IPv6-Based Dynamic Coordinated Call Admission Control Mechanism Over Integrated Wireless Networks

Sheng-Tzong Cheng and Jian-Liang Lin

Abstract—**Many wireless access systems have been developed recently to support users mobility and ubiquitous communication. Nevertheless, these systems always work independently and cannot simultaneously serve users properly. In this paper, we aim to integrate IPv6-based wireless access systems and propose a coordinated call admission control mechanism to utilize the total bandwidth of these systems to minimize the call blocking probabilities, especially the handoff call dropping probabilities. First, we propose an integrated hierarchical wireless architecture over IPv6-based networks to combine the wireless access systems including cellular systems (second-generation, General Packet Radio Service, or third-generation), IEEE 802.11 a/b/g WLAN, and Bluetooth. In the proposed architecture, mobile user can request a call with quality-of-service (QoS) requirements by any wireless network interfaces that can be accessed. When the proposed coordinated call admission control (CCAC) mechanism receives a request, it takes the QoS requirements of the incoming call and the available and reserved bandwidth of this wireless system into consideration to accept or reject this request. Besides, the mechanism can coordinate with other wireless systems dynamically to adjust the bandwidth reserved for handoff calls at each wireless system in this architecture so as to reduce the call blocking probabilities. Once the call is admitted, the mobile user is able to access heterogeneous wireless access networks via multiple interfaces simultaneously. Finally, we evaluate this system to show that the CCAC on the proposed architecture outperforms other mechanisms proposed before.**

Index Terms—**Call admission control, IPv6, quality-of-service (QoS), wireless.**

I. Introduction

SINCE the late 1980s, various wireless access systems such as second-generation (2G) cellular, IEEE 802.11 a/b/g WLAN, Bluetooth, third-generation (3G) cellular IMT-2000, and fixed wireless access (FWA) systems are increasingly popular to offer mobile users more convenient ways to access the Internet and to communicate with other users. Many access systems defined on the spectrum from several tens of megahertzs to several tens of gigahertzs were independently designed, implemented, and operated for different requirements. Therefore, it is essential to develop next-generation wireless access systems and to seamlessly integrate these wireless access systems to provide users mobile communication with quality-of-service (QoS) guarantee and mobility support.

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The authors are with the Department of Computer Science and Information Engineering, National Cheng Kung University, Tainan 701, Taiwan (e-mail: stcheng@mail.ncku.edu.tw; jenner@csie.ncku.edu.tw).

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An integrated wireless access system with three-tier hierarchical architecture is proposed in this paper. Three popular wireless access systems, Global System for Mobile Communication (GSM) [or General Packet Radio Service (GPRS), 3G], 802.11 a/b WLAN, and Bluetooth, form the three levels of the proposed architecture separately. The wireless access unit (AU) at the highest level, namely, the base station (BS), covers the largest area of services. The BS may coordinate with one or several access points (APs) of the middle level and the master devices (MDs) at the lowest level with overlapping serving areas. As a result, an IPv6-based integrated wireless network is formed to support mobile connections with various QoSs and multiple Internet protocol (IP) addresses. Namely, a user may claim a service with individual QoS requirements and each user may use more than one IP address to communicate with the AUs in this architecture (e.g., one IP address to access BS and one IP address to access AP in the hierarchical structure).

In the proposed architecture, we assume that the transmission bottleneck is the wireless link between the core network and mobile users. The AUs of these systems were stationary and connected with each other via wired IP network. Under such a context, a coordinated call admission control (CCAC) mechanism is essential to coordinate these AUs. The CCAC can accept or reject user requests depending on the QoS requirements of requesting calls and the current system load. Besides, calls can generally be categorized into new calls and handoff calls, in which a handoff call must be guaranteed to keep continuous connection for the purpose of seamless communication. To this end, our CCAC adopts the reservation mechanism of guard channel scheme and coordinates the AUs of different levels in this architecture to minimize the call blocking probabilities, especially the handoff call dropping probabilities. In addition to coordinates the AUs, a dynamic guard channel method is developed in this mechanism to reserve more bandwidth for new calls if necessary.

The rest of this paper is organized as follows. First, we present an overview of related work on the integrated IPv6 infrastructure, some QoS mechanisms over the Internet, and some wireless modeling methods in Section II. Then, we describe the proposed integrated wireless network architecture and the CCAC mechanism in Sections III and IV, respectively. In Section V, we analyze the performance of our CCAC mechanism and present analytic and simulation results about the call blocking probabilities of the proposed CCAC mechanisms and traditional methods. Finally, conclusions are drawn in Section VI.

II. Related Work

In the literature, heterogeneous networks were developed to make full use of various resources and to support a wide variety of users, applications, and access needs [1]. The heterogeneous network required a common platform that was based on a wireless-supporting IPv6 [11] to integrate different wireless access systems into a heterogeneous wireless network. The most outstanding feature of such a network was that mobile hosts could communicate over one or more wireless access networks. However, the issue of how the core network accepted one call based on its QoS requirement and the wireless resources was absent in the work.

Recent work on QoS over the Internet was primarily based on integrated services [2] and differentiated services [3]. Some QoS parameters were introduced and defined in these work on IPv6-based networks. Recently, there have been a number of call admission control mechanisms proposed to support user mobility [4], [5]. The capability of user mobility in these papers brought about the opinion that handoff calls were considered different from new calls. From the users' point of view, it is more unacceptable to be disconnected during a conversation than to be blocked at the beginning of a call. As a result, handoff calls should be treated with higher priority than new calls to minimize the handoff call dropping probability. To further decrease the handoff dropping probability, the bandwidth reservation by guard channel scheme [6] was adapted to reserve a fixed portion of the resources of each BS for handoff calls. In their work, the number of the guard channels was fixed and the mechanism did not adapt to the dynamic loading.

In other works, two guard channel assignments, the new call bounding and cutoff priority, were proposed [9]. These bandwidth reservation policies reserved a fraction of the system's total bandwidth for handoff calls. Whenever the bandwidth assigned to new calls or the bandwidth occupancy exceeded a certain threshold, the bandwidth reservation policies rejected the incoming new call. For the method of new call bounding, a threshold was set to enforce the upper bound of the total bandwidth assigned to new calls, and new calls will competed with handoff calls in the bandwidth until no available bandwidth or the total bandwidth allocated to new calls exceed the threshold. For the method of cutoff priority, a guard bandwidth is allocated to reserve a fixed portion of bandwidth to serve the handoff calls. Adopting this method, new calls compete with handoff calls in the bandwidth until the total assigned bandwidth was equal to the threshold, and a fixed portion of bandwidth was reserved for the handoff calls only.

Our paper addresses the issue of accessing the multitier wireless networks simultaneously and developing the dynamic guard bandwidth mechanism. We introduce a three-tier hierarchical architecture adopting PCS, wireless local area network (WLAN), and Bluetooth as the three wireless access systems. Besides the simulation results, we modify the models described in [7]–[10], and present an approximate model to analyze the performance of CCAC.

