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

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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 δ_{LH} and δ_{HL} as the transition rate from R_L to R_H and

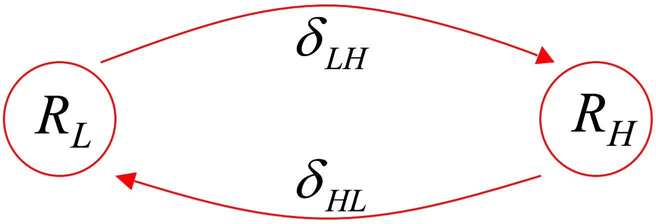

Figure 1. Video source model.

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 λ. λ is divided with λ_H and λ_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 μ. 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 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 $a_{ij}{}^{H}$ and $a_{ij}{}^{L}$ as the admission probabilities of a video call in state (i,j) which starts from R_H and R_L, respectively. $a_{ij}{}^{H}$ and $a_{ij}{}^{L}$ 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 following four 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 $S=\{s=(x,y) \mid 0 \le x+y \le 3\}$. Let p_{ij} be the steady state probability of state $(i\ j)$. Then, flow balance equations of the system are given by

$$\begin{aligned} & I_{i+1,j}p_{i+1,j}(i+1)\mu + I_{i,j+1}p_{i,j+1}(j+1)\mu \\ & + I_{i-1,j}p_{i-1,j}a_{i-1,j}{}^{H}\lambda_H + I_{i,j-1}p_{i,j-1}a_{i,j-1}{}^{L}\lambda_L \\ & + I_{i+1,j-1}p_{i+1,j-1}(i+1)\delta_{HL} + I_{i-1,j+1}p_{i-1,j+1}(j+1)\delta_{LH} \\ & = p_{ij}(a_{ij}{}^{H}\lambda_H + a_{ij}{}^{L}\lambda_L + i\delta_{HL} + i\mu + j\mu + j\delta_{LH})\,. \end{aligned} \tag{1}$$

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

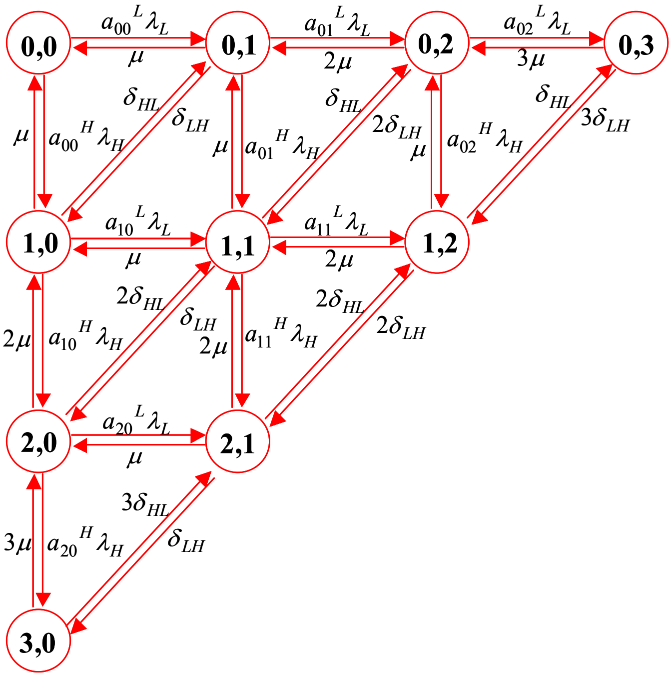

Figure 2. Simple example of state transition diagram

The steady state probability p_{ij} is obtained by equation (1) and the following normalization condition

$$\sum_{(i,j)\in S} p_{ij} = 1\,. \tag{2}$$

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 (R_L)is generated with the rate of λ_H (λ_L). Then, it may be admitted with the probability $a_{ij}{}^{H}$ ($a_{ij}{}^{L}$) or blocked with the probability 1-$a_{ij}{}^{H}$ (1-$a_{ij}{}^{L}$). Thus, p_B is given by

$$p_B = 1 - \sum_{(i,j)\in S} p_{ij}\left(\frac{a_{ij}{}^{H}\lambda_H + a_{ij}{}^{L}\lambda_L}{\lambda}\right). \tag{3}$$

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 γ be the E_b / N_0 requirement of the video call. Then, the indicator for system outage is defined as

$$\Psi_{ij} = \begin{cases} 1, & \text{if } \left(\dfrac{E_b}{N_0}\right)_{ij} < \gamma \\ 0, & \text{otherwise} \end{cases} . \tag{4}$$

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

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

$$p_{out} = \sum_{(i,j)\in S} p_{ij} \Psi_{ij} . \tag{5}$$

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.

