BIT ERROR RATE ANALYSIS FOR WIRELESS LINKS USING ADAPTIVE COMBINING DIVERSITY

ZACHAEUS K. ADEYEMO, PH.D.[1] , TESLIM I. RAJI, PH.D.[2]

[1,2]Department of Electronic and Electrical Engineering,
Ladoke Akintola University of Technology, PMB 4000, Ogbomoso, Nigeria.

[1]Author to whom correspondence should be sent

ABSTRACT

Mobile wireless communication is the fastest growing segment of the communication industry. However, it is faced with the challenge of providing reliable high-speed communications due to channel impediments which change over time in unpredictable ways. This paper presents a joint decision feedback equalizer and diversity combiner called adaptive diversity combining to combat the fast time-varying nature of mobile radio channels. The results obtained showed that the proposed technique is robust for signal transmission over mobile radio channels.

Keywords: *Adaptive Diversity Combining, Dispersive Link, Isi, Bpsk, Qpsk*

1. INTRODUCTION

Mobile wireless networking systems require a robust, flexible and efficient establishment of a communication link over the time-varying wireless channels to be able to support different quality of service (QoS) requirements for various kinds of services such as data, video and voice (Heung-No, 1999; Heung-No, 1998). The wireless radio link poses a severe challenge as a medium for reliable high-speed communication. It is not only susceptible to noise, interference and other channel impediments, but nature of these impediments change over time in unpredictable ways due to user movements causing the received signal to fluctuate or vary.

This variation is characterized by shadowing and by obstacles between the transmitter and receiver. These attenuate signal power through absorption, reflection, scattering and diffraction called the propagation mechanisms. When the attenuation is very strong, the signal is blocked (Goldsmith, 2005). The propagation mechanism causes the transmitted signal to undergo multiple propagations called multipath. The mobile multipath produces three effects: signal fading, delay spread and Doppler spread (Yumin and Donald, 1998). These effects combine to produce a faded signal at the receiving end of the communication link. Signal fading occurs due to the addition of multipath components which result in constructive interference if they are in phase, or destructive interference if they are out of phase, during unfavourable conditions. The delay spread causes the mobile channel to be selective especially in the urban environment where there are cluster of buildings and moving objects.

The resulting effect of frequency selectivity is the intersymbol interference (ISI) distortion. The Doppler spread determines how fast or slow the fading is; the effect is significant when mobiles are at highway speeds and the mobile communication link exhibits Doppler fading rates of up to about 100 Hz (Norm et al, 1991). Transmissions of digital information over wireless communication links such as terrestrial land mobile radio channels, indoor LAN channels and satellite channels have also received much research and development attention, but few at the highway speeds. Diversity combining was proposed in mobile communication (Ying et al, 2005) but the technique could not take into consideration, the tracking of channel variation. Adaptive equalization was proposed in some literatures which took into consideration channel variation by using some adaptive algorithms but failed to identify the strongest path which had high signal power or combining all the available paths before equalizing (Siamak and David, 2008; Dim, 1997).

In this paper, adaptive combining diversity called maximal ratio combining decision feedback equalizer (MRCDFE) is proposed to combat the problem encountered on highways. An unpredictable independent identically distributed two paths are combined using MRC technique but because of the severe delay the output is equalized by adaptive DFE using the least mean square (LMS) and recursive least square (RLS) algorithms for training and tracking purposes. Randomly generated data and a parrot image data were used as the source data in turn for the investigation. The results obtained showed that for a signal transmission without MRCDFE, high bit error rate (BER) values were obtained at every signal power used; while with MRCDFE, low BER values were obtained with both BPSK and QPSK signalling schemes. However, the performance of BPSK scheme was better than QPSK due to its lower BER values obtained. This is because QPSK has higher bandwidth than BPSK, thus accommodating more interfering signals which degrade the performance.

