Intersymbol Interference Distortion Cancellation Using a Modified Maximal Ratio Combiner in Mobile Wireless Communication

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Abstract

This paper presents a modified maximum Ratio Combiner (MRC) for correcting inter symbol interference (ISI) distortion in mobile wireless channel. Mobile wireless system produces fast frequency selective fading channel which is due to the variation of the channel in such a way that the coherent time will be less than the symbol period of the modulation schemes considered and the delay be greater than the symbol period. This causes overlapping of successful symbols and resulted in intersymbol interference (ISI). The modified MRC performance investigated uses a single Radio Frequency (RF) chain and a single Matched Filter (MF). The two paths were considered and combined using MRC at the RF stage. Then the received signal was evaluated in term of Bit Error Rate (BER) and the results were compared with the conventional MRC which used many RF chains and MF depending on the number of paths. The results obtained showed that the modified MRC gave approximately the same BER performance when compared with the conventional MRC receiver indicating the same performance over this ISI distortion channel. Also, the modified MRC receiver at the RF stage gave relatively lower processing time which is an indication of a lower complexity. Therefore, the modified MRC receiver has been shown to be capable of reducing the hardware complexity and the implementation cost of the system over the ISI channel.

Keywords: Maximum Ratio Combining, Matched Filter, RF chain, Multipath fading, GMSK

1. Introduction

Nowadays, mobile communications are undergoing a strong expansion due to their immense applications in various economic sectors of every nation, like Banking, Telecommunication, Marketing, Broadcasting and Security to mention but few. In order to design robust and highly-effective mobile communication systems to meet-up with this expansion, the characteristics of the radio channel in which systems will operate need to be considered. The knowledge creates a system running at high speed, using less bandwidth while minimizing error rate. Unfortunately, the mobile radio channel is the most chaotic media to work with. In reality, it is very difficult to predict the behavior of the channel (Huan, Tung and Duc, 2003).

In a radio communication system, when the signal is transmitted through the physical channels, it degrades as a result of obstacles along the signal path. As a results, the mobile system moves through zones with different signal levels, causing a fluctuation of the received signal (Rappaport, 2002). This variation or fluctuation at the receiver can be so severed as to produce a signal which is below the sensitivity of the receiver, thus, causing poor reception of the signals. The phenomenon is known as signal fading. Signal fading arises from multiple transmission paths at the receiver with different phase shift and delay spread which is the time spread between the first arrival and last path.

In a digital system, the delay spread leads to inter-symbol interference (ISI) whenever the received multipath components of a symbol extend beyond the symbol's time duration (Sklar, 1997). The fading channel associated with ISI is called frequency selective; here the coherent bandwidth of the channel is lesser than the signal bandwidth (Mohamed, 2007). Conventional MRC is proposed in (Adeyemo and Raji, 2010) (Deepmala, Ravi, 2012) (Adeyemo and Abolade, 2012) as one of the mitigating techniques against mobile multipath fading. However, the conventional MRC suffers the hardware complexity as a result of its multiple RF chains and Matched Filters which depends on the number of propagation path. In Conventional MRC, multiple copies of the same information signal were combined so as to maximize the instantaneous signal at the output (Adeyemo, 2009). The output of the conventional MRC is obtained from the weighted sum of all branches. The complex conjugate of the channel impulse response was used as the weight which multiplied each of the corresponding signal paths to cancel the phase variations introduced by the channel (Pornchai, Wannaree and Sawasd, 2009). System model of the conventional MRC diversity for N propagation paths and its output was given by (Sang, and Zhengado, 2007). The RF weighting of the conventional MRC is obtained as the conjugate of the channel impulse response (Adeyemo and Raji, 2010). In this paper, a modified MRC receiver with Maximum Likelihood Sequence Estimation (MLSE) equalizer is proposed to mitigate the induced ISI channel caused by multipath propagation effects.

