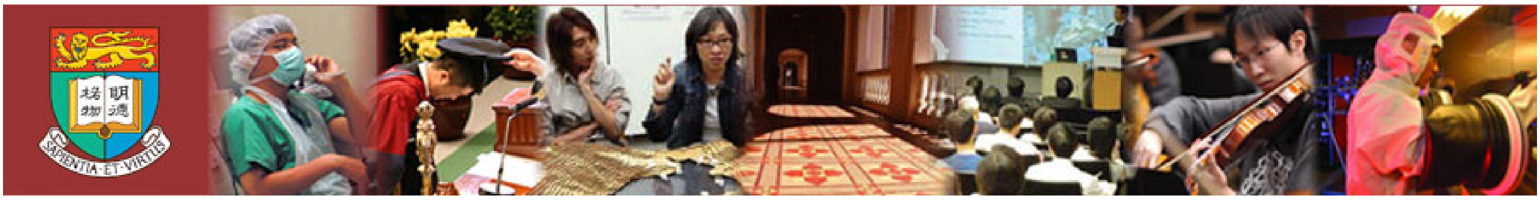

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Improved Pilot Symbol-Aided Transmission Technique for Hybrid Satellite and Terrestrial Mobile Systems

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ABSTRACT In the hybrid satellite and terrestrial mobile systems, robust transmission techniques are required to compensate the signal distortion introduced in the fading channels. Recently, the pilot symbol-aided techniques have been proved to be suitable for the transmission of digital signals over satellite mobile and terrestrial mobile channels. In this paper, an improved pilot symbol-aided transmission technique suitable for the hybrid systems is proposed. The proposed technique uses the distortion information in data symbols as well as in pilot symbols for the multipath fading compensation. Monte Carlo simulations have been carried out to investigate the effects of the proposed technique on the bit-error rate (BER) performances of 16PSK and 16QAM signals in satellite mobile and terrestrial mobile channels. Results have shown that, at high signal-to-noise ratios (SNRs), an improvement of more than two orders of magnitude in the BER performance can be obtained by the proposed technique, relative to those only using the pilot symbols.

1. Introduction

Satellite communications have undergone a new development phase in both technologies and applications. The concept of hybrid satellite and terrestrial mobile communication systems has been received much attention in recent years [1-3]. In WARC '92, a special spectrum allocation was made for a new service called the Future Public Land Mobile Telecommunication System (FPLMTS). The FPLMTS [3] is a hybrid system that enables a person to carry a handhold mobile terminal that can be reached virtually any location on earth. In the hybrid systems, multi-level signals are expected to cope the ever-increasing demand for radio spectrum. However, due to the severe multipath fading distortions introduced into the signals by the mobile channels, efficient transmission of multi-level signals cannot be easily achieved by traditional approaches.

Recently, the pilot symbol-aided techniques have been shown to be the simple and efficient approaches for the transmission of multi-level signals over fading channels [4-8]. Using these techniques, differential encoding/decoding of the signal is not required and coherent detection over fading channels is possible [5-8]. In a pilot symbol-aided system, the data symbol sequence is divided into frames of symbols for transmission. A known pilot symbol is inserted at the beginning of each frame. At the receiver, these pilot symbols are used for the multipath fading compensation. In these studies [5-7], the receivers are required to store up data symbols before the fading correction is applied. However, a simplified technique using linear extrapolation that requires no storage of the previous data symbols has been proposed in [8].

In this paper, an improved compensation technique that requires only the storage of one pilot symbol is proposed. This technique is an extension of the pilot symbol-aided scheme [8] that uses both the distortion information in the data symbols as well as in the pilot symbols. The technique also requires no storage of previous data symbols and introduces virtually zero delay to the received message. Since two possible communication channels (satellite mobile and terrestrial mobile channels) can be established in the hybrid system [2], Monte Carlo simulations have been carried out to investigate the BER performance of the proposed technique on 16PSK and 16QAM signals in both satellite mobile and terrestrial mobile channels. Results have shown that, at high SNRs, significant improvements in the BER performance can be obtained by the proposed technique.

The paper is organized as follows. Section 2 describes the system model used for the computer simulations. The improved multipath fading compensation technique is discussed in section 3. Simulation results and discussions are presented in section 4.