2. MATERIALS AND METHODS

System Model

The system model for the investigation consists of the transmitter, the mobile communication channel and the receiver. The transmitter produces the source data (randomly generated data or image data,) the input data is converted to bits, reshaped and modulated with each of BPSK and QPSK schemes. Square-root raised cosine filter is used to reduce the spectral occupancy and converts the modulated digital signal to analog signal suitable for transmission over the radio channel. This is shown in Figure 1.

The M-PSK modulated signal, denoted by s(t), is modeled as

$$s(t) = R\{u(t)\exp(j2\pi f_c t)\}$$

(1)

where, $u(t)$ = the complex modulating signal

f_c = the carrier frequency

$$\therefore s(t) = R\{u(t)\}\cos(2\pi f_c t) - \mathrm{Im}\{u(t)\}\sin(2\pi f_c t)$$

(2)

$$= x(t)\cos(2\pi f_c t) - y(t)\sin(2\pi f_c t)$$

(3)

Therefore,

$$u(t) = x(t) + jy(t)$$

(4)

The in-phase $x(t) = R\{u(t)\}$ and the quadrature $y(t) = \mathrm{Im}\{u(t)\}$

Mobile Wireless Channel

The wireless channel is modeled as the time-varying channel impulse response $c(\tau, t)$ and it is given by Goldsmith (2005) as

$$c(\tau, t) = \sum_{n=0}^{N(t)} \alpha_n(t) e^{-j\phi_n(t)} \delta(\tau - \tau_n(t))$$

(5)

where, $\alpha_n(t)$ = amplitude of n^{th} multipath at t and τ

$\tau_n(t)$ = delay of n paths at time t

$\phi_n(t)$ = phase shift at n path which depends on delay and Doppler spreads

$\delta(\tau - \tau_n(t))$ = impulse function that determines specific multipath component t and τ

The linear time-varying impulse response $c(\tau, t)$ of mobile channel is modulated by a random phenomenon because its characteristics change as a function of time in a random manner. Since the arrival of a large number of the N_m resolvable paths fall into one delay interval, the central limit theorem can be applied.

