A FRAMEWORK FOR DISTRIBUTED ACCESS CONTROL IN MULTIMEDIA WIRELESS CDMA NETWORKS

P.R. Larijani and R.H. Hafez*

Department of Systems and Computer Engineering, Carleton University
1125, Colonel By Drive Ottawa K1S, 5B6
Canada

الخلاصـة :

تناقش هذه المقالة بعض الصعوبات والمشاكل التي تواجه الشبكات اللاسلكية المتعددة الوسائط ، كما تعرض للمشاكل المتعلقة بتخصيص الطاقة والتحكم في عدد المستخدمين مع المحافظة على جودة الخدمة .

تقترح المقالة نظاماً جديداً لقياس ومتابعة جودة الخدمة مبنياً على تعريف كمية محددة يمكن عن طريقها تقدير كمية استخدام الشبكة بكل مستخدم . وهذه الكمية يمكن استخدامها في قبول أو رفض طلبات المستخدمين لدخول الشبكة . إنَّ التحكم في دخول الشبكة بطريقة معتمدة يساعد المشرفين على الشبكة في تأكيد جودة الخدمة .

ABSTRACT

This paper addresses some challenges that face multimedia CDMA wireless networks. We highlight problems related to power assignment, admission control, and other radio resource management functions. At the core of our approach is a novel definition of an index for Quality of Service (QoS). The proposed QoS vector can easily be defined on a network wide basis and be negotiated during the call set up. Furthermore, we show that it is possible for a radio resource manager to assess the radio resource requirements of the new connection based on the proposed QoS vector and to participate effectively in the end to end call set up negotiation. The paper also introduces a simple but effective method for access control to CDMA networks and a linear power assignment scheme to complement the proposed admission control strategy.

*To whom correspondence should be addressed.

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1. INTRODUCTION

During the last few years, there has been growing interest in cellular systems based on Code Division Multiple Access (CDMA) and recently CDMA has become a dominant technology in personal communications at 1.9 GHz in North America. One of the biggest advantages of CDMA is its ability to deliver bandwidth-on-demand without large signaling overhead [1]. Sources of vastly different characteristics can share a common CDMA channel, and they can change their data transmission rates from frame to frame. This considerable advantage is intrinsic to CDMA multiplexing. It provides flexibility and high capacity. One consequence of such flexibility is the problem of determining the system soft capacity. The capacity of a CDMA system is not fixed. It varies with user locations and the propagation parameters. In a multimedia scenario, the situation becomes more complicated, since different users transmit data at different rates and require different Quality of Service (QoS). There are still many open questions that need to be answered regarding the wireless multimedia CDMA communications. The radio resource management is among these open issues.

The wireless access is characterized by low bandwidth, high error rates and time-varying channel properties. These impairments interfere with the network ability to guarantee specific QoS to different applications. The inability of wireless networks to provide absolute guarantees is often expressed in the form of "outage probability" which is an inherent part of wireless design and it is an implicit admission that full performance guarantee cannot be offered.

The QoS required by different applications must ultimately be mapped onto the wireless transport resources. These transport resources are:

(*a*) Link bandwidth;
(*b*) Link buffering;
(*c*) Power, or the strength of the transmitted signal;
(*d*) Signal processing for error control, *e.g.*, forward error correction, channel equalization.

The allocation of link bandwidth and buffering is controlled by a multiplexer, which schedules the transmission of packets from various applications on a shared link and queues packets whenever traffic arrivals find the server busy. The allocation of power is managed by a power control algorithm, which attempts to compensate for the time-varying impairments of the wireless media such as fading and noise. Careful allocation of power is particularly crucial for wireless cellular networks.

Lastly, the application of signal processing resources for error control is constrained partly by technology, such as limitations on hardware complexity and available portable battery power, and partly by the accompanying load that signal processing places on other transport resources (particularly bandwidth).

Power control is the adjustment of the transmit powers of user signals. It can substantially affect the capacity and perceived quality of service of cellular CDMA wireless systems. Traditional power control methods for a single type and rate traffic, which maintain the received energy per bit of all the users at a prescribed level, may not be suitable for multimedia networks.

In a multimedia scenario, both information rates and grade of service requirements for different classes of users vary considerably. In such systems, the power control scheme must mitigate the near–far problem but it should also balance the dissimilarities among various classes of users [2–4]. Dissimilarities of services in a multimedia scenario introduce new challenges in power control design and power allocation plan.

