

Performance of a Pilot Symbol-Aided Technique in Frequency-Selective Rayleigh Fading Channels Corrupted by Co-Channel Interference and Gaussian Noise

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ABSTRACT The paper studies the effects of a pilot symbol-aided (PSA) technique on the performances of 16QAM and 16PSK in the frequency-selective Rayleigh fading channels corrupted by co-channel interference and Gaussian noise. The PSA technique employs both the pilot symbols and data symbols for fading estimation. Computer simulation results have shown that significant improvements on bit-error rate performances of the signals can be achieved through the use of the PSA technique.

I. INTRODUCTION

In current digital cellular systems, modulation with low spectral efficiency such as $\pi/4$ -quaternary-phase-shift keying ($\pi/4$ -QPSK) or Gaussian-minimum-shift keying (GMSK) are usually used. To cope with the ever-increasing demands for system capacity, spectrally-efficient modulations such as 16-ary quadrature-amplitude modulation (16QAM) or 16-ary phase-shift keying (16PSK) are expected to be used in future. However, due to the wide tracking bandwidth requirements, efficient transmission of these signals in the mobile environments cannot be easily achieved [1]. Pilot symbol-aided (PSA) techniques have been proposed to enable coherent transmission of digital signals over the fading channels [2]-[5]. In these studies, the fading estimation processes make use of only the pilot symbols but completely ignore the data symbols. Recently, a simple estimation technique that makes use of both the pilot and data symbols has been proposed and results have shown that, in the frequency non-selective fading channels, substantial improvements on bit-error rate (BER) performances, relative to those without using the data symbols for fading estimation, can be achieved [6].

This paper studies the effects of the same proposed technique on the performances of 16QAM and 16PSK in the frequency-selective Rayleigh fading channels corrupted by both co-channel interference (CCI) and additive white Gaussian noise (AWGN). A series of computer-simulation tests has been carried out to assess the technique and the

results on the BER performances of PSA-16QAM and PSA-16PSK are presented, together with those of non-PSA-16PSK for comparison.

II. SYSTEM MODEL

The baseband equivalent model of the data-transmission system used in the study is shown in Fig. 1. When the encoder has received the binary information $\{u_n\}$, it maps these signals into a data symbol $\{d_{k,i}\}$ according to the 16QAM or 16PSK signal constellations. For every $(L-1)$ -data symbols, a pilot symbol from a known sequence $\{p_{k,0}\}$ is inserted at the beginning of the frame, to form an L -symbol frame, as shown in Fig. 2. The transmission paths in Fig. 1 are mobile radio channels that introduce uncorrelated Rayleigh fading distortion to the input signals. The received signal at the receiver composes of the desired signal, the delayed signal, the CCI signal, and the AWGN. The combination of the desired (main-path) signal and the delayed signal accounts for the frequency-selective fading [7].

The signal-to-noise ratio is defined as

$$\Gamma = 10 \log \left(\frac{E_b}{N_0} \right) \quad (1b)$$

where E_b is the average transmitted bit energy and N_0 is the single-sided power spectral density of the AWGN.

The main-path-to-delayed-path carrier power ratio is defined as

$$\Phi = 10 \log \left(\frac{C}{D} \right) \quad (1b)$$

where C and D are the signal power of the main-path and the delayed-path, respectively.

The main-path-to-CCI power ratio is defined as

$$\Psi = 10 \log \left(\frac{C}{I} \right) \quad (1c)$$

where I is the power of the CCI signal.

The normalized delay is defined as

$$\frac{\tau}{T} \quad (1d)$$

where τ is the time-delay between the main-path and the delayed-path and T is the symbol duration.

III. MULTIPATH FADING COMPENSATION

The frame structure of the transmitted symbol sequence is shown in Fig. 2. The sample signal at the i -th position of the k -th received frame can be written as

$$r_{k,i} = q_{k,i} y_{k,i} + w_{k,i} \quad (2a)$$

where $q_{k,i}$ is either a pilot symbol or a data symbol, $y_{k,i}$ is the change at the i -th symbol of the k -th frame, and $w_{k,i}$ is the noise sample at the i -th symbol of the k -th frame.

