pp. 1621-1632.

[22] Vijay G. K. (2007): Wireless Communications and Networking, Morgan Kaufmann, United State of America.

[23] Goldsmith, A. (2004): Wireless Communication, Stanford University.