Performance of Wideband Mobile Channel on Synchronous DS-CDMA

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Abstract: - Direct-sequence code-division multiple access (DS-CDMA) is currently the subject of much research as it is a promising multiple access capability for third and fourth generations mobile communication systems. The synchronous DS-CDMA system is well known for eliminating the effects of multiple access interference (MAI) which limits the capacity and degrades the BER performance of the system. In this paper, we investigate the bit error rate (BER) performance of a synchronous DS-CDMA system over a wideband mobile radio channel. The BER performance is affected by the difference in path length ΔL and the number of arriving signals N. Furthermore, the effect of these parameters is examined on the synchronous DS-CDMA system for different users' number as well as different processing gain G_p. The promising simulation results showed the possibility of applying this system to the wideband mobile radio channel.

Key-Words: - Effect, Gain, Wideband, Synchronous, Direct –sequence, CDMA, BER.

1 Introduction

Direct-sequence code-division multiple access (DS-CDMA) using multicarrier modulation has been extensively studied recently, it is a promising multiple access capability for third and fourth generations wireless systems [1] – [4]. In this paper, we introduce the wideband mobile radio channel developed in [5], derive its impulse response, and investigate the bit error rate (BER) performance of a synchronous DS-CDMA system over this wideband channel. In the DS-CDMA system, the narrowband message signal is multiplied by a large bandwidth signal, which is called the spreading signal. The spreading signal is generated by convolving a pseudo-noise (PN) code with a chip waveform whose duration is much smaller than the symbol duration. All users in the system use the same carrier frequency and may transmit simultaneously. By assigning a specific spreading signal to each user, which is approximately orthogonal to the spreading signals of all other users, it is possible to allow many users to share the same carrier frequency and channel simultaneously. Therefore, the receiver performs a correlation operation to detect the message addressed to a given user and the signals from other users appear as noise due to decorrelation. The synchronous DS-CDMA system is presented for eliminating the effects of multiple access interference (MAI) which limits the capacity and degrades the BER performance of the system [6]. MAI refers to the interference between different direct sequence users [7]. With increasing the number of users, the MAI grows to be significant and the DS-CDMA system will be interference limited. Also, in indoor and mobile radio communication channels, the system performance is significantly degraded by multipath fading channels. The effective method to overcome the degradation in the performance due to multipath fading is diversity combining. The goal of diversity is to reduce the fading effect by supplying the receiver with several replicas of the same information signal transmitted over independently fading paths [8], [9]. In this paper, we investigate the BER performance of the synchronous DS-CDMA over a wideband transmission channel, the urban multipath fading channel, by using specific parameters as proposed in [5].

2 System and Channel Models

In this section we provide a mathematical description of the DS-CDMA system, in which an orthogonal spreading sequence is used. Also, we will derive the channel model impulse response from the power spectrum density (PSD) of the wideband channel.
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2.1 Transmitted Signal

Let us assume that there are k independent users transmitting signals in the DS-CDMA system. Each of them transmits a signal as described in [9]. The transmitted signals are simply expressed as

$$s^{(k)}(t-\delta^{(k)})=\sqrt{P^{(k)}}u^{(k)}(t-\delta^{(k)})a^{(k)}(t-\delta^{(k)}) \quad (1)$$

Where $P^{(k)}$ is the power of the transmitted signal, $u^{(k)}$ is a binary data (information) sequence, $a^{(k)}$ is a spreading signal (pseudorandom sequence), and $\delta^{(k)}$ is the time offset of the k^{th} users. These time values characterize asynchronism between different users. In our case, we assumed that the receiver is delay and phase synchronized.

The k^{th} user's data signal is a sequence of unit amplitude rectangular pulses of duration T_b; the pulses' values can be either -1 or +1 with equal probability. Each pulse represents an information bit for user k. This sequence is given by

$$u^{(k)}(t) = \sum_{j=-\infty}^{\infty} u_j^{(k)} g_{T_b}(t - jT_b) \quad (2)$$

Where,

$$g_{T_b} = \begin{cases} 1 & for \quad 0 \le t < T_b \\ 0 & otherweise \end{cases}$$

The spreading signal $a^{(k)}(t)$ is a sequence of unit amplitude rectangular chips of duration T_c and can be expressed as

$$a^{(k)}(t) = \sum_{i=-\infty}^{\infty} a_i^{(k)} \psi(t - iT_c) \quad (3)$$

Where $\psi(t)$ is a chip waveform that is time limited to [0, T_c] and normalized to have energy T_c, and $a_i^{(k)}$ is the i^{th} chip value of the k^{th} user. The chip value can be either -1 or +1 with equal probability. There are G chips per bit, and thus $G = T_b / T_c$ is the processing gain or spreading factor for user k. Also, we assume that the desired user is $k = 0$ and all other contribute to MAI.