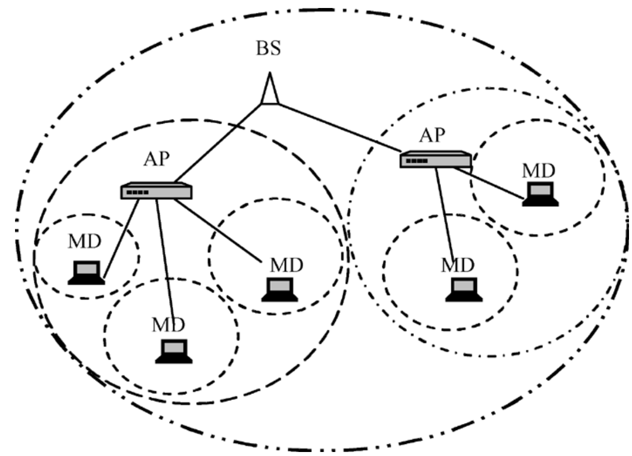

Fig. 1. Geographic configuration of the integrated wireless network.

III. Integrated Wireless Network Architecture

For the current technology of wireless communication, many wireless access systems provide convenient ways to access the Internet and to communicate with each other. These systems are designed independently, implemented, and operated to meet different requirements. But most of them cannot provide services for one user simultaneously. Consequently, wireless resources were not properly utilized and unbalanced load situations among these systems might occur. Therefore, an integrated wireless access architecture is essential to utilize the wireless resource. In addition, an appropriate call admission control mechanism is required to perform new-call admission and to provide seamless handoff among heterogeneous wireless networks. The proposed geographical network configuration is illustrated in Fig. 1. Three wireless access systems, PCS, 802.11 a/b WLAN, and Bluetooth personal area network (PAN) form the three levels of this hierarchical architecture, respectively. The BS, the AU at the highest level, covers the largest area of services. One BS may coordinate with one or several APs of the WLAN and the MDs of a Bluetooth PAN with overlapping serving areas. The lines between MD, AP, and BS mean the connections between these AUs that can communicate with each other based on the wired backbone network. Hence, the bandwidth controllers in these AUs may cooperate through these connections to admit or reject a call based on the available wireless resources and the threshold of upper level AUs. In this way, mobile users are able to use simultaneously different interfaces to access these wireless networks.

This architecture is based on an IPv6 network to guarantee the QoS requirements of every user. It also supports more than one IP address for one mobile user so that one user can access more than one wireless system simultaneously. A mobile user sends a request to establish a connection through the interfaces it has. Then, the user data flow can be spread over multiple interfaces that accept the request call in the application layer. The data packet in an IPv6 network has a QoS header to support the user to make a request with some QoS parameters, and the addressing space is larger than the addressing space of IPv4 networks to support rapid growth of the addresses assigned to mobile devices. On the top of an IPv6 network, a suitable call admission control mechanism is required to control the traffic and

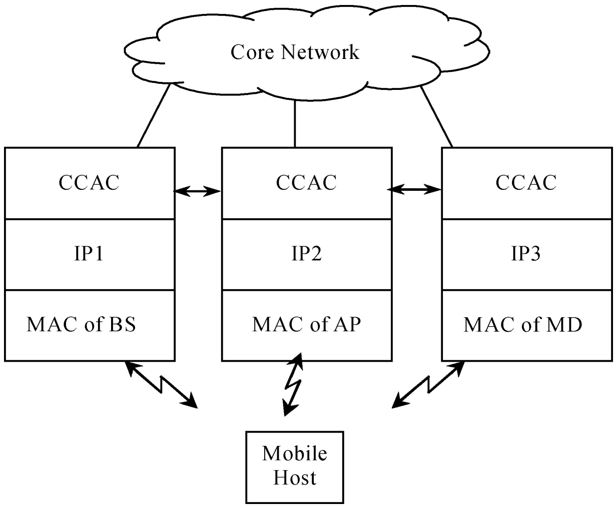

Fig. 2. Multiple access model and control mechanism of the integrated hierarchical wireless network.

system load. An CCAC mechanism is exploited here in this integrated hierarchical architecture that is shown in Fig. 2 to utilize the wireless resources of these systems efficiently and to guarantee the QoS requirements of every user with a minimal call dropping probability.

When a mobile user originates a call, the request with the QoS requirement is sent to the CCAC mechanism of the AU at the lowest level. We consider the bandwidth to be the primary QoS requirement in this paper. The CCAC of BS is the highest level and the CCAC of MD is the lowest level in this hierarchical architecture. When a CCAC receives a request message, it can coordinate with the other CCACs at different level if necessary, and decide whether the incoming call shall be accepted or rejected, based on the QoS requirement of this call and the available resources in every CCAC of AUs. For an admitted call, the bandwidth that is assigned by the AUs at three levels are allocated as well.

IV. Call Admission Control Protocol

Call admission control is one of the key elements to ensure the QoS in wireless networks. A call admission control policy not only can ensure that the network meets the QoS requirements of newly accepted calls, but also guarantee the QoS requirements of existing calls if they move across cells in their lifetime. In this paper, we consider the bandwidth resources to be the primary QoS requirements.

Based on the integrated wireless network architecture, an CCAC mechanism is developed. The CCAC can coordinate the MDs, APs, and BSs in the integrated wireless network to utilize the total bandwidth more efficiently. If an incoming call cannot be admitted by a lower CCAC, the lower CCAC will send insufficient bandwidth request to its upper CCAC to obtain enough bandwidth. In literature, two coordinated guard channel mechanisms, static coordinated new call bounding (CNCB) and static coordinated cutoff priority (CCFP), are proposed in which the threshold and guard bandwidth are fixed. To improve the performance based on the network condition, the dynamic guard bandwidth adjusting functions are proposed here. These methods can change the threshold or guard bandwidth dynamically based on the load of the integrated wireless network.

A. *Coordinated Call Admission Control (CCAC) Mechanism*

A CCAC mechanism is proposed to guarantee the QoS requirement of users in the integrated architecture described in Section III. When a user makes a call, the request is sent to the AU at the lowest level in the wireless access networks. The CCAC of the network in the lowest level of the architecture that receives the request makes decision based on the QoS requirements of this call and the available bandwidth of the network. If the CCAC of the network cannot admit this request because the available bandwidth is insufficient, it send an bandwidth shortage request to the CCAC of the network in the higher level and the CCAC will try to support the remaining portion of the request. If, after coordination with upper levels, the network cannot satisfy the QoS requirement of this incoming call, then the call is rejected. On the contrary, the call is admitted and may be served by more than one wireless network.

Each call can be viewed as a new call in the cell where it is initiated or a handoff call that is moving into the cell. A handoff call should have higher priority to obtain bandwidth for seamless communication. For this reason, the idea of guard channel can be used to reserve some bandwidth to serve the handoff call. In this paper, two types of CCAC mechanisms are developed, one is CCAC with new call bounding (CNCB) and the other is CCAC with CutofF priority (CCFP). The two types of mechanisms are designed to fit in the characteristics of the proposed integrated architecture in which the reserved resource is in terms of bandwidth instead of the number of channels.

The methods of CNCB and CCFP are illustrated in Figs. 3 and 4, respectively, and the notations used in these figures are described as follows. Given an AU_i, let the threshold T_i be the bound of the total bandwidth of all accepted new calls, the bandwidth G_i be the guard channel or the bandwidth reserved for the handoff calls, and C_i be the total available bandwidth. The notations of r, N_i, and A_i indicate the required bandwidth of the incoming call, the total bandwidth of accepted new calls, and the total bandwidth of all calls handled by the AU_i, respectively.