It is expected that the capacity limit will be reached in multimedia CDMA networks more often than in existing networks, which are designed primarily for voice traffic. This limit is due largely to the presence of high bit rate and high power traffic in the mixture of multi-media traffic. In order to protect the quality of the existing connections in a cell from degrading below acceptable levels, call admission control is necessary in multimedia CDMA networks.

This paper addresses some of the challenges of managing the radio resources in a CDMA wireless network and in particular focuses on multimedia networks that support real time traffic with stringent delay tolerance. Although most of discussions in this paper are directed at the reverse link of CDMA cells, they are applicable to the forward link as well. Some minor changes in notation are required.

Outline

Quality of service (QoS) is not a well defined concept in the wireless area. Typically, in a single media (single type of traffic) wireless connection, the traffic performance requirement is described in term of the channel signal-to-interference ratio, Bit Error Rate (BER), or an average Frame Error Rate (FER). Due to the heterogeneous nature of multimedia, this simple QoS model is no longer sufficient. Therefore, our first task is to clearly define the QoS for wireless multimedia.

In the next section of this paper, we suggest a QoS vector and present some argument in favor of its effectiveness in describing real time multimedia communications. This is followed by an articulation of the problem of power assignment and admission control in a multimedia CDMA wireless network. A general analytical model is presented to demonstrate the interdependency of power assignment and admission control processes. As part of these definitions, we argue that a general and optimum solution is hard to find and that some approximations are necessary. This argument is supported by the authors' previous work.

In Section 4, we introduce a decomposition approach that facilitates the task of finding a sub-optimum solution for the power and admission control problems. We outline the benefit and drawbacks of the decomposition method in details. An admission control and power assignment frame work is then introduced in Section 5. The proposed scheme is based on the decomposition technique.

The proposed power assignment and admission control schemes are elaborated on and different aspects of the proposals are described in the context of HOT-cell–COLD-cell scenario. A HOT-cell is a congested cell that is located in a cluster of less congested neighboring cells. This is an important practical case which leads to significant simplifications in developing an algorithm for admission control and power assignment.

Finally, a set of simulation results is presented in Section 6. The simulation confirmed the correctness of the analytical frame work that was developed in Section 5.

2. QUALITY OF SERVICE FOR MULTIMEDIA CONNECTION IN CDMA WIRELESS NETWORK

The QoS is an end-to-end service requirement. When two communicating entities negotiate specific requirements that ensure acceptable performance, and when the communication link involves a wireless access segment, the radio resource management must translate the negotiated QoS into physical resources. In wireless channels, the physical resources are closely associated with the concept of *S/I*. The question then becomes, how can we map the end-to-end QoS into this physical parameter?

In the case of multimedia, the problem is further complicated by the fact that one connection may consist of several traffic sub-flows. Each flow has its own QoS requirements. Due to the layered structure of existing communication networks, the physical layer cannot interpret the "control information" which is visible at the application layer. Consequently, different traffic sub-flows are not distinguishable in terms of their individual required performance. One solution to this problem is to use a single common QoS index that is acceptable to all sub-flows. In this section, we suggest a statistical common QoS index that fulfils this requirement.

We propose a QoS vector with three elements: (1) long term average FER; (2) short term peak FER; and (3) outage probability, which is defined as the percentage of time that the FER exceeds a predefined threshold. This proposed QoS vector can easily be defined on a network-wide basis and can be negotiated during call setup. Furthermore, this QoS vector can be easily mapped onto physical layer performance indices. There is one-to-one correspondence between frame error rate and the *S/I* of the physical channel. Mapping the link layer QoS to physical layer QoS will result in the following vector:

$$Q=[(S/I)^{+},(S/I)^{*},L]. \quad (1)$$

The first element, $(S/I)^{+}$, is the average signal to interference ratio. The second and the third elements $[(S/I)^{*}, L]$ are the system outage threshold level and outage probability. Outage probability is defined as the probability that the instantaneous S/I is below the threshold of $(S/I)^{*}$.

The proposed **Q** vector is easy to use to map the link layer QoS to the physical layer. It also facilitates the function of having a "radio resource management agent" at the base station.

Delay is another important factor that should be included in QoS vector in a general multimedia scenario. However, scope of this paper is limited to real time multimedia communication. In order to provide the stringent delay requirement of real time traffic, no ARQ or transmission scheduling is permitted and short transmission frame length at the transmitter is recommended. Apart from those considerations, radio resource management scheme has a minor role on providing the delay constraints in a real time environment.

Due to the above mentioned observation, we did not include delay index in our proposed QoS vector.

3. POWER ASSIGNMENT AND ADMISSION CONTROL PROBLEM FORMULATION

In this section, we define the "power control/call admission" problem and show their inter-dependency.