2. System Model

The baseband equivalent model considered in this study is shown in Figure 1. The information to be transmitted is carried by the binary digits $\{u_i\}$. When the encoder has received u_i, u_{i+1},.., u_{i+M-1} at time $t = iT$ seconds, it maps these signals into the appropriate M-ary data symbols d_i according to the 16QAM or 16PSK constellations. For every (L-1)-data symbols, a pilot symbol from $\{p_i\}$ is inserted to form an L-symbol frame. For

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16PSK signal, the pilot symbols, $\{p_i\}$, are pseudo random and selected from $\{u_i\}$. For 16QAM signal, $\{p_i\}$ are also pseudo random, but chosen from those signal vectors with largest energy level to minimize the degradation due to additive white Gaussian noise. Since the receiver has the prior knowledge of $\{p_i\}$, it is able to estimate the multipath fading distortion introduced in the transmission path and make the appropriate correction to the received data signal. At time $t = iT$, the data signal symbol is used to form the impulse $q_i \delta(t - iT)$, where q_i is either a data symbol or a pilot symbol, which is fed to the pre-modulation filter with an impulse response $a(t)$. The signal at the output of the filter is $\Sigma_i\, q_i\, a(t - iT)$ which is used to form the modulated signal. The latter is then up-converted, and fed to an antenna for transmission.

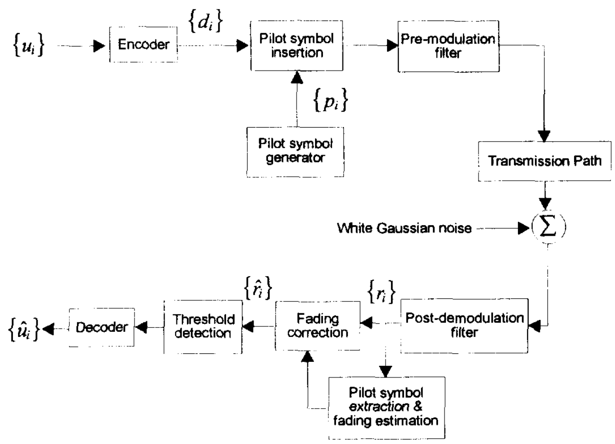

Figure 1 System Model

The transmission path in Figure 1 is a time-varying linear baseband channel that introduces Rician fading in a satellite mobile channel [9] or Rayleigh fading in a terrestrial mobile channel [10]. Thus, the input signal to the transmission path is multiplied by a complex-valued parameter $y(t)$ to give the output faded signal $\Sigma_i\, q_i\, a(t - iT)y(t)$ [10]. Stationary additive white Gaussian noise is assumed to be added at the receiver input.

At the receiver, the signal from the antenna is down-converted, demodulated and then filtered by a post-demodulation filter. The post-demodulation filter is taken to have the same impulse response $a(t)$ as the pre-modulation filter to give the corresponding baseband signal

$$r(t) = \left[\sum_i q_i\, a(t - iT)\, y(t) + w(t)\right] * a(t) \qquad (1)$$

where * denotes the convolution process, $y(t)$ represents the changes introduced into the signal by the transmission path, and $w(t)$ is the additive white Gaussian noise with one-sided power spectral density of N_0.

At time $t = iT$, the sample signal is given by

$$r_i = q_i y_i + w_i \qquad (2)$$

where $y_i = y(iT)$ and $w_i = w(iT)$.

Since the sequence of the pilot symbols is known at the receiver, y_i can be estimated from the distortion information in the pilot symbols. The receiver uses this information to correct the fading effects in the received data symbols. The threshold detector and decoder then operate on the corrected data symbols $\{\hat{r}_i\}$ to produce the binary data $\{\hat{u}_i\}$ at the output.

The signal-to-noise ratio (SNR) is taken as

$$\mathrm{SNR} = 10\left[\log\left(\frac{E_b}{N_0}\right)\right] \mathrm{dB} \qquad (3)$$

where E_b is the average transmitted energy per bit at the transmitter output of Figure 1 and N_0 is the one-sided power spectral density of the additive white Gaussian noise measured at the same point.

