Study of CDMA Multimedia Services for Mobile Communications [1]

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September 1998

[1] This work is partially supported by Ericsson Research Canada

1 Introduction

The first generation wireless networks used analog cellular technology. These were built in the 1980's and provided voice communications. In the 1990's digital cellular technology was introduced to provide voice and text data capabilities.

In the year 1996, about 96% of the wireless services are voice applications, only 4% are data applications. Spurred by the growth of internet, the demand for wireless data service is increasing rapidly. It is predicted that by the year 2005 almost 70% of the wireless service would be data service, while percentage of voice service would decrease to 30%. Thus current wireless networks will not be able to meet the future requirement.

The third-generation wireless network will begin operating early in the next century. Using advanced digital technology, third-generation systems will offer high-speed data rates, enabling them to integrate voice communications with a wide range of multimedia applications.

The basic services include[1]:

① Voice/high-quality audio;

② High-speed data transmission including still photographs;

③ Video conferencing and multimedia.

Future wireless scenarios for wideband wireless multimedia services can include:[2]

① Interactive news delivery (voice, video, E-mail, graphics);

② Interactive E-mail (text, graphics, video clips);

③ Interactive audio (CD-quality voice, video, graphics);

④ Video conferencing, file transfer web browsing, dynamic Internet-based games;

⑤ Downloading large files from intranets;

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Thus there will be a new set of requirements on a wireless system, such as:

① Support for high speed data communication,

② Support for both packet- and circuit-switched services, such as Internet traffic and video conferencing,

③ Higher network capacity, better usage of the frequency spectrum. Each user will require more capacity compared to todays voice services,

④ Support for several connections. Users will, for instance, be able to browse the Internet in parallel to voice calls and/or video conferencing.

2 Wideband Multimedia Network Features

Requirements on the third generation cellular systems will range from basic speech services to high speed data services, both circuit switched and packet switched. Data speeds will range from 8 kbit/s up to 384 kbit/s initially, and later, up to 2 Mbit/s. Services will be symmetric as well as asymmetric and will support applications like Internet browsing and video conferencing. Flexibility in bandwidth provisioning to individual users and high efficiency in bandwidth utilization is essential.

Wideband technology promises to best meet the above mentioned requirements. Wideband CDMA technology features include:

Higher capacity and increased coverage

This is achieved by better usage of the frequency spectrum.

Variable bit rates

In the nearer term, it is envisaged that a data rate of 2 Mbit/s will be required to support the services. Clearly, the data rate which can be supported in different environments at mobile speeds will be different. These include wireless data rates of 144 kbps at mobile speeds, 384 kbps at pedestrian speeds, and 2 Mbps in a stationary environment. The purpose is to enable wireless multimedia applications, including services such as wireless video and high-speed Internet access.

Both packet and circuit switched services

Packet services offer the possibility to always be "on line" with the host application without occupying a dedicated channel. Packet services makes it possible for the user to pay only for the amount of data transmitted and not for the connection time. Wideband CDMA has an optimized packet mode. It supports both fast packet transmission for infrequent packets and on a dedicated channel large or more frequent packets. Packet data services are important for building cost-effective applications for remote LAN and wireless Internet access. Still, high speed circuit switched services are needed for real time applications like video conference.

Multiple simultaneous services in each mobile terminal

Support for Hierarchical Cell Structures (HCS)

Three different service environments could be distinguished:

① Outdoor to indoor and pedestrian, which corresponds to the micro cell environment.

② Indoor office, which corresponds to the pico cell environment.

③ Vehicular, which corresponds to the macro cell environment.

3 W-CDMA vs. TD/CDMA

The definition of third generation mobile radio systems is proceeding very fast in the different regions America, Europe and Japan. Two rival groups, one led by Ericsson and Nokia, proposing the wideband CDMA (W-CDMA) concept and the other led by Alcatel, Siemens, Nortel and others, who tabled the time division CDMA (TD-CDMA), had been locked in negotiations with the European Telecoms Standards Institute (ETSI), Europe's standards-making body, with each lobbying to be branded as the third generation standard. But after two rounds of voting– one in December and one in January– ETSI members failed to produce a conclusive result, the two contestants agreed to a compromise unprecedented in the industry.

