Energy-Aware Call Admission Control Scheme in Wireless Cellular Networks

Xinbing Wang
Department of Electrical and
Computer Engineering
North Carolina State University
Raleigh, NC 27695
Email: xwang8@ncsu.edu

Wenye Wang
Department of Electrical and
Computer Engineering
North Carolina State University
Raleigh, NC 27695
Email: wwang@ncsu.edu

Abstract— **Traditional call admission control (CAC) schemes focus on only two parameters: call blocking probability and handoff dropping probability, although energy conservation is important and closely related to admission control. In this paper, we present an adaptive CAC to take a third parameter, energy consumption, into account as well. In order to reveal the relationship between CAC and energy consumption, *energy consumption rate* (ECR) is introduced. Based on a key observation of ECR that the same bandwidth variation of different mobile users may cause different rates of energy consumption, two algorithms are proposed, Victim Selection Algorithm (VSA) and Beneficiary Selection Algorithm (BSA), to reduce energy consumption. The performance of the proposed scheme for multi-class services model is analyzed, and simulation results demonstrate that lowest energy consumption is achieved by our scheme with improvement in blocking/dropping probabilities.**

I. INTRODUCTION AND MOTIVATION

It is widely recognized that future wireless networks will provide an increasing number of subscribers more applications, which require high bandwidth and huge amount of data transmission such as high resolution of multimedia service. The limited radio spectrum and short lifetime of batteries used in mobile terminals become the obstacles to provide these applications. Therefore, resource allocation and energy conservation are two important research issues in wireless communications.

Extensive research has been conducted on resource allocation with regard to call admission during the past few years [1], [2], [3], [4]. One of the existing solutions is to use the guard channel scheme (GCS), which assigns a higher capacity limit for handoff calls than that for new calls [3]. The difference between two limits is called "guard channels." In order to meet the requirements of heterogeneous traffic with time-varying characteristics, priority-based schemes are proposed in [4], which give a higher priority to handoff than to new calls to reduce handoff dropping probabilities. Furthermore, prediction-based approaches are presented to reserve bandwidth prior to the arrival of handoff requests [1], [2].

Another challenge in wireless networks is energy conservation. Because the battery life of a mobile terminal is one of the bottlenecks to support high quality multimedia service and long-live data transmission, many solutions are proposed to tackle the energy issue from different layers and perspectives [5], [6]. However, energy conservation is far from well addressed.

Most of the current efforts on resource allocation and energy consumption are separated. We find out that they are related to each other, which makes it possible for us to approach both problems simultaneously. We therefore develop a resource allocation scheme, which accounts for energy conservation. That is, in addition to reducing call blocking and handoff dropping probabilities, our scheme greatly saves energy consumption.

The basic idea of our approach is that both CAC and energy consumption are related to transmission rate. We explore the quantitative connection between CAC and energy consumption, which results in a function called "energy consumption rate" (ECR). ECR represents the energy consumption for each bit successfully transmitted. Based on the observation of ECR that the same bandwidth variation of different mobile users may cause different rates of energy consumption, we proposed two algorithms: Victim Selection Algorithm (VSA) and Beneficiary Selection Algorithm (BSA). VSA minimizes the expense of the energy consumption for admitting a new or handoff call. And, BSA maximizes the gain of the energy conservation upon the completion of a call. We show that without sacrificing call blocking/dropping probability, our scheme can significantly save energy consumption for mobile terminals compared to other CAC schemes.

The contribution of this paper is three-fold. First, we derive the energy consumption rate function, which discloses the relationship between CAC and energy consumption. Second, we propose an energy-aware CAC scheme, which greatly reduce energy consumption for mobile terminals. Third, we present the analysis of the proposed scheme for multi-class services model to meet the requirement of future wireless networks.

The remainder of the paper is organized as follows. In Section II, the relationship between CAC and energy consumption is described, and energy consumption rate function is defined. In Section III, a new CAC scheme is presented. In Section IV, the performance of the proposed scheme is analyzed. Numerical results are provided in Section V, and the paper is concluded in Section VI.

II. ENERGY CONSUMPTION RATE FUNCTION

In this section, we derive energy consumption rate function, which is the bridge between CAC and energy consumption. To obtain quantitative relationship between CAC and energy

0-7803-8794-5/04/$20.00 © 2004 IEEE

consumption, we first derive the channel gain between the base station and a mobile terminal. Then, we combine modulation and channel coding to acquire frame error rate. Based on frame error rate, we induce the number of retransmissions. Next, we calculate the transmission time given a certain amount of data. Finally, we derive energy consumption in terms of transmission power and transmission rate.

