WIRELESS COMMUNICATIONS AND MOBILE COMPUTING
Wirel. Commun. Mob. Comput. 2009; **9**:489–499
Published online 24 September 2008 in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/wcm.691

Efficient call admission control scheme for 4G wireless networks

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Summary

Next generation wireless networks (NGWNs) will utilize several different radio access technologies, seamlessly integrated to form one access network. This network has the potential to provide many of the requirements that other previous systems did not achieve such as high data transfer rates, effectives user control, seamless mobility, and others which will potentially change the way users utilize mobile devices. NGWN will integrate a multitude of different heterogeneous networks including (a) cellular networks, passed through multiple generations—1G, 2G, 3G, and 3.5G; (b) wireless LANs, championed by the IEEE 802.11 wireless fidelity (WiFi) networks; and (c) broadband wireless access networks (IEEE 802.16, WiMAX). In this paper, a new adaptive quality of service (QoS) oriented CAC scheme is proposed to limit the occurrence of hard IEEE 802.11 WLAN-UMTS handovers to mobile users using real time (RT) applications. This scheme is hybrid, based on the service class differentiation, the location in the heterogeneous infrastructure and a vertical handoff decision function as well. Simulation results show that our policy achieves significant performance gains. It maximizes the utilization of the resources available at the WLAN cells, and meets as much as possible the QoS requirement of higher priority users. Copyright © 2008 John Wiley & Sons, Ltd.

KEY WORDS: next generation heterogeneous wireless networks; QoS; call admission control; vertical handoff

1. Introduction

Increasingly heterogeneous wireless access consists of UMTS cellular systems interspersed with IEEE 802.11 WLAN access. It will offer a wide range of services available to users anywhere at anytime. This poses new challenges for delivering services to users who move about in such a heterogeneous infrastructure. Quality of service (QoS) provisioning in such networks is therefore a challenging task since each access network provides different levels of QoS, bandwidth, and coverage to the end user. Further, in the presence of a mix of services characterized by a wide range of QoS requirements in terms of transmission delay, throughput, etc., the system performance can vary considerably, thus rendering QoS provisioning even more difficult. To this end, the techniques developed to date for the enhancement of heterogeneous networks concentrate on improving their accessibility and QoS. Call admission control (CAC) constitutes a fundamental technique for QoS provisioning that limits the amount of traffic accepted in the

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network in order to provide better service to accepted connections. In heterogeneous wireless access network, selecting the best network to initiate a connection is an important consideration for overall network stability. The access decision can be based on criteria such as the required QoS level, bandwidth requirement, residual capacity in each available network, coverage, power consumption, and cost. Moreover, efficient admission control strategies should exploit the adaptability of certain services to give priority to non-adaptive service. Although the real-time service may have higher priority for the use of radio resources, the non real-time services also impose certain QoS requirements in terms of delay and throughput.

In this paper, we present a new adaptive QoS oriented CAC scheme to meet the rapidly increasing demand for providing multimedia services with diversified quality requirements in heterogeneous network. This policy is hybrid and based on the service class differentiation, the call origination point and a vertical handoff decision function. It aims at maximizing the use of available radio resources while selecting the best access network and meeting the QoS requirement of mobiles using real time (RT) services as much as possible while maintaining the minimum requirements of non-RT users having lower priority, especially when the system suffers from congestion. In our scheme, we introduce a resource allocation function that combines the user category and the priority of the class of service to which belongs the application currently in use. Its objective is to enhance the QoS provided to RT users connected to a WLAN access point and performing handovers to another neighboring WLAN access point.

The rest of the paper is organized as follows. In the next section, we present recent works devoted to CAC, followed by the architecture of our proposed CAC scheme in Section 3. In Section 4, we describe our simulation model, and we report some quantitative results. Finally, we present concluding remarks from the paper in Section 5.