2. Materials and Method

2.1 System Model

The system model consists of the transmitter, the mobile communication Channel and the Receiver. Source data (randomly generated binary data) is reshaped and modulated with each of BPSK, QPSK and GMSK schemes. Square-root raised cosine (SRRC) filter is used to reduce the spectral occupancy in case of BPSK and QPSK while Gaussian filter is used in case of GMSK. Modulator processes the digital message signal and filtered for suitable transmission over the channel. The system model is shown in Figure 1. The received signals at the RF stage were combined using MRC and then passed through the RF chain and matched filter for further processing which was finally demodulated with BPSK, QPSK and GMSK demodulators.
BPSK, QPSK modulated signal, denoted by $s_{BPSK/QPSK}(t)$ is modeled as

$$s_{BPSK/QPSK}(t) = k(t)cos\big(2\pi f_c t + \emptyset(t)\big) \qquad (1)$$

where, $k(t)$ is the complex modulating signal
f_c is the carrier frequency and $\emptyset(t)$ is the phase shift.

Equation 1 can be written as complex envelope form as

$$\tilde{s}_{BPSK/QPSK}(t) = k(t)exp[j2\pi f_c t] \qquad (2)$$

Also, $s_{GMSK}(t)$ can be modeled from the impulse response of the Gaussian low-pass filter $q(\ t\ )$ given as

$$q(\ t\ ) = \sqrt{2.\frac{\pi}{\ln(2)}}\,.(BT_s).exp\left(-2\left(\frac{(BT_s).\pi t}{In(2)}\right)^2\right)` \qquad (3)$$

where B is the half power band width and T_s is the symbol duration.
GMSK modulated signal can be modeled as

$$s_{GMSK}(t) = \ rect\left(\frac{t}{T}\right) * q(t) \qquad (4)$$

where $*$ is the convolution symbol, $rect(\,.\,)$ is the rectangular function obtained from the none return zero (NRZ) format of the burst of data to be transmitted and $q(t)$ is the impulse response of the Gaussian filter.

2.1.1 BPSK modulated signal

The BPSK modulated signal, denoted by $s_{BPSK}\ (t)$, is modeled by (Rappaport, 2002) as

$$s_{BPSK\ i}(t) = m(t)\sqrt{\frac{2E_s}{T_s}}\ \cos(2\pi f_c t + \emptyset_c), 0 \le t \le T_s \qquad (5)$$

Where E_s is the energy per symbol, T_s is the symbol period and f_c = the carrier frequency, $\emptyset_c$ is the phase shift and $m(t)$ is the binary data which takes on one of two possible pulse shape

2.1.2 Quaternary Phase Shift Keying Analytical Expression

Here, two bits are transmitted in a single modulation. The QPSK signal for this set of symbols states is given as (Rappaport, 2002) (Leon, 2002) as:

$$s_{QPSK\ i}(t) = \sqrt{\frac{2E_s}{T_s}}\ \cos\left(\frac{\pi}{2}(i-1)\right)\cos(2\pi f_c t) - \sqrt{\frac{2E_s}{T_s}}\ \sin\left(\frac{\pi}{2}(i-1)\right)\sin(2\pi f_c t) \qquad (6)$$

For $0 < t < T_s$ and $i = 1, 2, 3, 4$

2.1.3 *Gaussian Minimum Shift Keying (GMSK)*

Gaussian Minimum Shift Key (GMSK) yields a constant amplitude and continuous phase RF carrier signal. It has a much more constrained bandwidth because the Gaussian pulse rises and decays asymptotically with respect to a zero response level. The GMSK is generated by direct FSK modulation of a carrier with a baseband signal which is scaled in amplitude to produce a modulation index of 0.5 so as to produce a difference of 180° between the two values. Pre-modulation filter is used to reduce the bandwidth of a baseband pulse train prior to modulation so as to smooth the phase trajectory of the MSK signal resulting in FM modulated signal with narrow bandwidth. The reduction in the bandwidth is as result of smearing of the individual pulses in pulse train. The BER for GMSK is given by (Sanjay, 2011) as:

$$BER = Q\left(\sqrt{\frac{2\propto E_b}{N_o}}\right) \tag{7}$$

where:

$$Q = \frac{1}{2} erfc\left(\frac{x}{\sqrt{2}}\right) \tag{8}$$

$x =$ Euclidean distance between the two constellation points on the constellation diagram
$E_b =$ energy per bit
$N_o =$ noise power spectral density
$\propto = BT_b$ (product of Bandwidth and bit duration)

