Dynamic Code Assignment in Hybrid MC-CDMA/TDMA System[1]

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ABSTRACT
In the past decade, the market of wireless mobile communications has been growing at a rapid pace. A future wireless mobile network is desired to support integrated type of services including voice, data, video, and etc. A well-designed multiple access control (MAC) protocol is crucial in supplying satisfactory level of performance such as delay or throughput. A dynamic code assignment in hybrid Multi-Code CDMA/TDMA is proposed in this paper. The code assignment scheme is designed to follow the time-varying traffic characteristics of the mobile users. The base station (BS) assigns more codes to the mobiles during congestion but releases them when congestion subsides. Congestion is estimated from the queue lengths of the mobiles. A queueing model is established for performance analysis, in which the traffic source is taken to be a Markov-Modulated Poisson Process (MMPP). The analysis is started from a single connection and extended to multiple connections.

1. BACKGROUND

Demand for wireless mobile communications has been growing rapidly during the past decade. Technologywise, the trend has been to integrate different types of service including voice, data, and video into one network. Spread spectrum techniques accommodate different rates of transmission in the same frequency band. CDMA (Code Division Multiple Access) is the most popular spread spectrum technique and is currently employed in commercial applications.

Wide-band CDMA (WCDMA) has been chosen as a promising candidate for the radio-access technology of the third-generation (3G) mobile communication systems. WCDMA preserves the merits of narrow-band and is superior in several aspects [1]. But one drawback of the high data rate applications in CDMA is that if channel delay spread exceeds symbol duration, the conventional direct sequence spread spectrum (DS-SS) is subject to severe inter-symbol interference (ISI) and is practically not usable [2]. The MC-CDMA is a technique to reduce symbol rate. The performance of MC-CDMA in a fading channel is analyzed in [3].

A hybrid CDMA/TDMA is proposed in [4]. The hybrid CDMA/TDMA protocol shows edges over the pure TDMA and CDMA protocols. Compare with the pure TDMA, not only much lower data packet delay can be achieved but an increase in system capacity is possible by employing better inherent diversity techniques of CDMA. Compare with the pure CDMA, since resources can be used in both time and code domain in a more flexible manner, it becomes more suitable for multi-media applications. Furthermore, inter-collision between different types of service can be avoided by allocating different services in different slots [5]. In [6], a time-scheduled scheme (with hybrid CDMA/TDMA as a special case) is demonstrated to offer a better throughput but require still the same average power as the unscheduled transmission techniques. Due to the diverse characteristics of the integrated services, the hybrid CDMA/TDMA is preferred to the pure CDMA or TDMA protocol.

Fig. 1 illustrates the notion of integrating the CBR (constant bit rate), VBR (variable bit rate), and ABR (available bit rate) traffic in a hybrid CDMA/TDMA environment. In the figure, Nc, Nv, and Na denote the code ceiling that can be allowed during a CBR,VBR, and ABR slot, respectively. Notice that Na < Nv < Nc, mainly due to BER consideration.

2. SYSTEM DESCRIPTION AND PERFORMANCE ANALYSIS

The hybrid CDMA/TDMA configured in this paper can be used to accommodate multimedia type variable rate services. In a hybrid CDMA/TDMA, it is possible to assign one extra code beyond the code margin that the system can support because the CDMA system has the feature of graceful degeneration in capacity. In this paper, we propose a dynamic code assignment scheme according to the traffic condition of the MTs (mobile terminals). That means the BS allocates codes according to the state of the MTs. This state-dependent model is depicted in Fig. 2. The number of codes assigned is queue-length dependent. In Fig. 2, the number of deterministic servers equals the number of codes that the MT is assigned. This threshold type control is also reported in [7] and [8].

Through dynamic code assignment, those MTs with free codes shall release them to the other MTs. Enhancement in system utilization can thus be expected. Intuitively, jitter (delay variance) performance can be further enhanced. Flexible utilization of codes is a major attribute to jitter improvement.

