A Simulation Study of Interference and SIR in Integrated Voice/Data Wireless DS-CDMA Networks

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Abstract

The objective of this paper is to characterize the multiple access interference in a DS-CDMA integrated voice/data wireless network. The simulation model is designed for stream-based services and, consequently, accommodates voice calls and data calls of the long file transfer type. Our simulation results characterize a short term variation of uplink interference power. A key quantity that we investigate is the distribution of the cumulative instantaneous interference power. Another measure that we study is the fluctuation of the signal-to-interference ratio (SIR) at the base station. We also evaluate the SIR statistics in terms of cumulative distribution functions. Studies of this type are important for capacity enhancement in DS-CDMA wireless networks as they can lead to multiple access interference models that can be effectively employed in bandwidth management systems and in interference estimator-canceler algorithms.

1 Introduction

An integrated wireless network will support different services such as voice, facsimile, and asynchronous data. The general aim is to transport these services in a seamless and efficient manner. The critical issue for wireless networks is the multiple access technique which allows many uncoordinated users to share a common bandwidth. Code division multiple access (CDMA), a spread spectrum signaling technique, is currently being proposed and implemented for such networks. In CDMA, each user transmits signals through a channel by employing an assigned spreading code sequence and occupies the same entire allocated frequency band. We focus our attention on the use of direct sequence CDMA (DS-CDMA) for an integrated multiservice wireless network. In DS-CDMA, a carrier is phase modulated by a baseband information sequence and a much higher rate pseudorandom (PN) spreading code sequence. The ratio of the spreading code rate to the service rate is an important parameter and is known as the processing gain.

The primary purpose for using CDMA is to achieve high system capacity, defined as the number of simultaneous users per cell. CDMA wireless network capacity is limited by multiple access interference. The crosscorrelation between any two arbitrary PN sequences contributes to the level of multiple access interference. Nonzero crosscorrelation results because PN sequences
chosen are typically not orthogonal due to bandwidth constraints. The total multiple access interference power received is determined by all simultaneous users having nonzero crosscorrelation functions. Also, the near-far problem is a major concern that arises in such a network and is due to the fact that the power levels of received signals are very dissimilar. The usual remedy is to use power control; however, ideal power control is difficult to achieve in practice.

The objective of this paper is to characterize the multiple access interference in a DS-CDMA integrated voice/data wireless network. The multiple access interference generated in a CDMA system is a wideband, nonstationary stochastic process. The randomness of the interference comes from three stochastic sources, namely, radio propagation, traffic variation, and mobile distribution. Due to the specific nature of the multiplexing method used for CDMA networks, the long term average interference level depends to a large extent on certain general characteristics associated with the entire user population; whereas, the short term, instantaneous interference level depends on the temporal variation of the carried traffic, the spatial variation in portable terminal position, and the temporal variation in voice activity. The fluctuation of the interference also depends on certain CDMA system implementation details, e.g., the approach taken to mitigate fading, shadowing, and path loss through power control.

In this paper, we present the results of a detailed and precise simulation study and assess the impact of traffic parameters, voice activity, and spatial distribution of portable on uplink (mobile to base) interference. The simulation model is designed for stream-based services and, consequently, accommodates voice calls and data calls of the long file transfer type. We believe that studies of this type are important for capacity enhancement in DS-CDMA wireless networks as they can lead to multiple access interference models that can be effectively employed in bandwidth management systems and in interference estimator-canceller algorithms.

This paper is organized as follows. In Section 2, we present the system description and different models used in our study. The simulation parameters and details are described in Section 3. The results are discussed in Section 4. Finally, Section 5 contains our conclusions and remarks.

2 System Description and Models

2.1 DS-CDMA Wireless Network Model

We consider a DS-CDMA wireless network consisting of large number of mobile users. The whole service area is divided into cells and each cell is served by a base station. The users communicate via a radio link with one or multiple base stations interconnected to a mobile telephony switching office (MTSO) [1]. The same radio channel is reused in every cell. The following outlines the general features of the system model for a DS-CDMA wireless network.

1. The cells are drawn with traditional hexagonal geometry as shown in Fig. 1(a). The base station and mobile user antennas have omnidirectional beam patterns.
Figure 1: (a) Layout of hexagonal cells (b) Enlarged view of a single cell

2. Separate frequency bands are used for the uplink (mobile to base station) and the downlink (base station to mobile) channel. This ensures that the base stations experience interference only from the mobile stations and the mobile stations experience interference only from the base stations.

3. The downlink waveform is designed to carry a pilot signal for synchronization and power control purposes. Power control is discussed in the sequel.

