Call Admission Control for Real Time Multimedia Services with Variable Bit Rate in WCDMA Systems

Chae Y. Lee and Ki Won Sung
Dept. of Industrial Engineering, KAIST
373-1, Guseong-dong, Daejeon, Korea
chae@kaist.ac.kr, kwsung@kaist.ac.kr

Abstract—Call admission control for real time multimedia services with variable bit rate (VBR) is considered in this paper. In the WCDMA system, one of the most prevailing services will be the real time multimedia of which data rate changes dynamically. We propose two call admission schemes that effectively reflect features of VBR multimedia services and well satisfy the objective in this paper. The proposed schemes are based on SIR of the system. Especially, they anticipate the fluctuation of SIR due to the data rate change of each multimedia service and make an admission decision based on prediction of future SIR rather than current SIR value. The proposed schemes are compared with an admission policy whose admission decision depends only on the current SIR value.

I. INTRODUCTION

Recently, the demand for broad range of multimedia services has increased rapidly. Thus, the third generation (3G) wireless communication systems are designed for the multimedia communication. The wideband code division multiple access (WCDMA) technology is the most widely adopted 3G air interface [1]. Since the amount of resource required for multimedia transmission is much larger than that of the legacy voice service, more precise radio resource management (RRM) strategy is required to guarantee the quality of service (QoS) of mobile users. Call admission control (CAC) occupies an important part of the RRM in the wireless communication systems.

Many CAC schemes have been proposed for voice service, and recent works have started to focus on CAC for multimedia services [2-5]. However, the dynamic change of data rates, which is common in transmission of real time multimedia services, is not extensively addressed yet. CAC schemes for various multimedia services are proposed in [2-3]. However, services are assumed to be constant bit rate (CBR) traffics. In [4-5], multimedia services are modeled as variable bit rate (VBR) sources, but CACs in these works are based on maximum data rate of services rather than exploiting the change of data rates.

In the WCDMA system, one of the most prevailing services will be the real time video service. Because of large bandwidth requirement for high-quality service, it is expected that most of the services will be encoded with compression techniques [6]. In general, the compression algorithms generate VBR source, since the data rate of each frame depends on the instantaneous change of the scene or sound [7]. With VBR transmission, signal to interference ratio (SIR) of a cell fluctuates severely even with the same number of ongoing services. When CAC does not reflect the VBR aspect, the system may lead to a wrong admission decision. For example, a new service may be accepted when SIR becomes low for a moment, with heavy traffic in average, and vice versa. To prevent such a wrong admission decision, CAC scheme which reflects the features of VBR traffics is required.

In this paper, two CAC schemes for real time VBR video service are proposed. The proposed schemes are based on SIR of the system. Especially, they anticipate the fluctuation of SIR due to the data rate change of each video service and make an admission decision based on the prediction of future SIR rather than current SIR value. The objective of this paper is to minimize the new call blocking probability while keeping the outage probability below QoS threshold. SIR of a cell is modeled as continuous time stochastic process. With the stochastic model, the blocking probability of new service and the outage probability of existing services are obtained according to a specific admission scheme.

The remainder of this paper is organized as follows. In Section 2, the system model is explained. The behavior of each video service is modeled as a Markov chain. Then, blocking probability and outage probability are obtained with the stochastic modeling. Call admission control algorithms for real time VBR video service are proposed in Section 3. The proposed call admission algorithms are evaluated by numerical experiments in Section 4. Finally, the conclusion is presented in Section 5.

II. SYSTEM MODEL

Single class real time VBR video service such as video telephony and video conferencing is considered in this paper. Accurate modeling of VBR video source is the first step for predicting SIR. Since one of the most widely used models is the finite state Markov chain [7], we follow this modeling technique. To simplify further analysis, VBR video source is assumed to be a two-state continuous time Markov chain as shown in Fig. 1.

Each video source has two data rates \( R_L \) and \( R_H \), which respectively refers to the low data rate and the high data rate. We denote \( \delta_{LH} \) and \( \delta_{HL} \) as the transition rate from \( R_L \) to \( R_H \) and
\[ R_H \to R_L, \] respectively. Each video service can be started from either \( R_L \) or \( R_H \).

We investigate the uplink of a cell in the WCDMA system. In the downlink, a base station coordinates transmissions of all users in a cell. Thus, the variation of SIR due to VBR transmissions can be resolved by a proper resource allocation algorithm. On the contrary, the transmission of mobile is independent with each other in the uplink.