In our hybrid MC-CDMA/TDMA (under a fixed frame length), if a MT has data to transmit, a connection

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has to be established at first. The MT sends a request with its QoS (Quality of Service) parameters to the BS using a contention-based protocol. These QoS parameters include the acceptable BER (bit error rate), packet delay, delay jitter, and so on. It is processed by the call admission control to determine if the connection can be set up. After a connection request is honored, the BS allocates slots and codes to the MT for the forthcoming TDMA frames and notifies the MT of the results via a feedback channel. The allocation remains in effect but subject to marginal adjustment as long as the connection is active. In the course of a communication, each MT periodically reports to the BS its queue status at the beginning of each frame via a proper signaling channel.

The report of queue status is arranged as follows. We have said in our description of Fig. 2, two thresholds L and H are set for the buffer of each MT. When the queue length drops below the threshold L, the MT tells the BS that its queue status is *L* (low). When the queue length sits between L and H, the MT reports its queue status *M* (medium) to the BS. When the queue length exceeds H, the MT informs the BS of its queue status *H* (high). The BS uses this information to determine if fewer or extra codes should be given to the MT in the next frame.

Regarding performance analysis each individual MT in the MC-CDMA is treated as a multi-server queueing system where each code corresponds to a server. The number of servers attached to the buffer in Fig. 2 is not fixed since the codes assigned to the MT is adjusted in a time-varying manner. The source in Fig. 2 is either an MMPP (Markov-modulated Poisson process) or IPP (interrupted Poisson process) depending on whether it is a VBR or CBR source. Every packet is assumed to be of fixed length and consumes a transmission time of exactly one slot. Each MT is equipped with a finite buffer so that packet loss is inevitable. Loss may also occur if a packet can not be timely transmitted. For the CBR or real time VBR (rt-VBR), packets delayed beyond their time constraints are discarded. For the loss- or error-sensitive ABR traffic, a larger MT buffer or lower code ceiling is taken to offer a smaller packet drop rate. Therefore, under our assignment scheme, each MT can be modeled as an MMPP / D / c / K queue where c is a state-dependent integer-valued variable

We have conducted thorough performance analysis of the code assignment scheme proposed in the above. Readers may contact either author for a comprehensive version of the paper for details. We shall focus on the discussion of numerical results and their implications.

The selection of the thresholds L and H undoubtedly has impact on the QoS performance of our MC-CDMA/TDMA scheme. Our approach is to first assign codes to satisfy the packet delay requirement and then to decide on L and H to fulfill the jitter requirement.

We plot in Figs. 3-5 using different values of L and H, and c_0 = 4. Trends appearing in these figures are intuitively reasonable. When the thresholds L and H decrease, the mean number of codes assigned on the contrary increase; leading to better performance, i.e., lower packet delay and smaller jitter.

The separation Δ_{th} between the thresholds L and H has effect on the delay variance. If Δ_{th} is large, the queue length becomes less concentrated so that the jitter gets larger. To control, we may use a small Δ_{th} to get a small jitter. What is indicated here is we first choose an appropriate number of codes to make the (mean) packet delay conformed and set a proper Δ_{th} to control the jitter. To prevent either waste or shortage of codes we choose to set L at the mean of the queue length. We summarize our selection of the thresholds as follows:

1. Apply the MMPP/D/c/K queue to find the packet delay statistics. Determine the minimal number of codes needed to satisfy the mean delay requirement of the MT. Let the minimum code number be c_0;
2. Find the mean queue length L_{mean} of MMPP/D/ c_0/K queue;
3. Set L $= \lceil L_{mean} \rceil$ where $\lceil x \rceil$ denotes the largest integer $\leq x$;
4. Let H = L $+\Delta_{th}$ where Δ_{th} is to be determined in step 5;
5. Use the selected thresholds L and H to find the mean delay jitter of the MMPP/ D/ state-dependent c / K queue under different consideration of the Δ_{th}. Use the largest Δ_{th} so that the delay jitter can be maintained.

3. SUPERVISORY CONTROL

In dynamic code assignment schemes, each MT has the flexibility to use extra codes. This has the potential of making the system more unstable if too many MTs are given extra codes simultaneously. Code collision intensifies the multiple access interference (MAI) and worsens the BER. In other words, code assignment for each MT can not be done indifferent to the situation of other MTs. This justifies the need of a supervisory control.