In the satellite mobile channel, it is assumed to be Rician faded [9]. The ratio of the direct component power S to the multipath component power D is defined as

$$\mathrm{S/D} = 10\left[\log\left(\frac{S}{D}\right)\right] \mathrm{dB} \qquad (4)$$

3. Improved Pilot Symbol-Aided Technique

For simplicity, the pilot symbol is assumed to be inserted at the beginning of each frame to form an L-symbol frame [5] as shown in Figure 2.

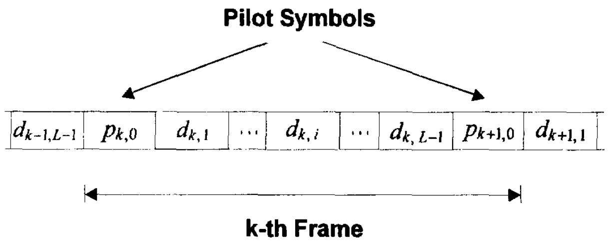

Figure 2 Frame Structure of Transmitted Symbol Sequence

The sample signal in the i-th position of the k-th received frame can be written as

$$r_{k,i} = q_{k,i} y_{k,i} + w_{k,i} \qquad (5)$$

where $q_{k,i}$ is either a pilot symbol or a data symbol.

For $i = 0$, the sample signal is

$$r_{k,0} = p_{k,0} y_{k,0} + w_{k,0} \qquad (6)$$

where $p_{k,0}$ is the pilot symbol in the k-th frame.

For $i = 1, 2, ..., L$-1, the sample signal is

$$r_{k,i} = d_{k,i} y_{k,i} + w_{k,i} \qquad (7)$$

where $d_{k,i}$ is a data symbol in the k-th frame.

Zeroth-Order Prediction

Since the pilot symbol $p_{k,0}$ is known at the receiver, $y_{k,0}$ can be obtained using Eqn. (6) as

$$y_{k,0} = \frac{r_{k,0}}{p_{k,0}} - \frac{w_{k,0}}{p_{k,0}} \tag{8}$$

At high SNRs, $y_{k,0}$ can be estimated as

$$\hat{y}_{k,0} = \frac{r_{k,0}}{p_{k,0}} \tag{9}$$

For i = 1, 2, ..., L-1, the signal $\hat{y}_{k,i}$ is estimated using zeroth-order predication as

$$\hat{y}_{k,i} = \hat{y}_{k,0} \tag{10}$$

The estimated signal $\hat{y}_{k,i}$ is used to correct the fading effects in the received signal sample, $r_{k,i}$. After the fading correction, the estimate of the data signal is

$$\hat{r}_{k,i} = \frac{r_{k,i}}{\hat{y}_{k,i}} \tag{11}$$

The resultant signal, $\hat{r}_{k,i}$ is then fed to a threshold detector to produce the data signal $\hat{d}_{k,i}$ which is a possible signal vector on the constellation. The signal $\hat{d}_{k,i}$ is then decoded into the binary data $\hat{u}_i$, $\hat{u}_{i+1}$, ..., $\hat{u}_{i+M-1}$ and the process repeats for all the received frames.

Improved Zeroth-Order Prediction

The proposed technique makes use of the data symbols as well as the pilot symbols for fading estimation and correction. The signal $\hat{y}_{k,0}$ is initially obtained from the pilot symbol using Eqn. (9) and is treated as an estimate of $y_{k,1}$, i.e.,

$$\tilde{y}_{k,1} = \hat{y}_{k,0} = \frac{r_{k,0}}{p_{k,0}} \tag{12}$$

This signal is then used to correct the fading effect in $r_{k,1}$ to give an estimate of the data signal

$$\hat{r}_{k,1} = \frac{r_{k,1}}{\tilde{y}_{k,1}} \tag{13}$$

The signal, $\hat{r}_{k,1}$, again is fed to a threshold detector to produce the data signal $\hat{d}_{k,1}$, which is subsequently decoded to give the binary data $\hat{u}_i$, $\hat{u}_{i+1}$, ..., $\hat{u}_{i+M-1}$. Since $\hat{d}_{k,1}$ is a possible signal vector on the constellation and $\hat{y}_{k,1}$ is closer to $y_{k,2}$ in a slowly-faded channel, an improved estimate of $y_{k,2}$ can be obtained by

$$\tilde{y}_{k,2} = \frac{r_{k,1}}{\hat{d}_{k,1}} \tag{14}$$

The signal $\tilde{y}_{k,2}$ is used to correct the fading effect in $r_{k,2}$. This process repeats until the end of the data symbols in the frame according to

$$\tilde{y}_{k,i} = \frac{r_{k,i-1}}{\hat{d}_{k,i-1}} \qquad \text{for } i = 2, 3, ..., L\text{-}1 \tag{15}$$

The whole process repeats for every frame.