Europe will now have a "family of standards" incorporating W-CDMA and TD-CDMA and which both groups will refine and specify over the next two years.

The European Commission is partly funding research activities in the ACTS (Advanced Communication Technologies and Services) framework related to third generation systems. Many research has been carried out under the FRAMES project. The ACTS FRAMES project [3] has the main goal to develop a radio interface proposal which fulfills the requirements on terrestrial third generation mobile radio systems. The definition of the original FRAMES Multiple Access scheme (FMA) has fulfilled these requirements and has taken into account GSM family with respect to harmonized radio parameters and the GSM core network. Based on these preconditions and the activities and decisions in different regions of the world the FMA scheme combines TDMA and CDMA techniques into one platform to cope with all possible Universal Mobile Telecommunication System (UMTS) scenarios and to address possible technical solutions from a global perspective:

- Mode 1 (FMA 1): wideband TDMA/CDMA with and without spreading feature
- Mode 2 (FMA 2): wideband CDMA

For W-CDMA radio interface, a set of centralized optimization algorithms are studied in [4]. A radio resource knapsack packing method is proposed which includes centralized and optimized packet scheduling and power control. The goal of the proposed algorithms is to maximize either the throughput or the value of the currently received packets of a cluster of cells. Simulation results show 55% - 75% bigger throughputs than reference schemes. Also the reduction of needed transmission power was large.

There were several key concerns with the two approaches that made a compromise inevitable. W-CDMA relies on the use of a 5 MHz carrier for both uplink and downlink communications. This means that operators would need n$\times$5 MHz of spectrum in both directions to run it. Since spectrum allocations vary from country to country and may not conform to this requirement, the chances of deploying W-CDMA worldwide uniformly would be remote. On the other hand, TD-CDMA can operate in almost any existing GSM band, or in spectrum set apart for UMTS and IMT-2000.

At the same time, the capabilities of W-CDMA are acknowledged as being more in line with UMTS and IMT-2000 requirements. These requirements include wireless data rates of 144 kbps at mobile speeds, 384 kbps at pedestrian speeds, and 2 Mbps in a stationary environment. The W-CDMA seems to be able to provide wide area cellular coverage, high mobility services, while the TD-CDMA seems to be the low mobility, local and in-building type of service.

Having taken account of this. ETSI is proposing that operators use W-CDMA in the paired UMTS bands of 2x60 MHz in a frequency-divided duplex (FDD) environment. In unpaired bands, or in instances where operators do not have similar allocations in uplink and downlink directions, TD-CDMA would have to be used, in a time-divided duplex (TDD).

Since spectrum and frequency sharing considerations are most critical in dense, urban environments, TD-CDMA could well be the preferred choice in the microcell environment, while W-CDMA would provide macrocell coverage. In the TD-CDMA case it could be used for asymmetric services, such as Internet access, because the nice thing about TDD is that you can adjust the ratio of how much spectrum is used for uplink and downlink. For example, you could run at 90 down and 10 up for very data-hungry services.

The need to service VBR traffic suggests employing a channelization technique with an underlying frame structure, where time is divided into frames, each of which is further subdivided into a number of slots. The slot size is chosen so that all possible user data rates are multiples of a basic rate. When a user with a variable bit rate has data to transmit, it sends a request for capacity to the scheduler. This request is normally in the form of the average number of channels or the maximum number of channels required per frame for the entire duration of the call. That is, the users make an explicit reservation for capacity for the first frame, and this capacity is implicitly reserved for all subsequent frames, until the call is terminated. The TD-CDMA approach, as illustrated in Figure 1, can cope with the bursty traffic better, when compared with W-CDMA.