In a wireless system, each base station (BS) handles incoming and outgoing calls of mobile terminals residing in its coverage area. We denote W as the total bandwidth controlled by a BS, and N as the number of active terminals with ongoing service in a cell. Let vector $\overrightarrow{\mathbf{P}} = [P_1, P_2, \ldots, P_N]$ be the transmission power of N terminals and vector $\overrightarrow{\mathbf{R}} = [R_1, R_2, \ldots, R_N]$ be the transmission rate. The channel gain for each user is represented by vector $\overrightarrow{\mathbf{H}} = [h_1, h_2, \ldots, h_N]$. Then, the signal-to-noise ratio, S/N, of mobile user, i, can be written as [7]

$$\frac{S}{N} = \frac{E_b^r R_i}{N_0 W} = \frac{h_i P_i}{\sum_{j \neq i} h_j P_j + \eta_0 W},$$

where N_0 is the noise level. We can rewrite this equation as:

$$\frac{E_b^r}{N_0} = \frac{E_b^t \cdot h_i}{\frac{\sum_{j \neq i} h_j P_j}{W} + \eta_0} \tag{1}$$

where η_0 is the white Gaussian noise level. It is known that bit error rate, $\mathbb{P}_{ber}$, for BPSK modulation [8], can be determined by a well-known formula [7]

$$\mathbb{P}_{ber}(E_b^t) = Q\left(\sqrt{\frac{2E_b^r}{N_0}}\right) = \frac{2}{\sqrt{2\pi}} \int_{\sqrt{\frac{2E_b^r}{N_0}}}^{\infty} e^{-\frac{x^2}{2}} dx. \tag{2}$$

Since the payload is encapsulated into frames during the transmission, the relationship between frame error rate and bit error rate depends on coding schemes [7]. In this work, we use *Reed-Solomon* (RS) code as an example because RS code is widely deployed by wireless communications [9]. It can be represented by $RS(n, k)$, where k is the length of source symbols and $n - k$ is the length of protection symbols. RS code can correct up to $t = (n - k)/2$ symbol errors. Thus, *symbol error rate*, $\mathbb{P}_s(E_b^t)$, and *frame error rate*, $\mathbb{P}_{fer}(E_b^t)$, using $RS(n, k)$ are given by

$$\begin{aligned} \mathbb{P}_s(E_b^t) &= 1 - (1 - \mathbb{P}_{ber}(E_b^t))^n, \quad \text{and} & (3) \\ \mathbb{P}_{fer}(E_b^t) &= \sum_{j=t+1}^{n} \binom{n}{j} \mathbb{P}_s(E_b^t)^j (1 - \mathbb{P}_s(E_b^t))^{n-j}. \end{aligned}$$

Then the total energy consumption, E_{total}, can be expressed as

$$E_{total} = T_{total} \cdot P = T_{total} \cdot R \cdot E_b^t \tag{4}$$

where T_{total} is the total transmission time of successful transmission.

In addition, total transmission time depends on the total amount of data, number of retransmissions, and transmission rate, that is

$$T_{total} \quad = \quad \frac{\Phi \cdot \Theta(\mathbb{P}_{fer}(E_b^t))}{R} \tag{5}$$

where Φ is the total amount of data to be transmitted, and $\Theta(\mathbb{P}_{fer}(E_b^t))$ is the average number of retransmissions, which is the function of the frame error rate, $\mathbb{P}_{fer}(E_b^t)$.

Since $\Theta(P_{fer}(E_b^t))$ can be represented by

$$\Theta(\mathbb{P}_{fer}(E_b^t)) = \frac{1}{1 - \mathbb{P}_{fer}(E_b^t)}, \tag{6}$$

Then, the total energy consumption from (6) can be rewritten as

$$E_{total} = \frac{E_b^t}{1 - \mathbb{P}_{fer}(E_b^t)} \cdot \Phi \tag{7}$$

Thus, the total energy consumption is related to the data volume in transmission, energy per bit, as well as transmission errors.