2. Call Admission Control: Background and Related Work

It is envisaged that next generation wireless networks (NGWNs) will utilize several different radio access technologies, integrated to form a heterogeneous network. An interesting example is the heterogeneous environment consisting of an UMTS cellular network and a WLAN. These access networks are characterized by their soft capacity and the support of multiple heterogeneous services with diverse quality requirements. In this context, the CAC becomes a complex problem. It is responsible for making access decisions in response to a user's access request, and then facilitates high capacity and spectrum efficient network usage.

Recent works on radio link management in wireless networks highlight the importance of access control techniques [1]. These techniques have been primarily proposed for the homogeneous networks. Today, they are defined as 'conventional' algorithms. The most representative of them and those designed for NGWN heterogeneous networks will be presented in this section. For example Reference [2] proposed an algorithm based on complete partition using the guarded channel policy to differentiate between new and handoff voice calls. In this scheme, called dynamic partition (DP), K_1 out of the C channels of a cell are reserved for both new and handoff voice calls and K_2 channels are reserved for data calls. The remaining (C-K_1-K_2) channels are shared in a fair manner by both voice and data calls. New voice calls can only use K_3 out of the K_1 channels.

According to the DP algorithm, when a new voice call arrives, a channel is sought in K_3. If a channel is available, it will be admitted. Otherwise, a channel is sought in the shared area. It will be blocked if there is no channel in both K_3 and the shared area. When a handoff voice call arrives, a similar search is done in the voice only area and then the shared area. It will be dropped only if there is no channel available both in the voice only and shared area. A similar decision is made for a data call arrival by first searching in the data only area and then the shared area.

In References [3] and [4] the authors proposed the dual threshold bandwidth reservation (DTBR) scheme for voice/data cellular network. This scheme is based on complete sharing (CS) and the authors showed that it offers higher network utilization than the DP and meets guaranteed QoS. In DTBR, the C channels of the cell are divided into three regions by two thresholds K_1 and K_2 ($K_1 > K_2$). When the network occupancy level L is less than the threshold K_2, both voice and data calls can be admitted into the system. When L is greater than K_2, no data call can be admitted into the system. When L is greater than K_1, no data call or new voice call can be admitted to the system. A handoff voice call will be dropped only if there is no channel available. One of the good features of the DTBR algorithm is that a higher priority call is never rejected while there is a bandwidth available for a lower priority call.

DOI: 10.1002/wcm

The idea of effective bandwidth was used in Reference [5] to assign effective bandwidth to a given multimedia user according to its traffic profile. Admission requests are grouped into different classes and interference from each class is characterized. New users are assigned their effective bandwidth based on QoS targets according to their classes and CAC admits new users of a particular class if total interference of all the classes is less than threshold. Hierarchical priority schemes have been studied [6] for multimedia services requiring soft and strict QoS requirements to set priorities at call level and burst level. The authors in Reference [7] present two different principles on which the CAC can be based. The first one indicates that admission control is performed according to the type of required QoS. In this case, the CAC is performed only for some types of service, like conversational and interactive. It is not performed for background class since no guaranteed QoS is required. For the second principle, the CAC is based on the current system load and the required service. In this way, if none of the suitable cells can efficiently provide the service required by the user equipment (UE) at call set up, the call should be blocked avoiding that the required service leads to increase the interference level to an unacceptable value. This action ensures that the UE avoids wasting power affecting the quality of other communications. In this case, it is also possible that the network initiates a re-negotiation of resources of the ongoing calls in order to reduce the traffic load.