Figure 2 illustrates the concept of number of active users. For an area with certain population, at a given time only a small portion of users will initiate call requests. Because of

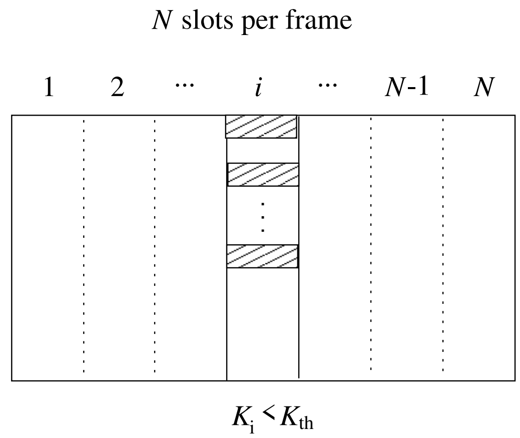

Figure 1: TD-CDMA approach

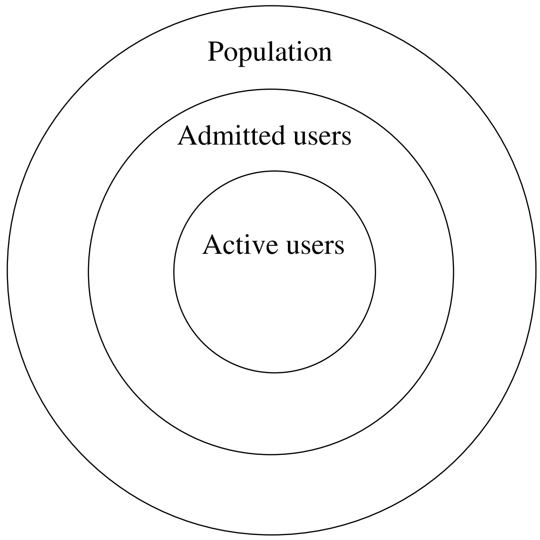

Figure 2: Illustration of active users

the call admission control, only a small portion of those users will be admitted and assigned a channel. Since multimedia traffic is bursty in nature, at any time only a certain number of those admitted users are transmitting. This number is called number of active users, as denoted by K.

In TD-CDMA, time is divided into frames, and each frame is further subdivided into N slots. Unlike pure TDMA, in each slot a number of users can transmit at the same time with different spreading codes. This way the constraint would be the BER requirement, reflected as maximum number of active users in that slot.

Each BER requirement corresponds to a maximum number of active users, denoted as K_{th}. When the number of active user K exceeds K_{th}, BER requirement could no longer be satisfied.

As we know, the data, voice and video services have vastly different QoS requirements, not only in terms of packet delay and loss, but more importantly in terms of received bit error rate (BER). As an example, since voice can sustain much more bit errors than data, the received SNR threshold for the voice packets can be much less than that for the data packets. The threshold of number of active users for voice will be much higher than that of data service.

4 Resource management – state of the art

We focus our attention on resource management of the third generation mobile systems. In third generation systems, cell sizes are expected to become smaller in order to accommodate high user density and multimedia traffic. Resource allocation schemes will have to be flexible to handle heterogeneous traffic and be dynamically adapted to the time-varying channel and user mobility.

A literature survey reveals that resource management gained much attention in the past. Zander [5] presented a quite general formulation of the radio resource management problem and reviewed some of the work previously published. An outlook over some of the key problems in resource management in third generation PCS is also given.

In [6] the notion of a connection group is introduced, where a mobile user simultaneously connects to multiple base stations using multiple links. The number of base stations and which base station to connect to are functions of the time-varying channel, mobility, current bandwidth need, and quality of service requirement. Once a call is admitted into the network, the resource management strategy will allow the mobile to dynamically configure its connections in such a way to minimize call dropping probability, maximize signal quality, and increase channel resource utilization efficiency. The performance of the protocol is analyzed in terms of call blocking and dropping probabilities and channel resource utilization. Results show that the proposed resource management scheme can support multimedia traffic with low call blocking and dropping probabilities and high channel utilization efficiency.

