Dynamic Resource Scheduling for Variable QoS Traffic in W-CDMA

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***Abstract*—W-CDMA is the strongest candidate as the air interface technology of the third generation mobile communication systems, which are expected to support multimedia services with QoS requirements. In this paper, we review the W-CDMA technology and consider the issues in multimedia support. We propose the *dynamic resource scheduling* mechanism for QoS provisioning in W-CDMA through *optimal power assignment* and *code hopping*. Our framework is able to carry variable QoS multimedia traffic, efficiently serving a wide range of classes with CBR, VBR, ABR and UBR characteristics. Dynamic resource scheduling improves capacity and throughput performance. Other advantages are power saving and faster convergence to the desired power level.**

I. Introduction

The explosive growth of Internet access in parallel with the technological advances in mobile communications have motivated mobile computing and multimedia applications in wireless mobile networks. The third generation wireless communication system, namely International Mobile Telephone (IMT-2000), is expected to support these applications with predictable service through the provisioning of their Quality of Service (QoS) requirements. QoS provisioning schemes are substantially dependent on the employed radio transmission technology, and Wideband CDMA (W-CDMA) is the strongest candidate as the air interface technology for IMT-2000 [1], [2].

Having reviewed the proposals for IMT-2000 [3] - [11], we have found Scheduled CDMA (S-CDMA), a hybrid CDMA/TDMA scheme proposed in [12], applicable to W-CDMA. We have adapted the S-CDMA structure into W-CDMA and we have enhanced the approach into a new framework. This paper presents our QoS provisioning mechanism, *dynamic resource scheduling*, for multimedia services in that framework via *optimal power control* and *code hopping*.

The rest of the paper is organized as follows: In section 2, we review the fundamental features of W-CDMA. In Section 3, we discuss the theory of optimal power allocation for multiple service rates in CDMA. In Section 4, we describe our framework and the dynamic resource scheduling approach, also elaborating on the advantages and performance enhancements of our scheme. Section 5 involves our concluding remarks and future work.

II. Wideband CDMA

Wideband CDMA (W-CDMA) represents the most appropriate air-interface technology to meet the future requirements of third-generation wireless communication services with data rates of up to 2 Mbps. Several proposals have been submitted to ITU-R [3]-[11]. There are certainly some differences between those proposals, such as types of spreading codes, error correcting codes and duplexing technology. In this paper, we consider the common system requirements and configuration, rather than analyzing one specific proposal. However, from time to time, we refer to NTT DoCoMo's W-CDMA system as an example [10], [11].

The system employs coherent detection and interference cancellation to enhance performance. Coherent detection and interference cancellation utilize pilot signals to estimate propagation path parameters, for both uplink and downlink channels. A hierarchical cell structure, adaptive smart antenna arrays, and inter-frequency hand-off are other features of the W-CDMA, that create a high-coverage radio environment as well as increasing capacity. Convolutional codes, turbo codes or concatenated codes (Reed-Solomon and convolutional codes) are the forward error control methods utilized [10], [11].

Wideband spreading provides good interference immunity, high-quality speech, and high speed data transmission [13]. A two-layered spreading structure, consisting of *spreading codes* and *scrambling codes*, is employed. Orthogonal Variable Spreading Factor (OVSF) codes are used as spreading codes and Gold codes are applied as scrambling codes in the NTT DoCoMo system [10], [11].

A. Channel Structure

W-CDMA defines logical channels according to the type of information transferred [3]-[11]. In this subsection, we

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provide an overview of the logical channels:

- Broadcast Control Channel (BCCH)
- Paging Channel (PCH)
- Forward Access Channel (FACH), a control channel from base station to mobile
- Random Access Channel (RACH), a control channel from mobile to station
- Dedicated Control Channel (DCH), a bidirectional channel for dedicated control information between mobile and base station
- Dedicated Traffic Channel (DTCH), a bidirectional channel that carries user information in circuit switched model
- User Packet Traffic Channel (UPCH), a bidirectional channel that transmits user data in packet switched model

Data and voice traffic are matched to DTCHs and channel selection is adaptive for packet traffic. Common physical channels (FACH, RACH) are used for low traffic (small and/or infrequent) packets, while dedicated physical channels (UPCH) are allocated for heavy traffic.