In Fig. 3, when the AU_i receive an incoming call request, the CCAC determines whether this incoming call is a new call or a handoff call first. If the incoming call is a new call and the total bandwidth of accepted new calls plus the bandwidth requirement of this incoming call is less or equal than the threshold, this call request is accepted. Otherwise, a bandwidth shortage request will be sent to the upper AU recursively for shortage bandwidth allocation until no upper AU can be sent and the call will be rejected. To decrease the new call blocking probability, we introduce the adjusting method to change the threshold of CNCB and the guard of CCFP in next section. If the method is involved, a new call may be admitted because of the larger threshold or the smaller guard. If the incoming call is a handoff call and the available bandwidth is insufficient to support the requirement of this incoming call, a bandwidth shortage request will be sent to upper AU until no upper AU can be sent and the call will be rejected. On the contrary, the incoming call is accepted.

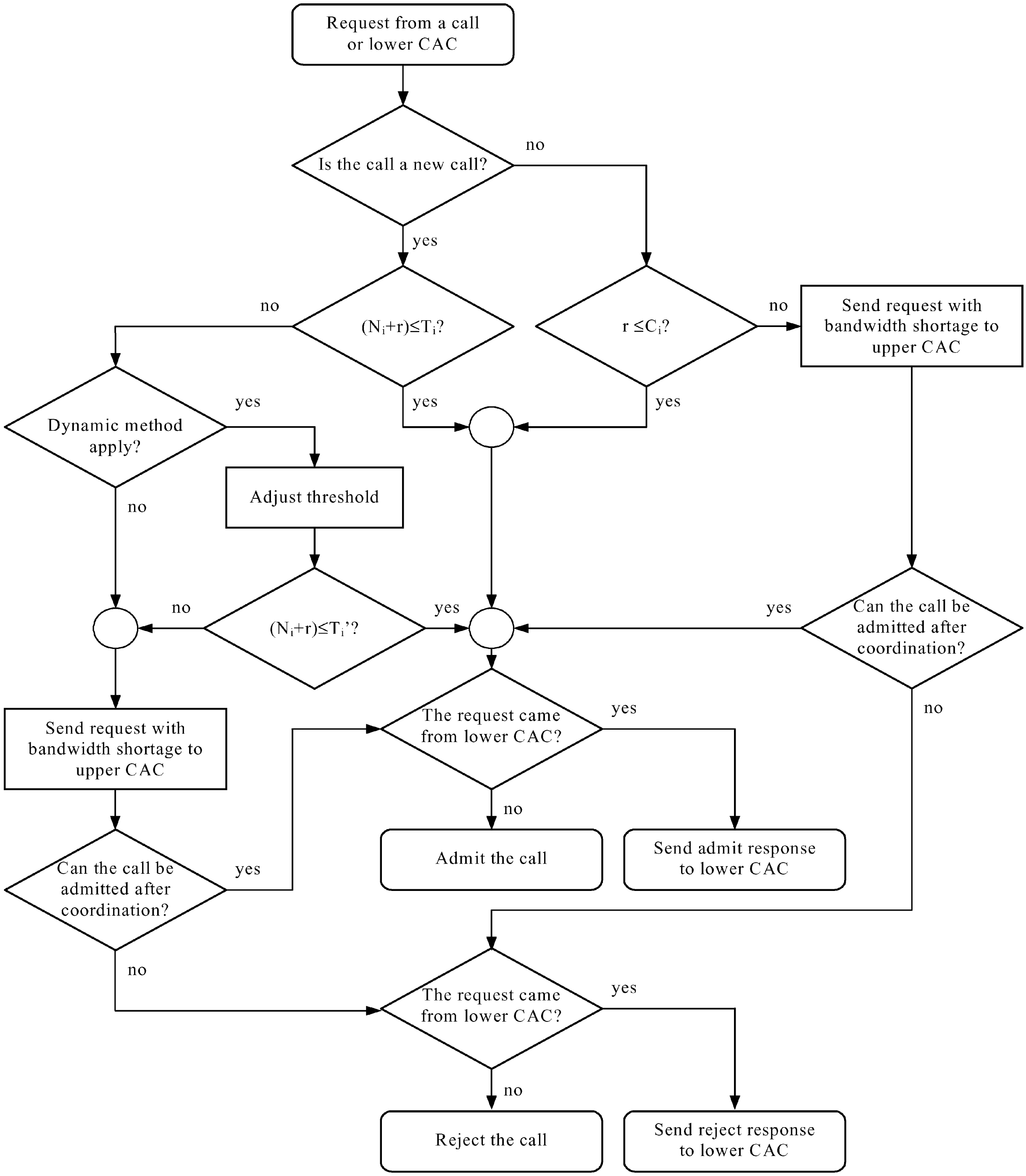

Fig. 3. CCAC with new call bounding (CNCB).

The flow chart of CCFP is presented in Fig. 4. The most significant difference between CNCB and CCFP lies in the way of processing an incoming new call. When the CNCB method is employed, the incoming new call will be accepted if the total bandwidth of all accepted new calls is less than the threshold T_i. On the other hand, in the CCFP method, the incoming new call will be rejected only if the remaining bandwidth reserving for the handoff calls is less than the guard G_i.

B. Dynamic CNCB

The guard channel policy, reserving bandwidth for handoff calls only, may reduce the bandwidth utilization and increase the blocking probabilities of new calls. When the threshold takes up most of the capacity, the handoff call dropping probabilities may increase. On the other hand, when the threshold holds less of the capacity, the new call blocking probabilities may increase and the system utilization may decrease. To increase the bandwidth utilization and decrease the new call blocking probabilities, the dynamic guard bandwidth adjustment is proposed in our CCAC mechanisms. The CNCB with adjustment (D-CNCB) can dynamically change the threshold based on the load of the AUs at the same level. When the threshold is revised, the new call requests may be accepted for the relaxed limitation of threshold. The D-CNCBs are introduced next.