3.1. Power Assignment Problem

Each mobile in a multimedia CDMA network is tagged with a QoS vector. Consider a CDMA cellular network with M cells and $N_j; j = 1,2,\ldots,M$ users in each cell. The power assignment is an optimization problem where the objective is to minimize the total average power transmitted by all users (while satisfying the QoS requirements). The problem can be stated as follows.

"Find a set of energy per bit values $\{E_{bij}\}$ $i = 1,2,\ldots,N_j$ where $j = 1,2,\ldots,M$ that minimizes the total average transmit power of all users, subject to the constraints in Equation (3)".

The average power is given as:

$$P_{ave} = \sum_{j=1}^{M} \sum_{i=1}^{N_j} E_{bij} . h_{ij} . \bar{r}_{ij} , \qquad (2)$$

where h_{ij} is the path loss encountered by user i in the jth cell and r_{ij} is the average bit rate of the same user. The two constraints are:

$$\begin{aligned} &(1) \quad E[(S/I)_{ij}] \geq (S/I)_{ij}^{+} && (i = 1,2,\ldots,N_j) && (j = 1,2,\ldots,M) \\ &(2) \quad \text{Prob}[(S/I)_{ij} \leq (S/I)^{*}{}_{ij}] \leq L_{ij} && (i = 1,2,\ldots,N_j) && (j = 1,2,\ldots,M), \end{aligned} \qquad (3)$$

where $E[.]$ is mean value operator; $(S/I)_{ij}$ is the instantaneous signal to interference ratio encountered by user i in cell j; $(S/I)^{*}{}_{ij}$ is the minimum acceptable signal to interference ratio for user i for an outage probability threshold equal to L_{ij}; and $(S/I)^{+}{}_{ij}$ is the acceptable average signal to interference ratio for the same user.

It is assumed that each user is actively communicating with one base station only. We further assume that the base stations are selected in an optimum way. In other words, each mobile is communicating with the base station that has the least pathloss and least interference.

In order to solve the optimization problem, the two constraints in Equation (3) should be expressed in terms of optimization variables. In the rest of this section, expressions for average signal to interference ratio and outage probability are derived in terms of $\{E_{bij}\}$.

The average signal to interference ratio can be calculated using the assumption that it is equal to the ratio of average desired user power to the average interference power.

$$E[(S/I)_{ij}] = \frac{(E_{bij}.h_{ij}.\bar{r}_{ij})}{\left[(\bar{r}_{ij}/w)\left(E[\sigma_2{}^2]+\sigma_T{}^2+\sum_{\substack{m=1\\m\neq i}}^{N_j} E_{bmj}.h_{mj}.\bar{r}_{mj}\right)\right]}, \tag{4}$$

where W is the total available transmission bandwidth and $E[\sigma_j^2]$ is the average inter-cell interference received at the jth cell; σ_T^2 is the background noise, which is assumed to be constant across all cells. Therefore, the first constraint can be expressed in terms of $\{E_{bij}\}$ as:

$$\frac{(S/I)_{ij}{}^{+})}{(h_{ij}.w)\left[E[\sigma_j{}^2]+\sigma_T{}^2+\sum_{\substack{m=1\\m\neq i}}^{N_j} E_{bmj}.h_{mj}.\bar{r}_{mj}\right]} \leq E_{bij} \, . \tag{5}$$

We can also write $E[\sigma_j^2]$ in terms of $\{E_{bij}\}$ as follows:

$$E[\sigma_j{}^2] = \sum_{\substack{k=1\\k\neq j}}^{M}\sum_{i=1}^{N_k} E_{bik}.\bar{r}_{ik}.h_{ik}{}^{(j)}; \tag{6}$$

$h_{ik}^{(j)}$ is the path gain/loss for user i in cell k with respect to the base station in cell j.

3.2. Admission Control Problem

If the set of power assignment inequalities in Equation (3) has a feasible solution then all the mobiles from each class of traffic will attain their required QoS. Admission control agent should ensure that the arrival of a new mobile does not violate the feasibility of power assignment set of inequalities.

A general and optimum solution for the power assignment problem and admission control problem is found and is reported in [2, 6]. Due to the nonlinear structure of the power assignment problem, the optimum solution is involved and might have excessive implementation complexity.

In this paper, a decomposition approach is suggested for solving the power assignment problem. By solving the linear and non-linear portion of power assignment inequalities separately and combining the results one can find a sub-optimum solution which is simpler than the optimum solution. This concept is explained in more details in the following section.