Definition: Energy consumption rate is energy consumption of each **successfully** transmitted bit given by

$$\Gamma(E_b^t) = \frac{E_b^t}{1 - \mathbb{P}_{fer}(E_b^t)}. \tag{8}$$

then, (7) can be further denoted as

$$E_{total} = \Gamma(E_b^t) \cdot \Phi. \tag{9}$$

In order to display the direct relationship between the energy consumption rate and transmission rate, we rewrite (8) in terms of transmission rate, R, as

$$\Gamma_r(R) = \frac{\frac{P}{R}}{1 - \mathbb{P}_{fer}(\frac{P}{R})} = \frac{P}{R - R \cdot \mathbb{P}_{fer}(\frac{P}{R})}. \tag{10}$$

In Fig. 1, an example of energy consumption rate, $\Gamma_r(R)$, is shown for $RS(16, 8)$ code [9], $h_i = 10^{-2}$ [8], $P = 20\ dBm$ and $N_0 = 5 \times 10^{-9}\ WHz$ [7]. We also test other RS codes and transmission power, P, for example, $RS(128, 112)$, $RS(255, 223)$, $P = 20\ dBm$. The following observations hold true for different RS codes and noise levels.

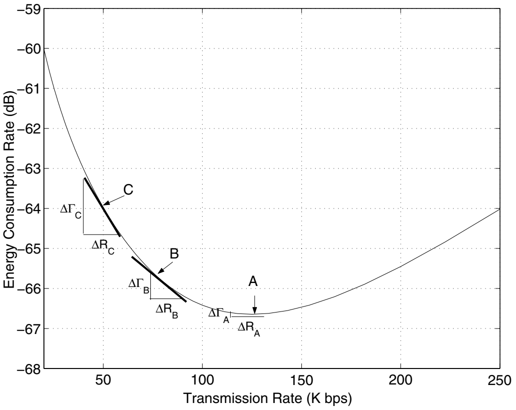

Fig. 1. An Example of Energy Variation VS. the Same Bandwidth Change.

Close look at the Fig. 1 reveals that the same variation of transmission rate leads to different change of energy consumption. For instance, there are three mobile terminals operating at points “A”, “B”, and “C”, respectively, in Fig. 1. When we decrease the bandwidth at “A”, “B”, and “C” by ΔR_A, ΔR_B and ΔR_C, the increases in energy consumption are different: $\Delta\Gamma_A$, $\Delta\Gamma_B$ and $\Delta\Gamma_C$. We can see that the increase in energy consumption of terminal “A” is the lowest and that of terminal “C” is the highest. This means that when we decrease the bandwidth for terminal “A”, it will not incur much of an increase in energy consumption. However, for terminal “C”, it will result in a great increase of energy consumption.

Therefore, the key observation is that the same bandwidth variation of different mobile users may result in different rates of energy consumption. We develop our resource allocation scheme based on this observation.

III. ENERGY-AWARE CALL ADMISSION CONTROL SCHEME

In this section, we will introduce how our energy-aware Call Admission Control Scheme (ECACS) combines energy conservation and CAC. ECACS consists of two phases: connection setup phase and channel adaptation phase. At the connection setup phase, ECACS can calculate the transmission power by (10) and have the mobile terminal operate at a threshold point. During the transmission, the transmission power of a mobile terminal may not operate at the threshold point all of the time due to its mobility or the interference variation from other terminals. Since the power control incurs expensive overhead to the mobile terminals and systems, we avoid adjusting the transmission power of on-going mobile terminals frequently.

A. Victim Selection Algorithm

Victim selection algorithm (VSA) determines which mobile terminals will become victims when bandwidth is insufficient for incoming call requests.

Upon the arrival of a request from a terminal, the BS accepts this request if the available bandwidth is greater than the minimum bandwidth requirement. Otherwise, the BS searches all ongoing services to find a victim whose derivative of $\Gamma_r(R)$ is the *minimum*, i.e., the rate of energy consumption is the minimum. If this terminal already operates at its lower bound, the bandwidth of this terminal cannot be reduced. As such, this mobile terminal cannot be treated as a “victim”. If the bandwidth of this terminal can be decreased, then the terminal becomes a victim. The BS will reduce the bandwidth of a chosen victim to a lower level to increase available bandwidth. This procedure will be repeated until the available bandwidth is greater than the requested bandwidth for accepting the new or handoff request.