For $i = 0$, the sample signal is

$$r_{k,0} = p_{k,0} y_{k,0} + w_{k,0} \quad (2b)$$

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

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

$$r_{k,i} = d_{k,i} y_{k,i} + w_{k,i} \quad (2c)$$

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

Since the pilot symbol $p_{k,0}$ is known at the receiver, $y_{k,0}$ can be obtained using (2b) as

$$y_{k,0} = \frac{r_{k,0}}{p_{k,0}} - \frac{w_{k,0}}{p_{k,0}} \quad (3)$$

At high signal-to-noise ratios, $y_{k,0}$ can be estimated as

$$\hat{y}_{k,0} = \frac{r_{k,0}}{p_{k,0}} \quad (4)$$

The proposed compensation process works with the frame lengths of 4, 8, 16, ..., or 2^n , where n is an integer, and consists of two compensation stages. The first stage works on the data symbols in the even-number positions (i.e., $i = 2, 4, \dots, L-2$), while the second stage works on the data symbols in the odd-number positions (i.e., $i = 1, 3, \dots, L-1$) of a frame.

Compensation for Data Symbols in Even-Number Positions

The changes on the pilot symbols due to fading in the k -th frame, $\hat{y}_{k,0}$, and in the $(k+1)$ -th frame, $\hat{y}_{k+1,0}$, can be obtained from $r_{k,0}$, $p_{k,0}$, $r_{k+1,0}$, and $p_{k+1,0}$, using (4). The estimate of $y_{k,L/2}$ is obtained as

$$\hat{y}_{k,L/2} = \frac{\hat{y}_{k,0} + \hat{y}_{k+1,0}}{2} \quad (5a)$$

This signal is then used to correct the fading effects in $r_{k,L/2}$ to give an estimate of the data signal

$$\hat{r}_{k,L/2} = \frac{r_{k,L/2}}{\hat{y}_{k,L/2}} \quad (5b)$$

which is threshold detected to produce the data symbol $\hat{d}_{k,L/2}$. If $L = 4$, the compensation process for the data symbols in the even-number positions is completed and the compensation process for the data symbols in the odd-number positions begins.

However, if $L = 8$, the compensation process for the data symbols in the even-number positions continues as follows. Since the detected data symbol $\hat{d}_{k,L/2}$ is a possible signal vector on the constellation and the estimate of $y_{k,L/2}$ using $r_{k,L/2}/\hat{d}_{k,L/2}$ is closer to $y_{k,L/4}$ and $y_{k,3L/4}$ than $\hat{y}_{k,0}$ and $\hat{y}_{k+1,0}$, respectively, in terms of time and in a slowly faded channel, better estimates of $y_{k,L/4}$ and $y_{k,3L/4}$ can be obtained as, respectively,

$$\tilde{y}_{k,L/4} = \frac{1}{2} \left(\hat{y}_{k,0} + \frac{r_{k,L/2}}{\hat{d}_{k,L/2}} \right) \quad (6a)$$

$$\tilde{y}_{k,3L/4} = \frac{1}{2} \left(\frac{r_{k,L/2}}{\hat{d}_{k,L/2}} + \hat{y}_{k+1,0} \right) \quad (6b)$$

These signals $\tilde{y}_{k,L/4}$ and $\tilde{y}_{k,3L/4}$ are used to correct $r_{k,L/4}$ and $r_{k,3L/4}$, respectively, to obtain the signals

$$\hat{r}_{k,L/4} = \frac{r_{k,L/4}}{\tilde{y}_{k,L/4}} \quad (6c)$$

$$\hat{r}_{k,3L/4} = \frac{r_{k,3L/4}}{\tilde{y}_{k,3L/4}} \quad (6d)$$

which are used to obtain the detected data symbols $\hat{d}_{k,L/4}$ and $\hat{d}_{k,3L/4}$.

If $L = 16$, the compensation process continues further. The corrected signals, $\hat{d}_{k,L/4}$ and $\hat{d}_{k,3L/4}$, are used together with the pilot symbols, $p_{k,0}$ and $p_{k+1,0}$, to correct the data symbols according to

$$\tilde{y}_{k,L/8} = \frac{1}{2} \left(\hat{y}_{k,0} + \frac{r_{k,L/4}}{\hat{d}_{k,L/4}} \right) \quad (7a)$$

$$\tilde{y}_{k,7L/8} = \frac{1}{2} \left(\frac{r_{k,L/4}}{\hat{d}_{k,L/4}} + \hat{y}_{k+1,0} \right) \quad (7b)$$

$$\tilde{y}_{k,jL/8} = \frac{1}{2} \left(\frac{r_{k,(j-1)L/8}}{\hat{d}_{k,(j-1)L/8}} + \frac{r_{k,(j+1)L/8}}{\hat{d}_{k,(j+1)L/8}} \right) \text{ for } j = 3, 5 \quad (7c)$$