B. Frame Structure

Figure 1 shows the general hierarchical frame structure. Uplink and downlink channels are similar. TPC and RI fields carry transmitter power control and rate information respectively in dedicated channels (DCH, DTCH, UPCH). Control channels (BCCH, PCH, FACH, RACH) do not have TPC and RI bits. N takes values as 64 and 72 [3]-[11].

C. Power Control

Transmitter power control (TPC) is essential to a CDMA architecture not only to solve the near-far problem, but also to increase system capacity. W-CDMA uses an adaptive TPC scheme through open loop and closed loop methods. In open loop power control, the transmitter adjusts its power against the channel's path loss. The path loss is estimated at receiver of the transmitting station by pilot symbols. Closed loop TPC is based on Signal to Interference Ratio (SIR) measurements from every TPC cycle, which is every time slot. Measured and desired SIRs are compared and the result is sent to the transmitter by TPC bits. Consequently fast closed loop TPC tracks rapid multipath fading [10]. We propose to enhance this TPC scheme further by optimal power assignment. We review the concept of optimal power control in the next section.

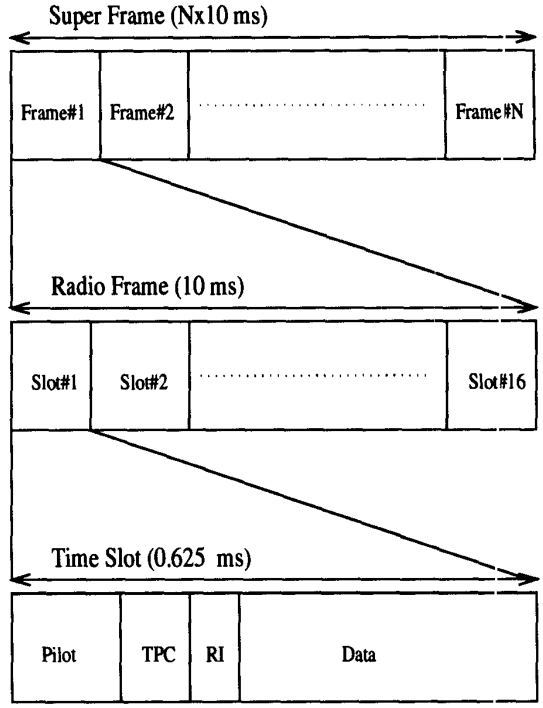

Fig. 1. Hierarchical frame structure

III. Optimal Power Control for Variable QoS

Several policies have been proposed for optimal power allocation for multiple rate in CDMA systems. In this paper, we make use of the approach that minimizes the total transmitted power under the given traffic and channel conditions, and QoS requirements [14]-[17]. We consider the uplink CDMA channel. The results can be easily applied to the downlink. Each session, i, specifies a minimum QoS (SIR), γ_i , and a maximum power limit, $\tilde{P}_i$.The path loss for each session is specified by h_i. The chip rate of all sessions is R_c, and the total system bandwidth is W. For background noise, additive white Gaussian noise with power spectral density, η_0, is assumed. The intercell interference is included in background noise. N_k is the number of sessions admitted into the current cell for radio frame k.

The problem is formulated as follows: Find the vector, $\overline{P} = [P_1 \ P_2 \ \cdots \ P_{N_k}]$ in order to minimize total power, $\sum_{i=1}^{N_k} P_i$, such that the QoS requirements and power constraints are satisfied through the following:

$$\frac{G_i.h_i.P_i}{\sum_{j\neq i} h_j.P_j + \eta_0.W} \geq \gamma_i$$

$$\text{with } P_i \leq \tilde{P}_i \text{ and } i,j = 1,\ 2,\ \cdots\ N_k \qquad (1)$$

G_i is the spreading factor defined as $G_i = \frac{W}{R_i}$, and R_i is the data rate of the radio frame. The optimal solution is obtained as:

$$P_i = \frac{g_i.\eta_0.W}{h_i.(1 - \sum_{j=1}^{N_k} g_j)} \quad (2)$$

where, g_i is called as the *power index*, expressed by:

$$g_i = \frac{\gamma_i}{\gamma_i + G_i}. \quad (3)$$

The solution is feasible as long as we can find a finite level for transmission power, below the maximum limit. This leads us to the following *Connection Admission Control (CAC)* test:

$$\sum_{j=1}^{N_k} g_j < 1 - \frac{\eta_0.W}{min_i(\frac{\hat{P}_i.h_i}{g_i})} \quad (4)$$

Inequality (4) checks for the availability of resources to admit an incoming call for the given interference conditions and required QoS. The call is accepted if the above inequality is satisfied [12], [16].