B. Beneficiary Selection Algorithm

Beneficiary selection algorithm (BSA) determines which mobile terminals will become beneficiaries when a service is terminated and extra bandwidth is available to be reallocated to the terminals with ongoing services. While the BSA is also based on energy consumption rate (ECR), the objective is to choose mobile terminals whose changing rate of ECR is the maximum to decrease the energy consumption, which results from the increase in bandwidth, as much as possible. Using Fig. 1 as an example, we can see that terminal “C” will be the beneficiary for BSA because it has the maximum decrease in energy consumption resulting from an increase in transmission rate compared to the other two terminals, A and B.

The algorithm for BSA is the following. The BS searches for a potential beneficiary from all the ongoing services to determine which terminal can benefit most by receiving more bandwidth, i.e., the derivative of $\Gamma_r(R)$ is the *maximum*. A higher level of bandwidth caused by the increase should not exceed the upper limit of bandwidth requirement for the “beneficiary” terminal.

IV. PERFORMANCE ANALYSIS: BLOCKING PROBABILITY

It is well known that call blocking probability and handoff dropping probability are two important parameters indicating the system performance. In this context, we consider handoff call and new call have the same priority; The handoff dropping probability will be the same as the call blocking probability. Therefore, we will not repeat the results for dropping probability.

We analyze the blocking probability of ECACS by assuming that the channel holding time is independent of the number of channels. For class k, we denote the mean of exponential channel holding time as $1/\mu_k$, regardless of the number of channels, which is the representative assumption used by resource allocation [1], [2], [3], [10]. Other traffic scenarios, for example channel holding time is dependent on the number of channels, are considered in our other work.

First, we present the system model. Then, probability measure space and continuous time Markov Chain (CTMC) are described. Based on CTMC, we derive the call blocking probability of ECACS.

A. System Model

We consider a system with multiple classes of services. There are a total of C channels to serve K classes of service. The arrival process of class k is Poisson distribution with mean λ_k. The service rate of class k is denoted by μ_k. We denote vector $\overrightarrow{N} = [n_1, n_2, \ldots, n_K]$ as the number of calls for each class, where n_k is the total number of channels in the system serving the class k requests. Since ECACS is an adaptive scheme, each class service may require a range of channels. Let b_k^i be the number of channels allocated to the i^{th} connection of class k for ECACS and b_k^L be the lower bound requirement of class k and b_k^U is the upper bound requirement of class k, i.e., $b_k^i \in [b_k^L, b_k^U]$.

B. Probability Measure Space and CTMC

Let $(\mathbf{\Omega}, \mathcal{F}, \mathbb{P})$ be the probability measure space of ECACS. The sample space $\mathbf{\Omega}$ is given as

$$\mathbf{\Omega} := \{\overrightarrow{N} \in \mathcal{I}^K : \sum_{k=1}^{K} \sum_{i=1}^{n_k} b_k^i \leq C\}, \qquad b_k^i \in [b_k^L, b_k^U], \tag{11}$$

where $\mathcal{I}$ is a set of non-negative integers and $\mathcal{I}^K$ is a set of K-dimensional non-negative vectors. Each sample represents a possible combination of $[n_1, n_2, \ldots, n_K]$ in the system. Moreover, $\mathcal{F}$ is the $\sigma-$algebra of $\mathbf{\Omega}$ and $\mathbb{P}$ is the probability measure of $\mathbf{\Omega}$.

Further, we define $\mathbf{\Omega_k} \subset \mathbf{\Omega}$ be a subset blocking an arriving class k request, given by

$$\mathbf{\Omega_k} := \{\overrightarrow{N} \in \mathcal{I}^K : C - b_k^L < \sum_{i=1}^{K} (b_i^L \times n_i) \leq C\}. \tag{12}$$

Next, we denote two indicators as

$$\mathbb{I}_k^+(\overrightarrow{N}) = \begin{cases} 1 & \text{if } \overrightarrow{N} + \overrightarrow{E}_k \in \mathbf{\Omega} \\ 0 & \text{otherwise} \end{cases}$$

$$\mathbb{I}_k^-(\overrightarrow{N}) = \begin{cases} 1 & \text{if } \overrightarrow{N} - \overrightarrow{E}_k \in \mathbf{\Omega} \\ 0 & \text{otherwise.} \end{cases}$$

Finally, let $\overrightarrow{\tau} = [\tau_1, \tau_2, \ldots, \tau_K]$ be service rate factor to describe the dependence relationship between channel holding time and the number of channels possessed by mobile terminals. For example, if the channel holding time is independent on the number of channels, we set $\tau = [1, 1, \ldots, 1]$.

