Performance of Multiple Symbol Differential Detection in the Mobile Radio Channel

[1]S.S. Periyalwar and [2]K.J. McGuirk

[2]Applied Microelectronics Institute, Halifax, NS, CANADA
[1]Department of Electrical Engineering, Technical University of Nova Scotia
P.O. Box 1000, Halifax, NS, CANADA B3J 2X4.
Tel: (902) 420-7715 Fax: (902) 422-7535
email: shalini@tuns.ca

ABSTRACT The performance of Multiple Symbol Differential Detection applied to differentially encoded QPSK signals, is examined by simulation in the mobile radio channel with slow Rayleigh and Rician fading, and cochannel interference (CCI). Performance gains observed in the slow Rician fading channel when compared to conventional differential detection, are maintained in the CCI environment. Using a signal quality measure from the Multiple Symbol Differential Detection algorithm for selection diversity, performance gains are observed over conventional differential detection in Rayleigh fading as well.

Technical Area: Radio Technology
Subtopic: Modulation and Coding

1. Introduction

The challenges in wireless communications research emanate from the requirement to design cost effective personal communication products that form an integral part of a very complex system. To meet these challenges, new engineering techniques are being proposed. Most of the current digital cellular and cordless telephone proposals are based on burst TDMA as a multiple access technique. TDMA bursts are generally as short as possible to minimize the delay in the receiver while generating the requirement for fast synchronization and resynchronization systems. For this reason, carrier and timing recovery for burst TDMA systems is an active research topic.

Bandwidth efficient digital modulation systems traditionally use coherent demodulation. A problem with carrier recovery in coherent systems arises when impairments such as multipath fading, Doppler shifts, delay spread, and other excessive forms of phase noise are prevalent, as in the mobile and portable radio channels. It is well known that in the AWGN channel, non-coherent demodulation requires a 1-3 dB power increase to maintain the same probability of error as coherent schemes. A theoretical power advantage also exists in the Rayleigh and Rician fading channels with coherent demodulation [1]. However, differential detection avoids the need for carrier recovery and therefore achieves fast synchronization. Differential detection also has the added advantage of hardware simplicity, but the 3 dB power degradation in the AWGN and slowly fading channels still make some form of coherent demodulation desirable. Thus, it is of interest to investigate methods of narrowing the performance gap between differential and coherent detection in the mobile radio channel.

The classical differential detection of multiple-phase shift keying (MPSK) utilizes the phase difference between two adjacent received symbols to make a decision on the current symbol. This is possible because the transmitted information was differentially encoded at the transmitter, thus the phase difference between adjacent symbols was transmitted, not the absolute symbol phase. Also the assumption is made that the received carrier reference phase is constant over at least two symbol intervals. Recent papers by Divsalar and Simon [2] and Wilson et al [3] have introduced Multiple Symbol Differential Detection (MSDD) and presented its performance in the AWGN channel. The goal of MSDD is to recover the performance lost when using differential detection relative to coherent detection, while attempting to maintain a robust and simple implementation. The amount of gain achieved using MSDD, relative to classical differential detection was impressive and justifies the investigation of this technique for radio fading channels.

MSDD uses a multiple (more than 2) symbol observation interval for improving the performance of differentially encoded MPSK. Maximum-likelihood sequence estimation of the transmitted phases is performed [2] rather than symbol-by-symbol detection as in conventional differential detection. The dominant trade-off is the performance recovered versus the additional complexity introduced.

Conventional differential detection for radio fading channels has been addressed in [4]. MSDD has been employed in conjunction with coherent and envelope detection for fading channels in the receiver proposed in [5]. An optimal receiver based on MSDD is examined in [6] for trellis coded MDPSK systems in Rayleigh fading channels. In other papers, a comparison study of MSDD and pilot symbol assisted modulation is carried out [7] for the Rayleigh flat-fading channel, and the error performance of MSDD is determined for correlated Rayleigh fading channels [8]. The performance of MSDD in cochannel interference or with selection diversity are topics that have not been treated in literature.