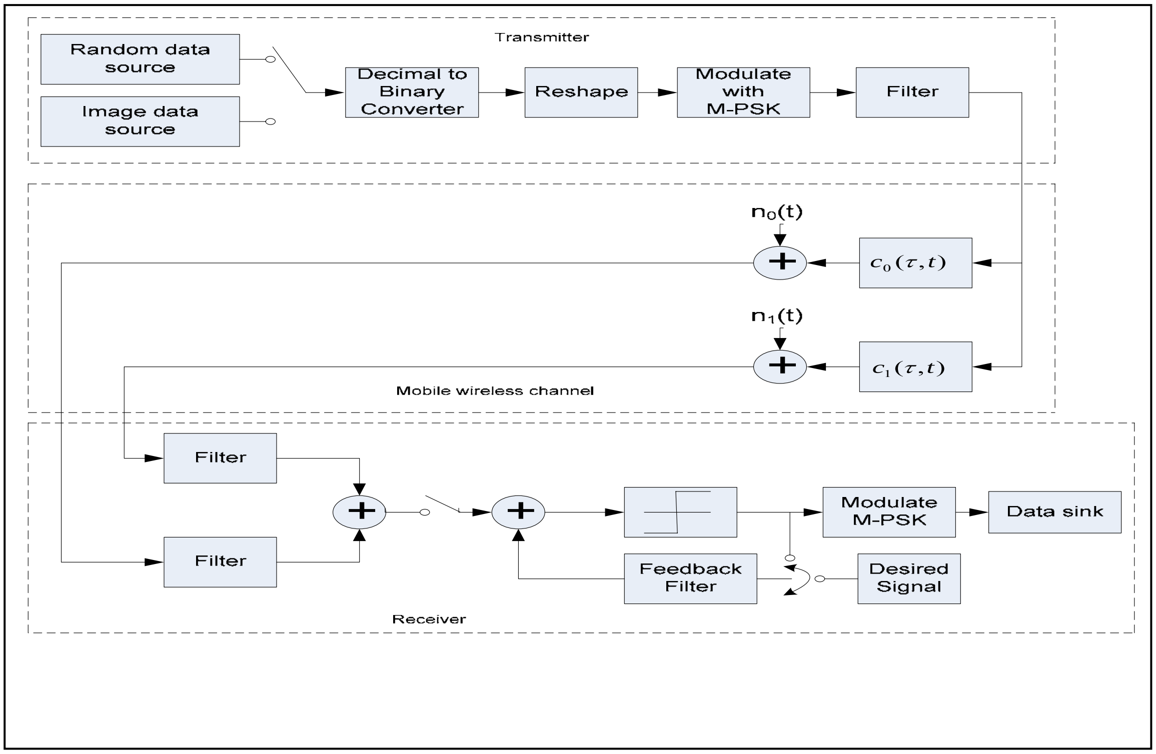


Figure 1: System Simulation Model

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 pdf of the real and imaginary parts are Gaussian. Since each resolvable path is modelled 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).

The Receiver

The receiver consists of the combined two independent identically distributed (i.i.d) paths using MRC. The output of MRC is a weighted sum of the two branches. The complex conjugate of the channel impulse response was used as the signal weights to cancel the phase variation that the channel introduced (Vijay, 2007; Pornchai et al,2009).

The received signal by the base station through only one path is

$$x(t) = c(\tau,t)s(t) + n(t) \tag{6}$$

where, $c(\tau,t)$ = time-varying impulse response of the channel

$s(t)$ = the transmitted M-PSK signal ; M = 2, 4

$n(t)$ = interfering signals modelled as AWGN

Therefore, Equation (5) becomes

$$c(\tau,t) = \sum_{n=0}^{2} \alpha_n(t) e^{-j\phi_n(t)} \delta(\tau - \tau_n(t)) \tag{7}$$

The received signal, $r(t)$, output of MRC is

$$r(t) = c_0(\tau,t)^* x_0(t) + c_1(\tau,t)^* x_1(t) \tag{8}$$

where, $c_0(\tau,t)^*$ and $c_1(\tau,t)^*$ are the conjugates of the channel impulse responses of the paths 1 and 2.

$x_0(t)$ and $x_1(t)$ represent the received signals through paths 1 and 2 respectively.

$$\therefore r(t) = c_0(\tau,t)^*\left[c_0(\tau,t)s_{M-PSK}(t)+n(t)\right] + c_1(\tau,t)^*\left[c_1(\tau,t)s_{M-PSK}(t)+n(t)\right]$$
(9)

If $c(\tau,t)=\alpha_i(t)\exp(j\theta_i(t)) \quad i=0,1$

$$r(t)=(\alpha_0^2(t)+\alpha_1^2(t))s_{M-PSK}(t)+c_0^*(\tau,t)n_0(t) + c_1^*(\tau,t)n_1(t)$$
(10)

$r(t)$ is then equalized using the feedback filter that takes the decision or the training sequence as inputs. The feedback filter estimates the residual from the past decision and subtracts it from the feedforward filter output. LMS and RLS algorithms were used to compensate for an unknown time-varying channel and also to update the filter coefficients and track the channel variation.

Binary Phase Shift Keying Analytical Expression

The transmitted BPSK signal is given by Rappaport (2002) and Sklar (2003) as

$$s_{BPSK}(t)=\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t+\phi_c) \qquad 0\le t\le T$$
(11) (for binary 1) and

$$s_{BPSK}(t)=\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t+\phi_c+\pi)$$
(12)

(for binary 0)

where

E_b = energy per bit

T_b = transmitted symbol

ϕ_c =the phase

BPSK is generally represented by Rappaport (2002) as

$$s_{BPSK}(t)=m(t)\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t+\phi_c)$$
(13)

m(t) = binary data which takes on one of two possible pulse shapes

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) and Leon (2002) as

$$s_{QPSK}(t)=\sqrt{\frac{2E_s}{T_s}}\cos\left[2\pi f_c t+(i-1)\tfrac{\pi}{2}\right]$$
(14) $0\le t\le T$; I = 1,2,3,4