For bandwidth management, Morikawa [7] presented a wireless access framework for real-time VBR (variable bit rate) transport for next-generation multiservice personal communication networks. He introduced an adaptive VBR service suitable for the mobile networks, where the network provides minimum bandwidth guarantees, and assigns "leftover" bandwidth on a best-effort basis. An adaptive VBR service will help to ease the bandwidth management in the network through guaranteeing only minimum bandwidth. In order to fit this service, he designed a layer source coder that separates VBR signal components into a CBR (constant bit rate) portion and a VBR portion. Specific resource allocation procedures are outlined for video traffic coded with a two-layer codec and voice traffic generated on a talkspurt-by-talkspurt basis. The protocol is designed with the basic premise that there is a relatively large number of unused voice slots on average that can be used to carry "add-on" video packets. Numerical examples show that prioritized video transport under consideration can significantly improve picture quality, and allow better utilization of wireless resources through statistical multiplexing.

In [8] the issue of bandwidth management in a CDMA integrated wireless-access network with heterogeneous services is considered. A framework for adaptive connection admission in the up-link direction is proposed. It is based on estimation of the interference at the base station receivers. The estimation algorithm employs a linear Kalman filter which is driven by a measurement of the interference and by predicted traffic parameters of the admitted connections. several generic variants of the control architecture for the up-link direction is derived to assess the main characteristics of the framework and to determine the trade-offs between complexity and performance. They vary from a fixed strategy with fixed power control to an adaptive strategy with full information about network state and adaptive power control. A numerical study of the proposed framework shows that the estimated value of the average interference adapts well to the real value under nonstationary and nonuniform environment. This feature results in high network utilization for arbitrary traffic conditions.

In [9] the relationship between the grade of service and the number of active users in CDMA networks was discussed. Based on the results, a bandwidth management strategy is proposed for CDMA networks transporting multimedia services. In order to mitigate the congestion of data calls under fully loaded cell conditions, a throttling back rate reduction method was studied.

In the mean time, CITR also has several on-going projects on bandwidth management strageties [10, 11]. From these we can conclude that resource management for wideband multimedia networks is a very interesting research topic and needs further investigation.

5 Research Issues

5.1 Resource Allocation

We propose to investigate various dynamic resource allocation schemes for wideband multimedia networks.

Hand-off

There are several kinds of hand-offs in wideband CDMA system:

① Intra-frequency hand-off

- soft handoff

  When in active mode, the mobile station continuously searches for new base stations on the current carrier frequency. During the search, the mobile station monitors the received signal level broadcasted from neighboring base stations, compared them to a set of thresholds and reports them accordingly back to the base station. Based on this information, the network orders the mobile station to add or remove base station from which the same user information is sent, simultaneously demodulated and coherently combined.

- softer handoff

  Softer hand-off is the special case of a soft handoff between sectors/cells belongs to the same base station site. Conceptually, a softer handoff is initiated and executed in the same way as an ordinary soft handoff.

② Inter-frequency hand-off

In wideband CDMA the vast majority of hand-offs are within one carrier frequency, i.e., intra-frequency hand-off. Inter-frequency hand-off may typically occur when hand-off happens between cells using different carriers, or between cells of different layers, or between different systems.

Since consideration of soft handoff or complicated hand-off schemes will add complexity to our analysis, we should address this issue later.

Power control

Power control (PC) is an effective technique to reduce cochannel interference and increase capacity for cellular radio systems. Power control schemes can be divided into two group, the *Signal-Level-Based* schemes and the *Signal-to-Interference ratio (SIR) balanced* schemes.

The *Signal-to-Interference ratio* (SIR) *balanced* schemes yield a "fair" distribution of the interference in the sense that all users experience the same SIR level. The maximum achievable SIR value and the optimum power values could be found by computing the eigenvalues and eigenvectors of the current link gain matrix. It is proved that with probability one, there exists an optimum power vector. So this approach is optimum as long as the measurements of link gains are accurate and fast enough.