Similarly, if $L = 32$, the compensation process continues with

$$\tilde{y}_{k,L/16} = \frac{1}{2} \left(\hat{y}_{k,0} + \frac{r_{k,L/8}}{\hat{d}_{k,L/8}} \right) \quad (8a)$$

$$\tilde{y}_{k,15L/16} = \frac{1}{2} \left(\frac{r_{k,L/8}}{\hat{d}_{k,L/8}} + \hat{y}_{k+1,0} \right) \quad (8b)$$

$$\tilde{y}_{k,jL/16} = \frac{1}{2} \left(\frac{r_{k,(j-1)L/16}}{\hat{d}_{k,(j-1)L/16}} + \frac{r_{k,(j+1)L/16}}{\hat{d}_{k,(j+1)L/16}} \right) \quad (8c)$$

for $j = 3, 5, \dots, 13$

Similar equations can be derived for $L = 64, 128, \dots, 2^n$. The compensation process continues until all the data symbols in the even-number positions are done. Then the compensation process for the data symbols in the odd-number positions begins.

Compensation for Data Symbols in Odd-Number Positions

For compensation of the data symbols in the odd-number positions, $\tilde{y}_{k,i}$ and $\hat{r}_{k,i}$ are obtained as

$$\tilde{y}_{k,1} = \frac{1}{2} \left(\hat{y}_{k,0} + \frac{r_{k,2}}{\hat{d}_{k,2}} \right) \quad (9a)$$

$$\tilde{y}_{k,L-1} = \frac{1}{2} \left(\frac{r_{k,L-2}}{\hat{d}_{k,L-2}} + \hat{y}_{k+1,0} \right) \quad (9b)$$

$$\tilde{y}_{k,j} = \frac{1}{2} \left(\frac{r_{k,j-1}}{\hat{d}_{k,j-1}} + \frac{r_{k,j+1}}{\hat{d}_{k,j+1}} \right) \text{ for } j = 3, 5, \dots, L-3 \quad (9c)$$

$$\hat{r}_{k,i} = \frac{r_{k,i}}{\tilde{y}_{k,i}} \quad \text{for } i = 1, 3, \dots, L-1 \quad (9d)$$

Of course, all the corrected signal samples $\{\hat{r}_{k,i}\}$ are fed to the threshold detector to produce $\{\hat{d}_{k,i}\}$ which are finally decoded into the binary data $\{\hat{u}_i\}$. The whole compensation process repeats for all the received frames.

It should be noted that the major advantages of this estimation technique are that it is simple to implement and the time-delay introduced by the compensation process is small which are particularly important for voice and some real-time applications.

IV. RESULTS AND DISCUSSIONS

A series of computer-simulation tests has been carried out to investigate the performances (after taking into account the power loss due to transmitting the pilot symbols [6]) of PSA-16QAM and PSA-16PSK in the frequency-selective fading channels. Throughout the tests, a normalized Doppler spread of 0.005 and a frame length of $L = 8$ are used.

The results on the performances of the signals as functions of Γ (signal-to-noise ratio) and Ψ (main-path-to-CCI power ratio) are shown in Figs. 3 and 4, respectively. The error-floors, i.e., $\Gamma = \infty$ dB, against the Φ (main-path-to-delayed-path carrier power ratio), and against the τ/T (normalized delay), are shown in Figs. 5 and 6, respectively. For comparison purpose, the performances of differentially-detected 16PSK (DD-16PSK) under the same conditions are also presented on the same figures. It can be seen that, in all the cases tested, both PSA-16QAM and PSA-16PSK outperform DD-16PSK. It is also noticed that PSA-16QAM has a slightly better performance than the PSA-16PSK.

V. CONCLUSIONS

A pilot symbol-aided technique using both the pilot symbols and data symbols for fading estimation has been studied. The results have shown that, through the use of the proposed technique, PSA-16QAM and PSA-16PSK outperform the DD-16PSK significantly.

