OPNET Simulation of Random Access CDMA Networks

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Abstract
As large mobile networks have become commonplace, the allocation of resources has become critical. The most important and restricted resource is the system bandwidth for this kind of networks. In order to use the system bandwidth efficiently, multiple access systems are used. For multiple access systems, MAC (medium access control) protocols have primary effect in the throughput and delay performance of the system. Among MAC protocols, the ALOHA scheme has enjoyed the advantage of simplicity, however, the throughput of ALOHA decreases under heavy traffic conditions. Alternative random access systems have been proposed based on code division multiple access (CDMA) systems to improve the throughput [1,2]. Random access CDMA systems have been shown to efficiently allocate scarce radio communication channels (bandwidth) in such a way that users with bursty traffic can share the same frequency without significant degradation to the overall throughput. However, large system simulation of random access CDMA networks with unslotted implementation has been difficult. Therefore, in this paper, we present an OPNET simulation of random access CDMA system. Such simulation can provide means to observe and report the system specifications and performance of the large CDMA networks under different circumstances.

Introduction

In recent years, there has been an increased demand for mobile data communications. To handle the bursty nature of data traffic and to efficiently allocate the resources among the users, packet-based multiple access protocols must be used. But most random access networks such as ALOHA typically suffer from collisions. However, if CDMA based MAC protocols are used some of the collided packets can be extracted correctly. So CDMA random access systems have drawn much attention and much literature has been devoted to improve system performance.

Most of the analyses of random access CDMA systems are based on slotted systems or circuit switched systems. In a slotted system transmission time is divided into slots, which consist of a packet interval time and a guard time. All users must synchronize their transmission to the beginning of the slot. The performance analysis of the slotted system is easy and the system performance only depends on the number of interfering packets (or users) within a slot. Unslotted systems are easy to implement because they do not require synchronization. However, their performance analysis is very difficult since the number of interfering users fluctuates during the packet interval. Most of the performance analysis of unslotted ALOHA depends on the perfect capture while the number of interference is assumed to be constant. [2].

The primary objective of this paper is to simulate unslotted random access CDMA systems using OPNET. OPNET is powerful simulation tool for large system simulation. However, unslotted random access CDMA simulation in OPNET requires some modifications of its pipeline stages. For example, as the level of interference changes during the packet interval, the bit error rate (BER) and the packet error rate (PER) need to computed by considering the number of collided packets and the duration of this collision (segment). Therefore, to calculate the BER (and PER) we propose two methods: Pre-generated BER tables and Simplified Improved Gaussian Approximation (SIGA) formula. The effect of thermal noise or background noise can be included into the BER tables or in SIGA approximation.

The rest of this paper is organized as follows. Next section we provide an overview of random access CDMA system model and in section III we describe our OPNET implementation of our CDMA system. In section IV, we present and evaluate simulation results. Concluding remarks are offered in section V.

Random Access CDMA System Model

In this section we give a brief overview of the random access CDMA system model. In this paper we consider a centralized spread spectrum system with infinite number of users. Every transmission is received by equal power. Bit errors are caused by multiple access interference and the thermal noise. Thus, we consider two approaches to determine bit errors with respect to multiple access interference and the thermal noise. For the first approach, we pre-generated bit error rate (BER) tables using MATLAB CDMA simulator that we built. Using the MATLAB simulator, we generated BER tables given number of users and signal to noise ratio, E_b / N_o. The reason for using BER table is that OPNET modulation pipeline works with BER tables as a function of E_b / N_o. OPNET picks bit errors given E_b / N_o. However, we found that using BER tables for CDMA simulation is impractical since many BER tables are needed. Therefore, we have looked at approximations based on multiple access interference and spreading gain. The next section describes these approximations.