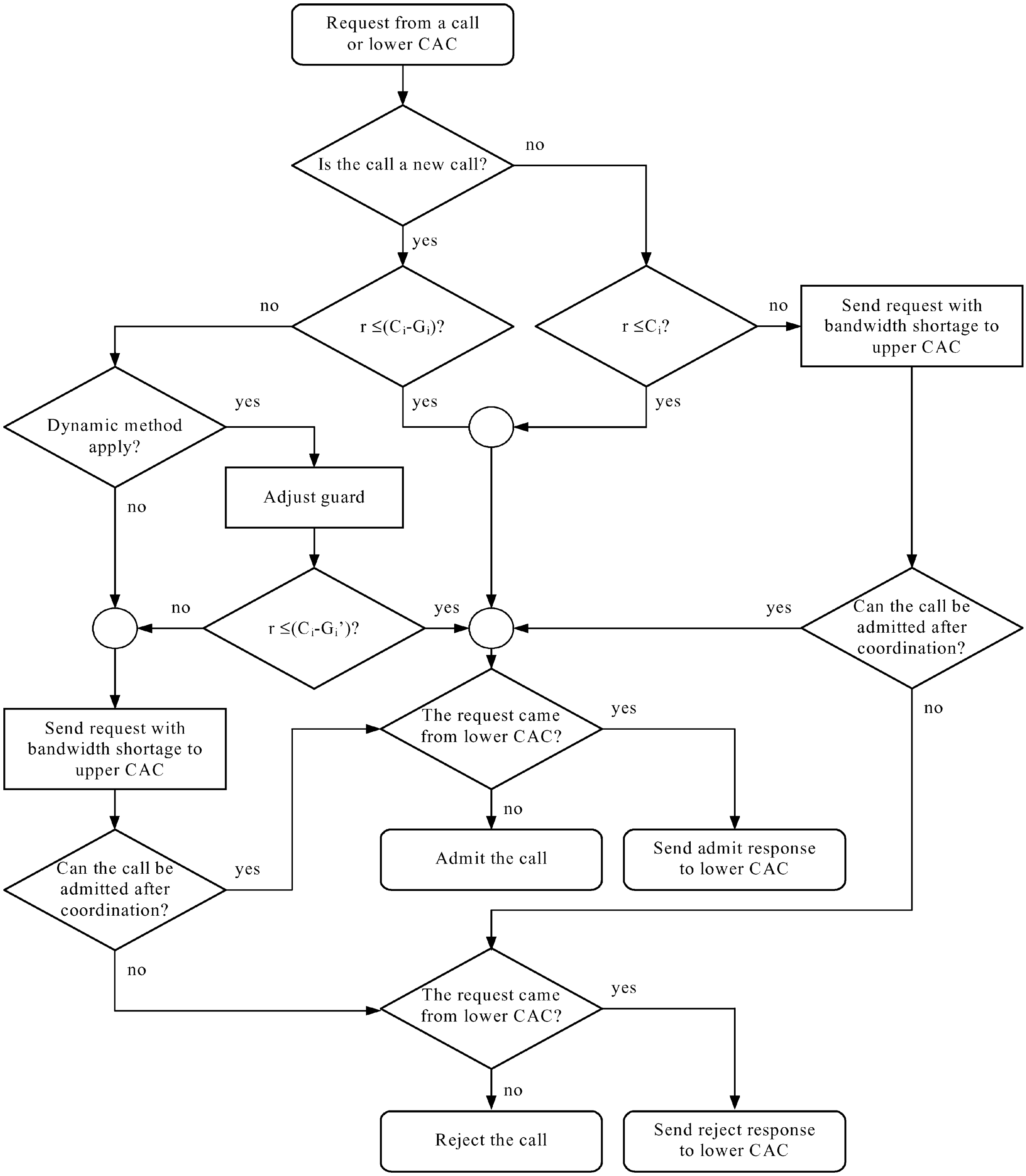

Fig. 4. CCAC with cutoff priority (CCFP).

1) Adjusting Method 1 (D-CNCB1): Let AU_i indicate the AU that receives the incoming new call request and AU_j denote an AU at the same level of the AU that receives the incoming new call request in which j is the identifier of AU. The first adjusting method utilizes the information of average handoff rate and the total assigned bandwidth of all AU_j. According to the information, we could predict the total bandwidth requirement of the AU_i at next assignment point if the request is accepted. The idea of this method is that when the traffic load of other AUs at the same level of the AU_i is much lighter, the predicted requirement of the handoff calls of the AU_i will be less than the bandwidth assigned to the handoff calls of the AU_i now. Therefore, if the predicted requirement can be fulfilled, the threshold will be increased provisionally to accept this new call request. The A_j and λh_j indicate the total bandwidth assigned to the calls handled in AU_j and the handoff rate of AU_j, respectively. The number of AU_j is defined to be n_i. The adjusting function is described in (1)

$$T_i' = \begin{cases} N_i + r, & \text{if } \left(\left(\sum_j A_j \lambda h_j \le n_i A_i \lambda h_i\right) \&\& \left((A_i + r) \le C_i\right)\right) \\ T_i, & \text{otherwise} \end{cases}. \quad (1)$$

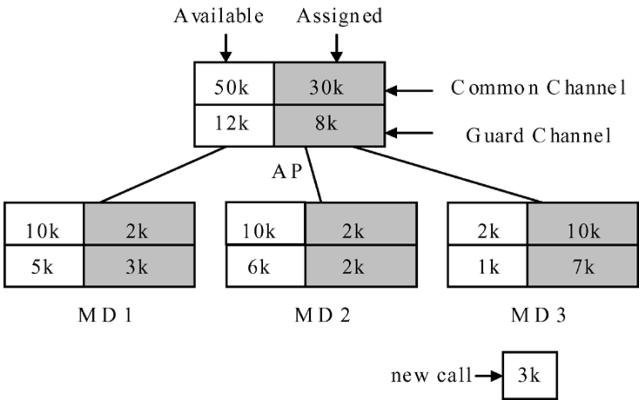

Fig. 5. Example of adjusting method.

2) Adjusting Method 2 (D-CNCB2): On account of the difficulties and complexities in gathering and storing the information of the handoff rate, the second approach is introduced to simplify the adjusting method 1. We assume that the handoff rates of all AUs are identical. Consequently, (1) can be modified as (2) below

$$T'_i = \begin{cases} N_i + r, & \text{if } \left(\left(\sum_j A_j \le n_i(A_i + r)\right) \&\& ((A_i + r) \le C_i)\right) \\ T_i, & \text{otherwise} \end{cases}. \tag{2}$$

An example is illustrated in Fig. 5. The threshold T is set as 10 kb/s and one mobile host in MD3 is requesting for 3 kb/s. It is obvious that MD3 cannot satisfy the request and must reject the call if the fixed guard bandwidth method is used. However, we can observe that MD1 and MD2 are underutilized. Therefore, the adjusting method can be performed in which $A_1\ (5\ \mathrm{kb/s}) \le [A_3 + r]\ (17\ \mathrm{kb/s})$ and $A_2\ (6\ \mathrm{kb/s}) \le [A_3 + r]\ (17\ \mathrm{kb/s})$, and the threshold T'_3 is set to 13 kb/s temporarily. As a result, the new call can be admitted then.

C. Dynamic CCFP

The dynamic CCFP changes the guard bandwidth reserving for the handoff calls based on the traffic load of the neighboring cells. The CCFP with the adjustment methods are introduced next.

1) Adjusting Method 1 (D-CCFP1): Dynamic CCFP1 needs the information of average handoff rate and the total assigned bandwidth of all AU_j to admit more new calls. According to the adjusting method, the D-CCFP will obtain more available bandwidth to accept the incoming new call on account of decreasing the guard bandwidth of the AU_i temporarily. The adjusting function is described in (3) shown at the bottom of the page.

2) Adjusting Method 2 (D-CCFP2): The D-CCFP2 takes the information of the total allocated bandwidth of all AU_j into account to dynamically change the guard bandwidth of the AU_i. When the allocated bandwidth of every AU_j is less than the allocated bandwidth of the AU_i if the new call is accepted, the available bandwidth of the AU_i in the next decision point will be larger than the requirement of the handoff calls. It means that no handoff calls will be dropped in the next decision point if we admit the new call now. In Fig. 5, we can observe that the resources of MD3 is insufficient to accept this new call because the the total guard bandwidth G_3 is 1 kb/s. When the D-CCFP2 is performed, since $A_1 \le A_3 + r$ and $A_2 \le A_3 + r$, the guard bandwidth of MD3 can be 0 kb/s temporarily. Therefore, the new call can be accepted and will not interrupt any handoff call in the next decision point. The adjusting function of D-CCFP2 is presented in (4) shown at the bottom of the page.