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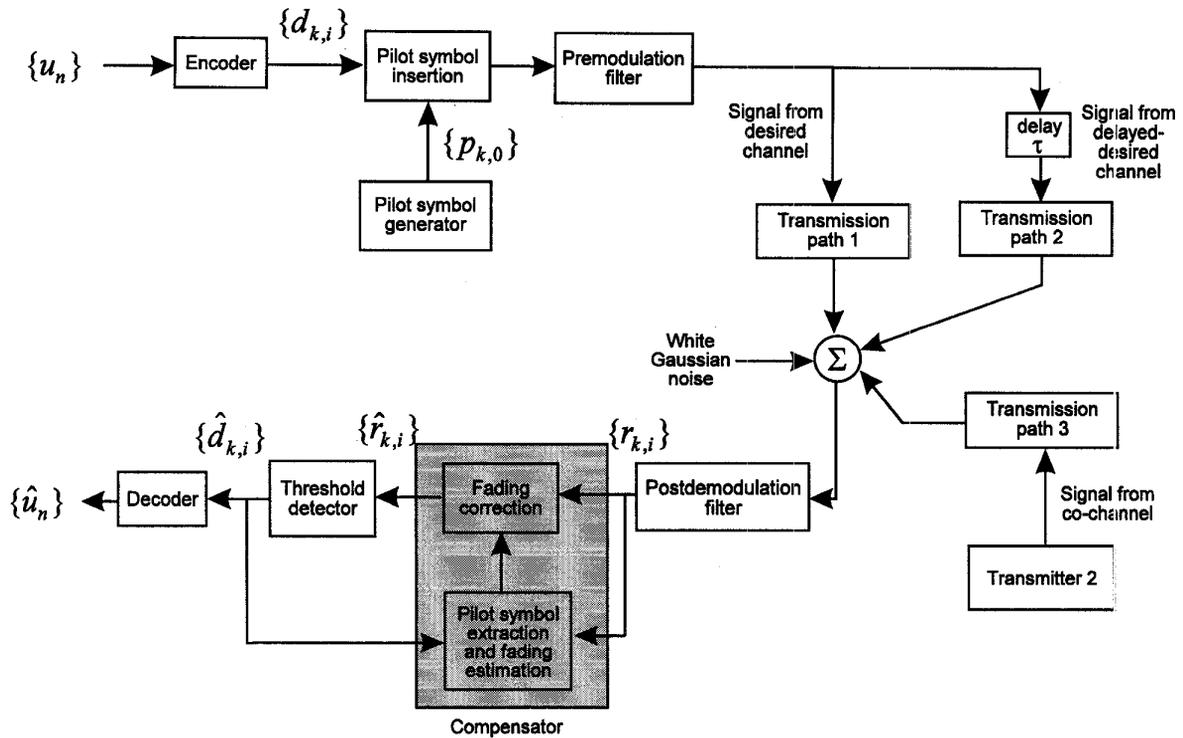


Fig. 1 Model of System

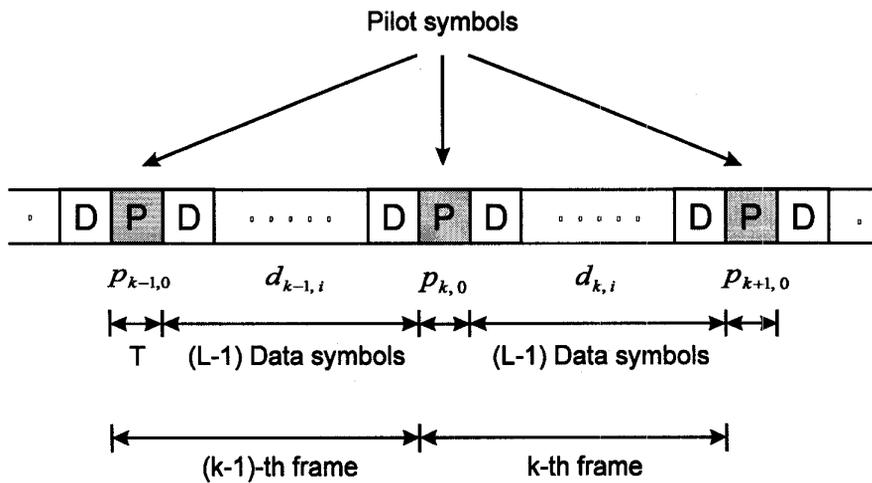


Fig. 2 Frame Structure of Transmitted Symbol Sequence

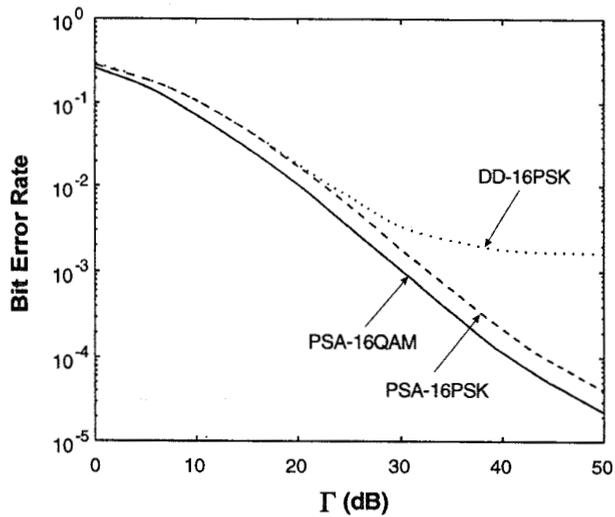


Fig. 3 BER Performances of PSA-16QAM, PSA-16PSK, and DD-16PSK as functions of Γ , with $\Psi = \infty$ dB and $\Phi = \infty$ dB