2.2 Wideband Channel Model

The propagation model is used to evaluate the wideband transmission as shown in figure (1). It assumes that multipath waves arrive at a receiver point under these conditions as follows [5]:

1. The number of arrival signal is N; each signal has amplitude $A_i(f)$ and path length L_i. These amplitude and path lengths are independent of each other and are distributed uniformly within a fixed range.
2. $A_o(f)$ is a line of site (LOS) direct signal amplitude and the amplitude of non-direct signals as reflected or refracted is $A_i(f)$ ($i \geq 1$). Also, L_o for LOS is defined as the minimum distance (path length) of arriving signals.
3. The angles of arrival (θ_i) of the signals are distributed over 2π uniformly in a horizontal plane.
4. The amplitude of each signal is constant over ($f_c + \Delta F$) and centered at a transmission radio frequency of f_c.
5. The bandwidth of the receiver is ($2\Delta f$) and centered at f_c, where $\Delta f < \Delta F$.

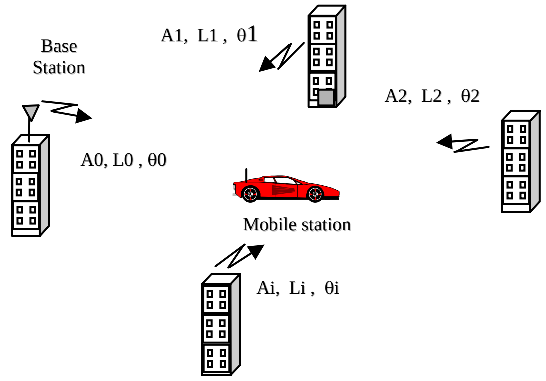

Fig. 1: Wideband Propagation Model

The power spectrum density (PSD) of the received signal is expressed as a function of the bandwidth ($2\Delta f$) as follows [5]:

$$P(f)=2\Delta f\{\sum_{i=0}^{N} A_i^2(f)+\sum_{i=0}^{N}\sum_{j=0}^{N}\frac{A_i(f)A_j(f)}{K\Delta L_{ij}\Delta f} \times [\cos(K\Delta L_{ij} f_c).\sin(K\Delta L_{ij}\Delta f)]\} \quad (4)$$

where

$K = 2\pi / c$, and c is the velocity of light.

Also, $\Delta L_{ij} = L_i - L_j$ and $\sum_{i=0}^{N}\sum_{j=0}^{N}$ means $i \neq j$.

The ratio of power spectrum density a'^2 is denoted as

$$a'^2 = \frac{A_o^2(f)}{A_i^2(f)}, \text{ where } a = 20\,LOG(a') \qquad (5)$$

Equation (4) shows the received signal level for wideband transmission; the first term represents the mean valued (LOS signal) and the remaining term represents the instantaneous signal variation (multipath signal) as the receiver moves along the street. The wideband multipath channel is modeled as in figure (2). s_i (t) and τ_i represent direct (LOS) and the non-direct signals, and the time delay respectively; where i = 0:N, N is the total number of arrival signals.

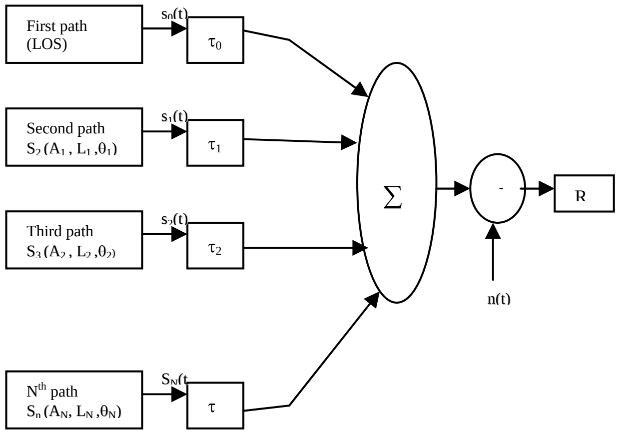

Fig. 2: The model of the wideband channel

After verifying the power spectrum density (PSD) of the received signal function as shown in equation (4), we derive the channel transfer function by taking the roots of the PSD function. Then, by applying the inverse fast Fourier transform (IFFT) to the transfer function, we get the impulse response of the wideband multipath channel, *h(t).*

$$h(t) = f^{-1}(\sqrt{P(f)}) \qquad (6)$$

2.3 Received Signal

The total received signal, *r(t)*, which convolved the transmitted signal, *s(t)*, with the impulse response of the wideband channel, *h(t)*, plus the Additive White Gaussian Noise (AWGN), n(t), having a double sided power spectral density (PSD) $N_o/2$ can be written as

$$r(t) = \sum_{k=0}^{K-1} \sum_{l_k=0}^{L-1} \sqrt{P^{(k)}}\, s^{(k)}(t-\delta^{(k,l_k)}) \otimes h^{(k,l_k)}(t) + n(t) \qquad (7)$$

From this equation (7), the signals from many users arrive at the input of the correlation receiver, which is typically used to filter the desired user's signal from all other users' signals that share the same bandwidth at the same time. Thus, the total received signal contains both the desired user's signal and *K*-1 undesired users' signals as well as the channel noise. Also, there are the multipath components of both the desired and interfering users.