The role of a central supervisor is to handle code assignment for each MT using the state information collected from all the MTs. When there are too many MTs in the H state, the supervisor can not let each of such MTs have its desired c_0+1 codes. In this case, the first two of these MTs can be given c_0+1 codes. The rest are still c_0 codes.

To analyze the performance of this supervisory system, we need queue information from every MT. It involves a high-dimensional Markov chain and is not easy to treat. An approximate model is proposed in [9] to get around.

The supervisory control is to prevent the number of *H*-state MTs from exceeding two. This may be a bit too conservative since more than two *H*-state MTs may not necessarily lead to the code overassignment for the MTs may carry highly unbalanced traffic. To better utilize the resource, we further modify the control as follows. The supervisor again collects the state information from all the MTs. The condition of telling a collision is when the total number of codes assigned exceeds two from the code ceiling. If collision occurs, all the *H*-state MTs are only assigned c_0 codes. In this modified control, more than two MTs are permitted to enter the *H* state and employ c_0 +1 codes so the performance may be improved.

4. NUMERICAL RESULTS AND DISCUSSIONS

In the following numerical examples, the parameters are

$$Q=\begin{bmatrix}-0.003 & 0.003\\ 0.006 & -0.006\end{bmatrix}$$

$$q=(q_1,q_2)=\frac{1}{s_1+s_2}(s_2,s_1)=(0.6666\quad 0.3333),$$

$$\Lambda=\begin{bmatrix}0.2 & 0\\ 0 & 0.8\end{bmatrix},\ l_0=\begin{bmatrix}0.2\\ 0.8\end{bmatrix},\text{ and } l_{tot}=ql_0=0.6,$$

$$\left[\frac{C}{I}\right]_R \triangleq \frac{P(R)}{[N_0+I_0(R)]B_{ss}} \quad (1)$$

the packet arrival rate of the MMPP varies from 2 to 7 times of l_0,

buffer size K = 40,

the code assignments are 3, 4, and 5 codes for *L*, *M*, and *H* state, respectively.

Fig. 6 plots the queue length distribution of the controlled and uncontrolled schemes, respectively. The packet arrival rate is 5 l_0, i.e., (l_1, l_2) = 5*(0.2, 0.8) = (1.0, 4.0); the code assignment is 4, and the thresholds are L=5 and H=10. We clearly notice the difference between the dynamic code assignment scheme (controlled) and the fixed code assignment scheme (uncontrolled). In particular, the queue length in the controlled case becomes more concentrated and reduces the delay jitter. Furthermore, the queue length distribution above the threshold H drops sharply because of the additional code assigned in the *H* state.

We shall compare three cases in the following. One is the performance of the uncontrolled queue (case a), another is the performance of the controlled queue with L=5 and H=10 (case b), and the third is the performance of the controlled queue with the thresholds L and H set up using the criteria proposed in this paper (case c). In case c, the arrival rate varies from 2 to 7, and we set c_0=4, Δ_{th}=5, and L = the mean queue length, i.e., the corresponding thresholds L are {1, 2, 3, 11, 22, and 25}.

From Figs. 7 and 8, we observe that both the mean packet delay and the delay jitter of the controlled schemes are much better than the uncontrolled case. The mean queue length under dynamic code assignment scheme shortens significantly so that the drop probability is smaller and the throughput gets higher (see Fig. 9). From Fig. 10, we notice that the mean number of codes assigned is less than the fixed code assignment. In these figures, we also provide simulation results with the 90% confidence intervals to demonstrate that our approximation is considerably good.

From Figs. 7 to 10, we observe in general that dynamic code assignment outperforms fixed code assignment scheme. In addition, dynamic code assignment consumes less number of codes on the average. At high load (arrival rate > 5), the performance of case c is worse than case b. This is because the criterion is "to satisfy" the QoS requirement not "to minimize" the delay and jitter. Clearly, case c is not overall optimal. Smaller thresholds L and H give better performance but consume more codes. There is clearly a tradeoff between performance and resource requirement.