Since the pilot symbols carry no data information, the information rate of the system is reduced. To maintain the same throughput of the system, the data rate must be increased by a factor of $L/(L\text{-}1)$. In addition, since a portion of the transmitted signal power is used for transmitting the pilot symbols, for a given transmitted power of the system, the energy per data symbol is reduced by factor of

$$10 \log\left[\left(\frac{|P_p|}{|P_d|}\right)\left(\frac{1}{L-1}\right)+1\right] \text{ dB} \tag{16}$$

where $|P_p|$ is the average energy in the pilot symbols

$|P_d|$ is the average energy in the data symbols.

Since all vectors in the 16PSK signal have the same energy level, Eqn. (16) for 16PSK signal can be reduced to

$$10 \log\left(\frac{L}{L-1}\right) \text{dB} \tag{17}$$

4. Simulation Results and Discussions

Monte Carlo simulations have been carried out to investigate the effects of the proposed technique on the BER performance of 16PSK and 16QAM signals used in the system of Figure 1. In all simulations, a transmission rate of 32 kb/s, a S / D of 7 dB for Rician channel, and Doppler spreads ($f_D T$) of 1.25×10^{-3} and 1.0×10^{-2} of the symbol rate have been used. The BER performances of the systems using ordinary and the improved compensation techniques, with frame lengths of 4, 8, 16, and 32 are shown in Figures 3-6 for a Rician fading channel ($f_D T$ of 1.25×10^{-3} and 1.0×10^{-2}) and in Figures 7-8 for a Rayleigh fading channel ($f_D T$ of 1.25×10^{-3}).

In Figures 3-8, it can be noted that the smaller the value of frame length (L), the better are the performances of the systems. This is particularly obvious in fast fading conditions because the estimates of the changes in the signal are needed to be updated more often. However, the improvement in the BER performance using the proposed technique is found to be greater in the case of larger frame lengths. This is because the estimates using the ordinary technique are already quite accurate when L is small (say L = 4).

In a fast-faded ($f_D T$ of 1.0×10^{-2}) Rician channel, the technique can reduce the BER performance by two orders of magnitude in both 16PSK signal (from 1×10^{-1} to 1×10^{-3} at L equals 32, and SNR equals 35 dB shown in Figure 5) and 16QAM signal (from 6×10^{-2} to 4×10^{-4} at L equals 32, and SNR equals 35 dB shown in Figure 6).

At low SNRs, the technique does not gain much advantages over the ordinary technique because the noise reduces the accuracy of the estimated signals $\tilde{y}_{k,i}$, $\hat{y}_{k,i}$, and $\hat{r}_{k,i}$. However, significant improvement can be obtained when the SNR is greater than 20 dB in a fast-faded Rician channel (Figures 5 and 6) and in a slowly-faded Rayleigh channel (Figures 7 and 8). In a slowly-faded Rician channel (Figures 3 and 4), substantial advantages can also be achieved when the SNR is greater than 30 dB. The simulation results also indicate that the performance of 16QAM signal is slightly better than 16PSK signal in all the conditions under tested.

5. Conclusions

An improved multipath fading compensation technique using the data symbols as well as the pilot symbols is proposed in this paper. The technique is an extension of the ordinary pilot symbol-aided schemes. The distinct advantage is the substantial improvement in the BER performance of the systems, especially with large frame lengths. Monte Carlo simulations have been carried out to investigate the BER performance of the proposed technique in Rician fading and Rayleigh fading environments. Results have been shown that, at high SNRs, an improvement of more than two orders of magnitude in the BER performance can be obtained by the proposed technique.