Now, we turn our attention to introduce CTMC. We know that under the assumption at the beginning of this section, the system we study can be treated as a CTMC. We are particularly interested in the transition between each state. Let $\nu(\overrightarrow{N_1}, \overrightarrow{N_2})$ denote the probability transition rate from state $\overrightarrow{N_1}$ to $\overrightarrow{N_2}$, then we have

$$\begin{aligned} \nu(\overrightarrow{N}, \overrightarrow{N} + \overrightarrow{E}_k) &= \lambda_k \\ &\quad (\overrightarrow{N}, \overrightarrow{N} + \overrightarrow{E}_k \in \mathbf{\Omega}), \\ \nu(\overrightarrow{N}, \overrightarrow{N} - \overrightarrow{E}_k) &= n_k \tau_k \mu_k \\ &\quad (\overrightarrow{N}, \overrightarrow{N} - \overrightarrow{E}_k \in \mathbf{\Omega}), \\ \nu(\overrightarrow{N} - \overrightarrow{E}_k, \overrightarrow{N}) &= \lambda_k \\ &\quad (\overrightarrow{N} - \overrightarrow{E}_k, \overrightarrow{N} \in \mathbf{\Omega}), \\ \nu(\overrightarrow{N} + \overrightarrow{E}_k, \overrightarrow{N}) &= (n_k + 1)\tau_k \mu_k \\ &\quad (\overrightarrow{N} + \overrightarrow{E}_k, \overrightarrow{N} \in \mathbf{\Omega}) \end{aligned} \tag{13}$$

where $k = 1, 2, \ldots, K$, and $\overrightarrow{E}_k$ is a K-dimensional vector of all 0 except for a 1 in the k^{th} place. For example, $\overrightarrow{E}_2 = [0, 1, 0, \ldots, 0]$.

C. Probability Measure of Blocking

Based on CTMC analysis in the previous subsection, the global Morkovian equilibrium balance equation can be expressed by

$$\begin{aligned} &\left[\sum_{k=1}^{K} \lambda_k \mathbb{I}_k^+(\overrightarrow{N}) + \sum_{k=1}^{K} n_k \tau_k \mu_k \mathbb{I}_k^-(\overrightarrow{N}) \right] \mathbb{P}(\overrightarrow{N}) \\ &= \sum_{k=1}^{K} \lambda_k \mathbb{I}_k^-(\overrightarrow{N}) \mathbb{P}(\overrightarrow{N} - \overrightarrow{E}_k) \\ &\qquad + \quad \textstyle\sum_{k=1}^{K} (n_k + 1)\tau_k \mu_k \mathbb{I}_k^+ \mathbb{P}(\overrightarrow{N} + \overrightarrow{E}_k), \end{aligned} \tag{14}$$

where $\mathbb{P}(\overrightarrow{N})$ is the probability measure of state $\overrightarrow{N}$.

By the observation of (14), the expression of $\mathbb{P}(\overrightarrow{N})$ follows

$$\mathbb{P}(\overrightarrow{N}) = \frac{1}{\mathbb{G}(\mathbf{\Omega})} \prod_{k=1}^{K} \frac{\rho_k^{n_k}}{\tau_k^{n_k} n_k!}, \qquad \overrightarrow{N} \in \mathbf{\Omega}, \tag{15}$$

where $\rho_k = \frac{\lambda_k}{\mu_k}$, and

$$\mathbb{G}(\mathbf{\Omega}) = \sum_{\overrightarrow{N} \in \mathbf{\Omega}} \prod_{k=1}^{K} \frac{\rho_k^{n_k}}{\tau_k^{n_k} n_k!}. \tag{16}$$

We can verify that $\mathbb{P}(\overrightarrow{N})$ given in (15) is the solution of (14).

Then, the blocking probability measure of class k is equal to the measure of all of the blocking elements in $\mathbf{\Omega_k}$, given in (12). Hence, the blocking probability measure of class k, $\mathbb{B}_k(\overrightarrow{\tau})$, can be written as

$$\mathbb{B}_k(\overrightarrow{\tau}) = \frac{\mathbb{G}(\mathbf{\Omega}_k)}{\mathbb{G}(\mathbf{\Omega})} \tag{17}$$

where $\overrightarrow{\tau} = [1, 1, \ldots, 1]$. $\mathbf{\Omega}$ and $\mathbf{\Omega}_k$ are given in (11) and (12), respectively. Function $\mathbb{G}(\cdot)$ is defined in (16).