3 Simulation and Result

In this section, we present and discuss the results of the BER performance of the synchronous DS-CDMA system over a wideband multipath channel as presented in [5]. The physical parameters of this channel model that were used in Equation (4) for addressing the simulation results are based on the following values:

1. The number of arrival signal is N = 20.
2. The carrier frequency f_c = 1.9 GHz.
3. The difference distance between the arrival signal and the one just next to it is varying from (0:15) and is defined by path length difference $|\Delta L_{ij}|$.
4. The bandwidth of the received signal is denoted as Δf, and it equals 90 MHz, whereas that is a wide band transmission.

After numerous testing times of the channel for different N and ΔL_{ij}, we found that the channel fade depth becomes shallower when the number of arriving signals N and path length difference ΔL_{ij} are increased. So the impulse response of the channel level depends on both N and ΔL_{ij} which agrees to [5]. Further, we found the suitable values, N and ΔL_{ij}, for the synchronous DS-CDMA system are 20 arrival signals and (0:15) meter(s), respectively.

In Figure (3), we illustrate the average BER for the different number of active users, 4, 8, 16, 32 with G_p = 128, processing gain. It can be seen that, with the same N and ΔL_{ij}, there is difference in BER performance between 4 users and 32 users by 3.5 dB at 7*10e-3 due to MAI. Also, the performance decreases with the increasing number of users when the E_b/No is larger than 5 dB. In addition, the simulation, solid lines, and theoretical, dotted lines, results approach each other with increasing Eb/No for different users, 4, 8, 16, 32.

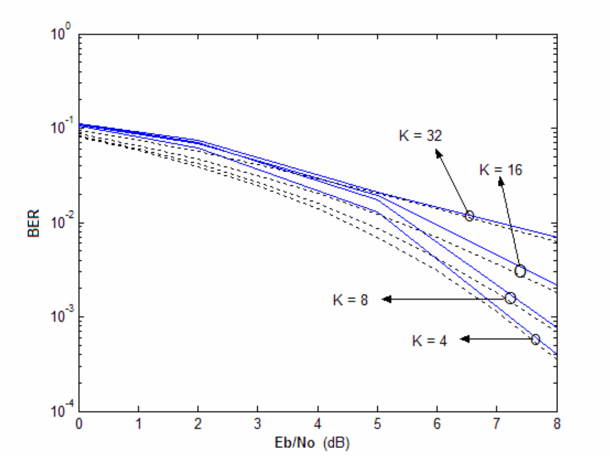

Fig. 3: G_p=128, N=20 arrival signals, ΔL_{max} = 15 m, simulation curves, solid lines, and theoretical curves, dotted lines.

Figure (4) shows the BER performance over a wideband multipath channel, as a function of the processing gain (Gp = 32, 64, and 128). The arrival signals N, the maximum path length difference , and Eb/No are set to 20, 15 m, and 8 dB, respectively. We note that the performance of the system depends on Gp. It is noteworthy that Gp has a negative effect on the number of users, K. As Gp increases, the probability of error increases, too. Hence the bigger the processing gain Gp, the greater is the effective power advantage of the wanted signal over the interference power [10].

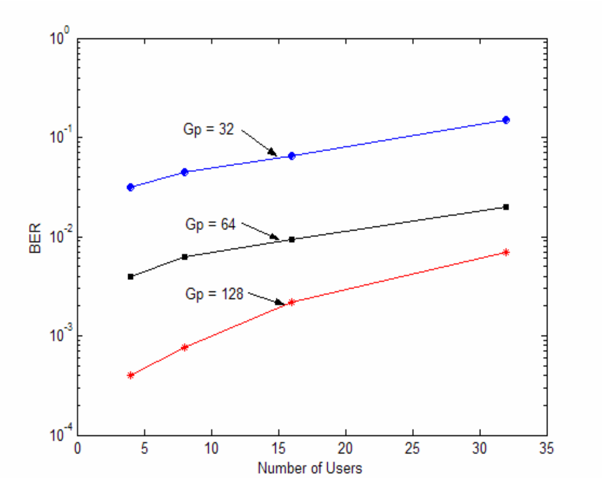

Fig. 4: BER performance for different processing gains, Gp, with different users at N=20 arrival signals and ΔL_{max} = 15 m.

4 Conclusion

In this paper, the main idea behind is to evaluate the bit error rate (BER) performance of the synchronous DS-CDMA system over a wideband mobile radio channel. This channel power spectrum density (PSD) is introduced and its impulse response is derived. In order to demonstrate the potential of this work, various simulation results have been presented.

After several tests of the channel for different N and ΔL_{ij} to be applied to the DS-CDMA system, we found proper values (N = 20 arrival signals and ΔL_{max} = 15 m) to achieve better performance. Furthermore, BER improvement is achieved with increasing the G_p and decreasing the number of users. Also, we note that the simulation BER performance for different users approaches the theoretical BER performance. Finally, we can see that the wideband transmission channel yields very good performance for synchronous DS-CDMA at specific propagation parameters, N and ΔL_{ij} .

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