4. LINEAR ADMISSION AND POWER CONTROL

The power assignment agent should set the target power levels for mobiles in a way that QoS vector for mobiles are satisfied. One can expect that a real time power assignment agent can be overwhelmed with the complexity of calculation that is involved in finding the optimum power levels directly from the set of equations in (3). More information on the complexity of optimum power assignment can be found in [2].

In this paper we seek a sub-optimum approach in finding the required power levels at the base station. The sub-optimum results are not optimum in utilizing the cell capacity but are considerably simpler in term of implementation. Furthermore, we consider only a HOT cell scenario where other cell interference power is negligible compare to intra cell interference power.This will allow one to ignore the correlation that exists among the power levels in different cells in CDMA wireless network and consequently a tractable solution can be found.

Our proposed idea for a decomposition method is based on a linear power assignment algorithm that works according to the average *S/I* requirements or the linear set of inequalities in the power assignment problem and a linear admission control that ensures the linear solution resulted from power assignment satisfies the nonlinear constraints as well.

In a multimedia scenario, traffic bit rates can change significantly. Allowing a power assignment agent to react to the sudden changes of bit rate, can result in to instability in the CDMA cells. One advantage of linear power assignment lies in the fact that the power control is based on the average values and is not affected significantly by the sudden traffic bit rate fluctuation.

A closed form solution for power assignment problem with linear constraints under a HOT cell scenario can be found as [1, 2]:

$$E_{bi} = \Gamma^*_{opt}.(S/I)_i^+.E[10^{\xi/10}], \tag{7}$$

where E_{bi}, Γ^*_{opt} are the energy per bit for the mobile i, the optimum power coefficient respectively. $E[10^{\xi/10}]$ is the average shadowing parameter that takes into account the effect of imperfect power control. (Γ^*_{opt}) can be calculated as [2, 7]:

$$\Gamma^*_{opt} = \frac{[(\sigma_T{}^2/w)]}{\left[1-\left(\left(\sum_{i=1}^{N_i}(S/I)_i^+.\bar{r}_i\right)/w\right)\right]}; \tag{8}$$

$\bar{r}_i$ is the average bit rate of the ith mobile. Due to the concave nature of the linear constraints, the minimum power solution can be found by solving the following system of linear equations:

$$E[(S/I)_i] = (S/I)_i^+ \qquad (i = 1,2,...,N). \tag{9}$$

The closed form expression in Equation (7) can be found consequently.

Based on Equation (7), base stations can determine the required power level of each mobile at the base station. Utilizing a similar signaling command as the existing power control scheme in IS-95, standard mobiles transmit power levels can be adjusted.

Because the linear power assignment algorithm provides only average *S/I* element of QoS vector for each mobile, there should be another mechanism that statistically guarantees the outage requirements of QoS vector. Based on our decomposition approach this task is assigned to the admission control agent.

A sufficient condition that is derived from Equation (7), to satisfy the non-linear conditions in Equation (3) under the HOT cell scenario can be found as:

$$\text{prob}(I \geq (w\Gamma^*_{opt}/\beta_{\max}) - \sigma^2{}_T) \leq L, \tag{10}$$

$$\beta_{\max} = \max\{(S/I)^*{}_i/(S/I)^+{}_i\} \qquad i = 1,2,\ldots,N$$

$$L = \min\{L_i\}; \qquad i = 1,2,\ldots,N; \tag{11}$$

I is the total interference at the base station and can be calculated as:

$$I = \sum_{i=1}^{N} E_{bi}.10^{\xi/10}.r_i\ , \tag{12}$$

where E_{bi} is the received energy per bit for the ith mobile and r_i is the ith mobile's instantaneous bit rate. Assuming that the linear power assignment algorithm is implemented in the cell, then:

$$E_{bi} = \Gamma^*_{opt}.(S/I)^+{}_i\,.$$

The condition in Equation (10) is a sufficient condition, because it is the worst case outage constraint for mobiles in the cell. Setting the outage probability equal to its minimum value while the overload probability is calculated for the maximum value guarantees that all the outage constraints in the cell are more relaxed than the condition in Equation (10).

The admission control agent should ensure that the condition in Equation (10) remains valid at all time, and if the admission of a mobile results in the violation of this condition, that mobile should be blocked upon its access request.

Based on the above mentioned argument, the admission control agent should be able to estimate or predict the probability expression in Equation (10) with a reasonable accuracy.

5. ADMISSION CONTROL ALGORITHM

Our proposed admission control is based on linear prediction of the Lth percentile of interference power distribution where L is the minimum outage probability index in the QoS vector. If the predicted outage value at the instance of a new call request is less than the target outage value, then the new call will be admitted.