V. Performance Analysis

In this section, we develop the analytic model and evaluate the performance of proposed methods. We compare the simulation results of the ordinary CAC and the proposed CCAC mechanisms. In Sections V-A and V-B, we introduce the system model and traffic model that is used throughout the paper. In Sections V-C and V-D, we describe in details the analytic models of the CNCB and the CFCP mechanism, respectively. Finally, we provide the corresponding results in Section V-E.

A. System Model

In this system, a slot is the basic unit of QoS requirement. Without loss of generality, we assume that the capacity C of an AU is in terms of the number of slots. Since the AUs at the same level can be assumed to be homogeneous, the performance can be deduced from the performance of a single cell analyzed in isolation. The parameters of the system model we used are described in Table I.

$$G'_i = \begin{cases} C_i - (A_i + r), & \text{if } \left(\left(\sum_j A_j \lambda h_j \le n_i A_i \lambda h_i\right) \&\& ((A_i + r) \le C_i)\right) \\ G_i, & \text{otherwise} \end{cases} \tag{3}$$

$$G'_i = \begin{cases} C_i - (A_i + r), & \text{if } \left(\left(\sum_j A_i \le n_i(A_i + r)\right) \&\& ((A_i + r) \le C_i)\right) \\ C_i, & \text{otherwise} \end{cases} \tag{4}$$

TABLE I
PARAMETERS OF SYSTEM MODEL

Parameter	Description
C	The total capacity
n	The number of lower-level AUs that were covered by AU_i
η_n	New call arrival rate from the AUs that covered by AU_i
η_h	Handoff call arrival rate from the AUs that covered by AU_i
$E[N_c]$	Average number of calls that are holding channels in a cell
P_n	The new call blocking probability
P_h	The handoff call dropping probability

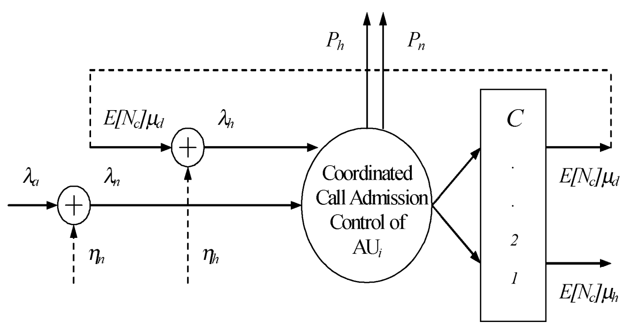

Fig. 6. Coordinated call admission control scheme.

Fig. 6 provides a schematic representation of the proposed approach. Let C denote the capacity of AU_i. P_n and P_h denote the blocking probabilities of new calls and handoff calls of AU_i, respectively. If AU_i is at the highest level in this system, the blocking probabilities P_n and P_h will be the performance criteria that we need. Otherwise, the blocking probabilities P_n and P_h will be the parameters of the input traffic load of upper AU. Since the CCAC of AU could send request to the CCAC of upper AU when request was rejected, the arrival process of blocked new and handoff calls are assumed to be Poisson. Let n denotes the number of AUs that were covered by AU_i if AU_i is not at the lowest level in this system. From the assumptions, we obtain that the arrival process for blocked new calls and handoff calls from lower level are all Poisson with mean arrival rate η_n and η_h that are given by

$$\eta_n = \begin{cases} nP_n\lambda_n, & \text{if } AU_i \text{ is not at the lowest level} \\ 0, & \text{if } AU_i \text{ is at the lowest level} \end{cases} \tag{5}$$

$$\eta_h = \begin{cases} nP_h\lambda_h, & \text{if } AU_i \text{ is not at the lowest level} \\ 0, & \text{f } AU_i \text{ is at the lowest level} \end{cases}. \tag{6}$$

B. Traffic Model

The traffic model makes the commonly used assumptions that new calls are generated according to independent Poisson process with mean arrival rate λ_a. Furthermore, the mean call holding time is exponentially distributed with mean $1/\mu_h$. The mean dwelling times in a cell, that is, the time spent in one cell before handoff to a neighboring cell, is also exponentially distributed with mean $1/\mu_d$. The parameters of traffic model are listed in Table II.

TABLE II
PARAMETERS OF TRAFFIC MODEL

Parameter	Description
λ_a	Call arrival rate with Poisson distribution
T_n	Call holding time that have an exponential distribution with mean $E[T_h]=1/\mu_h$
λ_h	Handoff call arrival rate with Poisson distribution
T_d	Call dwelling time that have an exponential distribution with mean $E[T_d]= 1/\mu_d$

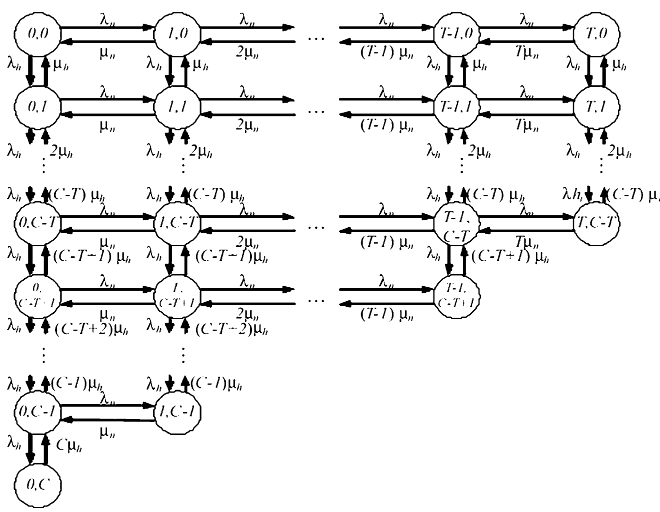

Fig. 7. Transition diagram of the CNCB mechanism.

In Fig. 6, it is obviously that the mean arrival rate of new calls and handoff calls are given by

$$\lambda_n = \begin{cases} \lambda_a+\eta_n, & \text{if } AU_i \text{ is not at the lowest level} \\ \lambda_a, & \text{if } AU_i \text{ is at the lowest level} \end{cases} \tag{7}$$

$$\lambda_h = \begin{cases} E[N_c]\times\mu_d+\eta_h, & \text{if } AU_i \text{ is not at the lowest level} \\ E[N_c]\times\mu_d, & \text{if } AU_i \text{ is at the lowest level} \end{cases}. \tag{8}$$

C. CNCB Mechanism

Fig. 7 indicates the state transition diagram of the CNCB mechanism in an AU. T denotes the threshold of slots that could be assigned to the new calls. This diagram of the two-dimensional Markov chain is formed with the state space $S = \{(n_n, n_h) \mid 0 \le n_n \le T, (n_n+n_h) \le C\}$, where n_n is the number of new calls and n_h is the number of handoff calls in the cell.

