MULTIPLE ACCESS FOR BROADBAND WIRELESS NETWORKS

Quality of Service for Multimedia CDMA

Nikos Dimitriou and Rahim Tafazolli, University of Surrey

Georgios Sfikas, Lucent Technologies

ABSTRACT

This article investigates the problem of call admission control in cellular networks using code-division multiple access, which is mainly viewed as an interference management problem. Our approach is to study the effects of various system parameters and user profile characteristics on the generation of multiple access interference (MAI). Different CAC schemes are presented, and different user and system characteristics that affect the CDMA system operation are listed. The focus of our work is on the emerging third-generation wireless systems and particularly on the Universal Mobile Telecommunications System. Analytical and simulation tools were constructed for quantifying these system characteristics. The results obtained by these two models show that the outage probability for a system is very sensitive to the user bit rate and quality of service requirements. The combination of different service types has a significant effect too; even a small number of high-bit-rate users can degrade the low-bit-rate users' performance and considerably increase their outage probability. The use of a CAC algorithm is expected to guarantee the service offered to accepted users.

INTRODUCTION

The objective of a wireless multimedia system is to provide to users radio access to services comparable to those currently offered by the fixed infrastructure, resulting in a seamless convergence of both fixed and mobile services. The need for global integration and interoperability of the existing second-generation systems — Global System for Mobile Communications (GSM), code-division multiple access (CDMA), satellite personal communication networks (PCNs) — as well as the need for further development of these systems to support multimedia services, has resulted in the standardization procedure named by the International Telecommunication Union (ITU) the International Mobile Communications 2000 (IMT-2000) initiative.

This procedure was done in parallel in different parts of the world and led to the development of proposals for terrestrial systems by the European Telecommunications Standards Institute (ETSI) in Europe, Telecommunications Industry Association (TIA) in the United States, Association of Radio Industries and Businesses (ARIB) in Japan, and Telecommunications Technology Association (TTA) in South Korea. Each standardization body submitted its own proposal to ITU by June 1998. Then in December 1998 five standards organizations, namely ARIB and Telecommunications Technology Committee (Japan), ETSI (Europe), Committee T1 (United States) and TTA (Korea), agreed to launch the 3rd Generation Partnership Project (3GPP) whose objective was the convergence of all the aforementioned proposals. In order to work toward this global harmonization, 3GPP has modified some parameters of the proposals (e.g. the chip rate has changed from 4.096 to 3.840 Mchips/s, a new downlink pilot structure has been adopted, the asynchronous/synchronous base station operation has been modified). Consequently some of the system details listed in this article may not be applicable by publication time.

In March 1999 the final decision was made to select a single access scheme, wideband CDMA (W-CDMA), with three optional modes: direct sequence (DS) frequency-division duplex (FDD) based on ETSI's and ARIB's FDD proposal; multicarrier (MC) FDD based on TIA's CDMA-2000 proposal, and DS time-division duplex (TDD) based on ETSI's proposal. The last obstacle for the development of IMT-2000 was resolved by the end of March 1999, when Ericsson and Qualcomm settled their differences over CDMA intellectual property rights, and Ericsson took over Qualcomm's CDMA research and development. The completion of 3GPP's work on the UMTS standard is expected later this year (Release '99), and the first commercial systems should be deployed by 2002 [1]. In addition to the standardization procedures, field trials of cellular CDMA have been conducted in Germany (T-Mobil), the United Kingdom (Vodafone, Orange) and other European countries. CDMA activities in Europe also include business and residential telephone services provided by a CDMA wireless local loop in Poland, Romania, Russia, and Ukraine [2].

In the rest of the article the following issues will be addressed. Initially, multimedia CDMA systems will be presented with an emphasis on the emerging UMTS and its limitations. Then, the capacity of a cellular multiservice UMTS system is studied, and the outage probability of such a system is presented. This introduces the next section, which describes the call admission

This work was carried out when Georgios Sfikas was at the University of Surrey.

control (CAC) schemes used to maintain the provided quality of service (QoS) in a UMTS multiservice system. The results for two CAC schemes are then presented and compared.

MULTIMEDIA CDMA SYSTEMS

CDMA is a multiple access scheme where the terminals transmit continuously and together on the same frequency band. Each user is assigned a distinct spreading code. All the codes have noise-like characteristics with very small cross-correlation. A receiver can separate the information received from a particular user by using the spreading code allocated to this user. This modulation/demodulation technique is called *spread spectrum*. A great deal of research is being done on the following terrestrial multimedia CDMA systems, which are the basis for the IMT-2000 standard:

