Coherent Detection Method with Compensation at Transmitter in Time Division Duplex System

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Abstract

We proposed a pre-compensation method combining two wireless communication schemes, TDD(Time Division Duplex) whose forward and reverse links use the same frequency, and the coherent detection as the best detection scheme to give a better mobile to base stations type communication system. The method is that the mobile station observes and estimates the channel characteristic from the received signal, and pre-compensates the transmitted signal adapting to the fading channel to improve the performance. Although preamble signals are necessary in the conventional method to observe and estimate the channel characteristic, the proposed method needs not the preamble signals, which decrease the information rate. Computer simulations show better BER performance than the differential detection that is usually used in Rayleigh fading channel.

1. Introduction

Recently, the growing demand of mobile communication like portable telephones, car telephones and PHS (Personal Handy phone System) increases rapidly [1]. We need communication systems with more capacity and higher quality. One of suitable for the demand is Time Division Duplex (TDD) system [2-5], in which only one frequency channel is used for transmitting and receiving signals between the base and mobile stations. TDD scheme is effectively applied to pre-diversity or power control in mobile communication [2-5]. The other one is coherent detection with advantages that less signal-to-noise-ratio (SNR) than differential detection on the same Bit-error-rate (BER) is required. However, it is difficult to carry out the coherent detection due to changing amplitude and phase in the fading channel. Therefore preamble signals are necessary to estimate the channel characteristic and compensate it at the conventional coherent detector [6-7].

In this paper, we propose a new coherent detection method for mobile radio communication using TDD scheme. The method is that the mobile station observes and estimates the characteristics of the channel from the received signal transmitted at base station on forward link, and compensates the fading in advance. Although preamble signals are necessary in conventional methods, the method we proposed needs not the preamble signals which decrease the information rate. Computer simulations show better BER performance than the differential detection, which has been usually used in Rayleigh fading channel. The paper is organized as follows. TDD system and the coherent detection explained in chapter 2. The proposed system is described in chapter 3. Computer simulation results are presented and discussed in chapter4, and finally, the conclusions are discussed in chapter5.

2. Conventional System

2.1 Coherent detection

Fig. 1 shows the typical coherent detection system for BPSK(Binary Phase Shift Keying) modulation in the transmitter and receiver with the oscillator

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frequencies f_c and $f_c^{'}$ respectively. These frequencies must be same as $f_c = f_c^{'}$ and the phases between the received signal and local oscillator at the receiver must be adjusted for coherent detection. It is difficult for the coherent detector to detect a signal in the fading channel, since the phase and amplitude fluctuations disturbs the detection system. Therefore, we need preamble signals that estimate the fading channel characteristics for stabilizing the system in the conventional coherent detection. However, the preamble signals embedded in the transmitted signal reduce the information rate.

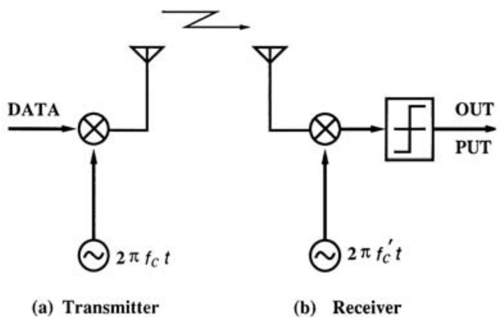

Fig. 1 Coherent Detection

2.2 TDD System

The FDD(Frequency Division Duplex) technique has traditionally been used for both wireless and wired duplex communications. In the FDD systems two separate frequency channels are used for transmitting and receiving signals as illustrated in Fig. 2.

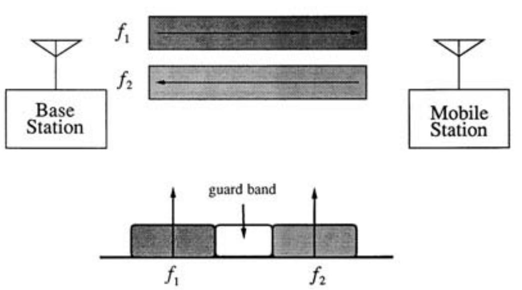

Fig. 2 FDD System

In the TDD system the forward and the reverse link communications are carried out in the same frequency band, with the vase station and the mobile station alternately transmitting and receiving information signals as illustrated in Fig. 3. Frame and Burst are defined as Fig. 3.

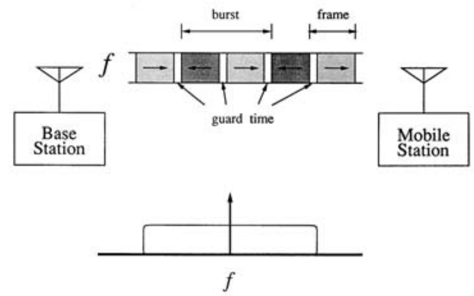

Fig. 3 TDD System

The TDD technique(also known as Ping Pong) has the advantages as follows.