Let $\rho_n = \lambda_n/\mu_d + \mu_h$ and $\rho_h = \lambda_h/\mu_d$. From the detailed balance equation, we obtain

$$P(n_n, n_h) = \frac{\rho_n^{(n_n)} \times \rho_h^{(n_h)} \times P(0,0)}{n_n! \times n_h!} \tag{9}$$

for $0 \le n_n \le T$, $n_n + n_h \le C$, $n_h \ge 0$, and from the normalization equation, we obtain

$$P(0,0) = \frac{1}{\sum_{n_n=0}^{T} \sum_{n_h=0}^{C-n_n} \frac{\rho_n^{(n_n)} \times \rho_h^{(n_h)}}{n_n! \times n_h!}}. \tag{10}$$

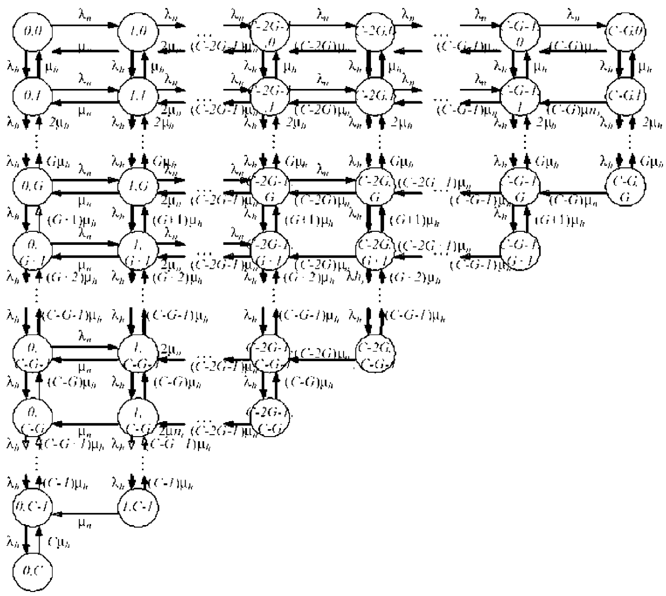

Fig. 8. Transition diagram of the CCFP mechanism.

From (10), we can derive the equations of new call blocking probability and handoff call dropping probability as follows:

$$\begin{aligned} p_n &= \sum_{(n_n=T)or(n_n+n_h=C)} P(n_n,n_h) \\ &= P(0,0)\left(\sum_{n_h=0}^{C-T}\frac{\rho_n^T\rho_h^{(n_h)}}{T!n_h!}+\sum_{n_h=C-T+1}^{C}\frac{\rho_n^{(C-n_h)}\rho_h^{(n_h)}}{(C-n_h)!n_h!}\right) \end{aligned} \quad (11)$$

$$p_h = \sum_{n_n+n_h=C} P(n_n,n_h) = P(0,0)\sum_{n_h=C-T}^{C}\frac{\rho_n^{(C-n_h)}\rho_h^{(n_h)}}{(C-n_h)!n_h!}. \quad (12)$$

D. CCFP Mechanism

The state transition diagram of the CCFP mechanism is shown in Fig. 8. We can observe that in some states, the flows are no longer symmetric. It can be solved by some global balance equations to find the steady-state probabilities. But as we mentioned before, solving the global balance equations may be computationally intensive when the dimension is large. For this reason, we present an approximation that can obtain results with fewer errors. We choose the state $S = \{(n_n,n_h) \mid (C-1) \geq (n_n+n_h) \geq (C-G+1)\}$ in which the flows that move into or from this state are asymmetrically. For local equilibrium, we observe that the flows of handoff calls can be regared as symmetrically, and we can obtain the following equation for the approximate model:

$$\begin{aligned} P(n_n,n_h)&\times n_n\times(\mu_d+\mu_h) \\ &= P(n_n+1,n_h)\times(n_n+1)\times(\mu_d+\mu_h) \\ &\Rightarrow P(n_n,n_h) = \left[\frac{(n_n+1)}{n_n}\right]\times P(n_n+1,n_h) \end{aligned} \quad (13)$$

when $n_n \to \infty$, $P(n_n,n_h) \approx P(n_n+1,n_h)$.

From this approximation, we can obtain the following stationary distribution for this model:

$$P(n_n,n_h) = \begin{cases} \frac{\rho_n^{(n_n)}\times\rho_h^{(n_h)}\times P(0,0)}{n_n!\times n_h!}, & \text{if } 0\leq n_n+n_h\leq C-G \\ P(\max(C-G-n_h,0),n_h), & \text{if } C-G\leq n_n+n_h\leq C \end{cases} \quad (14)$$

where

$$\begin{aligned} P(0,0) &= \sum_{n_n+n_h=0}^{C-G-1}\frac{\rho_n^{(n_n)}\times\rho_h^{(n_h)}}{n_n!\times n_h!} \\ &\quad + \sum_{n_h=0}^{G-1}(n_h+1)\times\frac{\rho_n^{(C-G-n_h)}\times\rho_h^{(n_h)}}{(C-G-n_h)!\times n_h!} \\ &\quad + \sum_{n_h=G}^{C-G}(G+1)\times\frac{\rho_n^{(C-G-n_h)}\times\rho_h^{(n_h)}}{(C-G-n_h)!\times n_h!} \\ &\quad + \sum_{n_h=C-G+1}^{C}(C-n_h+1)\times\frac{\rho_h^{(n_h)}}{n_h!}. \end{aligned} \quad (15)$$

And from this stationary distribution, we can obtain the new call blocking probability and handoff call dropping probability as follows:

$$\begin{aligned} p_n &= \sum_{n_n+n_h=G}^{C} P(n_n,n_h) = P(0,0) \\ &\quad \times\left(\sum_{n_h=0}^{G-1}(n_h+1)\times\frac{\rho_n^{(C-G-n_h)}\times\rho_h^{(n_h)}}{(C-G-n_h)!\times n_h!}\right. \\ &\quad + \sum_{n_h=G}^{C-G}(G+1)\times\frac{\rho_n^{(C-G-n_h)}\times\rho_h^{(n_h)}}{(C-G-n_h)!\times n_h!} \\ &\quad \left. + \sum_{n_h=C-G+1}^{C}(C-n_h+1)\times\frac{\rho_h^{(n_h)}}{n_h!}\right) \end{aligned} \quad (16)$$

$$\begin{aligned} p_h &= \sum_{n_n+n_h=C} P(n_n,n_h) = P(0,0) \\ &\quad \times\left(\sum_{n_h=G}^{C-G}\frac{\rho_n^{(C-G-n_h)}\times\rho_h^{(n_h)}}{(C-G-n_h)!\times n_h!}+\sum_{n_h=C-G+1}^{C}\frac{\rho_h^{(n_h)}}{n_h!}\right). \end{aligned} \quad (17)$$

E. Analytic and Simulation Results

We present numerical and simulation results to show the performance of the proposed call admission control mechanisms in this section. We consider a system with one BS, two APs, and seven MDs, where three MDs were covered by one AP, and the other four MDs were covered by the other AP. The QoS requirement of each call is one slot. We choose the following set of parameters for all AUs: $C = 30$, $T = 20$, $G = 10$, and $\mu_h = \mu_d = 0.01$. λ_a of APs and BS equal to 0.01, and λ_a of MDs is varying from 0.1 to 0.6. It means that the new call traffic load ρ_n varies from 10 to 60.