Simplified Improved Gaussian Approximation (SIGA)

There have been many research efforts on the calculation of bit error rates of CDMA systems. The exact calculation is computationally difficult so emphasis has been on approximations. [3-5]. One attractive approximation is to assume multiple access interference as Gaussian noise. This is called standard Gaussian approximation (SGA). However, this approximation is often accurate only when there are large number of simultaneous users on the channel: other wise, this approximation can be optimistic. In [5], it is found that SGA can be improved. Thus, improved Gaussion approximation (IGA) is complicated and requires significant computational time to evaluate. Holtzman [3] presented a simplified technique to evaluate this equation for the case of perfect power control. This simplified bit error rate expression is based on the fact that a continuous function may be expressed as its Taylor series expansion [3]. Thus, simplified improved Gaussian approximation provides the probability of bit error as

$$P_e \approx \frac{2}{3} Q\left(\sqrt{\frac{N^2}{2*\mu_\psi + \frac{No}{2Eb}*N^2}}\right) + \frac{1}{6} Q\left(\sqrt{\frac{N^2}{2*(\mu_\psi + \sqrt{3}\sigma_\psi) + \frac{No}{2Eb}*N^2)}}\right) + \frac{1}{6} Q\left(\sqrt{\frac{N^2}{2*(\mu_\psi - \sqrt{3}\sigma_\psi) + \frac{No}{2Eb}*N^2)}}\right) \quad (1)$$

where E_b is the energy per bit. We assume AWGN with two-sided spectral density of No/2. Q function can be defined as

$$Q(v) = \frac{1}{\sqrt{2\pi}} \int_v^\infty \exp(-\frac{x^2}{2}) \quad (2)$$

When all users are assumed to have unit power, their mean and variance are given by

$$\mu_\psi = \frac{N}{6}k, \quad \sigma_\psi^2 = \frac{k}{4}\left[\frac{23N^2}{360} + N\left(\frac{1}{20} + \frac{k-1}{36}\right) - \frac{1}{20} - \frac{k-1}{36}\right] \quad (3)$$

$$P_i = 1, \quad i = 0, 1, \ldots, k$$

where k is the number of interfering users and N is the spreading gain. We can successfully get the packet when all the bits of the packet are correct, otherwise we drop the packet. In simulation packet generation is assumed to be Poisson with λ. The probability of k packets enter the network in a one slot (slot length=1) is given by

$$P(k) = \frac{\lambda^k}{k!}\exp(-\lambda) \quad (4)$$

The lengths of the packets are constant so the process time is deterministic. Moreover we can model the system as M/D/∞. The throughput can be calculated as in [4] and the probability of packet success is

$$P_S(L) = \sum_{k=0}^{\infty}\sum_{k_1=0}^{\infty} P_S(k, L, k_1)(1 - P_e(k)) \quad (5)$$

Where the $P_S(k, L, k_1)$ is defined as the probability of number of interfering is k_1 on first bit and the packet is transmitted successfully from first bit to L-1 bit and number of interfering packets become k on the L-th bit. Finally the throughput is obtained as in [4]

$$Th = \lambda P_S(L) \quad (6)$$

OPNET Simulation of Random Access CDMA System

Here we describe a simulation model for the random access CDMA systems in OPNET. Our model consists of two parts, which are pipeline stages and the receiver-transmitter nodes. Our transmitter nodes generates packets with exponential inter arrival time. And the receiver gets the packets and collects the throughout statistics. We modified the pipeline stages in order to calculate BER rate and number of interfering users during a packet interval. A sample network model is shown in the figure 1. The transmitters are located randomly. All of them generate fixed length packets whose inter arrival times are exponential. During pipeline stages the receiver calculates the number of interfering user and BER. Then, it tests if the desired user's packet is in error based on its BER. Then receiver counts the error free packets and determines the throughput. Here we provide detailed description of the modifications in OPNET radio receiver module's pipeline for stages 7-11:

Pipeline Radio Stage 7 (Received Power): In this pipeline stage first we detect whether the packet is valid or not. In the default construction of this pipeline stage, "signal lock" attribute of the radio receiver object is used to prevent simultaneous correct reception of multiple packets but in our system we employ CDMA so we need multiple packet reception. In our pipeline stage we did not use signal lock so we can receive multiple packets.