2.2 Spatial Distribution of Mobiles

The users are randomly located in the simulated system area. The location of mobiles is denoted by \((r, \theta)\). The probability density functions of the polar coordinates are

\[ p(r_m) = \frac{1}{R}, \quad 0 \leq r_m < R \]

\[ p(\theta) = \frac{1}{2\pi}, \quad 0 \leq \theta < 2\pi \]

where \(R\) is the radius of the circle that circumscribes the hexagonal cell. The parameters are shown in Fig. 1(b).

2.3 Radio Propagation Model

The radio propagation is largely influenced by three nearly independent factors: path loss, shadowing and multipath fading [2]. Path loss is the deterministic attenuation of the signal power. It is due to \(r_m\), the distance between the mobile unit and the fixed station and is proportional to \(r_m^{-\eta}\), where \(\eta\) is the path loss component. Typical values of path loss component \(\eta\) are 2, 3 and 4. Shadowing is the random variation of the signal due to local topographic conditions, antenna height, and environmental conditions. It is modeled by a log-normal random variable. Usually,
the standard deviation $\sigma_{dB}$ of log-normal shadowing is expressed in dB instead of natural units and typical values range from 5-12 dB. Multipath fading is the result of signal reflections from boundaries within the mobile environment. It causes the instantaneous envelope of the received signal to be Rayleigh distributed. With these assumptions, the received power from a mobile at distance $r_m$ can be expressed as in [3]

$$P_R = U^2 e^\xi K r_m^{-\gamma} P_T,$$

(3)

where $U$ is a Rayleigh distributed random variable with unit power, $e^\xi$ accounts for the shadowing ($\xi$ is Gaussian with zero mean and variance $\sigma^2$), $K r_m^{-\gamma}$ is the path loss, and $P_T$ is the transmitted power. The variance $\sigma$ is related to $\sigma_{dB}$ by the relationship $\sigma = (0.1 \log_{10}) \sigma_{dB}$. Here, we assume that the effects of Rayleigh fading are averaged, and, thus $U$ is taken to be unity.

2.4 Service and Traffic Models

In this study, we consider voice and stream-based data services. For stream-based services, a call is continuously transmitted over a relatively long duration. Though voice is a stream-based service, it is modeled as being intermittent with a certain duty factor $\alpha$, in which conversational speech is characterized by periods of activity called talkspurts and periods of silence [4]. This is a two state Markov model as shown in Fig. 2. The talkspurt and silence periods are independent and exponentially distributed with means of $1/\beta=1.0$ second and $1/\gamma=1.35$ second for a voice activity factor of $\alpha=1/(1+1.3)=0.425$ or 42.5% [5]. Mobile terminals incorporate a voice-activity monitoring technique to exploit this burst source model. This implies that the transmitter is not active or is transmitting at reduced power (and rate) during silent periods in human speech [1, 6].

Stream-based data services include data services for which a large amount of digitized information is transmitted over a relatively long duration. The applications are facsimile and long file transfer. These data services require continuous transmission on a constant power basis during the entire service duration.
In the integrated network, traffic is generated by voice and stream-based data users. A large population of users is assumed in each cell and a small number of this population needs service at any time. The appearance and disappearance of the users are taken to follow a Poisson distribution. An idle voice user generates new voice calls at the rate of $\lambda_v$ (calls/sec/user) and an idle data user generates new messages at the rate of $\lambda_{vd}$ (calls/sec/user), both with exponential inter-arrival time. Another important parameter for voice and data calls is the call holding time or service duration, denoted by $T_v$ and $T_{vd}$, respectively. Holding time is a random quantity having a negative exponential probability density function. The quantities $\lambda_v T_v$ and $\lambda_{vd}T_{vd}$ denote the offered average traffic measured in Erlangs for individual voice and data users, respectively [7].

2.5 Power Control Model

Power control is essential in any DS-CDMA wireless network to mitigate the near-far problem. This problem arises because the transmitters in a cell are located at different geographical distances from the receiver and the received powers at the base station are unequal. The power control model we have chosen is taken from [1] and is very effective in combating path loss and shadowing. In this model, the individual mobile adjusts its own transmission power in accordance with the received downlink pilot signal level. Also, because of shadowing, when a mobile initiates a call, it does not necessarily mean that the call will be served by that cell. The home cell for the call will be chosen as the one with the smallest radio propagation attenuation to the mobile. In fact, the mobile measures the power levels of pilot signals from all nearby base stations and is connected to the base station that require minimum transmission power. Thus, the base station index $k$ with which the mobile establishes radio link is chosen by the following equation

$$r_k e^{-\xi_k} = \min \{r_m e^{-\xi_m}\},$$

(4)

where $r_m$ is the distance of the mobile from the $m$th cell site and $\xi_m$, $m = 0, 1, 2, \ldots$, are independent Gaussian random variables with variance $\sigma$. Note that the power control algorithm
Table 1: Simulation Parameters Used in the System Model