Rayleigh distribution

This is used to describe the statistical time-varying nature of the envelope of an individual multipath component. The Rayleigh distribution is given by Vijay (2007) as

$$P(r)=\frac{r}{\sigma^2}\exp\left(\frac{-r^2}{\sigma^2}\right) \qquad 0\le r\le\infty \qquad (15)$$

Where, σ = rms value of the received signal

$\frac{r^2}{2}$ = instantaneous power

σ^2 = local average power of the received signal before detection

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. BER 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. In simple form,

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

BER expression is given by Rappaport (2002) as

$$BER=\int_0^\infty P_b(E/r)P(r)dr$$
(16)

where, $P_b(E/r)$ = the conditional error probability

$P(r)$ = the pdf of the SNR

White Noise

White noise is a random signal with a flat power spectral density; that is, the signal contains equal power within fixed bandwidth at any centre frequency. White noise is usually applied in context of frequency domain and hence, white noise is commonly applied to a noise signal in the spectral domain. The white noise is thermal noise. Gaussian white noise is a noise with a Gaussian amplitude distribution. Gaussian white noise is a good approximation of many real-time situations and it generates mathematical traceable models. But because these models are so frequently used, the term additive has been added. Additive White Gaussian Noise (AWGN) has become a statistical tool for analysis and application in telecommunication engineering.

Simulation method

The simulation of the model under study was carried out using MATLAB application package because of the controllability and repeatability of parameters, which is very difficult to do at highway speeds in the field test. The simulation was carried out with each of the different data sources namely: random data and parrot image data. The data sources are converted to binary using MATLAB's de2bi() function, reshaped, gray-coded and modulated with BPSK and QPSK scheme in turn. Then copies of the faded signal were created and MRCDFE performed accordingly. The following parameters and system configurations were used:
Modulation: BPSK and QPSK
Carrier frequency: 900 MHz
Bandwidth of signal: 200 ns
Noise: AWGN
Receive & Transmit Filter: Square-root raised cosine pulse shaping
Number of MRC Paths: 2
Equalizer algorithms: LMS and RLS
Number of feedback weights: 17
Mobile speed: 90 km/h
Fading type: Rayleigh fading

3. RESULTS AND DISCUSSION

The BER performances as a function of SNR for two i.i.d paths in mobile multipath fading channel with BPSK and QPSK transmission schemes using MRCDFE at the receiver are shown in Figures 2 to 4 for the random data transmission; while Figure 5 depicts the result of the image data transmission.

Figure 2 shows the BER performance when BPSK signal was transmitted over the fast Rayleigh fading channel at a mobile speed of 90 km/h. it can be observed that at SNR of 4 dB, 55% of BER was obtained without MRCDFE, while with MRCDFE, BER of 4% was obtained and the value decreases to 0.2% at SNR of 12 dB, and AWGN had BER of 0%. In Figure 3, where QPSK signal was transmitted over the channel under study at 90 km/h, the BER of 22% was obtained at SNR of 4 dB with MRCDFE, however, the value decreases to 1.1% at SNR of 12 dB. Figure 4 shows the combination of the BER performances of both BPSK and QPSK signalling schemes. The result obtained shows that as the noise power decreases, the signal power increases. With MRCDFE, increase in SNR decreases the BER, however, BPSK scheme performed better giving lower value of BER than the corresponding QPSK scheme.

At SNR of 9 dB, BER of 46% was obtained without MRCDFE but, with MRCDFE and BPSK, 0.8% of BER was obtained indicating very low error; while for QPSK scheme, 13% of BER was obtained.