- Wideband FDD CDMA-UMTS standard #1
  This system follows the concept of Interim Standard 95 (IS-95), developed by Qualcomm and adopted by TIA in 1993. To accommodate larger multiple rates, an extended bandwidth per carrier is used (5 MHz). The carrier frequency and bandwidth allocations are the following:
  — Uplink 1920–1980 MHz (60 MHz total, 12 carriers)
  — Downlink 2110–2170 MHz
  The spreading factor varies between 4–256, and the supported bit rates range between 8 kb/s–2 Mb/s (information source rate). The modulation is quadrature phase shift keying (QPSK) in both directions, and the coding schemes that can be used are the following:
  — Convolutional coding 1/3 or 1/2 rate, with constraint length 9 (256 states) and bit error rate (BER) = 10^{-3}.
  — Turbo coding at rate 1/3 and 1/2 (under investigation in 3GPP). They have been proposed to replace the concatenation of convolutional and Reed-Solomon codes, BER = 10^{-6} [3].
- Wideband TDD CDMA-UMTS standard #2
  In this system the 5 MHz bandwidth is used for both the uplink and downlink directions (unpaired band) during different time slots. The modulation is QPSK in both uplink and downlink. The forward error correction schemes are the same as in the FDD scheme. The characteristics (logical channels, frame format, etc.) of UMTS-TDD are similar to those of GSM. Generally, the intention of both FDD and TDD standards is to make them suitable to coexist with GSM and allow the users to seamlessly hand over between all three systems [3, 4].
- Overlapped carrier-multicarrier CDMA.
  Multicarrier CDMA is a form of CDMA where the spreading procedure is applied in the frequency domain rather than in the time domain, as in DS-CDMA. Each user's signal is transmitted via a large number of orthogonal carriers (orthogonal frequency-division multiplexing). These carriers have partially overlapped spectral positions, which result in improved spectral efficiency. In addition, since the bit periods are larger than the delay spread of the channel, the channel is deemed narrowband, and the distortion caused by intersymbol interference is minimal. Therefore, there is no need for the use of guard intervals between successive bits [5].

Multicarrier CDMA is a form of CDMA where the spreading procedure is applied in the frequency domain rather than in the time domain, as in DS-CDMA.

UMTS SERVICES

The multimedia services that have been investigated for UMTS by the ETSI consist of the following four different classes:

- Service class A (low-delay data) includes delay-constrained (20–50 ms) connection-oriented services with BER < 10^{-3} for the 8 kb/s service and BER < 10^{-6} for the higher-bit-rate services (144–384 kb/s).
- Service class B (low-delay data) describes the delay-constrained (50 ms), connection-oriented, variable bit rate (VBR) services (peak rates 64/144/384/2048 kb/s) with BER < 10^{-6}.
- Service class C (long constrained delay) includes connectionless services with similar bit rates as in class B. Maximum delay is 300 ms and BER < 10^{-6}.
- Service class D (unconstrained delay data) supports best effort connectionless services (peak rates 64/144/384/2048 kb/s). There are no delay limits, and BER < 10^{-8}.

The cellular configuration in UMTS supports various cell sizes, such as picocells (radius < 100 m), microcells (100 m < radius < 1km), and macrocells (radius > 1 km). This means that the network may consist of a number of different cell tiers, which will handle users with different traffic and mobility characteristics [3, 4].

CDMA CAPACITY ESTIMATION

Several studies investigate the capacity of cellular CDMA systems. In [6] the authors studied the single-service CDMA network with respect to the MAI caused by users in the same and adjacent cells. They calculated the maximum number of users per cell, assuming perfect power control, sectorization, and voice transmission with an activity factor; they also proposed an expression for the outage probability of a CDMA network. In [7] the Erlang capacity of a power-controlled CDMA system was investigated. The received E_b/I_0 was compared to measurements and was fitted by a lognormal random variable. The authors presented an expression to calculate the Erlang capacity as a function of the Erlangs per cell, intercell interference factor, and power control standard deviation. In [8] the authors investigated the reverse link performance of a slotted DS-CDMA system providing voice and data services. The key point of this article was the proposed model for MAI generated by users capable of supporting more than one service. The authors assumed that the received power by a user at the base station was lognormally distributed. They concluded that the power of the composite signal, consisting of all the user signals at the base station, was lognormally distributed. Moreover, they calculated the mean and the variance of the received power as a function of the number of users, the mean, and the variance of each service type.

MULTIMEDIA CAPACITY INVESTIGATION

The objective here is to determine the capacity of a CDMA cellular system with respect to the sys-

Service type	Bit rate (kb/s)	E_b/N_0 (dB)	Outage threshold (dB)	Power factor (dB)
Voice	8	5.6	–21.49	0
LCD 144	144	3.2	–11.33	10.15
UDD 144	60.8	2.7	–15.58	5.9

Table 1. *Tested UMTS services.*

tem outage probability. The outage probability is defined as the probability that the QoS provided to an existing connection will drop below a certain threshold. In other words, it is the probability that the received signal-to-interference ratio (SIR) will drop below a specific SIR or E_b/I_0 threshold (linked with the BER of the connection).