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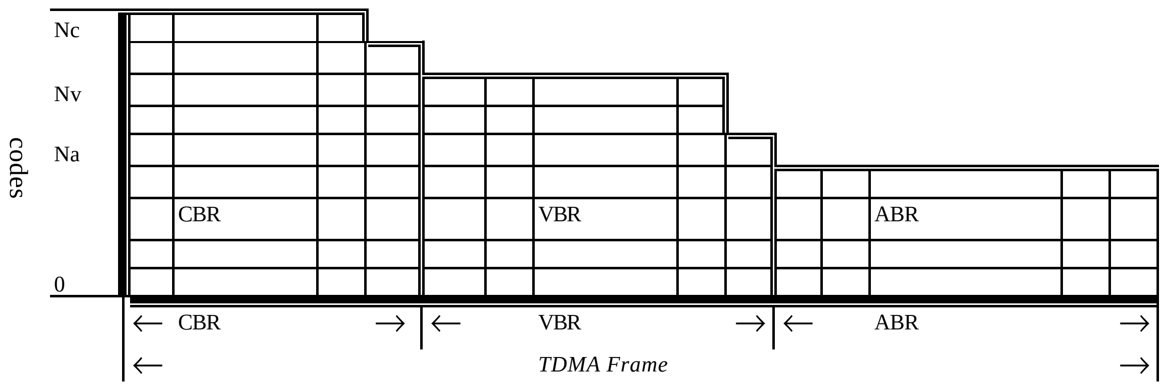

Fig. 1. Integration of the CBR, VBR, and ABR traffic in a hybrid CDMA/TDMA configuration.

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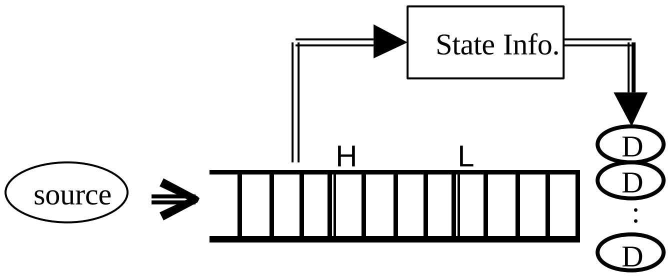

Fig. 2. The queueing model of a MT that uses a dynamic code assignment scheme.

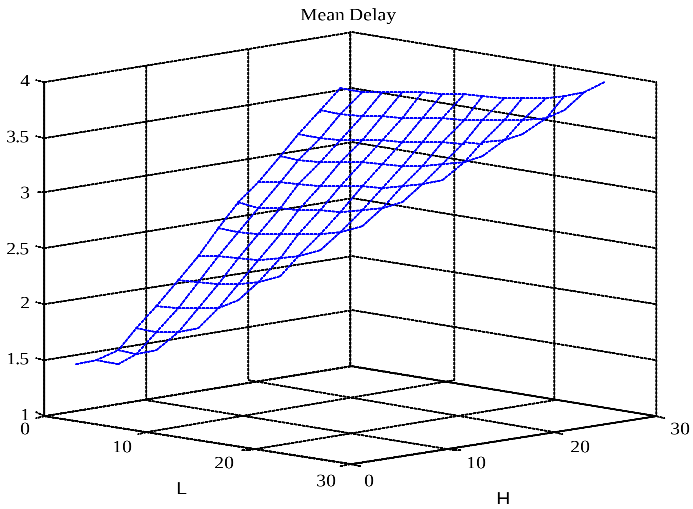

Fig. 3. Mean packet delay for different thresholds L and H

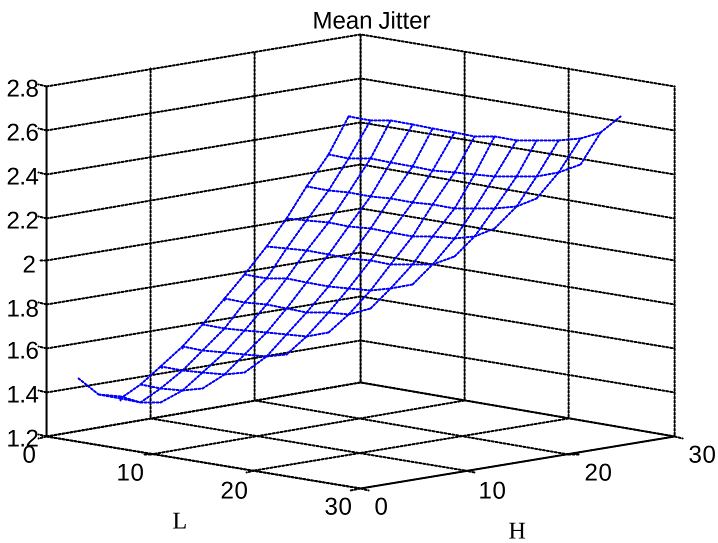

Fig. 4. Delay jitter for different thresholds L and H.