Pipeline Radio Stage 9 (Number of Interfering Users): This pipeline stage is invoked when two or more packets are simultaneously present at the same radio receiver. When invoked this pipeline stage calculates the width of the collision (segment of the packet that overlaps with interfering packets) and the number of interfering users for this segment. We store the interfering power levels into a new variable in order to calculate the number of interfering users in the next pipeline stage.

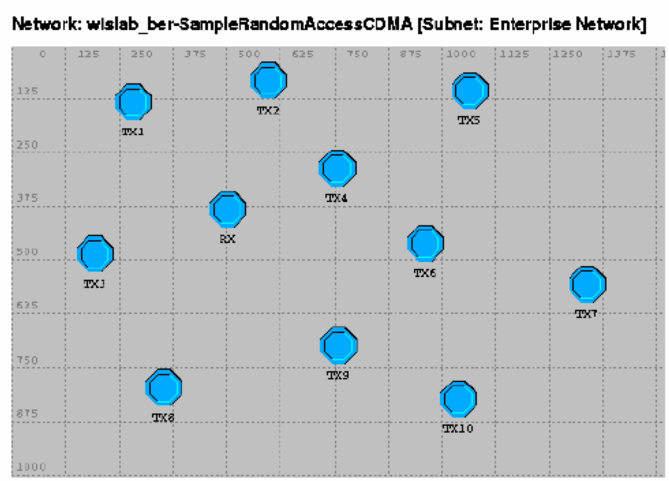

Figure 1: Transmitter and Receiver Modules in Random Access CDMA Simulation

Pipeline Radio Stage 10 (Signal to Noise Ratio): The simulation kernel automatically subtracts the average received power from the accumulated noise (interfering users' power) attribute as interfering packets complete transmission without entering the pipeline stage 9. We calculate the number of interfering user by comparing the interfering users' power. At every packet arrival or departure we compare the interfering power with the stored interfering power level at the previous stage. If the interfering power increases we can recognize that a new packet has arrived and increase the number of interfering user. On the other hand if the interfering power decreases we recognize that one of the packets has finished and we decrease the number of interfering user.

Pipeline Radio Stage 11 (Bit error rate): In this stage we calculate the BER for each segment of the packet overlapped by interfering users by using or pre-generated BER tables or SIGA as given in equation (1).

Simulation Results

In our simulations, we used both methods to find the bit error rates for different number of interfering users. For the first method we used MATLAB to generate the bit error rate tables and then, include these tables into our OPNET simulation. (BER vs. #of users). For the second method we directly calculated BERs by using SIGA formula for every segment of packet which may be subject to different multi-access interference.