A mathematical model has been developed to determine the outage limits of a multiple-service CDMA system and the maximum aggregate capacity that can be achieved for different system parameters. We developed an extension to the mathematical model of [8] to study the outage behavior of a CDMA system with three different services. This was also investigated by performing simulations. In each cell a specific number of users per service was generated, and then the individual SIRs were measured. This step was repeated many times, and each time the same users were located in different positions in the cell (randomly selected) in order to estimate the outage probability for each service class. The propagation channel in these simulations consisted of inverse fourth power path loss and lognormal shadowing of zero mean and standard deviation equal to 8 dB. Power control errors were also assumed, which caused the received power at the base station to have a standard deviation of 1–2 dB. Table 1 presents the system parameters used in both analytical and simulation models.

The E_b/N_0 values were obtained by the link-level simulations conducted in [4]. The Power Factor for each service is the ratio of the received power of a service to the received power of the lowest bit rate service (in that case the voice service)

$$\text{Power factor} = \frac{E_{b,i} R_{b,i}}{E_{b,v} R_{b,v}},$$

where $E_{b,i}$, $R_{b,i}$ are the energy per bit and bit rate of each service, and $E_{b,v}$, $R_{b,v}$ are the energy per bit and bit rate of the voice service, respectively. The outage threshold is defined as the minimum SIR the connection can have to maintain the requested QoS (bit error rate). All services were considered to have 100 percent activity, and the UDD service was assumed to have a constant average bit rate of 60.8 kb/s. Initially, assuming perfect power control conditions (all users of the same service were received with the same power at the base station), the admissible combinations of users were determined. These combinations are presented in Fig. 1.

It is evident that there are specific limits on the maximum number of users per service that can coexist at the same time. The capacity per service changes linearly with respect to the capacity variation of the other two services. If imperfect power control is assumed, these results will change since, in that case, the received power of each user will vary lognormally with a specific standard deviation. Assuming that the power control error is the same for all services (all services have the same mobility characteristics and the same power control command rate), the outage probability will be the same for all services in the system. Figure 2 shows the outage probability vs. the number of voice/LCD-144/UDD-144 users in a UMTS system providing these three services.

It can be seen that the simulation and mathematical results are closely matched. The increase of the power control error from 1 to 2 dB causes the outage probability to increase substantially. This happens because the increased variability of the received signal raises the total MAI variance resulting in higher probability for the E_b/I_0 to be below the specified threshold. Moreover, since the users that join the network have a higher bit rate (and consequently generate a higher MAI), the outage probability increases more rapidly.

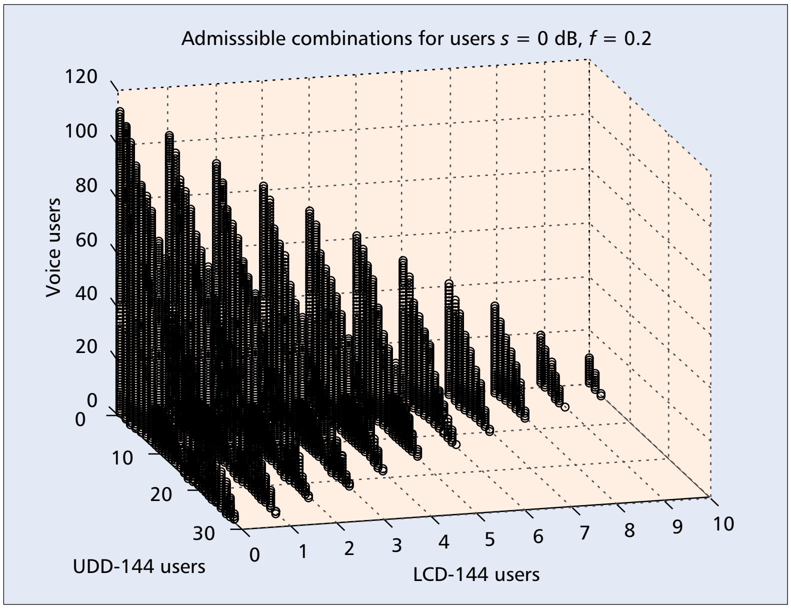

Figure 1. *Admissible combinations of users for perfect power control (*s *is the power control error standard deviation ,* f *is the intercell interference factor).*

CAC Techniques

Contrary to frequency-division multiple access (FDMA) and time-division multiple access (TDMA), in CDMA there is not an absolute number of maximum available channels that can be allocated to potential users. The limits in CDMA capacity are determined by the MAI that is generated at the base station by all the uplink signals transmitted by users, in either the same or other cells. The user position can affect in different ways the interference that is caused to neighboring base stations (intercell interference). For example, if the user is close to a base station, the user's transmitted power (in order to be properly received at the base station) is less than the power the same user should transmit from a position near the cell boundary (due to power control by the base station). This means that the interference experienced by the adjacent base station will