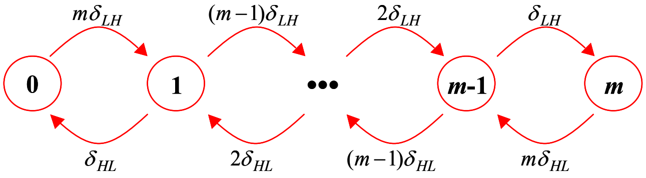

Figure 3. Birth-death process within a level

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 δ_{LH} and δ_{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:

$$\pi_0(m) = \frac{1}{1 + \sum_{n=1}^{m} \dfrac{[m!/(m-n)!]\delta_{LH}{}^n}{n!\delta_{HL}{}^n}} ,$$

$$\pi_n(m) = \frac{[m!/(m-n)!]\delta_{LH}{}^n}{n!\delta_{HL}{}^n \pi_0(m)} , \ 1 \le n \le m . \tag{6}$$

Let Φ_m be the outage probability of level m . Then, Φ_m is given as follows:

$$\Phi_m = \sum_{(i,j)\in L_m} \pi_i(m) \Psi_{ij} , \tag{7}$$

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.

$$a_{ij}{}^H \Phi_{m+1} \le p_{QoS} \text{ and } a_{ij}{}^L \Phi_{m+1} \le p_{QoS} , \ \forall (i,j) \in L_m . \tag{8}$$

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.

$$a_{ij}{}^H = a_{ij}{}^L = \max\left[1, \frac{p_{QoS}}{\Phi_{m+1}}\right], \ \forall (i,j) \in S \tag{9}$$

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.

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

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

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.

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

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

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

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 λ_H and λ_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 δ_{HL} and δ_{LH} is changed throughout the experiments. We fix δ_{LH} as 10μ, and change the value of δ_{HL} from $0.1\delta_{LH}$ to $10\delta_{LH}$. The left half of Fig. 6 and 7 illustrates the situation where δ_{HL} is less than δ_{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 δ_{HL} is larger than δ_{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_L and R_H as 192 Kbps, we vary R_L 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

[1] H. Holma and A. Toskala, WCDMA for UMTS, Wiley and Sons, 2000.

[2] D. Ayyagari and A. Ephremides, “Optimal Admission Control in Cellular DS-CDMA Systems With Multimedia Traffic,” IEEE Transactions on Wireless Communications, Vol. 2, No. 1, 2003.

[3] J. Y. Lee, J. G. Choi, K. Park, and S. Bahk, “Realistic Cell-Oriented Adaptive Admission Control for QoS Support in Wireless Multimedia Networks,” IEEE Transactions on Vehicular Technology, Vol. 52, No. 3, 2003.

[4] W. S. Jeon and D. G. Jeong, “Call Admission Control for CDMA Mobile Communications Systems Supporting Multimedia Services,” IEEE Transactions on Wireless Communications, Vol. 1, No. 4, 2002.

[5] T. C. Wong, J. W. Mark, and K. C. Chua, “Joint Connection Level, Packet Level, and Link Layer Resource Allocation for Variable Bit Rate Multiclass Services in Cellular DS-CDMA Networks With QoS Constraints,” IEEE Journal on Selected Areas in Communications, Vol. 21, No. 10, 2003

[6] U. K. Sarkar, S. Ramakrishnan, and D. Sarkar, “Modeling Full-Length Video Using Markov-Modulated Gamma-Based Framework,” IEEE/ACM Transactions on Networking, Vol. 11, No. 4, 2003.

[7] B. Maglaris, D. Anastassiou, P. Sen, G. Karlsson, and J. D. Robbins, “Performance Models of Statistical Multiplexing in Packet Video Communications, IEEE Transactions on Communications,” Vol. 36, No. 7,1988

[8] K. S. housen, I. M. Jacobs, R. Padovani, A. J. Viterbi, L. A. Weaver, and C. E. Wheatly III, “On the Capacity of a Cellular CDMA System,” IEEE Transactions on Vehicular Technology, Vol. 40, No. 2, 1991.

[9] S. M. Ross, Introduction to Probability Models, Fifth Edition, Academic Press, UK,1993.