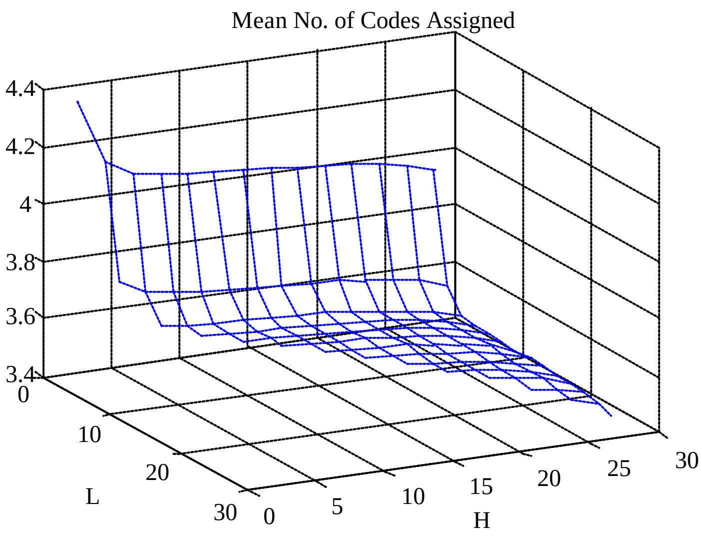

Fig. 5. Mean code assignment for different thresholds L and H.

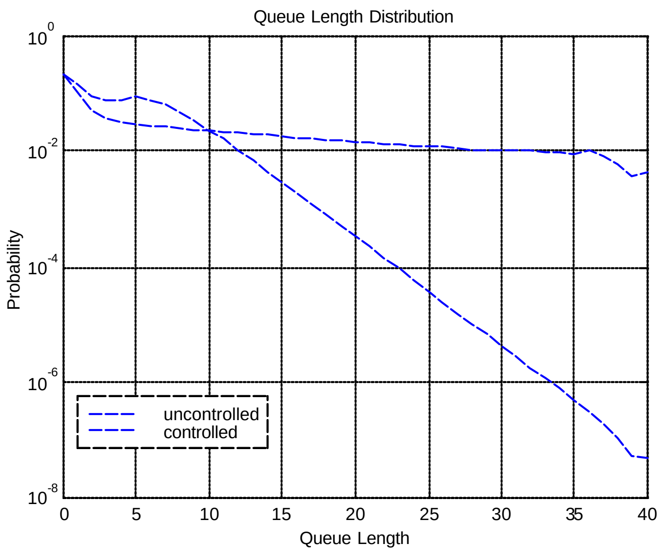

Fig. 6. The controlled and uncontrolled queue length distribution (log-scale).

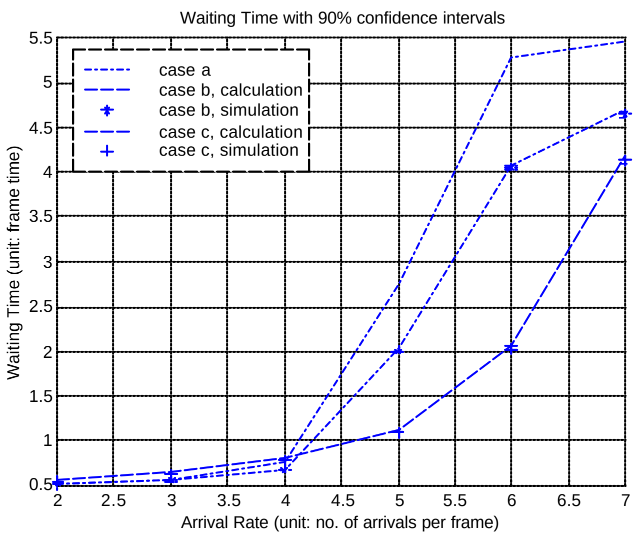

Fig. 7. Mean packet delay behavior when threshold L is set to equal the mean queue length.