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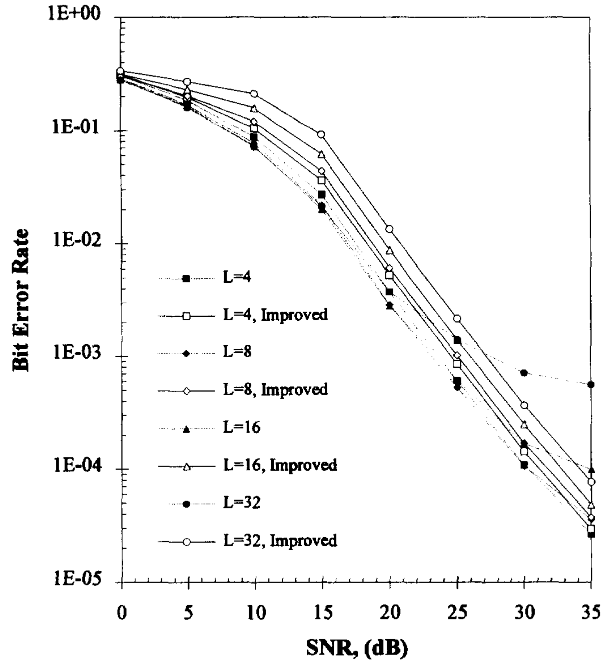

Figure 3 Performance of 16PSK in Rician Channel ($f_D T = 1.25\times10^{-3}$)

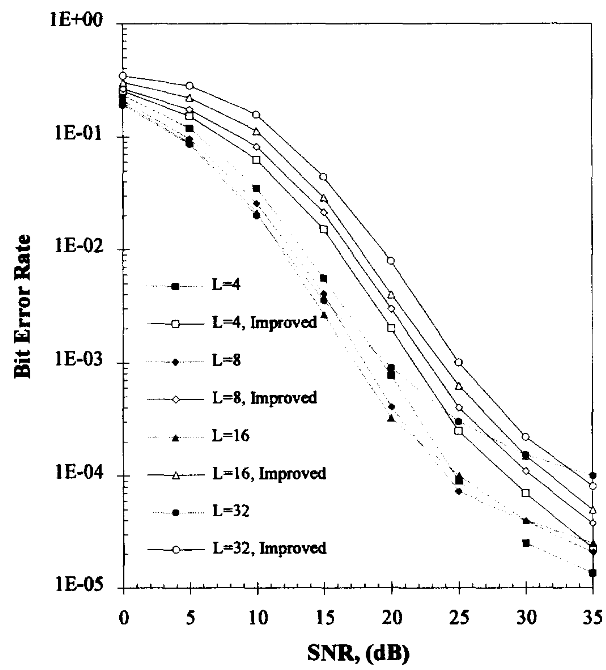

Figure 4 Performance of 16QAM in Rician Channel ($f_D T = 1.25\times10^{-3}$)

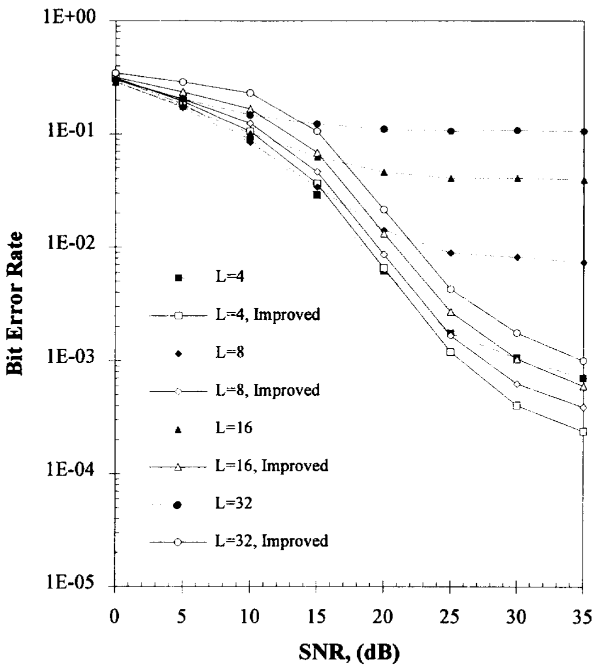

Figure 5 Performance of 16PSK in Rician Channel
($f_D T = 1.0 \times 10^{-2}$)