Denoted by $f_k(t)$, the empirical distribution of interference power given the active user vector K and by $MRC(L)$ (Minimum Required Capacity), the Lth percentile of $f_k(t)$. $MRC(L)$ can be calculated as:

$$MRC = \min\{c\} \qquad \text{such that} \qquad \int_c^{\infty} f_k(t) \le L\,. \tag{13}$$

We propose to use a linear estimator to predict the $MRC(L)$ and to carry on the admission control process based on the elements of the predictor vector. The linear estimator has one element per each class of traffic in the cell and can be found by solving the following minimization equation:

$$\min\{E_k[(MRC(L)-(K.e))^2]\}\,. \tag{14}$$

A class of traffic is defined as the set of mobiles with a similar QoS vector and similar traffic pattern. $e = [e_1\ e_2\ \dots\ e_N]$ is the estimator vector when there are N classes of traffic present in the network. E_k is the expectation operator with respect to the active user vector.

A gradient descent algorithm is used to adjust the estimator adaptively. In the proposed adaptive linear estimator technique, the value of $MRC(L)$ is measured by periodical measurement of total interference power at the base station every T seconds where T is a design parameter [2, 5]. The difference between the measured $MRC(L)$ and the estimated value derived from the estimator is used as the error function in a gradient descent algorithm.

The linear predictor vector is updated based on the following equation:

$$e_{t_n+1} = e_{t_n} + \alpha.\text{error}.K_{t_n}\,, \tag{15}$$

where, $\text{error} = MRC(L) - (K_{t_n}.e_{t_n})$,

$e_{t_n} = [e_1\, e_2 \dots e_N]$ is the estimator vector at time t_n, and α is the adaptation coefficient.

A closed form expression for the adaptive estimator vector that describes the relationship between the estimator indices and the traffic parameters can be found in [2].

6. SIMULATION RESULTS

The system that is simulated is an asynchronous cellular CDMA network with 16 equal size square cells. The total bandwidth shared by all the users using DS-CDMA signaling is assumed to be equal to 10 MHZ. Cell size is considered to be 1.5×1.5 km.

Separate frequency bands are used for the reverse link and the forward link, in order that the mobiles only experience interference from the base stations in adjacent cells and the base stations only experience interference from the mobiles.

Base stations are located at the center of the cell. An omni directional antenna is used at the receiver. Each mobile is power controlled only by the base station of its home cell.

Three classes of real-time multimedia traffic are considered:

(*a*) variable rate low bit rate video;

(*b*) fixed bit rate video;

(*c*) variable bit rate voice.

ON–OFF Markovian model is used to model the statistical variation of the bit rate for class (*a*) and (*c*) traffic. The first class of traffic is assumed to have an activity ratio of 25% with peak bit rate of 128 kb/s, the second class of traffic is modeled as fixed bit rate source with 64 kb/s transmission rate. The third class of traffic is assumed to have an activity ratio of 40% with 32 kb/s peak bit rate. Markovian model for traffic has been adopted due to its simplicity. More details and some discussion on the impact of traffic models on radio resource management can be found in [2].

Call arrival process in a cell is modeled as independent Poisson process with a mean arrival rate of λ_k $(k = 1,2,3)$ for each class of traffic.

It is assumed that users' terminals are equipped with output buffers that accumulate the generated data during a time window of "*T*", which is a design parameter and is set equal to 20 ms in the set of simulation result presented in this paper. The buffered data is transmitted at the fixed rate of 144 Kb/s, which results in a processing gain of 69.4.

The outage probability for each class of traffic when linear power assignment is implemented as underlying power assignment method is studied, and the results are shown in Figure 1. In this experiment, the signal to interference ratio for each user during its connection life time is monitored, and empirical outage probability is estimated. The outage probability is averaged over the users belonging to the same class of traffic. Call duration time is set equal to the simulation time at each trial (no call departure) and is long enough to provide a reliable estimate for the outage probabilities. It is important to note that outage probabilities increase without any bound as the number of mobiles in the network increases. This points to the need for the use of admission control process in the cell.