(i). Guard band, which separates forward and reverse channels, is unnecessary. Therefore it is easy to frequency bands.

(ii). The system generally offers an economical system design. Since both the forward and the reverse links use the same frequency channel, the receiver and the transmitter filters and oscillators can be the same.

(iii). The bandwidth of TDD system is twice wider than FDD system. Filters in TDD system do not need to have higher Q as FDD system does.

(iv). The utilization of the same frequency band for both forward and reverse channels results in high correlation between the frequency patterns of the forward and reverse links.

There have been a lot of reports using TDD advantages. In this paper, we utilize (iv) mainly. The concept of whole TDD system is shown in Fig. 4.

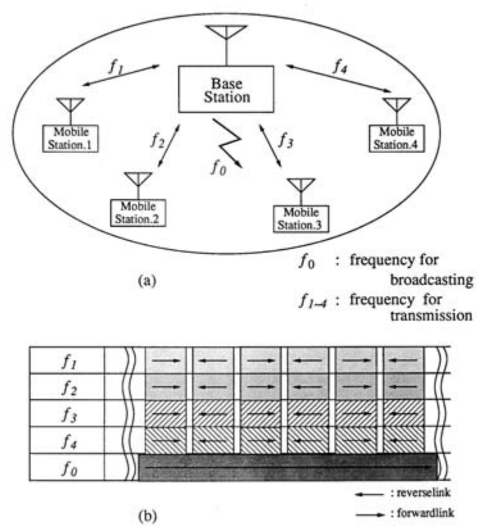

Fig. 4 TDD System

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3. Proposed System

In the proposed coherent detection system, the phase fluctuation in the fading and the frequency offset between the received signal and local oscillators have to be compensated using TDD scheme. The method for the estimation and compensation are explained as follows.

3.1 Estimation method of frequency offset

There have been some reports about estimating the frequency offset in block demodulators. The proposed system estimate the frequency offset by the following method. Multiplying the received signal and local oscillator at the receiver with the fixed frequency offset between the transmitter and receiver that have to be estimated and compensated demodulates the data. The phase fluctuating values due to the frequency offset is much larger than one due to the fading. So it is possible to get an approximate value by calculating an average for a long period and many samples. The frequency offset $\Delta \hat{f}_c$ is found by calculation as following equations

$$\Delta \hat{f}_c = \sum_{n=0}^{k-1} (\theta_{n+1} - \theta_n)/(k-1) \tag{1}$$

Where k and θ_n are the total sample number (the total bits) in one frame and the phase at the received bit which is removed from the data component respectively. The frames are shown in Fig. 3. θ_n can be written as;

$$\theta_n = \frac{1}{2}\arctan\left(\frac{2\theta_R\theta_I}{\theta_R^2\theta_I^2}\right) \tag{2}$$

Where θ_R and θ_I are the real part and imaginary part of θ_n.

3.2 Pre-compensation method of phase fluctuations

Here we describe a pre-compensation method to stabilize the coherent detector at the base station. Using the values of (1), (2) the phase fluctuation is pre-compensated. The transmitting signal from the base station is expressed as follows.

$$A\cos(2\pi f_c t + \theta_d),\ \ \theta_d = \{^{0(data=0)}_{\pi(data=1)} \tag{3}$$

Where A, f_c and θ_d are the amplitude of signals, the frequency of the base station oscillator and the binary modulated phase. Demodulated signal at mobile station ignoring the noise component is

$$\frac{A'}{2}\cos(\theta_d + \theta_f - 2\pi\Delta f_c t) \tag{4}$$

Where A' is proportional to A, Δf_c is the frequency offset between base station oscillator and mobile station oscillator, and θ_f is the phase fluctuation due to the fading. The transmitted signal from the mobile station and the demodulated signal without any compensation method ignoring the noise component are follows.

$$B\cos\{2\pi(f_c + \Delta f_c)t + \theta_d\} \tag{5}$$

$$\frac{B'}{2}\cos(\theta_d + \theta_f + 2\pi\Delta f_c t) \tag{6}$$

In use of the compensation method the transmitted signal from the mobile station and demodulated signal ignoring the noise component are written as;

$$B\cos\{2\pi(f_c + \Delta f_c)t + \theta_d - \hat{\theta}_f - 2\pi\Delta \hat{f}_c t\} \tag{7}$$

$$\frac{B'}{2}\cos\theta_d(\theta_f = \hat{\theta}_f, \Delta f_c = \Delta \hat{f}_c) \tag{8}$$

Where $\hat{\theta}_f$ is the estimated phase fluctuation and $\Delta \hat{f}_c$ is the estimated frequency offset. Seeing (8), we understand possibility to compensate the fading effect.