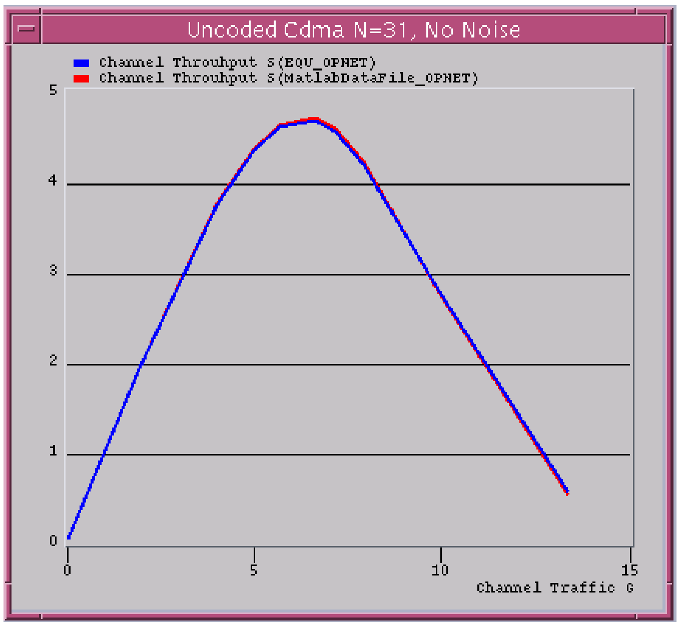

Figure 2: Simulation Results of Random Access CDMA with N=31 and without noise

Figure 2 shows the results obtained using both methods. There is a slight difference between two. We predict that this difference is due to numerical errors. In this simulation there are randomly located 20 transmitters and 1 receiver. All the transmitters' packet generation rate is Poisson. We see that the results are quite similar. Also these results agree with the theoretical results presented in [4]. In an unslotted ALOHA packet network the maximum throughput (1/2e) is reached at offered load 0.5. By using CDMA, the maximum throughput is increased to 4.7 at offered load 7.

In our simulation model we can directly define the background noise or thermal noise with respect to the desired user's power level (SNR), E_b / N_o. Figure 3 shows the result for N=31 with E_b / N_o =10dB. The effect of thermal noise degrades the performance. So the maximum throughput (2) is reached at offered load 4.

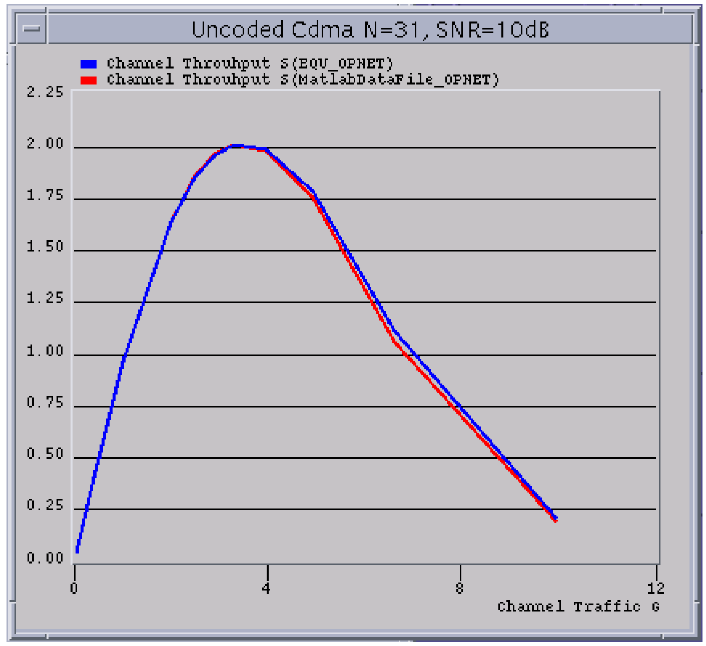

Figure 3: Simulation Results of Random Access CDMA with N=31 and with noise

Conclusions and Future Work

OPNET simulation methods for CDMA system for uncoded systems have been discussed. Instead of using many BER tables (modulation curves) for different number of users, we proposed to use SIGA in the pipeline stage of OPNET. Thus, only the necessary bit error rate is calculated for every segment of the packet according to number of interfering users and E_b / N_o. We choose the SIGA because of its simplicity and accuracy. In order to compare the results, throughput of unslotted random access CDMA system with fixed packet length has been analyzed by nonperfect captures. In analysis, we assumed that packet generation is Poisson and the packet length is fixed so the system modeled as M/D/∞. We saw that our simulation results are similar with the theoretical results.

As a future work, we are considering ways to simulation coded CDMA system using an OPNET. Our primary goal is to develop a generic CDMA module for OPNET, which can simulate coded and uncoded CDMA systems for different spreading gain, different number of users, channel conditions, and receivers. Here we only provided the description of an OPNET implementation of an uncoded and unslotted random access CDMA system.

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