IV. Fast-Optimal-Dynamic Power Control for W-CDMA

Efficient support of multimedia traffic requires intelligent resource allocation, and power is a major resource in W-CDMA. The function of TPC in current W-CDMA architectures is to adjust the signal strength according to channel impairment and interference level; the concept of optimal power allocation, explained in the previous section, is not implemented. Moreover, only two levels of error QoS in terms of Bit Error Rate (BER), have been defined in the proposals: BER=10-3 and BER=10-6 [10]. Multimedia traffic has a wider range of BER requirements: $10^-11 \leq$ BER $\leq 10^-3$ [17]. In this paper, we propose an improved W-CDMA system with *dynamic resource scheduling* to addresses all these problems.

A. Dynamic Resource Scheduling

We propose a centralized architecture where the base station considers the back logged sessions for every radio frame. As in S-CDMA [12], the base station collects transmission requests from the mobiles (Figure 2). However, our scheduler is radio frame based, rather than being time slot based as in S-CDMA.

Before requesting a connection for a session, its traffic descriptors are matched to a W-CDMA channel by *rate matching*, [3]-[11], in the mobile station. Considering ATM as an example, the mobile would match the specifications such as Peak Cell Rate (PCR), Sustainable Cell

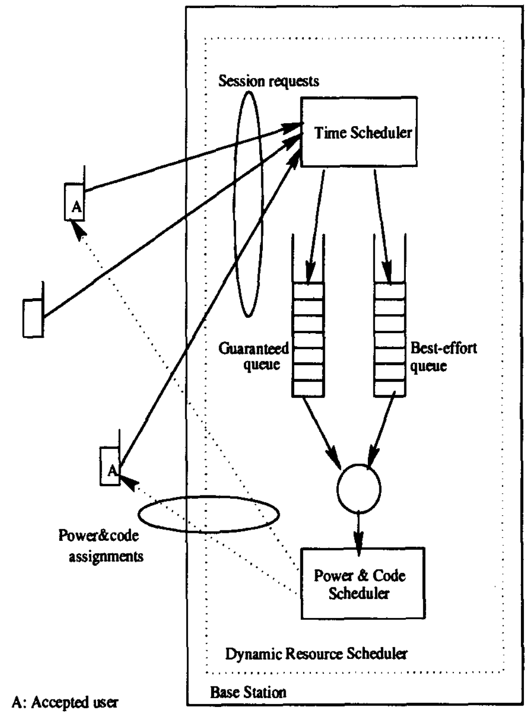

Fig. 2. Base station scheduler

Rate (SCR) for Variable Bit Rate (VBR) services, and the Minimum Cell Rate (MCR) for Available Bit Rate (ABR) services to the appropriate symbol rate. Unspecified Bit Rate (UBR) or best effort services are to be served in case of excess resources, i.e. channel and power. The end-to-end QoS requirements are matched to W-CDMA layer as receiver *SIR* and *delay*. The *W-CDMA connection parameters: average/minimum/maximum symbol rate, SIR, delay* are obtained.

Having specified the *W-CDMA connection parameters*, the mobile station sends a request to the base station over the control (RACH) channel. The base station collects requests from all mobiles and orders them in the *guaranteed queue* planning their transmission within their delay requirements. This refers to *time scheduling*. The best effort type requests are buffered in the *best-effort queue*, in a First Come First Serve fashion (Figure 2).

After buffering the current requests, the base station performs connection admission control. It first determines the spreading factor for each session request in the guaranteed queue and checks for availability of a OVSF code with that spreading factor. If an OVSF code is available, the power index is computed, as explained in Section 3. Then, the base station employs the CAC test in equation (2) for the requests at the head of the guaranteed queue, and it finds out the number of admitted sessions for the next radio frame. For VBR services, CAC considers the maximum symbol rate (rate for PCR) to provide guaranteed service. For CBR services, it uses average symbol rate, and for ABR it considers minimum symbol rate. If the guaranteed queue is empty, or the next request in guaranteed queue is not feasible, CAC serves the best effort queue. The base station allocates a spreading code, *admission code*, for each accepted session.