In this paper, the performance of Multiple Symbol Differential Detection applied to differentially encoded QPSK signals, is ex-

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amined by simulation in the mobile radio channel with slow Rayleigh and Rician flat fading, and cochannel interference (CCI). Performance gains observed in the slow Rician fading channel when compared to conventional differential detection, are maintained in the CCI environment. Using a signal quality measure from the Multiple Symbol Differential Detection algorithm for selection diversity, performance gains are observed over conventional differential detection in Rayleigh fading as well. Section II of this paper describes the simulation model. Sections III and IV contain the results and the conclusion, respectively.

2. System Model

The differentially encoded QPSK signal s(t) generated in the transmitter, is perturbed in the channel by AWGN, flat fading, and cochannel interference. A block diagram of the channel is shown in Figure 1.

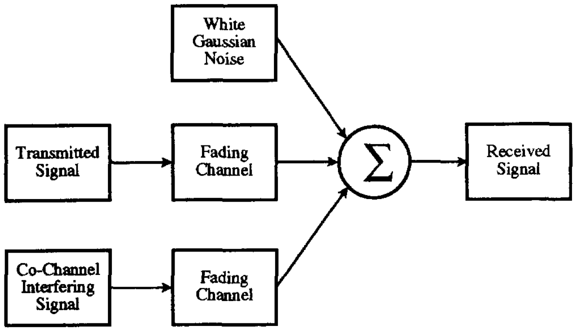


Figure 1 *A Block Diagram of the Channel Model*

In the presence of Rayleigh or Rician multipath fading, the signal is perturbed by both envelope and phase variations. Thus, the received MPSK signal in the *k*th interval becomes

$$r_k = \rho_k s_k e^{j\theta_k} + \alpha_i \rho_{k_i} s_{k_i} e^{j\theta_{k_i}} + n_k \qquad (1)$$

where s_k is the transmitted signal, θ_k is an arbitrary phase introduced by the channel, n_k is a sample of zero-mean complex Gaussian noise with variance α^2, and $\rho_k e^{j\theta k}$ is a complex Gaussian noise process representing multipath fading. The second term in (1) represents the cochannel interference (CCI) signal, and α_i is the interference ratio. The fading envelope ρ_k is a normalized random variable with a Rician probability density function given by

$$P(\rho_k) = \begin{cases} 2\rho_k(1+K)\exp\left[-K-\rho_k{}^2(1+K)\right] I_0\left(2\rho_k\sqrt{K(1+K)}\right), & \rho_k \geq 0 \\ 0, & \text{Otherwise} \end{cases} \qquad (2)$$

where the Rician fading parameter *K* represents the ratio of the direct and specular signal components to the diffuse component. As a special case, $K = 0$ yields Rayleigh fading and $K = \infty$ yields the AWGN channel.

The received signal is demodulated using Multiple Symbol Differential Detection (MSDD). The MSDD decision metric makes a maximum likelihood sequence estimation of N-1 MPSK symbols based on an observation over N symbols. For the simulations in this paper, MSDD observation intervals of N=2 (conventional differential detection), N=3, and N=5 are employed.

The block diagram in Figure 2 represents a transmission system employing postdetection two-branch selection diversity.

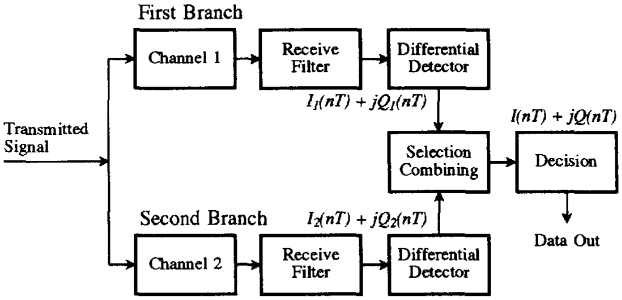


Figure 2 *Transmission System Model Employing Postdetection Two-Branch Selection Diversity*

The *m*th branch of the differential detector output at the sampling instant *n*T can be represented in complex form as

$$I_m(nT) + jQ_m(nT) = z_m(nT)z_m^*((n-1)T) \qquad (3)$$

where $I_m(nT)$ and $Q_m(nT)$ are the in-phase and quadrature components. The conventional selection rule or the signal quality measure used in the selection combiner can be denoted mathematically as

$$\begin{aligned} &\text{if } |z_1(nT)| \geq |z_2(nT)| \text{ then} \\ &\qquad I(nT) + jQ(nT) = I_1(nT) + jQ_1(nT) \\ &\text{else} \\ &\qquad I(nT) + jQ(nT) = I_2(nT) + jQ_2(nT) \\ &\text{end} \end{aligned} \qquad (4)$$

It is important to note that with the above system the branch used for the decision process can change on a per symbol basis.