Due to the stringent delay requirement of real time video service, transmission buffer is not considered in further analysis. A new video call in a cell is generated by exponential distribution with parameter \( \lambda \). \( \lambda \) is divided with \( \lambda_H \) and \( \lambda_L \), which respectively denotes the generation rate of calls that starts from \( R_H \) and from \( R_L \). The call completion rate is also exponentially distributed with parameter \( \mu \). Let \( N_H \) and \( N_L \) respectively be the number of high rate and low rate video calls in a cell. System state is defined as a row vector \( S = (s \in S) = (x, y) \) such that \( s = (i, j) \) if \( N_H = i \) and \( N_L = j \). The state space of all feasible states is denoted by \( S \).

We define \( a_y^H \) and \( a_y^L \) as the admission probabilities of a video call in state \((i, j)\) which starts from \( R_H \) and \( R_L \), respectively. \( a_y^H \) and \( a_y^L \) depend on a specific call admission scheme. Thus, the proper determination of admission probabilities in each state is main issue in this paper.

Within the state space \( S \), the four following kinds of state transitions are possible: a new call is admitted in the cell, one of the ongoing calls leaves the cell, a call increases the transmission data rate, a call decreases the transmission data rate. Fig.2 illustrates a simple example of the state transition diagram with the state space of \( S = \{ s = (x, y) \ | 0 \leq x + y \leq 3 \} \).

Let \( p_B \) be the steady state probability of state \((i, j)\). Then, flow balance equations of the system are given by

\[
\begin{align*}
I_{i+1,j}P_{i+1,j}(i+1)\mu + I_{i,j+1}P_{i,j+1}(j+1)\mu \\
+ I_{i-1,j}P_{i-1,j}\lambda^H + I_{i,j-1}P_{i,j-1}\lambda^L \\
+ I_{i+1,j+1}P_{i+1,j+1}(i+1)\mu + I_{i,j+1}P_{i,j+1} = p_B (a_y^H \lambda_H + a_y^L \lambda_L + i\mu + j\mu + j\delta_H).
\end{align*}
\]

In (1), \( I_{i,j} \) is the binary indicator variable whose value is one if \((i, j) \in S \), and otherwise, zero.

The steady state probability \( p_y \) is obtained by equation (1) and the following normalization condition

\[
\sum_{(i,j) \in S} p_y = 1. \quad (2)
\]

Recall that our objective is minimizing the blocking probability of new call request while keeping the system outage probability below a given threshold. Blocking probability is defined as the portion of users whose admission request is denied. Also, outage probability is defined as the portion of time that the system experiences an outage. We denote the blocking probability and outage probability by \( p_B \) and \( p_{out} \), respectively.

Suppose the system is in state \((i, j)\). A new call request with initial data rate of \( R_H \) is generated with the rate of \( \lambda_H (\lambda_L) \).

Then, it may be admitted with the probability \( a_y^H \) \( (a_y^L) \) or blocked with the probability \( 1 - a_y^H \) \( (1 - a_y^L) \). Thus, \( p_B \) is given by

\[
p_B = 1 - \sum_{(i,j) \in S} p_y \left( a_y^H \lambda_H + a_y^L \lambda_L \right). \quad (3)
\]

Another performance measure to be obtained is the system outage probability. Outage is defined as a situation where the ratio of bit energy to noise density \( (E_b / N_0) \) falls below the predefined threshold value. Since \( E_b / N_0 \) value is different in each state, outage may or may not occur according to the state of the system. Thus, we have a binary indicator variable for
each state. Let \((E_b / N_0)_{ij}\) be the \(E_b / N_0\) value of state \((i,j)\) and \(y\) be the \(E_b / N_0\) requirement of the video call. Then, the indicator for system outage is defined as

\[
\psi_{ij} = \begin{cases} 1, & \text{if } \left(\frac{E_b}{N_0}\right)_{ij} < y \\ 0, & \text{otherwise} \end{cases}
\]  

(4)

The uplink \(E_b / N_0\) of the CDMA system is investigated in [1, 8].