Remark: Such product form of blocking probability given in (17) is available under the assumption that the channel holding time is irrelevant to the number of channels, which is stated at the beginning of this section. On the contrary, if the channel holding time is dependent on the number of channels, then blocking probability cannot be described in product form according to the knowledge so far. However, the assumption that the channel holding time is *exponentially* distributed with mean $1/\mu_k$ can be expanded to any *arbitrary* distribution with mean $1/\mu_k$ by so called "insensitivity" property [11].

V. NUMERICAL RESULTS

In this section, we present numerical results from our simulation to illustrate the effectiveness of our scheme as compared to other representative schemes: Non-Prioritized Scheme (NPS) [12] and Adaptive REsource Allocation Scheme (AREAS) [13]. Since NPS is the simplest resource allocation scheme with minimum overhead, it has been proposed for the next generation personal communication system (PCS). And, AREAS is a typical adaptive scheme for resource allocation.

As to the space limit, here, we only provide one set of simulation results under the assumption that the channel holding time depends on the bandwidth allocated for the transmission. This can be applied to the general scenario that there is a certain amount of data to be transmitted. The more channels it possessed, the less transmission time, and vice versa. We demonstrate that ECACS yields better performance in both blocking probability and energy consumption compared to the other two schemes.

We assume the amount of data to be transmitted is exponentially distributed with mean Φ and consider a system with the total number of channels, $C = 100$ providing 2 class services. The parameters for each class are listed in Table I.

TABLE I

SIMULATION PARAMETERS.

Parameters	Class 1	Class 2
Arrival Rate: λ (call/min)	[1,40]	10
Data Volume: Φ (KByte)	180	180
Transmission Rate (Kbps/channel)	8	8
# of Channels for NPS	7	3
# of Channels for AREAS	{4,7,9}	{2,3,5}
# of Channels for ECACS	[4,9]	[2,5]

Figs. 2 and 3 depict the call blocking probability of Class 1 and Class 2 as the increase of λ_1 from 1 call/min to 40 call/min. The blocking probability of ECACS is lower than that of AREAS, which shows that ECACS can yield better performance than AREAS. They are both lower than that of NPS. And blocking probability of Class 1 is higher than the corresponding blocking probability of Class 2, because Class 1 requires more channels than Class 2.

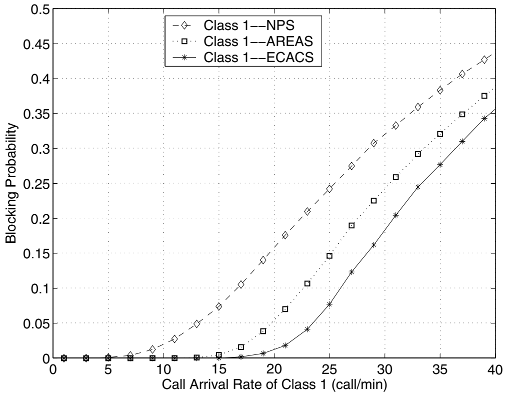

Fig. 2. Call Blocking Probability of Class 1.

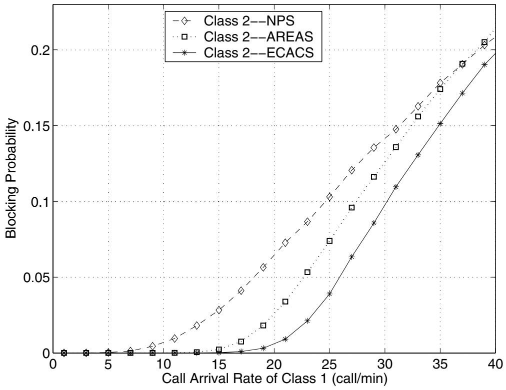

Fig. 3. Call Blocking Probability of Class 2.

Fig. 4 displays the energy consumption as a function of λ_1. Three solid lines are for Class 1, and three dotted lines are for Class 2. The two lines of NPS for Class 1 and Class 2 overlap, and the two lines of ECACS are very close to each other. We can see the energy consumption of ECACS is much smaller that that of the other two schemes.