In the wideband CDMA proposal, closed loop power control is used in both uplink and downlink. The closed loop power control adjusts the mobile station transmit power in order to keep the received SIR at a given level. So the method of deriving the optimum transmit power can still be used. In order to make it implementable, we need to find out a way to limit the number of excessive hand-offs caused. These, however, will be left out on the first stage.

Hierarchical Cell Structures

To serve the users with different mobilities, the Hierarchical Cell Structures are employed in wideband CDMA system. For example, fast moving vehicles can be served by macro cells, while indoor portable by pico cells. We will only consider a homegenous system with simple cell structure on the first stage. However a new model will be needed in the future to cope with the Hierarchical Cell Structures.

5.2 Traffic Modeling

As the first step, we could start with the following assumptions:

- Bursty voice model with the date rate no higher than 16 kbps. Bursty video model with the date rate no higher than 384 kbps.
- Packet switching
- Outdoor vehicular environment, thus we can benefit from the work by Rappaport[12] while building the propagation model
- homogeneous system with non-Hierarchical Cell Structures
- The new call arrival processis a Poisson point process with state independent mean λ.
- The unencumbered session duration, T, is a random variable having a negative exponential probability density function. The mean of T is $\bar{T} = \mu^{-1}$.

- The hand-off call arrival process follows a Poisson point process. The hand-off call arrival rate is not directly calculated from the new call arrival rate in that cell.

- Like the unencumbered session duration T, the dwell time of a mobile in a cell, T_D, is a random variable having a negative exponential probability density function. The mean of T_D is $\bar{T_D} = \mu_D^{-1}$.

- Each user will be able to support both voice, data and slow-motion video services in wideband multimedia systems.

We will assume in our analysis that the load per station is fixed, and that the total system load is varied by increasing the number of active users. Since our goal is to investigate the effect of traffic mix on overall performance, four different scenarios will be considered:

- voice dominant

- video dominant

- equally dominant

- data dominant

The actually percentage of each type of traffic for each scenario, is detailed in Table 1 [13].

Table 1: Traffic scenarios

	Voice Dominant	Video Dominant	Equally Dominant	Data Dominant
Voice (%)	70	10	33.3	20
Video (%)	10	70	33.3	10
Data (%)	20	70	33.3	70

Traffic model for voice

It has been known for years that a single voice source is well represented by a two–state process: Human speech consists of an alternating sequence of active, or *talk spurt*, intervals, typically averaging 0.4–1.2 sec in length, followed by silence (inactive) intervals averaging 0.6–1.8 sec in length. Figure 3 portrays this phenomenon.

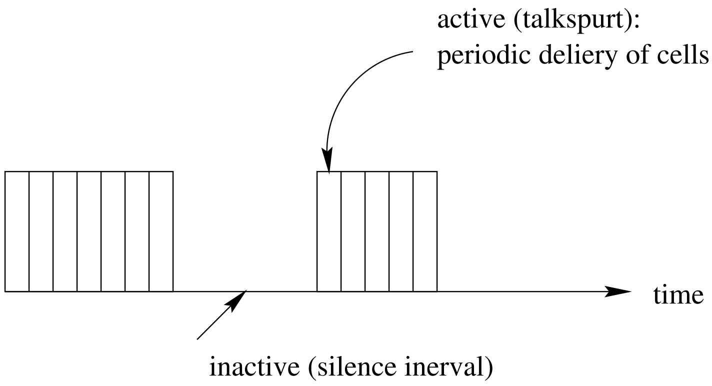

Figure 3: Traffic characteristics of voice

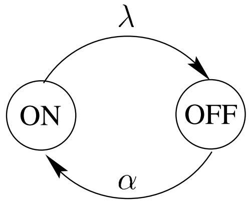

Figure 4: On-off model of voice traffic

To a reasonably good approximation, the states may be assumed to be exponentially distributed in length [14]. This gives rise to the two-state birth-death model of Figure 4. The parameter λ represents the rate of transition out of the silent state; α is defined to be the rate of transition out of talk spurt. The average talk spurt is thus $1/\alpha$ sec in length. The average silence interval is $1/\lambda$ sec in length.