The results obtained from Figures 1 to 4 are justifiable in that 1 bit represents 1 symbol in the transmission of BPSK scheme; this limits the bandwidth. When 2 bits are used to represent 1 symbol in the QPSK transmission, it increases the bandwidth; this allows other interfering signals to be transmitted along with the main signal. MRCDFE also combines the two copies of the transmitted signal and then equalized them using the RLS and LMS algorithms.

Figure 5 shows the results of the image transmissions using the two modulation schemes. It can be observed that the qualities of the received images are in agreement with the results of the random data transmissions.

Therefore, the combination of BPSK and MRCDFE is robust against the mobile Rayleigh fading at highway speeds.

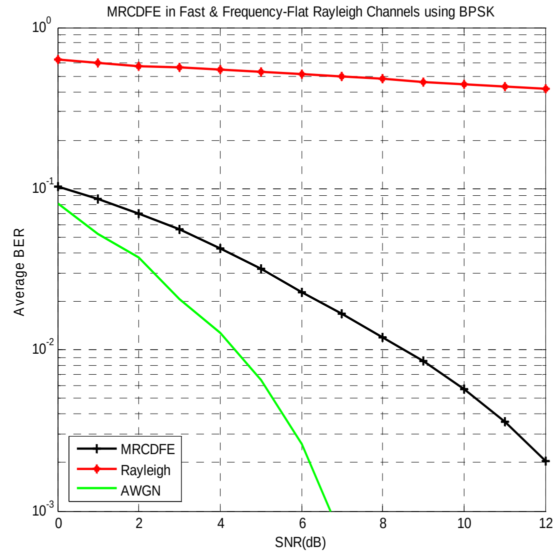


Figure 2: BER performance of MCRDFE with BPSK modulation at a mobile speed 90 km/h.

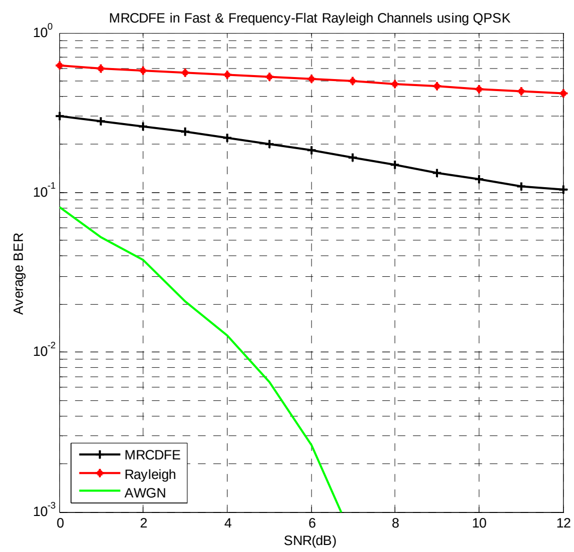


Figure 3: BER performance of MCRDFE with QPSK modulation at a mobile speed 90 km/h.

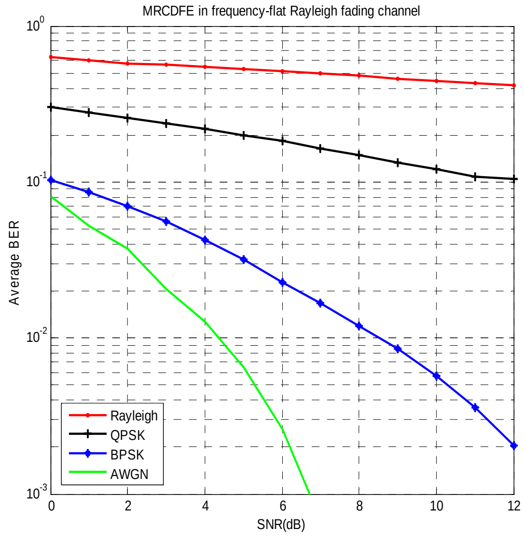
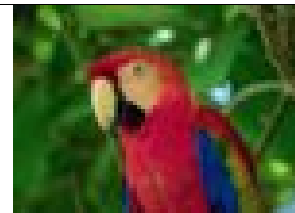
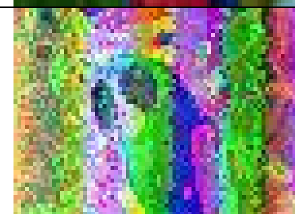
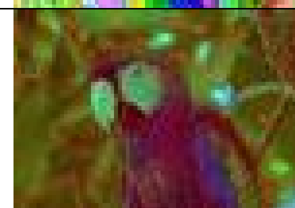
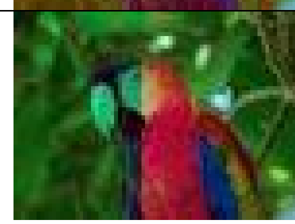