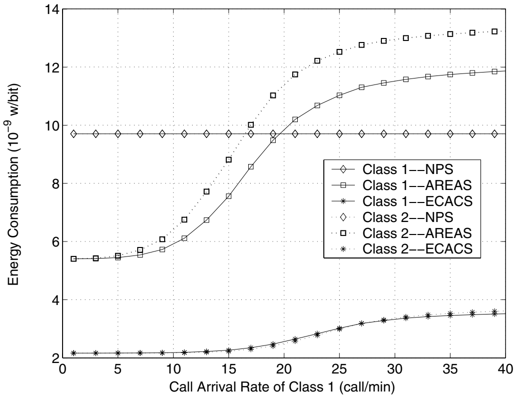

Fig. 4. Energy Consumption of Class 1 and Class 2.

VI. CONCLUSION

This paper presented a new adaptive CAC scheme, ECACS, which allows CAC to take energy conservation into account. The scheme resulted from exploring the relationship between CAC and energy consumption, i.e., energy consumption rate function (ECR). The key observation of ECR was that the same bandwidth variation of different mobile terminals may yield different rates of energy consumption. Based on the observation, we proposed a Victim Selection Algorithm and Beneficiary Selection Algorithm, which allowed resource allocation to take energy consumption into consideration. Moreover, performance of ECACS for multi-class services model was analyzed. Simulation results illustrated that lower call blocking probability and lowest energy consumption were successfully achieved by ECACS.

REFERENCES

[1] J. Hou and Y. Fang, "Mobility-based call admission control schemes for wireless mobile network," *Wireless Communications and Mobile Computing*, vol. 1, pp. 269–282, July-Sept 2001.

[2] T. Zhang, E. Berg, J. Chennikara, P. Agrawal, J. Chen, and T. Kodama, "Local Predictive Resource Reservation for Handoff in Multimedia Wireless IP Networks," *IEEE Journal on Selected Areas In Communications*, vol. 19, pp. 1931–1941, Oct 2001.

[3] Y. Fang and Y. Zhang, "Call Admission Control Scheme and Performance Analysis in Wireless Mobile Networks," *IEEE Transaction on Vehic. Technology*, vol. 51, pp. 371–382, March 2002.

[4] E. Elalfy, Y. D. Yao, and H. Heffes, "Adaptive Resource Allocation with Prioritized Handoff in Cellular Mobile Networks under QoS Provisioning," in *Vehicular Technology Conference*, vol. 4, pp. 2113 –2117, 2001.

[5] Q. Zhang, Z. Ji, W. Zhu, and Y. Zhang, "Power-Minimized Bit Allocation for Video Communication Over Wireless Channels," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 12, pp. 398–410, June 2002.

[6] Y. Eisenberg, C. E. Luna, T. N. Pappas, R. Berry, and A. K. Katsaggelos, "Joint Source Coding and Transmission Power Management for Energy Efficient Wireless Video Communications," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 12, pp. 411–424, June 2002.

[7] J. G. Proakis, "Digital Communication," *McGraw-Hill*, 2002.

[8] J. Mark and W. Zhuang, "Wireless Communications and Networking," in *Prentice Hall, NJ*, Jan 2003.

[9] A. A. Daraiseh, "New results on the performance of Reed-Solomon codes in wireless data networks," in *IEEE Vehicular Technology Conference*, vol. 2, pp. 1480–1484, July 1999.

[10] P. Ramanathan, K. M. Sivalingam, P. Agrawal, and S. Kishore, "Dynamic Resource Allocation Schemes During Handoff for Mobile Multimedia Wireless Networks," *IEEE Journal on Selected Areas in Communications*, vol. 17, pp. 1270–1283, July 1999.

[11] R. Schassberger, "The Insensititivity of Stationary Probability in Networks of Queues," *Advances in Applied Probability*, vol. 10, pp. 906–912, 1978.

[12] L. Ortigoza-Guerrero and A. H. Aghvami, "A prioritized handoff dynamic channel allocation strategy for PCS," *IEEE Transactions on Vehicular Technology*, vol. 48, pp. 1203–1215, July 1999.

[13] J. Lee, T. June, S. Yoon, S. Youm, and C. Kang, "An Adaptive Resource Allocation Mechanism Including Fast and Reliable Handoff in IP-Based 3G Wireless Networks," in *IEEE Wireless Communications*, vol. 7, pp. 42–47, Dec 2000.