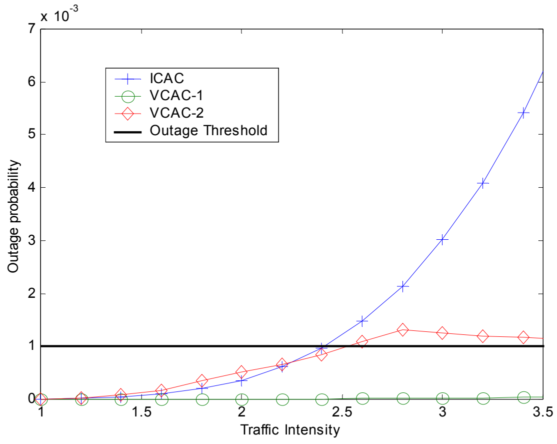

Figure 4. Outage probability according to traffic intensity

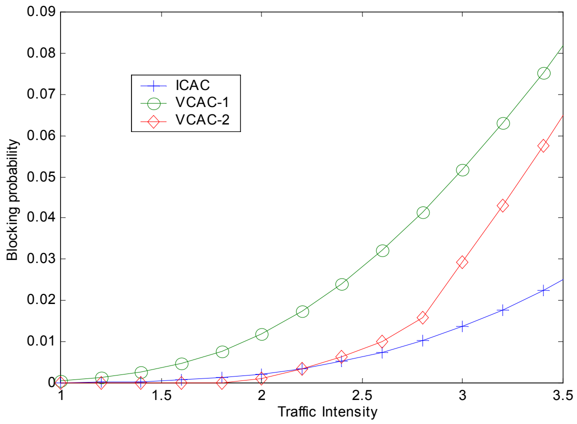

Figure 5. Blocking probability according to traffic intensity

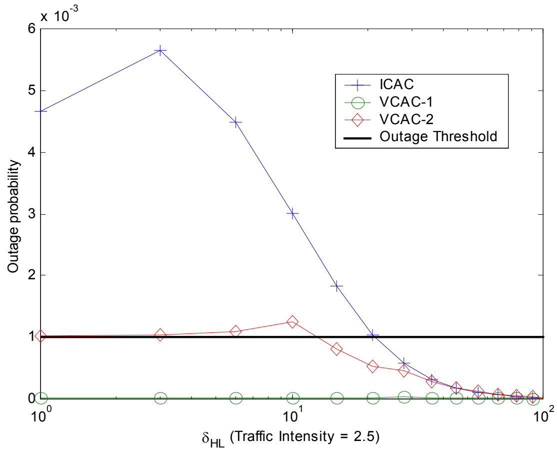

Figure 6. Outage probability according to δ_{HL}

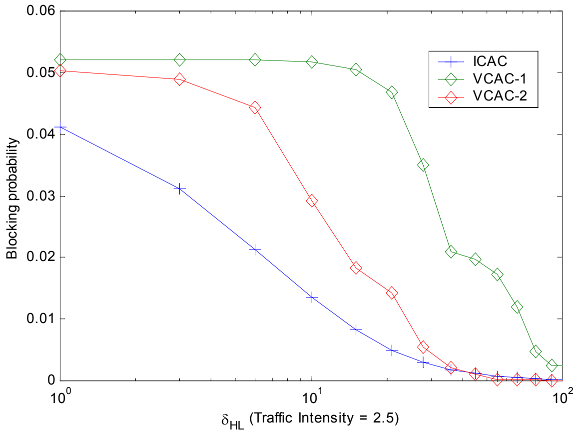

Figure 7. Blocking probability according to δ_{HL}

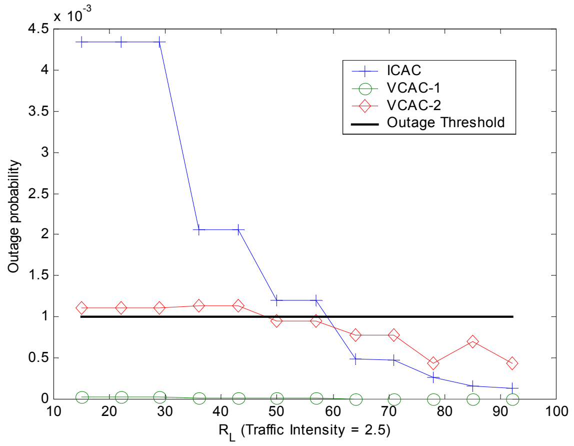

Figure 8. Outage probability according to R_L

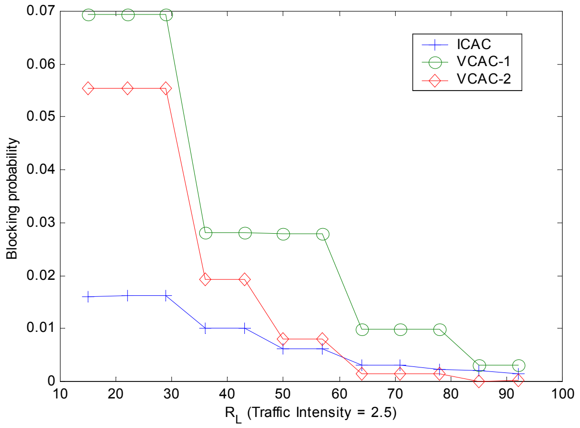

Figure 9. Blocking probability according to R_L