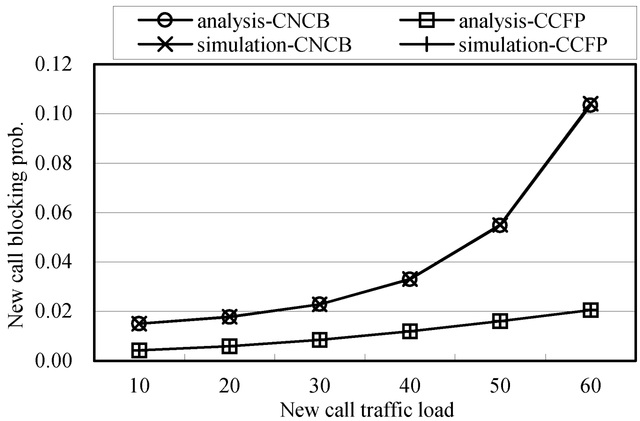

Fig. 9. New call blocking probabilities of analysis and simulation results.

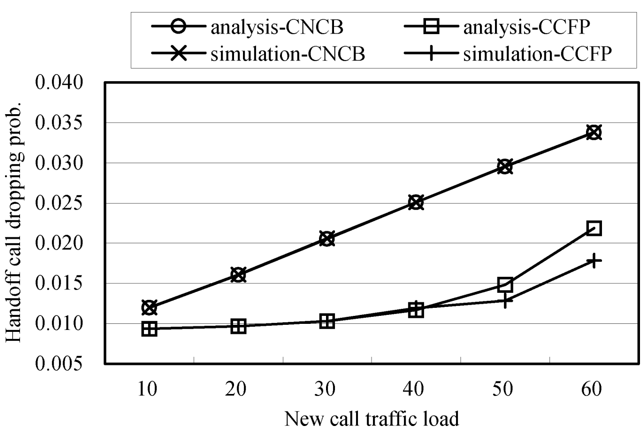

Fig. 10. Handoff call dropping probabilities of analysis and simulation results.

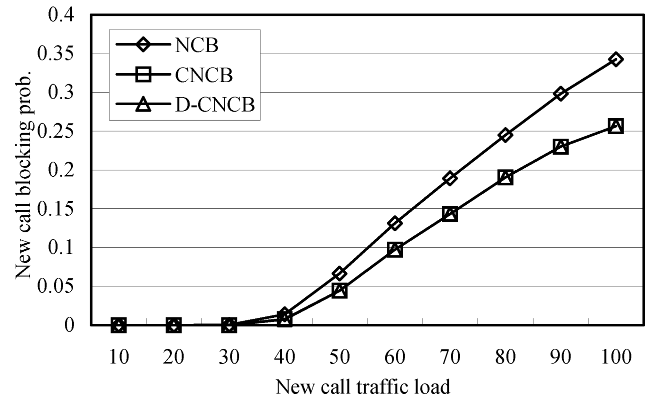

Fig. 11. New call blocking probabilities of different NCBs.

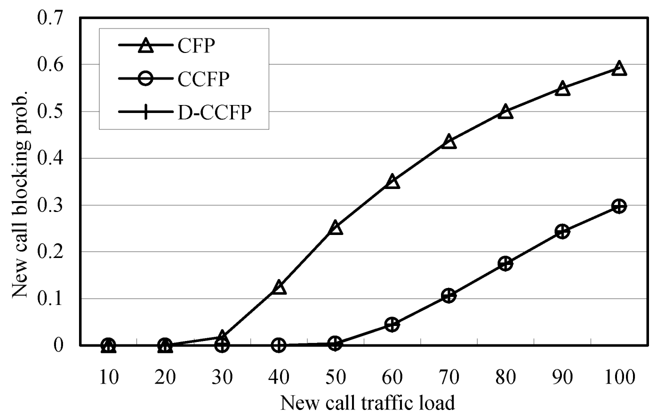

Fig. 12. New call blocking probabilities of different CFPs.

Figs. 9 and 10 show the new call blocking probabilities and handoff call dropping probabilities of analysis-CNCB, analysis-CCFP, simulation-CNCB, and simulation-CCFP versus the new call traffic load, respectively. In Fig. 9, we observe that the new call blocking probability of analysis-CNCB is almost the same as the new call blocking probability of simulation-CNCB. But the new call blocking probability of analysis-CCFP is a little larger than the simulation-CCFP on account of the approximation.

In Fig. 10, we observe that the handoff call dropping probability of the simulation-CNCB is almost the same as the handoff call dropping probability of the analysis-CNCB, and the difference in the handoff call dropping probability between the analysis-CCFP and the simulation-CCFP is larger than the difference in the new call blocking probability between these two methods. We also obtain that if the traffic load increases, the difference in the handoff call dropping probability between analysis-CCFP and simulation-CCFP will increase slightly. Nevertheless, the analysis results still can prove the correctness of our simulation results in substance.

In the simulation, we choose the following set of parameters for all AUs: $C = 50$, $T = 40$, $G = 10$, $\mu_h = \mu_d = 0.01$. λ_a of APs and BS equal to 0.01, and λ_a of MDs is varying from 0.1 to 1.0. It means that the new call traffic load ρ_n varies from 10 to 100. In Figs. 11 and 12, we conduct simulations to compare the new call blocking probabilities of NCB, CNCB, D-CNCB, and CFP, CCFP, D-CCFP, respectively. Figs. 13 and 14 depict the handoff call dropping probabilities of NCB, CNCB, D-CNCB, and CFP, CCFP, D-CCFP, respectively.

From Fig. 11, we observe that the new call blocking probability of NCB is higher than the new call blocking probabilities of CNCB and D-CNCB when the traffic load changes from 10 to 100. The D-CNCB performs a little better than the CNCB when the traffic load is light and the new call blocking probabilities of these two methods will tend to be the same value if the traffic load increases. For example, when new call traffic load equals to 50, the new call blocking probabilities of the NCB, CNCB, and D-CNCB are 0.066 566, 0.044 159, and 0.044 098, respectively. But when new call traffic load equals to 90, the new call blocking probabilities of the NCB, CNCB, and D-CNCB become to 0.298 21, 0.230 152, and 0.230 151, respectively. That makes sense because when the traffic loads of neighboring AUs are heavy, the predicted requirement of handoff calls in next decision point will be larger than the assigned bandwidth now. Therefore, the adjusting method cannot change the threshold to accept the new call.

From Fig. 12, we observe that the methods of CCFP and D-CCFP perform much better than the method of CFP when the traffic load changes from 10 to 100. In addition, the D-CCFP also performs a little better than the CCFP when the traffic load is light and the new call blocking probabilities of these two methods will tend to be the same value if the traffic load increases. For example, when new call traffic load equals to 50, the new call blocking probabilities of the CFP, CCFP, and D-CCFP are 0.252 662, 0.003 855, and 0.003 683, respectively. But when

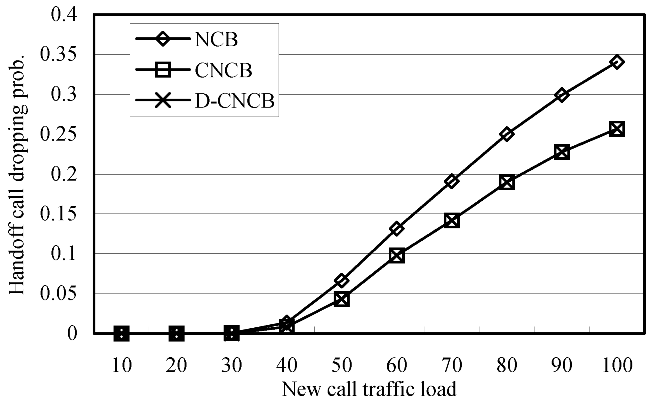

Fig. 13. Handoff call dropping probabilities of different NCBs.