2.2 *Mobile Wireless Channel*

The wireless channel is modeled as the time varying impulse response $h(t,\tau)$ channel (Goldsmith, 2005) as

$$h(t,\tau) = \sum_{i=0}^{N-1} a_i(t,\tau) exp[j\Theta_i(t,\tau)]\delta\left(\tau - \tau_i(t)\right) \tag{9}$$

where:

$a_i(t,\tau)$ is the attenuated amplitutde of i^th multipath at time *t* and delay τ
$\tau_i(t)$ is the delay of i^th paths at time *t.*
$\Theta_i(t,\tau)$ is the phase shift at i^th path which depends on the delay spread and Doppler spread
$\delta(\tau - \tau_i(t))$ is the unit impulse function which determines the specific multipath component at time t, and excess delay τ_i

The received fading signal $h(t)$ without LOS can be expressed as

$$h(t) = \sum_{i=0}^{N-1} a_i(t)\ \cos(2\pi f_c t + \emptyset_i(t)) \tag{10}$$

where N is the number of paths,
$\emptyset_i(t)$ is the phase which depends on varying paths length, changing by 2π.

The linear time-varying impulse response $h(t,\tau)$ of mobile channel is modeled by a random phenomenon because its characteristics change as a function of time in a random manner. Therefore, the sum of the replicas and each resolvable channel path can be approximated as complex-valued Gaussian process in time with zero mean. At any time t, the probability density function (pdf) of the real and imaginary parts is Gaussian. Since each resolvable path is modeled as a complex-valued Gaussian process, by changing the complex Gaussian random variables to polar coordinates, it is straight forward to conclude that the envelope of the attenuation is Rayleigh and the phase is uniformly distributed (Ramjee, and Hiroshima, 2002) (Yee and Satorius, 2003).

When there is relative motion between the transmitter and the receiver, channel impulse response on the signal becomes

$$h(t) = \sum_{i=0}^{N-1} a_i(t)\ \cos[2\pi t(f_c + f_d) + \emptyset_i(t)] \qquad (11)$$

where f_d is the Doppler frequency

Equation 7 can be further expressed in terms of the inphase and quadrature form as

$$h(t) = \sum_{i=0}^{N-1} I(t)\, cos2\pi f_d t - Q(t) sin2\pi f_d t \qquad (12)$$

where, In-phase $I(t) = \sum_{i=0}^{N-1} a_i(t)\, cos(2\pi f_d t + \emptyset_i(t))$ (13)

Quadrature $Q(t) = \sum_{i=0}^{N-1} a_i(t)\, sin(2\pi f_d t + \emptyset_i(t))$ (14)

2.3 The Receiver

The received signals from two independent identically distributed (iid) paths are combined using a modified MRC at the Radio Frequency (RF) stage. It is made up of two RF weighting, the summer, one RF chain and one Matched filter. The received RF baseband signal at the ith path can be expressed in complex form as

$$\tilde{y}_i(t) = Re\{y_i(t) expj2\pi f_c t\} \qquad (15)$$

$$y_i(t) = h_i(t,\tau)s(t) + n_i(t)\ , i = 0, 1 \ldots \text{N-1} \qquad (16)$$

where:

$h_i(t,\tau)$ is the complex channel gain between the transmit antenna and the ith receive antenna element.

$y_i(t)$ is the received signal at the antenna i^{th} path.

$s(t)$ is the equivalent low-pass transmitted signal,

$n_i(t)$ is the thermal noise modeled as AWGN at the ith receive antenna

f_c is the carrier frequency.

Each output of the RF weighting blocks is derived from the Hilbert transform of the received signal $y(t)$ and is modeled as

$$\widetilde{w_i}(t) = h_{i,Re}(t,\tau)(\tilde{y}_i(t)) + h_{i,Im}(t,\tau)\big(\tilde{y}_i(t-\tau)\big) \qquad (17)$$

Then all the RF weighting, $\widetilde{w_i}(t)$ outputs in each path can be combined to produce

$$\tilde{w}(t) = \sum_{i=0}^{N-1} h_{i,Re}(t,\tau)(\tilde{y}_i(t)) + h_{i,Im}(t,\tau)(\tilde{y}_i(t-\tau)) \qquad (18)$$