Having determined the admitted services, the base station performs *power scheduling*. The optimal power level for each session is calculated by equation (2). The control information, involving assigned code and power level is sent to the mobile station over the common control channel (FACH).

The mobile stations set their initial power to the optimally calculated levels. This assignment takes path loss and multiple access interference into account. However, the channel might be subject to fading or shadowing due to obstacles in the propagation path. Moreover, the interference and path loss levels might change due to mobility. Fast closed loop TPC of the W-CDMA system, as described in Section 2.3, takes care of these issues and maintains the desired QoS. In other words, optimal power assignment is fine tuned by closed loop TPC.

In dynamic resource scheduling, equation (2) is employed for each radio frame and power levels are assigned each time. Path loss and interference information is available as the base station keeps track of the ongoing sessions. The calculated optimal power level might be different for each radio frame as the number of interfering sessions and the path loss experienced might change over time. Power assignment remains optimal as long as the information rate and BER requirements are fixed throughout the session. The variable nature of VBR services can cause inefficiency. We propose *code hopping* to solve this problem.

B. Code Hopping

When a session is admitted into the system, it is assigned a spreading code according to its initial matched rate defined in CAC. Using the admission code for the entire course of the session is possible for CBR, ABR and UBR services. CBR service has a constant rate; ABR service is satisfied with the minimum rate guarantees; UBR performance is best effort. The BER requirement also remains unchanged for these services. However, for VBR sessions, like video or Internet, both information rate and required BER levels might change according to the frame being transmitted.

During the CAC test for VBR sessions, the maximum rate (PCR) is specified, and the admission code is assigned with respect to this maximum rate (PCR). Using the admission code with the low spreading factor throughout the whole session is inefficient as we can afford to use a higher spreading factor, G_i, when the information rate decreases. With a higher G_i, the power index, g_i decreases, and leads us to a *lower optimal power*. By lowering the transmit power of the session, the interference on other users is decreased.This yields an increase in capacity since CDMA systems are interference limited. Therefore, changing the spreading factor creates *statistical multiplexing gain* that lets new users into the system. Best effort type (UBR) sessions can be efficiently served through this capacity improvement.

In our framework, we propose assigning *a set of codes* for VBR sessions corresponding to the matched rates in the traffic specification. Rate Information (RI) field in the uplink control channel in W-CDMA can be used to notify the base station. The base station computes and assigns optimal powers according to the new spreading factor for each radio frame. The system performs *code hopping* for appropriate spreading gain according to the data rate, and dynamically changes the power level.

Another enhancement is utilizing the changes in SIR requirements. S_i for the next radio frame can be sent via the control channel. The streaming approach in joint source/channel coding for video transmission[18] can be exploited in conjunction with resource allocation.

V. Concluding Remarks and Future Work

In this paper, we have addressed the issues in multimedia traffic support in W-CDMA. W-CDMA is able to carry circuit switched and packet switched data at various rates. Open loop and closed loop power control schemes in W-CDMA combat the effects of path loss, fading and interference during transmission, but they are not optimal in resource sharing point of view. We propose dynamic resource scheduling for QoS provisioning in W-CDMA systems via optimal power assignment and code hopping. Power assignment is optimized with respect to service rates and BER requirements of the requests, as well as taking path loss into account. By code hopping, we propose to change the spreading factor during the course of a session in order to serve variable rate sessions more efficiently. Code hopping creates a statistical multiplexing gain, which causes an increase in instantaneous capacity to accommodate best effort services. Our framework is able to carry variable QoS traffic, efficiently serving different classes with CBR, VBR, ABR and UBR characteristics. Dynamic resource scheduling improves capacity and throughput performance by the statistical gain through code hopping. We also propose that dynamic resource scheduling is advantageous for power saving by faster convergence to the desired power level as well as lower outage probability.We are currently working on the application of our framework in the NTT DoCoMo W-CDMA system for our simulations. A relevant extension of this work would be incorporating time scheduling into our QoS provisioning approach.

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