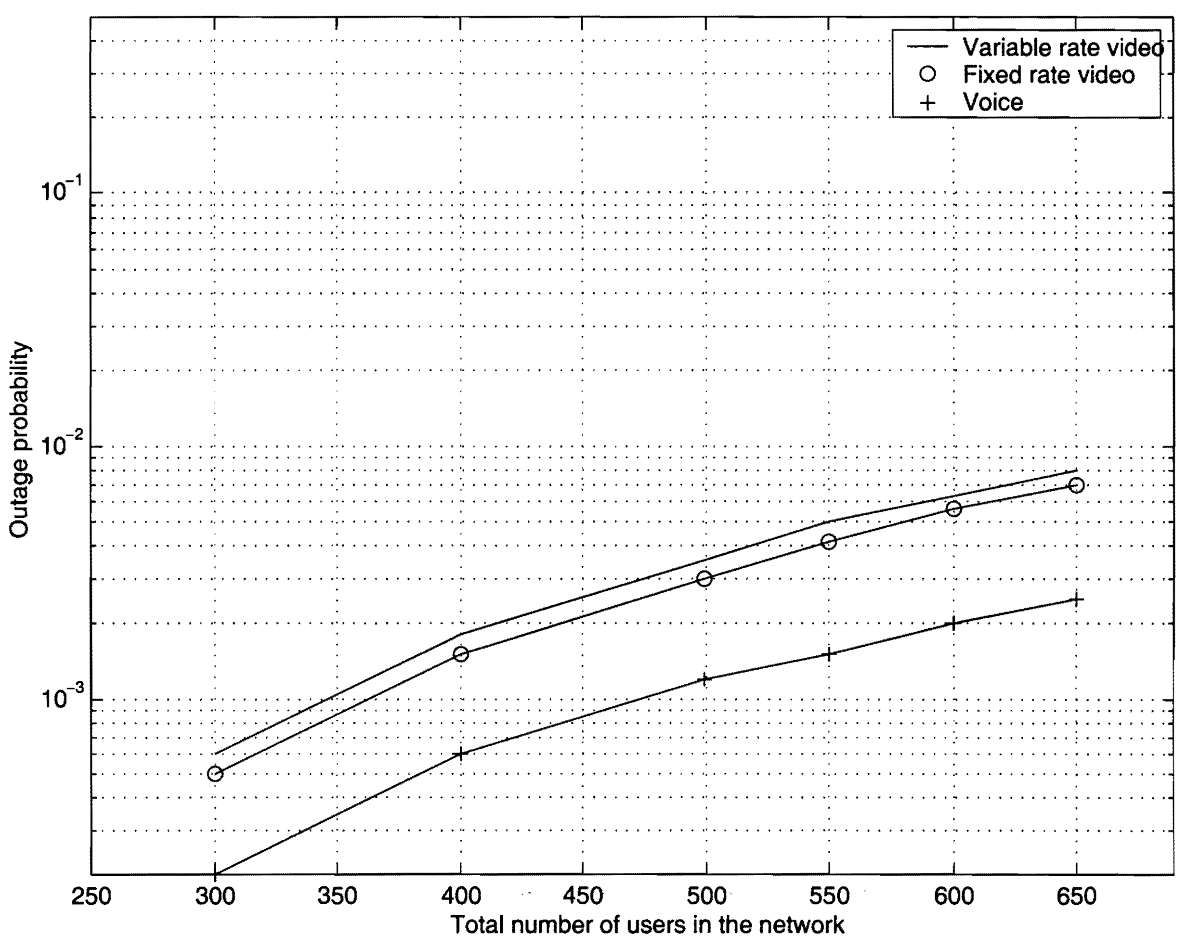

Figure 1. Outage probability for different classes of traffic under linear power assignment. Average required signal to interference ratios: Variable rate video: 8.5 dB; Fixed rate video: 7 dB; Voice: 5 dB.

We studied the convergence and tracking performance of the adaptive estimator technique. The simulation program was run for three different adaptation factors. Heavy traffic intensity is considered (90 Erlang), which is the worst case scenario for access control due to the large number of arrivals between two successive interference measurements. Call duration is modeled as an exponentially distributed random variable. Samples are collected over a five-second window with a sampling resolution of 0.5 ms. The results are presented in Figure 2. In these curves, the error (Y-axis) represents the relative difference between the estimated Lth percentile derived from adaptive estimator algorithm and the measured Lth percentile using histogram. As one can expect, there is a trade off between fast convergence and good tracking performance. It is due to the use of gradient descent algorithm.

The effect of the outage threshold level, as well as the outage probability threshold, on the blocking probability is studied. Simulation results are presented in Figures 3 and 4.

The adaptation factor was set at 0.05 during this simulation. Average required S/I is set 1.5 dB higher than the required threshold level (Outage threshold level) for all three classes of traffic. The blocking probability for a wide range of system parameters are found to be reasonably low. This is an indication of efficiency of admission control scheme in regulating the multimedia mobile access to the cell.