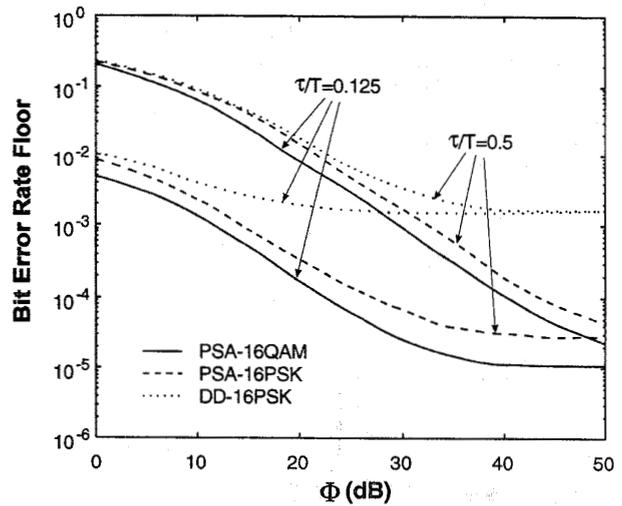


Fig. 5 BER Floors of PSA-16QAM, PSA-16PSK, and DD-16PSK as functions of Φ , with $\Gamma = \infty$ dB and $\Psi = \infty$ dB

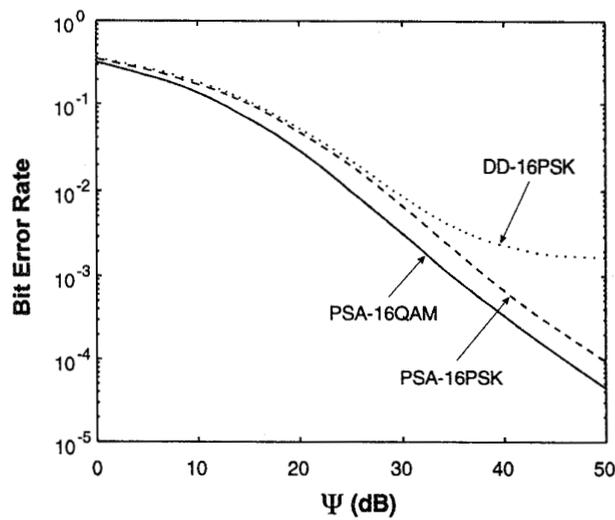


Fig. 4 BER Performances of PSA-16QAM, PSA-16PSK, and DD-16PSK as functions of Ψ , with $\Gamma = \infty$ dB and $\Phi = \infty$ dB

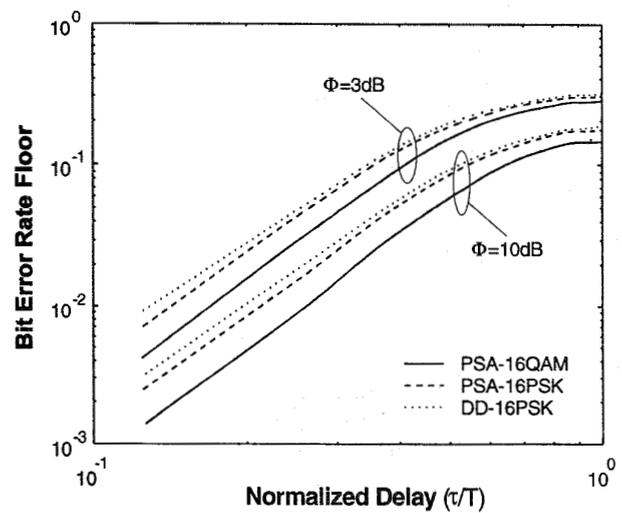


Fig. 6 BER Floors of PSA-16QAM, PSA-16PSK, and DD-16PSK as functions of τ/T , with $\Gamma = \infty$ dB and $\Psi = \infty$ dB