3.3 Demodulation method at base station

At the base station, the error of compensated phase fluctuation at the mobile station due to fading is tracked and revised by LMS algorithm defined as follows.

$$Y_m = C_{m-1}V_m \tag{9}$$

$$e_m = d_m - Y_m \tag{10}$$

$$C_m = C_{m-1} + \mu e_m V_m^* \tag{11}$$

Where V_m, C_m, Y_m, μ, d_m and e_m are the input signal vector, coefficient vector, the output value, step gain, ideal value of input and coefficient of error respectively. V_m^* is the conjugate of V_m.

The error of the pre-compensated frequency offset at the mobile station is revised as follows. The error at each frame(the phase is assumed to be constant in the

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frame) is derived by the error of the frequency offset pre-compensation at the mobile station. And the values of the error are adding up every frame, therefore signals are demodulated subtracting the total value of error. Proposed base station system is shown in Fig. 5.

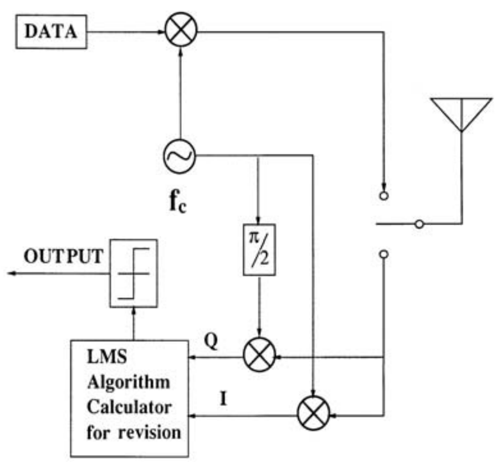

Fig. 5 Base station system in TDD

4. Simulation Results

Table.1 shows the conditions for computer simulations. The fading has Rayleigh distributed amplitude and uniformly distributed phase from zero to 2π .

Table 1. Simulation Conditions

Modulation	Coherent BPSK
Data rate	64 [kbit/sec]
Frame length	100 [bit]
Frequency offset	1000 [Hz]
Doppler frequency	10 [Hz]
Number of frame to estimate frequency offset	100 [frame]

4.1 Parameter decision of LMS algorithm

Fig. 6 shows BER performance versus step gain where Doppler frequency and SNR are 10 Hz and 5dB respectively.

BER is minimum at about 0.04 as shown in Fig. 6. The parameter the step gain of LMS algorithm should be set at 0.04.

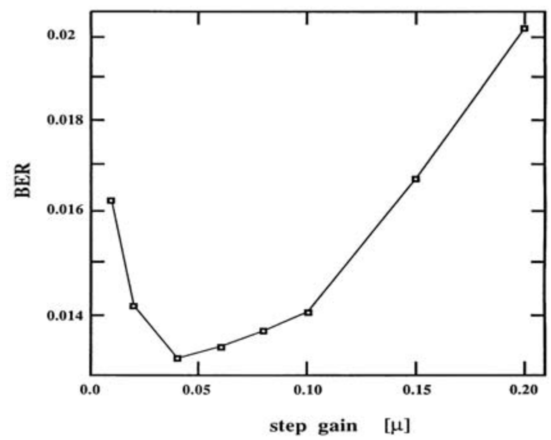

Fig. 6 BER performance versus step gain

4.2 BER performance compared with conventional method

Fig. 7 shows the BER performance versus SNR on the base station in the proposed system, where the Doppler frequency is 10 Hz. The proposed system achieves a significant improvement that is about 4 dB compared with DPSK system at BER=10^{-3}. The reason is that DPSK system is influenced by the phase fluctuation due to the frequency offset and fading, but the proposed system estimates and compensates these influences.

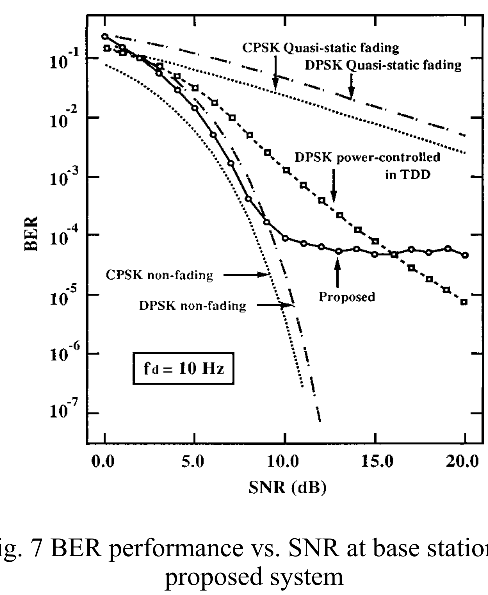

Fig. 7 BER performance vs. SNR at base station of proposed system

However there is a floor at BER performance, because of the existence of rapid phase fluctuations, which cannot be compensated at the transmitter and receiver.