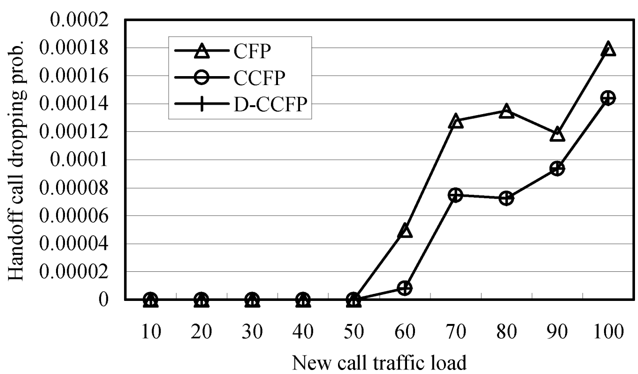

Fig. 14. Handoff call blocking probabilities of different CFPs.

new call traffic load equals to 90, the new call blocking probabilities of the NCB, CNCB, and D-CNCB become to 0.550 158, 0.242 956, and 0.242 956, respectively. The D-CCFP performs almost the same as the CCFP does when the traffic load changes from 90 to 100.

Figs. 13 and 14 show the handoff call dropping probabilities of NCB, CNCB, D-CNCB, and CFP, CCFP, D-CCFP, respectively. In Fig. 13, we observe that the handoff call dropping probabilities of CNCB and D-CNCB always smaller than the handoff call dropping probability of NCB when new call traffic load changes from 10 to 100, and we also note that the CNCB performs almost the same as D-CNCB does. For example, when the traffic load equals to 30, the handoff call dropping probabilities of NCB, CNCB, and D-CNCB are 0.000 238, 0.0002, and 0.000 199, respectively, and when the traffic load equals to 100, the handoff call dropping probabilities of NCB, CNCB, and D-CNCB are 0.340 511, 0.256 794, and 0.256 793, respectively. It indicates that the adjusting method will not increase the handoff call dropping probabilities.

In Fig. 14, we can also observe that the CCFP and D-CCFP perform much better than the CFP when the traffic load varies from 10 to 100. And the handoff call dropping probabilities of these methods are much smaller than the handoff call dropping probabilities of NCB, CNCB, and D-CNCB. Once again, we found that the handoff call dropping probability of D-CCFP almost the same as the handoff call dropping probability of CCFP. From Figs. 13 and 14, we found that D-CNCB and D-CCFP always perform as better as CNCB and CCFP do and will decrease the new call blocking probabilities slightly that were shown in Figs. 11 and 12.

VI. Conclusion

The presented architecture provides an approach to enable the efficient use of accessible wireless systems. The basic concept is that the services especially the data services can be delivered via more than one wireless access system. Using different wireless access interfaces to deliver the user data can support better QoS and guarantee the QoS requirement with seamless communication. Besides, a CCAC is proposed to utilize the resources using dynamic guard bandwidth policy that can minimize the new call blocking probabilities and the handoff call dropping probabilities.

We can derive from the results of our simulation that a CCAC utilizes the total bandwidth and decreases the call blocking probability thanks to the coordination among these wireless access systems. Besides, to support user seamless mobility, the CCAC use guard bandwidth reserved for the handoff calls. Using the guard bandwidth decreases the handoff call dropping probability. The methods of adjusting the guard bandwidth dynamically for admitting new calls and handoff calls, respectively, are exploited in the CCAC, and the simulation results demonstrate that the CCAC we proposed can reduce the call blocking probability and utilize the systems bandwidth as well.

References

[1] G. Wu, M. Mizuno, and P. J. M. Havinga, "MIRAI architecture for heterogeneous network," *IEEE Commun. Mag.*, vol. 40, no. 2, pp. 126–134, Feb. 2002.
[2] R. Braden, D. Clark, and S. Shenker, "Integrated services in the Internet architecture: An overview," IETF, RFC 1663, 1994.
[3] S. Blake *et al.*, "An Architecture for Differentiated Services," IETF, RFC 2475, 1998.
[4] N. Montavont and T. Noel, "Handover management for mobile nodes in IPv6 networks," *IEEE Commun. Mag.*, vol. 40, no. 8, pp. 38–43, Aug. 2002.
[5] S. Dixit, Y. Guo, and Z. Antoniou, "Resource management and quality of service in third-generation wireless networks," *IEEE Commun. Mag.*, vol. 39, no. 2, pp. 125–133, Feb. 2002.
[6] O. T. W. Yu and V. C. M. Leung, "Adaptive resource allocation for prioritized call admission over an ATM-based wireless PCN," *IEEE J. Sel. Areas Commun.*, vol. 15, no. 7, pp. 1208–25, Sep. 1997.
[7] Y. Fang and Y. Zhang, "Call admission control schemes and performance analysis in wireless mobile networks," *IEEE Trans. Veh. Technol.*, vol. 51, no. 2, pp. 371–382, Mar. 2002.
[8] Q.-A. Zeng and D. P. Agrawal, "Modeling of handoffs and performance analysis of wireless data networks," in *Proc. IEEE Int. Conf. Parallel Processing Workshops*, Sep. 3–7, 2001, pp. 491–496.
[9] J. Hou, J. Yang, and S. Papavassiliou, "Integration of pricing with call admission control to meet QoS requirements in cellular networks," *IEEE Trans. Parallel Distrib. Syst.*, vol. 13, no. 9, pp. 898–910, Sep. 2002.
[10] W. Zhuang, B. Bensaou, and K. C. Chua, "Adaptive quality of service handoff priority scheme for mobile multimedia networks," *IEEE Trans. Veh. Technol.*, vol. 49, no. 2, pp. 494–505, Mar. 2000.
[11] S. Deering and R. Hinden, "Internet protocol, version 6 (IPv6) specification," IETF, RFC 2460, 1998.
[12] T. S. Rappaport, *Wireless Communications Principles and Practice*. Englewood Cliffs, NJ: Prentice-Hall, 2002.

Sheng-Tzong Cheng received the B.S. and M.S. degrees in electrical engineering from National Taiwan University, Taipei, Taiwan, in 1985, 1987, respectively, and the M.S. and Ph.D. degrees in computer science from the University of Maryland, College Park, in 1993 and 995, respectively.

He was an Assistant Professor of Computer Science and Information Engineering at National Dong Hwa University, Hualien, Taiwan, in 1995, and became an Associate Professor in 1996. He is currently a Professor in the Department of Computer Science and Information Engineering, National Cheng Kung University, Tainan, Taiwan. His research interests are in design and performance analysis of mobile computing, wireless communications, multimedia, and real-time systems.

Jian-Liang Lin received the B.S. degree in computer science and information engineering from National Chiao-Tung University, Hsin-Chu, Taiwan, in 1995. Currently, he is working towards the Ph.D. degree in computer science at National Cheng-Kung University, Tainan, Taiwan.

His research interests include wireless networks and mobile computing, particularly, the radio resource management in the 3G cellular systems.