The new signal quality measure is derived directly from the MSDD decision rule. For N=2, the simplest case, the diversity selection rule can be denoted as

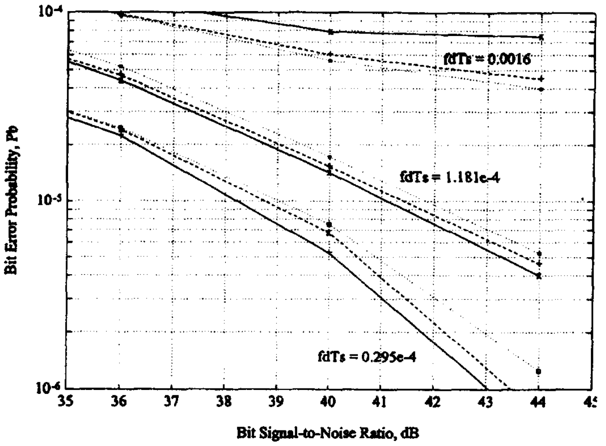
$$\begin{aligned} &\text{if } \mathrm{Re}\left\{r_k r_{k-1}^* e^{-j\Delta\hat{\phi}_k}\right\}_{(1)} \geq \mathrm{Re}\left\{r_k r_{k-1}^* e^{-j\Delta\hat{\phi}_k}\right\}_{(2)} \text{ then} \\ &\qquad r_k r_{k-1}^* e^{-j\Delta\hat{\phi}_k} = r_k r_{k-1}^* e^{-j\Delta\hat{\phi}_k}\Big|_{(1)} \\ &\text{else} \\ &\qquad r_k r_{k-1}^* e^{-j\Delta\hat{\phi}_k} = r_k r_{k-1}^* e^{-j\Delta\hat{\phi}_k}\Big|_{(2)} \\ &\text{end} \end{aligned} \qquad (5)$$

where the bracketed number represents the diversity branch. The main thrust behind using the phase term in the signal quality measure is to choose the signal with the most consistent received carrier reference phase over the N symbols. For N=2, only 2 symbols are used in the measure. Since the stability of the reference phase is the basic premise of differential detection, one would not expect this measure to provide significant gains.

As the observation interval increases, the importance of the stability of the reference phase over N symbols is paramount. Therefore, if a signal quality measure takes into account the phase error over all N (N>2) MSDD symbols, and picks the branch with the smallest phase error, performance gains should be achieved.

3. Simulation Results and Discussion

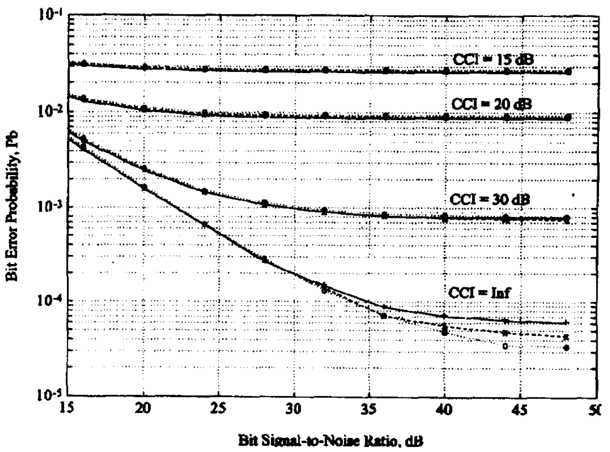
Figure 3 shows the bit error performance of MSDD in frequency flat Rayleigh fading for various values of N and normalized doppler rate. As expected, faster variations in the channel produce higher bit error rates when compared to the slower fading channel. Also, a larger MSDD observation interval N results in a higher error floor, most notably in the fast fading channel. As well, the performance is asymptotically improving at higher SNR values for very slow fading and longer observation intervals. This is due to the quasi-static nature of the slow fading channel at slower velocities, which are typical of indoor or pedestrian speeds.