From (4), the system outage probability is given by

\[
P_{out} = \sum_{(i,j)\in S} p_{ij} \psi_{ij}.
\]  

(5)

In this section, we first describe the behavior of VBR video source as a two state Markov chain. Then, SIR of a cell is modeled as a continuous time Markov process, and the steady state probability is obtained. Finally, we derive two performances measures, blocking probability and system outage probability. It should be noted, however, that the steady state probability and performance measures are not obtained practically until we determine admission probabilities in all states. The determination of admission probabilities, \(a_{ij}^H\) and \(a_{ij}^L\), will be discussed in the next section.

III. CALL ADMISSION CONTROL SCHEMES

CAC is defined as the decision of whether to admit a new call request or not. It rejects the new call request if its admission sacrifices the QoS of ongoing calls. Two CAC schemes for VBR video service are proposed, namely variable bit rate call admission control (VCAC)–1 and VCAC–2. These admission control schemes are compared with instantaneous call admission control (ICAC), which makes an admission decision based on the instantaneous SIR of the system.

A. VCAC–1

System states are grouped into several super-states to simplify the CAC problem. Let us introduce the concept of level, which is a group of states with the same number of ongoing calls. Level \(m\) is defined as set of states such that state \((i,j)\) is in level \(m\) if \(i + j = m\).

With the introduction of level, four kinds of system transitions are divided into two categories of transitions: intra-level transition and inter-level transition. Increase or decrease of transmitted data rate belongs to intra-level transition. On the other hand, entering of a new call and leaving of an ongoing call constitute the inter-level transition. It means that the admission decision is only concerned with the inter-level transition. Thus, we can concentrate on the inter-level transition when we determine the admission probabilities.

The main idea of the proposed VCAC–1 is to approximate the system state transition with transition among levels. In other words, we convert the unit of admission decision from state to level.

For a state \((i,j)\) which belongs to level \(m\), \(\pi_i(m)\) is defined as the steady state probability within level \(m\). Note that \(j = m - i\). Since the state transition within a level is only concerned with \(\delta_{LL}\) and \(\delta_{HL}\), the state transition diagram within level \(m\) is expressed by a birth-death process as given in Fig. 3. Steady state probability of birth-death process is easily obtained [9]. Thus, \(\pi_i(m)\) is as follows:

\[
\pi_0(m) = \frac{1}{1 + \sum_{n=1}^{m} \frac{n!}{m!} \delta_{LL}^{m-n} \pi_0^0}, \\
\pi_n(m) = \frac{n! \delta_{LL}^{m-n} \pi_0^0}{m! \delta_{HL}^{m-n} \pi_0^0}, \quad 1 \leq n \leq m.
\]  

(6)

Let \(\Phi_m\) be the outage probability of level \(m\). Then, \(\Phi_m\) is given as follows:

\[
\Phi_m = \sum_{(i,j)\in L_m} \pi_i(m) \psi_{ij},
\]  

(7)

where \(L_m\) is the state space of level \(m\).

When a call is admitted in a system, system state moves from level \(m\) to level \(m+1\). To ensure that the outage probability remains below the QoS threshold, the following conditions should be satisfied.

\[
a_{ij}^H \Phi_{m+1} \leq P_{QoS} \quad \text{and} \quad a_{ij}^L \Phi_{m+1} \leq P_{QoS}, \quad \forall(i,j) \in L_m.
\]  

(8)

\(P_{QoS}\) denotes the threshold of outage probability.

While satisfying condition (8), new call blocking probability should be minimized. Thus, the propose VCAC–1 determines the admission probabilities as follows:

\[
a_{ij}^H = a_{ij}^L = \max \left(1, \frac{P_{QoS}}{\Phi_{m+1}} \right), \quad \forall(i,j) \in S
\]  

(9)

B. VCAC–2

Numerical results which will be shown in Section 4 indicate that the proposed VCAC–1 well bounds the system
outage probability below $p_{QoS}$. However, VCAC–1 tends to give low outage probability compared to the outage threshold. Low outage probability is favorable in the view of bit error rate, but it also leads to increased blocking probability.

To settle the problem of low outage probability, we propose VCAC–2, which is a simple revision of VCAC–1. The outage performance mainly depends on the admission probabilities. Low outage probability indicates that the admission probabilities should be increased. Thus, the following proportional expression is approximately established, though not exactly.

$$a_{ij}^H (VCAC - 1): p_{out} = a_{ij}^H (VCAC - 2): p_{QoS}.$$ (10)

The same expression also holds for $a_{ji}^L$.