Equation (15) can be substituted in equation (18) to give

$$\tilde{w}(t) = \sum_{i=0}^{N-1} Re\big\{h_{i,Re}(t,\tau)y_i(t)\ +\ h_{i,Im}(t,\tau)y_i(t-\tau)\exp(-j2\pi f_c\tau)\big\} expj2\pi f_c t (19)$$

where $h_{i,Re}$ and $h_{i,Im}$ are the Real and Imaginary of the complex channel gain and τ is the delay time. It was observed for the value of τ in equation (20) justified the mathematical expression in equations (21) and (22).

$$\tau = \frac{1}{4f_c} \qquad (20)$$

$$s(t-\tau) \cong s(t), \tag{21}$$

$$\exp(-j2\pi f_c\tau) = -j \tag{22}$$

Equation; 16, 20, 21 and 22, can be substituted into equation 19 to give

$$\widetilde{w}(t) = \sum_{i=0}^{N-1} Re\left\{\begin{matrix} h_{i,Re}(t,\tau)[h_i(t,\tau)s(t)] - jh_{i,Im}(t,\tau)h_i(t,\tau)s(t-\tau) + \\ h_{i,Re}(t,\tau)n_i(t) - jh_{i,Im}(t,\tau)n_i(t,\tau) \end{matrix}\right\} expj2\pi f_c t \tag{23}$$

Taking out the real component from the equation (23) gives

$$\widetilde{w}(t) \cong \sum_{i=0}^{N-1}[|h_i(t,\tau)|^2 s(t) + h_i^*(t,\tau)n_i(t)]\; expj2\pi f_c t \tag{24}$$

The output of the summer can be down converted to the baseband signal by passing $\widetilde{w}(t)$ through the RF chain to give

$$w(t) \cong \sum_{i=0}^{N-1}[|h_i(t,\tau)|^2 s(t) + {h_i}^*(t,\tau)n_i(t)] \tag{25}$$

where ${h_i}^*(t,\tau)$ is the conjugate of the channel complex gain at the time t and delay τ.

The received baseband signals are then passed into the matched filter to further remove the spectral occupancy.

The output of the Matched filter is obtained by convolving the MF impulse response with the $w(t)$. This can be expressed in equation (26) and (27) using SRRC and Gaussian filter respectively as

$$w(T) = w(t) * p(kT-t) \tag{26}$$

$$w(T) = w(t) * q(kT-t) \tag{27}$$

where $*$ is the convolution operator, $p(kT-t)$ and $q(kT-t)$ are the time inverse function of the impulse response of the SRRC filter and Gaussian filter respectively as proposed in (SPS, 2012) (Swarna, Prasanna, and David, 2011). Mathematical expression for the impulse response of SRRC and Gaussian filter were reported in (3GPP TS, 2012) (Ambreen, and B. Felicia, 1999) respectively. Therefore, equations (26) and (27) can be simplified and expressed as:

$$w(T) = u_s(T) + u_n(T) \tag{28}$$

where:

$u_s(T)$ is the discrete signal component of the matched filter's output
$u_n(T)$ is the discrete noise component of the matched filter's output

Therefore,

$$w(T) \cong \sum_{i=0}^{N-1}[|h_i(t,\tau)|^2 s(T) + h_i^*(t,\tau)n_i(T)] \tag{29}$$

where:

$s(T)$ is the transmitted data
$n_i(T)$ is the discrete noise and
$h_i(t,\tau)$ is the channel impulse response at the delay τ
$h_i^*(t,\tau)$ is the conjugate of the channel impulse response at the delay τ

For the combined baseband signal from two propagation paths, the output of the modified MRC is given as

$$w(T) \cong [(h_0^2(t,\tau) + h_1^2(t,\tau)]\; s(T) + {h_0}^*(t,\tau)n_0(T) + {h_1}^*(t,\tau)n_1(T) \tag{30}$$

The signal at the output of the MF is fed into the Maximum Likelihood Sequence Estimation Equalizer (MLSE) where the error due to ISI is removed using Viterbi algorithm. Then, the output signal from the equalizer is passed to the appropriate BPSK, QPSK and GMSK demodulator. Bit Error Rate (BER) is estimated from the demodulator output by comparing with the transmitted signal.