<table>
<thead>
<tr>
<th>Item</th>
<th>Symbol, unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell radius</td>
<td>R, meter</td>
<td>200</td>
</tr>
<tr>
<td>Total number of cells</td>
<td>N, -</td>
<td>37</td>
</tr>
<tr>
<td>Propagation path loss coeff</td>
<td>η, -</td>
<td>3</td>
</tr>
<tr>
<td>Standard deviation of shadowing</td>
<td>σ_{dB}, dB</td>
<td>8</td>
</tr>
<tr>
<td>Average length of a voice call</td>
<td>T_v, seconds</td>
<td>180</td>
</tr>
<tr>
<td>Average length of a data call</td>
<td>T_{d}, seconds</td>
<td>100</td>
</tr>
<tr>
<td>Arrival rate of new voice calls</td>
<td>λ_v, calls/sec/user</td>
<td>0.002, 0.004</td>
</tr>
<tr>
<td>Arrival rate of new data calls</td>
<td>λ_{d}, calls/sec/user</td>
<td>0.004, 0.008</td>
</tr>
</tbody>
</table>

assumes reciprocity between uplink and downlink channels from propagation loss point-of-view. In this study, the power control is implemented by scanning the forward link signal from seven closest base stations as shown in Fig. 3.

3 Simulation Parameters and Schemes

The results of our study have been obtained by computer simulations. Table 1 summarizes the simulation parameters used in this paper.

The outputs of the simulation are interference and SIR. We compute the interference power received at the central base station. The uplink SIR is determined for an active mobile located within the central hexagonal cell, and the mobile is assumed to be connected to the central base station. The reason for computing the interference power and SIR at the central base station comes from the assumption that the uplink performance of any mobile in the central cell approaches that of any cell in an infinite network. This implies that a computation of this type will be applicable to any mobile located in the system area.

The users are randomly located in the simulated system area with a uniform density of M_v voice users and M_d stream-based data users per base station. The uplink interference consist of interference from mobiles within the same cell and, in addition, interference due to mobiles in surrounding cells. They are called intracell, I_{intra}, and intercell, I_{inter}, interferences, respectively. The total interference I can be written as I = I_{intra} + I_{inter} + N_{th}, where N_{th} is the background noise. Since we consider an interference limited case N_{th} is set to zero.

The simulation program generates call arrivals and departures for individual user in the time domain, i.e., the simulation of calls from initiation to termination. It randomly selects a location for a call and computes the transmitted power assuming that the power control is in effect. The received power at the central base station is then computed by considering the path loss and
shadowing. Fig. 3 shows the geometry for computing the power received at one base station (cell 
#1) from a mobile station at distance $d$ away in another cell (cell #2).

The duration of time simulated ranges up to 16000 seconds. Simulation clock resolution is 
equal to 10 milliseconds. There are two simulation programs: *simulation program-1* and *simulation 
program-2*. The latter program employs a voice activity monitoring technique for voice users, 
whereas the former program does not. Other parameters are shown in Table 1. The traffic is 
varied by changing the number of users per cell. The results were taken after the system has 
reached steady state.

The simulation of voice and data calls follows our service model. Considering the effect of 
voice monitoring, the power from each voice call becomes *intermittent*, i.e. $P_v$ during talkspurt 
and $d_P P_v$ during silence period, where $0 < d_P < 1$. The reduced power is necessary in order to 
maintain link synchronization. Here, the value of $d_P$ is set to 0.125. The transmission rate will 
also be reduced during the silence period of a voice call in a DS-CDMA network. It is also found 
that, in a call of 100 seconds in length, there are approximately 39-47 talkspurts which conforms 
to the number given [5]. A typical simulated voice call is shown in Fig. 4(a). The stream data 
users, on the other hand, require continuous transmission with power $P_{sd}$ during the entire service 
duration. The power levels mentioned here refer to the power at the receiver input point of the 
base station in the home cell.

The coordinates of the mobile are randomly picked using (1) and (2). The physical layout of 
the hexagonal geometry prevents the radius from being picked exactly as in (1). The resultant 
histogram is shown in Fig. 4(b).
Figure 5: Temporal variation of interference power from simulation program-1 as a function of voice and data users. (a): \(M_v=10, M_{sd}=5\), (b):\(M_v=50, M_{sd}=20\) and (c): \(M_v=100, M_{sd}=40\).

4 Interference and SIR - Results

Instantaneous interference power is computed as a function of \(\{M_v, M_{sd}\}\) to assess the impact of traffic parameters, voice activity, and spatial distribution of mobiles. The signal powers from each interferer are summed at the central base station to determine short-term interference power. Sets of users representing the different services have been chosen such that they categorize two classes: one set \(\{M_v = 10, M_{sd} = 5\}\) represents a small number of users and the other two sets \(\{M_v = 50, M_{sd} = 20\}\) and \(\{M_v = 100, M_{sd} = 40\}\) represent a large number of users. The total instantaneous interference power is plotted at a resolution of 100 milliseconds from the two simulation programs mentioned above. The reason for investigating two scenarios is that we are also interested in characterizing the interference as a result of voice activity.