Fig. 8 shows BER performance versus SNR in the proposed system and conventional system. The conventional compensation method by LMS algorithm uses already known signals (10 bits) in every frame and is a post-compensation.

As Fig. 8 shows, there is also a floor of BER performance in using LMS algorithm method. The floor can be shifted down to less than BER = 10^{-3} and which is enough for voice communication by interleave and forward error correction. And so on it is possible to improve the floor.

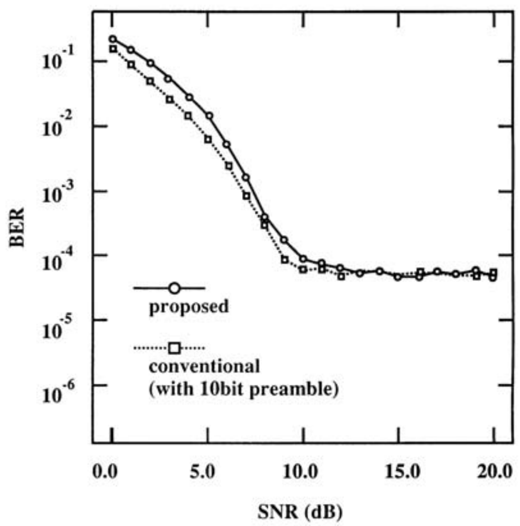

Fig. 8 BER performance vs. SNR

4.3 BER performance on variety of frame length

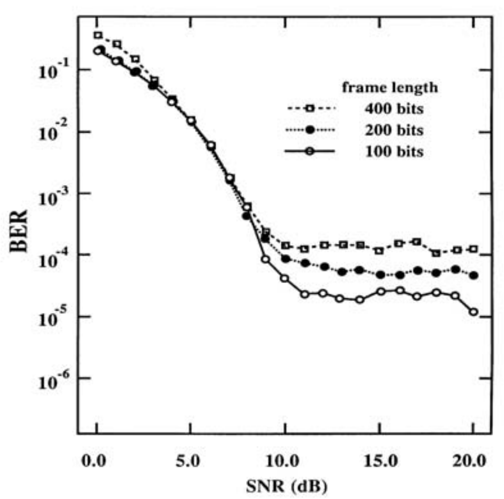

Fig. 9 BER performance vs. SNR on base station of proposed system

Fig. 9 shows BER performance versus SNR on the base station in the proposed system, whose parameter is the frame length. The frame length is shorter; the BER performance is better performance. The reason is that the frame length is shorter; the auto correlation between the forward and reverse links in TDD is higher. Therefore the phase fluctuation is estimated and compensated well.

4.4 BER performance on variety of Doppler frequencies

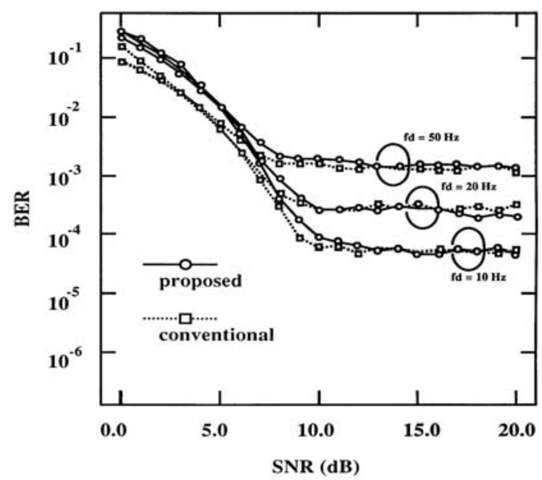

Fig. 10 BER performance vs. SNR on base station of proposed system

Fig. 10 shows BER performance versus SNR on the base station in the proposed system whose parameter is the Doppler frequency. The Doppler frequency is smaller; the BER performance is better performance. The reason is that the Doppler frequency is smaller; the phase fluctuation in one frame is smaller. Thus, the auto correlation between the forward and reverse links is higher; the phase fluctuation is estimated and compensated well.

5. Conclusion

In this paper, pre-compensation method for a new coherent detection using TDD scheme has been proposed.

Our proposed scheme is that after the fading channel characteristic is estimated, the transmit signal is compensated at the transmitter and revised at the receiver. This scheme does not need known data used in conventional systems.

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The computer simulation showed that the proposed system achieves about 4dB improvement compared with DPSK system usually used in the mobile communications at BER = 10^{-3}. Comparing with the conventional coherent system with known data (preamble data), the proposed system achieved the improvement of transmitting efficiency and almost the same BER performance.

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