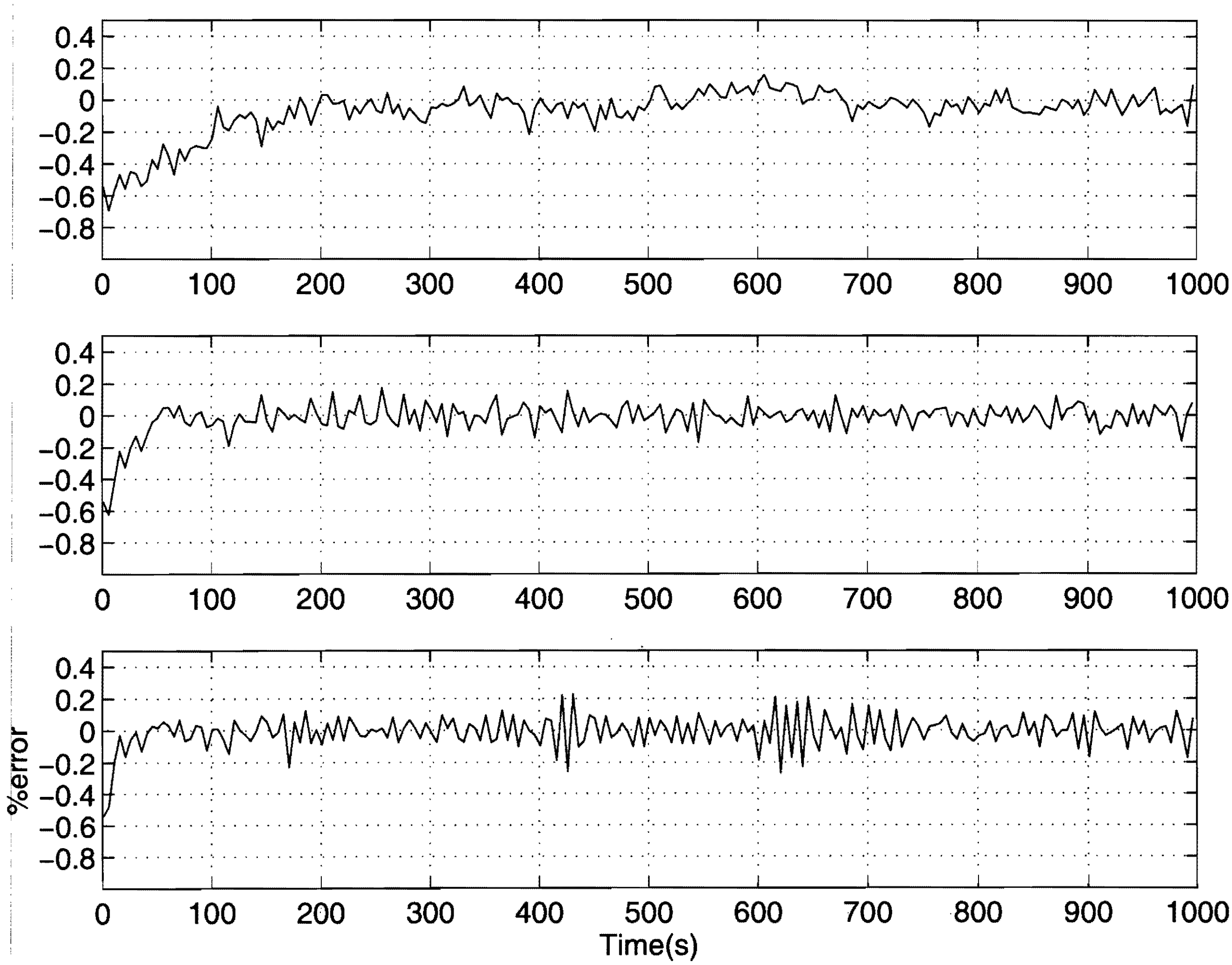

Figure 2. Convergence speed and tracking performance for different adaptation coefficients.