2.4 Rayleigh distribution

Rayleigh fading is the specialized model for the stochastic fading when the nature of the channel is probabilistic and there is no line of sight signal, sometimes considered as a special case of the more generalized concept by a Rayleigh distribution. Lord Rayleigh proposed that the received signal $r(t)$ can be expressed as [3]

$$r(t) \ = \rho(t) \, cos \, (2\pi \, fct \ + \theta(t)) \tag{31}$$

The received signal has Rayleigh amplitude $\rho(t)$ which is found from

$$\rho \ (t) = \sqrt{I^2(t) + Q^2}(t) \tag{32}$$

and a uniform phase $\theta(t)$ between 0 and 2π. The probability density of the amplitude is described by the "Rayleigh distribution". Rayleigh probability density function (PDF) $f_R(r)$ is given by (Vijay, 2007) as

$$f_r \ (r) \ = \frac{r}{\sigma^2} \, exp \left[-\frac{r^2}{2\sigma^2} \right], \qquad r \geqq 0 \tag{33}$$

where:

r is the amplitude of the received signal

σ^2 is the parameter of the distribution

2.5 Bit Error Rate (BER)

Bit error rate is a key parameter that is used in assessing systems that transmit digital data from one location to another. BER is applicable to radio data links, Ethernet, as well as fibre optic data systems. When data is transmitted over a data link, there is a possibility of errors being introduced into the system. If this is so, the integrity of the system may be compromised. As a result, it is necessary to assess the performance of the system, and BER provides an ideal way in which this can be achieved and assesses the full end to end performance of a system including the transmitter, receiver and the medium between the two. BER is defined as the rate at which errors occur in a transmission system. [5] mathematically expressed BER as,

$$BER \ = \frac{number \ of \ bits \ in \ error}{total \ number \ of \ bits \ sent} \tag{34}$$

BER expression is given by [2], [8] as

$$BER = \int_0^\infty \ p_b \left(\frac{E}{r}\right) p(r) dr \tag{35}$$

where $p_b \left(\frac{E}{r}\right)$ is the conditional error, $P(r)dr$ is the pdf of the Signal to Noise Ratio (SNR)