MSDD N Value	2	3	5
Graph Line Type	....	--------	———

Figure 3 Bit Error Probability versus E_b/N_0 for MSDD of DQPSK in Frequency Flat Rayleigh Channel

Figures 4 and 5 show the comparisons between the MSDD symbol observation interval and Rayleigh fading with co-channel interference for a fixed normalized Doppler rate of 0.0016 and 0.295e-4, respectively. From Figure 4, it can be concluded that the detrimental effects of the larger observation interval observed when CCI = ∞ is reduced as the CCI becomes more prominent. The effect of CCI is to increase the error floor for both conventional differential detection and MSDD.



MSDD N Value	2	3	5
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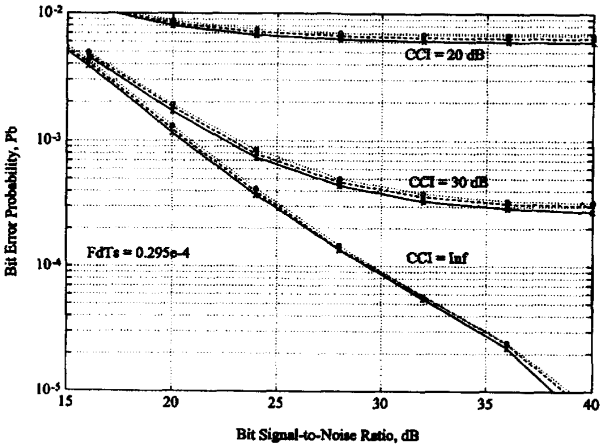
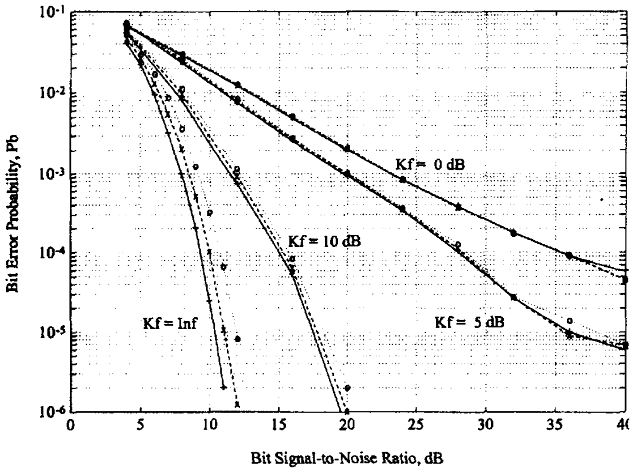
Figure 4 Bit Error Probability versus E_b/N_0 for MSDD of DQPSK in Rayleigh Fading and Co-Channel Interference ($f_dT_s = 0.0016$).



MSDD N Value	2	3	5
Graph Line Type	....	--------	———

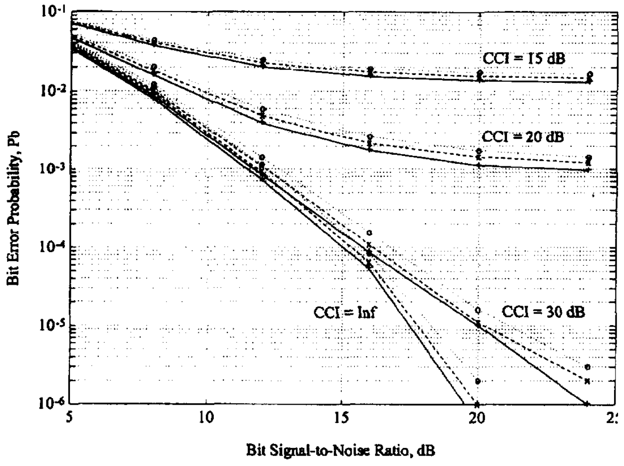
Figure 5 Bit Error Probability versus E_b/N_0 for MSDD of DQPSK in Rayleigh Fading and Co-Channel Interference