Fig. 5 shows the instantaneous interference power from simulation program-1. It shows considerable short-term variation of interference power. This variation is attributed to the sudden arrival and departure of mobiles and the spatial distribution of mobiles. Fig. 6 shows the total interference power from simulation program-2. It shows that interference power fluctuates much more rapidly due to the impact of voice activity. In either case, the interference is certainly a non-stationary process.

An important observation is the variation in interference power. It is defined as the difference between the highest and lowest received interference power. It is desirable that the variation be as low as possible. The variation is best observed from Fig. 7 which plots the cumulative distribution.
Figure 6: Temporal variation of interference power considering voice activity as a function of voice and data users. (a): $\{M_v=10, M_{sd}=5\}$, (b): $\{M_v=50, M_{sd}=20\}$ and (c): $\{M_v=100, M_{sd}=40\}$.

function (cdf) of interference power. It is seen that the variation in interference power is relatively large for small number of users. As the number of users in the network increases, the variation decreases. This is indicated by the cdf's for $\{M_v = 50, M_{sd} = 20\}$ and $\{M_v = 100, M_{sd} = 40\}$ as compared to the cdf for $\{M_v = 10, M_{sd} = 5\}$.

Another measure that we study is the fluctuation of the signal-to-interference ratio (SIR) at the base station. The SIR of the uplink received signal is important in determining the radio link performance of any active user. Fig. 8 shows the short-term temporal variation of uplink SIR at the base station during a time interval of three minutes. Results are plotted and compared from two simulation programs. Dashed lines shows the results from simulation program-1 whereas the solid lines show the values of SIR considering voice activity monitoring, i.e., from simulation program-2. It is observed that voice activity monitoring technique improves the average SIR in the mobile to base link, but it also introduces rapid variation of SIR over time. Since the average length of a voice call is three minutes, it shows that the uplink SIR of an active talking mobile varies many times during each call.

In order to examine the effects of individual arrival rates on the variation of SIR, we formulate an experiment to simulate equal traffic in a single cell for a different number of users. For this, we assume that the total arrival rates in a cell can be written as $M_v \lambda_v$ and $M_{sd} \lambda_{sd}$ respectively. We have chosen $M_v = 50, 100$ and $M_{sd} = 20, 40$ to represent a large number of users and the total traffic simulated is 36 Erlangs/cell for voice users and 16 Erlangs/cell for data users, respectively. The cumulative distribution function of SIR is plotted in Fig. 9. It is observed that the variation
Figure 7: Cumulative distribution function of interference power as a function of voice and data users. (a): \( M_v=10, M_{sd}=5 \), (b): \( M_v=50, M_{sd}=20 \) and (c): \( M_v=100, M_{sd}=40 \).

in SIR is nearly equal for two cdf's. This appears to substantiate the fact that variation of SIR is due to the total traffic per cell rather than to the individual arrival rates of different services.

5 Conclusions

This paper has investigated the multiple access interference in an integrated voice/data network. The simulation results demonstrate the temporal variation of uplink interference power. Different factors such as arrivals and departures of cochannel portables, voice activity, and spatial distribution of mobiles contribute to such temporal variation. The interference can be modeled as a non-stationary process. It is observed that the variation in interference power is larger for a small number of users per cell, as compared to a relatively large number of users per cell.

Temporal variation of interference has a considerable impact on radio link performance of any active user. The SIR is found to fluctuate many times during a typical call duration. The variation of SIR is seen to be dependent on total traffic per cell from different services.

There are other issues in a practical network which appear to further contribute to this non-stationarity. These are multipath fading; non-uniform traffic, known as hot-spot traffic; and non-ideal power control. The packet-based data services in a future generation wireless network will also have considerable impact on interference in a DS-CDMA network [8]. Work is currently underway to further understand the interference resulting from packet-based services.
Figure 8: Temporal variation of SIR (resolution-10ms) as a function of voice and data users. (a): \( M_v=10, M_d=5 \), (b): \( M_v=50, M_d=20 \) and (c): \( M_v=100, M_d=40 \).

There are many important applications of this study. An important issue in DS-CDMA networks is the interference estimate that would form the input to a bandwidth management system (BMS), the output of which would be call admission and data congestion control policy decisions.

Another important application is in the area of interference cancelation strategies. Since a DS-CDMA network is interference limited, interference cancelation methods will certainly improve the capacity. A direction seems to be toward interference estimation and cancelation algorithms, where the challenge requires wideband, non-stationary interference estimation for subsequent cancelation.

Acknowledgments

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References

Figure 9: Cumulative distribution function of SIR for equal traffic (Erlangs/cell) with two sets of individual arrival rates for different services.