The composite model for N such independent voice sources multiplexed together can then be found quite simply.

Traffic model for video

We will consider video services with date rate up to 384 kbps. For video service, it is no longer valid to use a single two–state on-off model to represent the characteristic of this kind of traffic.

The mini on-off source analysis provides a good approximation for video traffic. Specifically, M independent video sources are multiplexed together. Each source is characterized by an on/off model, as shown in Figure 5. So for each source, the date rate would be $384/M$ kbps. If $M \geq 10$, the approximation will be good enough to represent the real characteristics

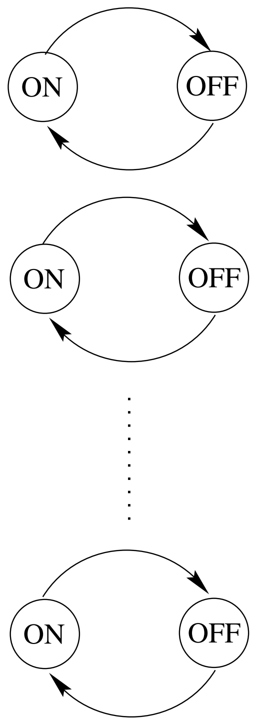

Figure 5: mini on-off source model of video traffic

of the video traffic [15].

For statistically multiplexed voice and slow-motion video, Markov-modulated Poisson process (MMPP) is also suitable to model the traffic [14]. For the sake of simplicity, we will use the mini on-off source model.

Traffic model for data

Based on recent results from ethernet LAN traffice studies, it has been argued that data traffic is dimodal and possesses self-similar characteristics. We will use a two-state PMPP source, with a fixed Hurst parameter to model the data traffic [13].

6 Conclusions

In this report, by reviewing the wideband multimedia network features in the third generation wireless network, we propose several possible study issues for the future CDMA multimedia services in mobile communications. We expect that by studying a good manner for channel assignment and using the multiuser detector to improve the quality of service, the wideband CDMA will proivde good multimedia services.

We will focus our attention on questions arised while allocating resource of the system:

- how to assign the channel

  The selection could be made in a random manner. We do not distinguish the difference services. Whenever there is a request for channel, we pick up a slot randomly and assign it to that user. Alternatively we can assign slots according to the service required, and let users requesting same service be assigned in the same slot. Or else we can try to find an optimum algorithm which will maximize the capacity of system, as long as the number of active users in each slot meets the requirement.

  For services of high bit rate, more bandwidth needs to be assigned. Different algorithms will have very different results, and it is our intention to investigate on this matter to find the optimum way.

- how to react when K exceeds K_{th} in a certain slot

  We can either block this slot from being assigned to new users, or let it go as it is. Some optimum algorithm may be found to re-arrange all the slots to achieve best performance.

- how to maintain different QoS for voice, video and data traffic

  To make full use of the limited system resource and meet the communication requirement, a resource allocation scheme is in need which can cope with the nature of various bit rates, different QoS requirement for multimedia services.

- Reducing soft blocking

  For CDMA system, blocking is not as clearly as defined. For any given frame, the number of users is not limited by the available bandwidth, but rather by the total amount of interference which can be tolerated. Therefore, there is no maximum number of channels. At any time, new users can transmit, as long as the receiver can handle these new users. Soft blocking occurs when new users are blocked because the interference is beyond a certain threshold, yielding unacceptable performance.

In multimedia services, the data, voice and video services have vastly different QoS requirements). One possible solution to reduce soft blocking probability is to use multi-stage multiuser detection techniques. For critical services like data service, we can use a multiuser detector with enough stages to ensure a high BER requirement. For voice and video services, however, we can reduce the number of stages and maintain satisfactory realtime communication [16].

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