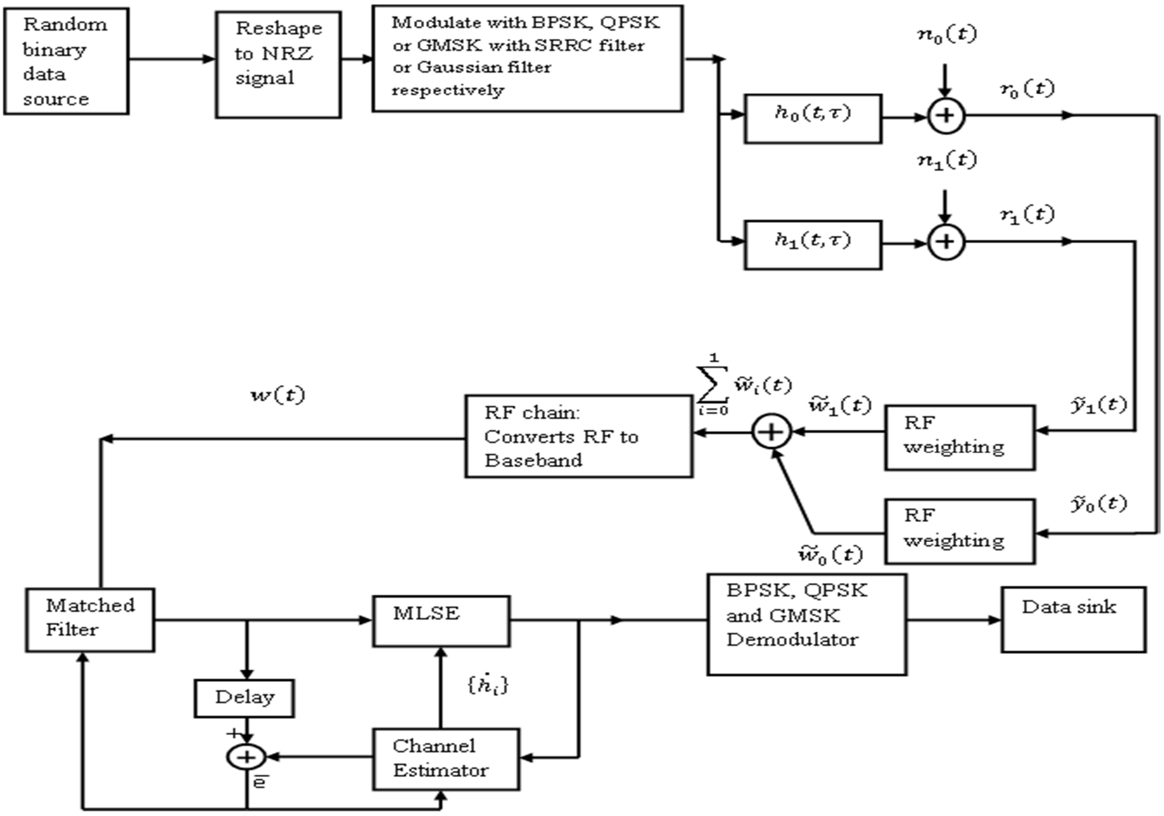

Figure 1. System model

2.6 *Simulation method*

The simulation of the system model under study was carried out using MATLAB application package because of the controllability and repeatability of parameters, which is very difficult to achieve at highway speeds in the field test. The simulation was carried out using randomly generated binary data which was reshaped to Non Return to Zero (NRZ) data format for BPSK, QPSK and GMSK modulation scheme in turn. Then two copies of the faded signal were created and combined using MRC at the RF stage. The following parameters and system configurations were used in the simulation:

Modulation scheme: BPSK, QPSK and GMSK
Carrier frequency: 1800 MHz
Bandwidth of signal: 60 Hz
Symbol periods, *Ts*: 16.67 ms
Delay spread τ_m: 18 ms
Noise: AWGN
Transmit Filter: Square root raised cosine pulse shaping for BPSK, QPSK and Gaussian for GMSK
Receive Filter: Matched Filter
Number of MRC Paths: 2 paths
Mobile speed: 120 km/h
Fading type: Rayleigh fading

3. *Results and Discussion*

The results obtained from using BPSK, QPSK and GMSK signaling schemes with a modified and conventional MRC receiver over two paths at mobile speed of 120 km/h, in a terrestrial mobile environment are presented in Figure 2 to 4. The terrestrial multipath mobile environment is simulated based on Jakes model for Rayleigh fading channel. Bit Error Rate (BER) in figure 2 to 4 showed that both MRC were able to mitigate the fading due to the fast and frequency selective nature of the mobile channel, haven produced a lowest BER with GMSK, lower BER with BPSK and low BER with QPSK. Figure 5 shows the BER performance of the three modulation schemes in a plot to reveal easily the performance comparison of the considered modulation schemes. Results of the simulation showed that at the mobile system speed of 120 Km/h, Modified MRC gave mean BER of 0.0393, 0.0946, 0.0029 against mean BER of 0.0457, 0.0988 and 0.0036 of the conventional MRC, using BPSK, QPSK and GMSK signaling scheme respectively. Consequently, it can be observed that the modified MRC performs better than the conventional MRC in terms of BER, this is justified with the fact that combining the received signal at the RF stage rather than the baseband stage favours better cancelation of the phase variation introduced by the channel.

Considering two paths at highway speed of 120 km/h, figure 6 shows that the modified MRC has shorter processing time compare to the conventional MRC, because modified MRC has shown 91.68 % and 56.1% reduction in processing time when the modulation schemes are BPSK or QPSK and GMSK respectively. The relatively lower processing time is an indication of a lower hardware complexity and even low cost.

4. Conclusion

The effect of ISI distortion cancellation using a modified maximal ratio combiner which makes use of one RF chain and one matched filter over the fast and frequency selective has been investigated with BPSK, QPSK and GMSK signaling schemes. Binary data has been reshaped using NRZ, modulated using the schemes considered before the transmission over fast and frequency selective fading channel. The radio frequency paths were combined at the receiver using MRC and demodulated accordingly. The performance of the modified MRC diversity is evaluated using BER and processing time and then compared to the conventional MRC diversity in removing ISI distortion, modified MRC is found to give a better performance in term of BER indicating that the modified MRC receiver model has reduced the problem of ISI distortion and the hardware complexity of the conventional MRC receiver, consequently the implementation cost due to shorter processing time. The use of one RF chain and one matched filter has drastically contributed to the lower processing period of the modified MRC with MLSE.