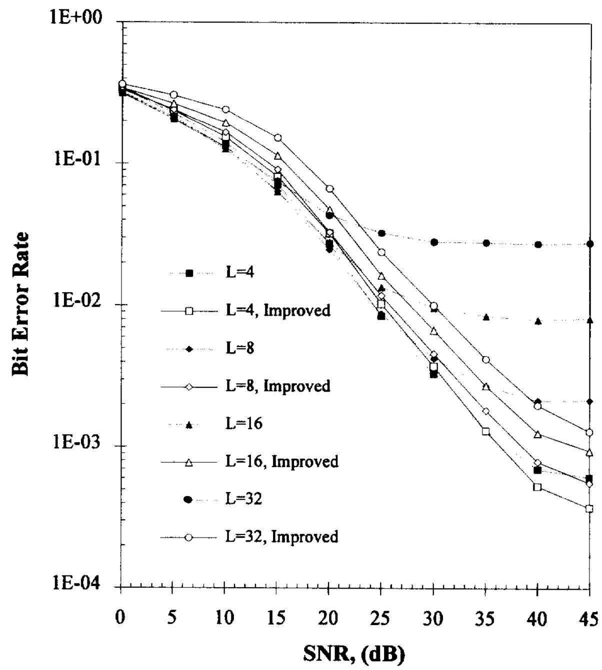

Figure 7 Performance of 16PSK in Rayleigh Channel
($f_D T = 1.25 \times 10^{-3}$)

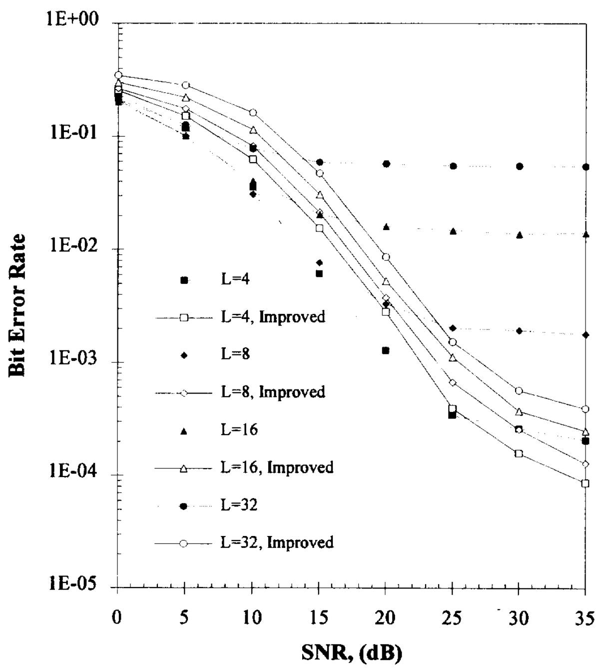

Figure 6 Performance of 16QAM in Rician Channel
($f_D T = 1.0 \times 10^{-2}$)

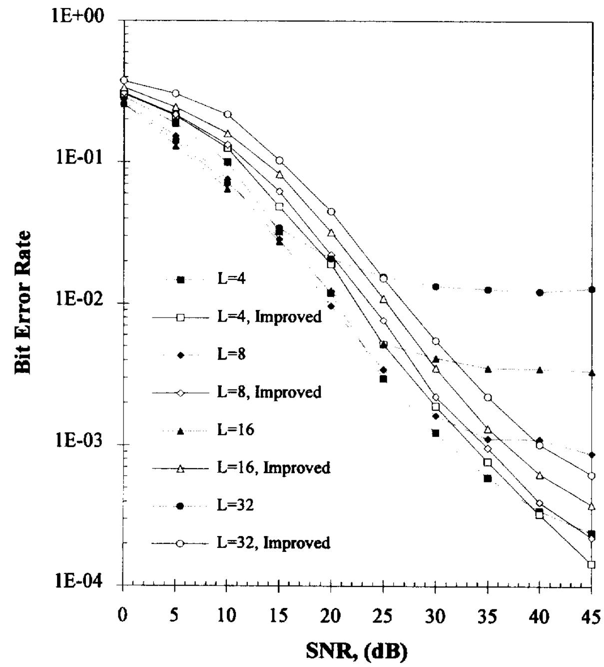

Figure 8 Performance of 16QAM in Rayleigh Channel
($f_D T = 1.25 \times 10^{-3}$)