VCAC–2 is based on the result of VCAC–1. If outage probability with VCAC–1 is less than the outage threshold, the additional adjustment is executed.

$$a_{ij}^H (VCAC - 2) = \min \left[ 1, \frac{a_{ij}^H (VCAC - 1)p_{QoS}}{p_{out}} \right].$$ (11)

C. ICAC

ICAC is a simple admission control scheme which is introduced for the comparison with VCAC–1 and VCAC–2. When a call requests to enter a cell, ICAC determines whether to admit the call or not, based on instantaneous SIR. Thus, ICAC does not reflect the VBR nature of real time video service. ICAC rejects a new call request if the admission of the new call results in outage right after the entrance of the call. Thus, admission probabilities are given by

$$\begin{cases} a_{ij}^H = 0, & \text{if } \Psi_{i+1,j} = 1 \\ a_{ij}^L = 0, & \text{if } \Psi_{i,j+1} = 1 \\ a_{ij}^H = 1, & \text{otherwise} \\ a_{ij}^L = 1, & \text{otherwise} \end{cases}.$$ (12)

IV. NUMERICAL RESULTS

In this section, we examine the performances of the three call admission schemes: VCAC–1, VCAC–2, and ICAC. VBR video service is considered with high data rate of 144 Kbps and low data rate of 48 Kbps.

First, the effect of traffic intensity is examined in Fig. 4 and Fig. 5. While maintaining $\delta_{HL} = \delta_{LH} = 10 \mu$, traffic intensity is varied from 1 to 3.5. Traffic intensity is defined as $(\lambda_H + \lambda_L) / \mu$, where $\lambda_H$ and $\lambda_L$ are assumed to be identical. As shown in the figures, ICAC gives the lowest blocking probability. However, it is due to the sacrifice of outage probability. Since ICAC considers only the current SIR, it cannot cope with the change of SIR, which results in dramatic increase of outage probability. Oppositely, VCAC–1 well meets the outage requirement. However, low outage probability makes the blocking probability too high. VCAC–2 keeps the outage probability near the QoS requirement, and gives lower blocking probability than VCAC–1.

In Fig. 6 and Fig. 7, ratio of $\delta_{HL}$ and $\delta_{LH}$ is changed throughout the experiments. We fix $\delta_{LH}$ as $10 \mu$, and change the value of $\delta_{HL}$ from $0.1 \delta_{LH}$ to $10 \delta_{LH}$. The left half of Fig. 6 and 7 illustrates the situation where $\delta_{HL}$ is less than $\delta_{LH}$, which means that ongoing services are likely to be in the high data rate during its connection. SIR is anticipated to be worse than the current one in this condition. ICAC is, however, based on only the current SIR. Consequently, the outage probability of ICAC becomes very high. VCAC–2 gives well bounded outage probability at any condition. VCAC–1 results in very low outage probability but relatively high blocking probability. On the other hand, the right half of the graphs depicts that $\delta_{HL}$ is larger than $\delta_{LH}$. Thus, video calls will spend more time in the low data rate. It leads to low traffic load in the future. Therefore, all CAC schemes shows good performances.

The effect of the difference between high data rate and low data rate is examined in Fig. 8 and Fig. 9. While maintaining the sum of $R_H$ and $R_L$ as 192 Kbps, we vary $R_H$ from 15 Kbps to 96 Kbps. In other words, we vary the value of $R_L / R_H$ from 0.08 to 1. When $R_L$ approaches to 96 Kbps, the difference of $R_L$ and $R_H$ decreases to zero. In this CBR like circumstance, frequent changes of SIR do not occur. Thus, the performances of VCACs and ICAC are almost the same. As low data rate decreases, the merit of VCACs becomes clear since large difference of low rate and high rate causes the effect of VBR transmission more definitely.

V. CONCLUSION

Call admission schemes for real time video service with VBR transmission is considered in this paper. We use the Markov chain modeling technique and propose two call admission control schemes. Numerical results show that the proposed schemes well satisfy the outage requirement and minimize the blocking probability.

REFERENCES


Figure 4. Outage probability according to traffic intensity

Figure 5. Blocking probability according to traffic intensity

Figure 6. Outage probability according to δ

Figure 7. Blocking probability according to δ

Figure 8. Outage probability according to R

Figure 9. Blocking probability according to R