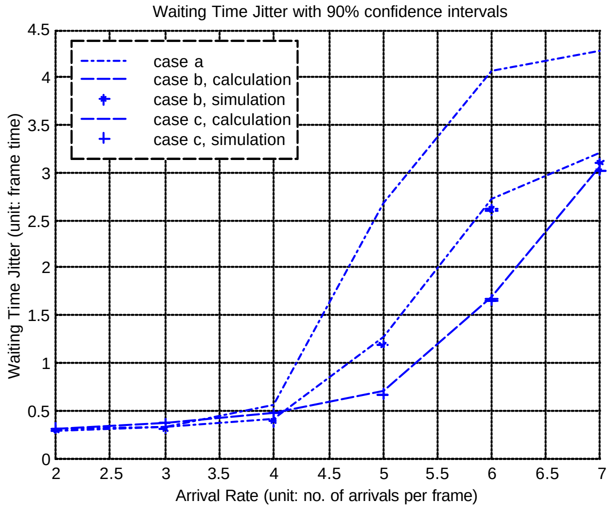

Fig. 8. Delay jitter behavior when threshold L is set to equal the mean queue length.

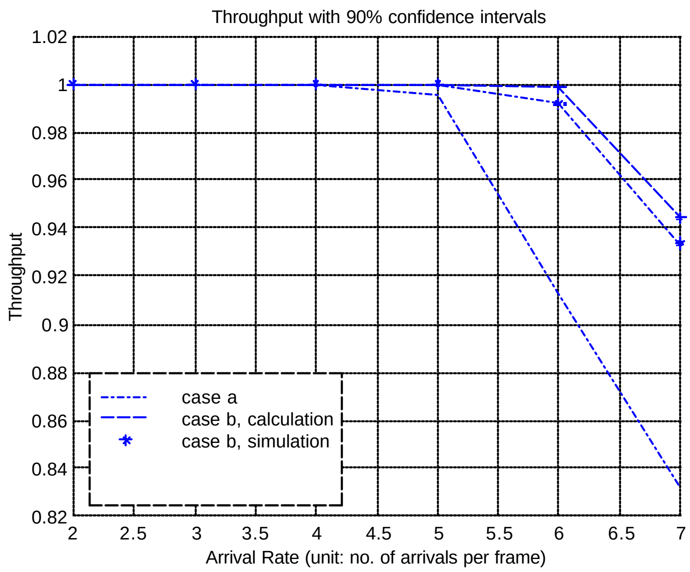

Fig. 9. Throughput behavior when threshold L is set to equal the mean queue length.

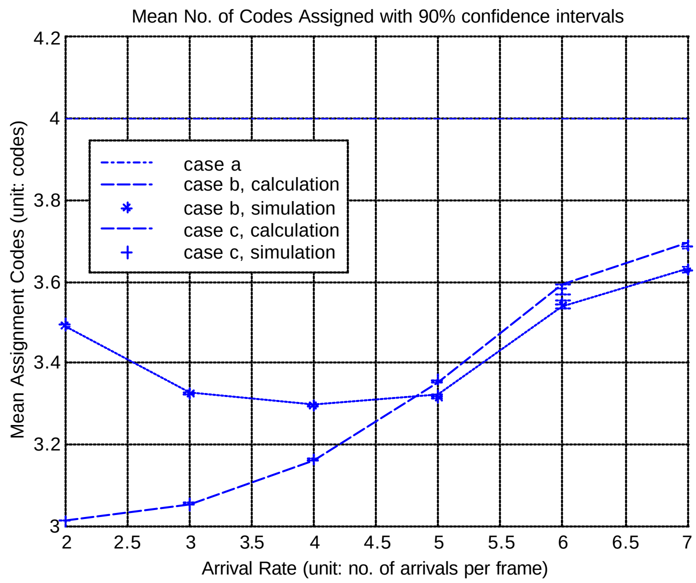

Fig. 10. Mean code assignment behavior when threshold L is set to equal the mean queue length