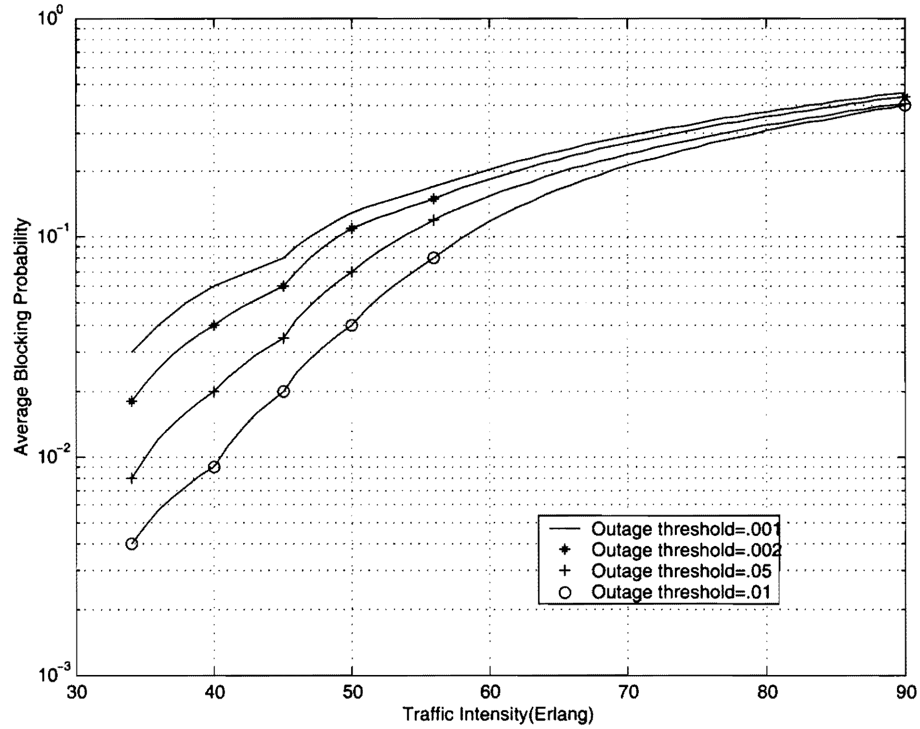

Figure 3. Average blocking probability versus *outage probability threshold.*

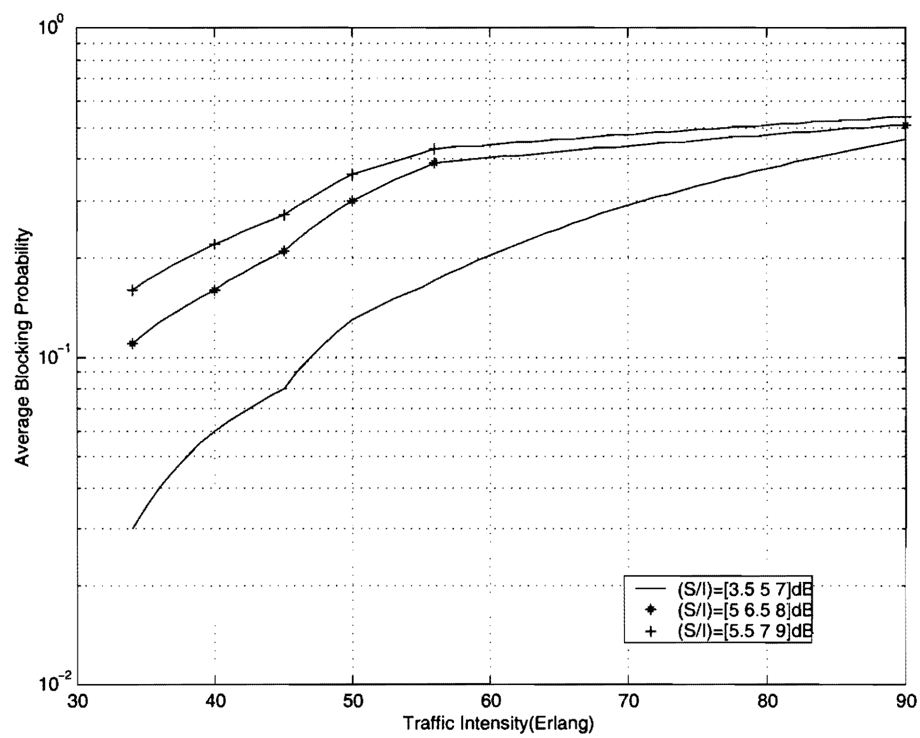

Figure 4. Average blocking probability versus *required S/I threshold. The* S/I *vector represents the* S/I *threshold in outage index of QoS vector for each class of traffic.*

CONCLUSIONS

A linear power assignment algorithm is introduced and developed in this paper. The main advantage of this algorithm is its simplicity and robustness compared to the non-linear power assignment method. However, the linear power assignment is a sub-optimum scheme in utilizing the cell capacity.

The problem of admission control when different media with different QoS requirements are sharing a CDMA channel is studied. We proposed an adaptive access control method based on a simple linear estimator and the cell load measurement. We investigated the impact of different system parameters on the performance of proposed frame work. Further more, effectiveness of the proposed admission control scheme is demonstrated by estimating the blocking probability for different system parameters.

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