Figure 4: BER performance of MCRDFE with BPSK and QPSK modulations at a mobile speed 90 km/h.

ORIGINAL	
RAYLEIGH	
QPSK Transmission	
BPSK Transmission	

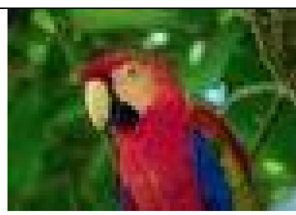
AWGN	

Figure 5: Image signal output of MRCDFE at SNR of 10 dB and 90 km/h.

4. CONCLUSION

In this paper, bit error rate performances for wireless links using adaptive combining diversity with BPSK and QPSK transmission schemes have been evaluated with random data and also with a parrot image data. The model for the system has been developed and simulated using appropriate parameters and configuration. The adaptive combining diversity processed the faded signals by combining and equalizing the signals using RLS and LMS algorithms for training and tracking purposes.

The erroneous bits for each of the signalling schemes were obtained and the BER computed for SNR of 0 to 12 dB. The results obtained showed that MRCDFE is robust for signal transmission in a fast Rayleigh fading channel, producing better significant performance with BPSK signalling scheme due to the lower BER values obtained but at the expense of the bandwidth.

Moreover, the qualities of the received images in the image transmission over the fast Rayleigh fading channel at a mobile speed of 90 km/h were also in agreement with the results obtained for the random data transmission. This verifies the effectiveness of the MRCDFE system for real-time applications.

This paper has shown that the unpredictable behaviour of wireless links can be drastically reduced with the use of adaptive combining diversity, MRCDFE, with BPSK modulation scheme.

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AUTHOR PROFILES:

Adeyemo, Z. Kayode holds a B.Eng., M.Eng. in Electrical Engineering from University of Ilorin, Ilorin, Nigeria. He obtained his Ph.D in Electronic and Electrical Engineering from Ladoke Akintola University of Technology, Ogbomoso, Nigeria. Dr. Adeyemo has been teaching Communication Engineering courses at both undergraduate and postgraduate levels for over seven years. He is the Ag. Head of the Department of Electronic and Electrical Engineering, Faculty of Engineering and Technology, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso. He is a member, Nigerian Society of Engineers (NSE), Institute of Electrical and Electronic Engineering (IEEE) and a registered member of Council for the Regulation of Engineering in Nigeria (COREN). His research interest is on signals processing in mobile communications.

Raji, T.I. is a Professor in the Department of Electronic and Electrical Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria. He received his B.Sc., M.Sc. and Ph.D. in Electronic and Electrical Engineering. He served as the Head of Department of Electronic and Electrical Engineering, University of Ife, now Obafemi Awolowo Univerisity, Ife, Nigeria from 1983 to 1985 and the Pioneer Head of Department of Electronic and Electrical Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria from 1990 to 1995. He was the Dean of Faculty of Engineering and Technology between 1995 and 1999. He was the Dean of Postgraduate School between 2001 and 2005 and later acted as the Ag. Vice Chancellor of the same institution in 2005. He teaches Electrical Engineering courses both at the undergraduate and postgraduate levels. His research interest is in Communication Engineering.