The bit error performance of MSDD in the Rician fading channel for various values of the Rician K-factor is reported in Figure 6 for $f_dT_s = 0.0016$. It was found that as the value of the Rician K-factor was increased, the performance of MSDD improved over that of conventional DQPSK offering a gain of 1 dB at BER = 10^{-3}. This is due to the fact that as the K-factor approaches infinity, the channel becomes predominantly AWGN. The effects of CCI with slow Rician fading (K=10 dB) is shown in Figure 7. It is observed that the gains obtained using MSDD are maintained over the various values of CCI used.



MSDD N Value	2	3	5
Graph Line Type	…………	--------	———

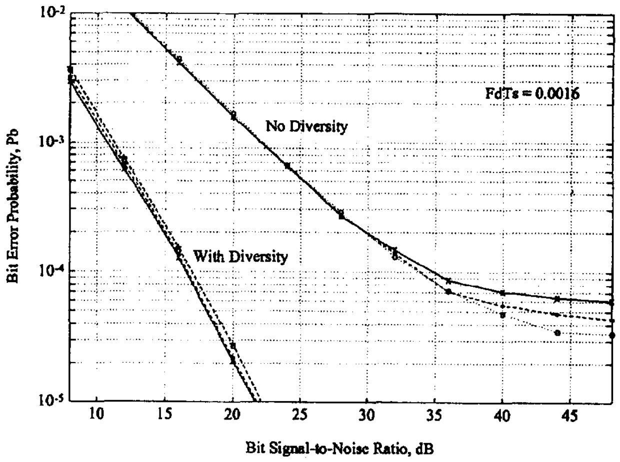
Figure 6 Bit Error Probability versus E_b/N_0 for MSDD of DQPSK in Rician Fading Channel ($f_dT_s = 0.0016$, $K_f = 0$, 10, and ∞)



MSDD N Value	2	3	5
Graph Line Type	…………	--------	———

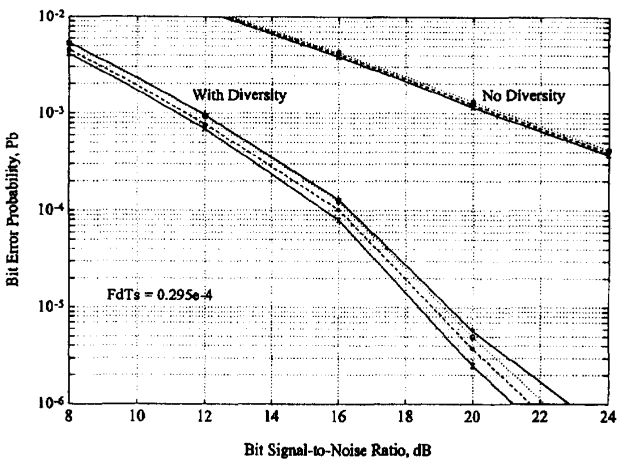
Figure 7 Bit Error Probability versus E_b/N_0 for MSDD of DQPSK in Rician Fading and CCI ($f_dT_s = 0.0016$, $K_f = 10$ dB)

Next, the performance of the MSDD diversity selection algorithm is evaluated. Figure 8 shows the performance under frequency flat Rayleigh fading. It is evident that diversity is a very good technique for combating this type of fading. The performance of selection diversity and MSDD with N=2 are almost identical - MSDD is slightly better. As the observation interval is increased to N=3 and N=5, the performance of the new signal quality measure surpasses the conventional technique by approximately 0.5 dB at an BER of 10^{-4}. Figure 9 illustrates the performance under very slow fading conditions. In this case we see a notable improvement in performance as the observation interval is increased, with a gain of 1.1 dB at BER = 10^{-4} for N=5. An asymptotic improvement of 1.7 dB is observed as well.