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educational background is listed. The degrees should be listed with type of degree in what field, which institution, city, state, and country, and year degree was earned. The author's major field of study should be lower-cased.

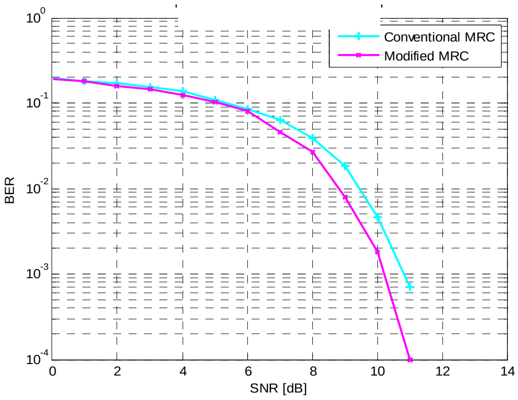

Figure 2. Simulated BER against SNR for conventional MRC And modified MRC using BPSK with two paths at Mobile speed of 120 km/h

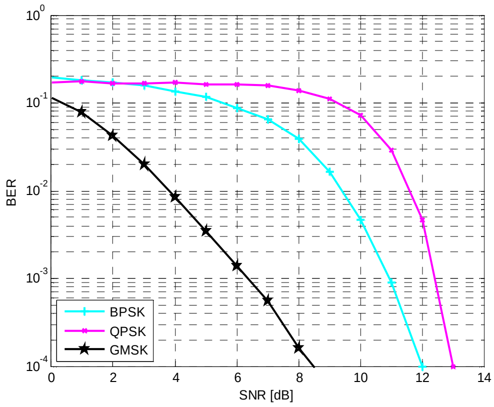

Figure 3. Simulated BER against SNR for conventional MRC and modified MRC using QPSK with two paths at

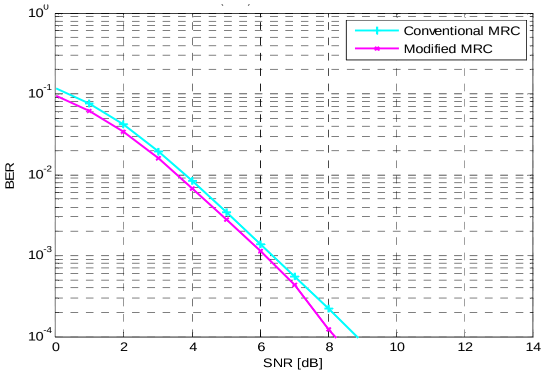

Figure 4. Simulated BER against SNR for conventional MRC and modified MRC using GMSK with two paths at mobile speed of 120 km/h

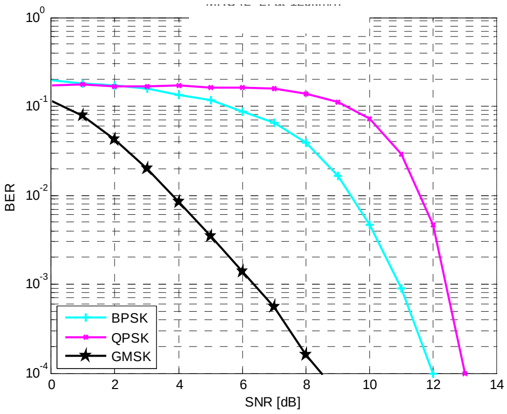

Figure5: Simulated BER against SNR for the modified MRC using BPSK, QPSK and GMSK schemes with two propagation paths at mobile speed of 120 km/h.

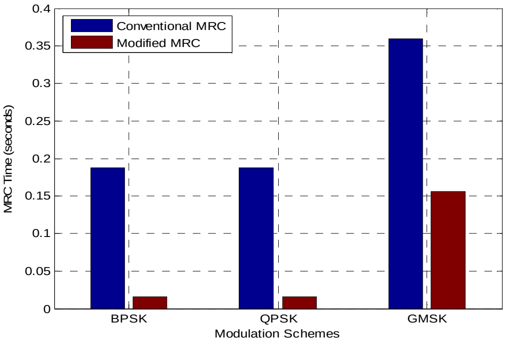

Figure 6: Histogram representation of the processing time of the conventional and modified MRC.

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