MSDD N Value	2	3	5	Selection Diversity
Graph Line Type	o…………	*--------	x———	+ --------

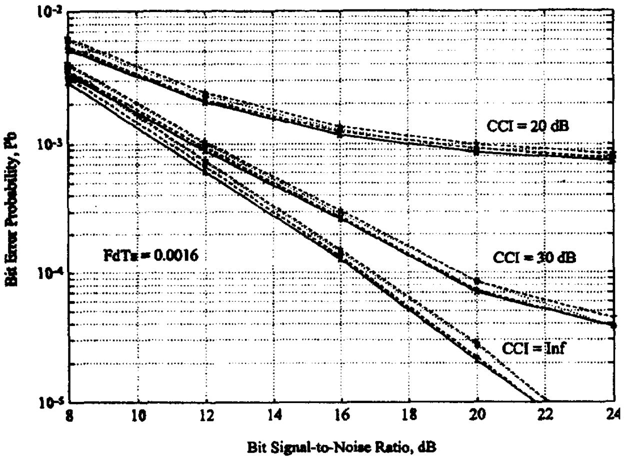
Figure 8 Bit Error Probability versus E_b/N_0 for MSDD of DQPSK with Diversity and without Diversity ($f_dT_s = 0.0016$)



MSDD N Value	2	3	5	Selection Diversity
Graph Line Type	o…………	*--------	x———	+ --------

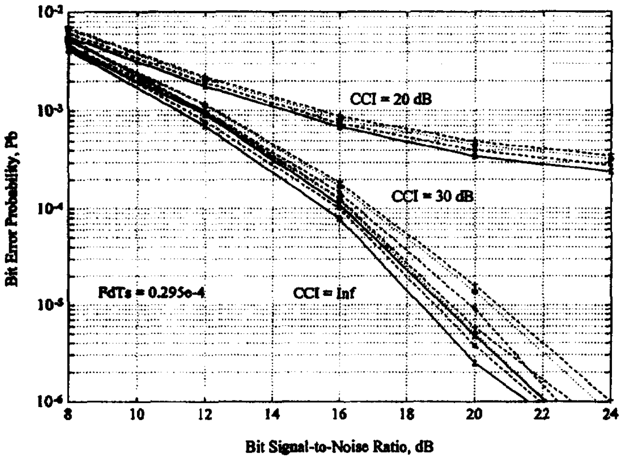
Figure 9 Bit Error Probability versus E_b/N_0 for MSDD of DQPSK with and without Diversity ($f_dT_s = 0.295 \times 10^{-4}$)

Figures 10 and 11 show the error performance for diversity over a frequency flat Rayleigh fading channel and CCI. It is observed that the performance gain achieved as the MSDD observation interval increases is maintained or improved in the presence of CCI. The benefit of diversity selection in the CCI environment can be observed by comparing Figure 11 with Figure 5.



MSDD N Value	2	3	5	Selection Diversity
Graph Line Type	o···········	*--------	x———	+ --------

Figure 10 Bit Error Probability versus E_b/N_0 for MSDD of DQPSK with Diversity and CCI ($f_dT_s = 0.0016$)



MSDD N Value	2	3	5	Selection Diversity
Graph Line Type	o···········	*--------	x———	+ --------

Figure 11 Bit Error Probability versus E_b/N_0 for MSDD of DQPSK with Diversity and CCI ($f_dT_s = 0.295 \times 10^{-4}$)

The gains observed in the simulations have to be weighed with respect to the complexity of the MSDD scheme versus conventional differential detection. In this regard, the complexity of MSDD on a per bit decoded basis, i.e. normalized complexity = ($N^2M^{N-1})/((N-1)LOG_2(M))$). The normalized complexity for $M = 4$ and $N = 2$, would be 8, while for $M = 4$ and $N = 5$ would be 800, respectively, which is a factor of 100. To avoid the potentially large computational requirements for the MSDD optimal detector, the development of low complexity implementations have been realized [3, 9].

4. Conclusion

Multiple Symbol Differential Detection of DQPSK signals was examined in the mobile radio channel using simulation analysis. Performance gains over conventional differential detection were observed in the quasi-static slow fading Rayleigh and Rician fading channels. By employing a signal quality measure for selection diversity derived from the MSDD decision metric, gains were observed over conventional selection diversity.

Acknowledgement

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