More recently, CAC algorithms between heterogeneous wireless networks have been proposed. In Reference [8], authors describe a CAC algorithm with service differentiation for voice and data traffic in a topology where isolated hotspots are meshed into a larger cellular network. In Reference [9], a two-tier architecture for a wire/wireless CAC is proposed. Calls that are likely to perform handovers in the future are given the highest priority of admission. A measurement-based handover decision algorithm is proposed in Reference [10], in a loose coupling architecture between wide area access networks and isolated WLAN networks. A micromobility management method is proposed to mitigate the impact of handovers on performance. To support heterogeneous networks, adaptive policies based access management systems were also proposed. In Reference [11] for example, a bandwidth adaptation scheme based on per flow degradation was proposed for heterogeneous wireless networks by defining a concept called degrade profile. In the cases where the bandwidth of an access network is full and the ongoing calls are using bandwidth more than the minimum needed bandwidth, degradation is done upon arrival of new or handoff calls. Here, in order to admit calls, this scheme degraded the longest calls in the system with a hope that those flows have bigger probabilities to quit the system and leave fewer degraded connections. The authors in Reference [12] proposed a bandwidth adaptation scheme based on per class degradation. Here, in order to admit a call, the lower possible priority class calls are degraded. Ongoing higher priority class calls are not affected by arrival of lower priority calls. The performance analysis in Reference [12] showed that the per class adaptation scheme is better in terms of fairness (by treating flows of the same class equally) and simplicity. But the per flow scheme is better in terms of resource utilization.

On the basis of the policies presented above, we have developed a 'none conventional' CAC scheme in the context of a UMTS–WLAN architecture. Its features are presented in the following section.

3. Call Admission Control Scheme: Description and Architecture

We propose a handover-based CAC algorithm for new call requests in UMTS/WLAN heterogeneous networks. Its main objective is to limit the occurrence of hard WLAN–UMTS handovers that may cause a disruption in the packet flow, if connections could be handled by neighboring WLAN access points. The admissions either into the WLAN hotspot or into the UMTS cell depend on several parameters such as the position in the network, the anticipated direction, the type of service, the available bandwidth, the interference levels, the power consumption, and the information security.

The CAC algorithm evaluation is performed considering the network topology depicted in Figure 1. It shows two WLAN hotspots with overlapping coverage area integrated inside the UMTS cell coverage area and in which users equipped with dual UMTS and WLAN interfaces move across cells.

In this system, we identify three categories of users based on the type of handover they are likely to perform. Each of them can use either a RT or a non-RT service. The users' categories 1, 2, and 3 are defined according to the call origination point and the anticipated direction, on which depend priorities assigned to these users.

DOI: 10.1002/wcm

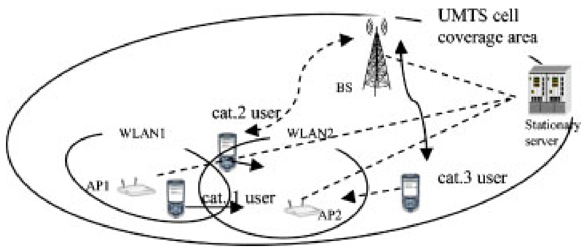

Fig. 1. Network topology.

Users of category 1 are connected to WLAN1 and move out its coverage area toward WLAN2 and redirect their connections to its access point AP2. If they are rejected, they perform a handover to UMTS. The category 2 is of those establishing new connections inside the WLAN2 hotspot and trying to connect to its access point. In case they are rejected, they use the UMTS network. The users belonging to the third category are those who are connected to the UMTS and request a redirection of their connections to use the WLAN2.

We consider that not all calls likely to perform a handover should be given a higher priority of admission. The priority level will be given according to the user category. Indeed, the vertical handoff from UMTS to WLAN was defined in Reference [13] as a desirable handoff. This is due to the fact that WLAN technologies are short-range networks and they offer lower cost to users than UMTS. On the other hand, the mobile terminal's connection has to remain seamless as a user connected to the WLAN roams out of the WLAN domain. Thus, the handoff from the WLAN to the UMTS was defined to be a necessary handoff. It is qualified as a hard handover since it may cause a disruption in the packet flow. Since more priority should be given to necessary handoffs than desirable handoffs, users of category 1 are then given the highest priority over all other users. Admission to the WLAN hotspot implies a faster connection set-up time and thus, category 2 users are given an intermediate priority. Users of category 3 are given the last priority since these users are performing desirable handoffs.

In this paper, the new CAC function we proposed is a handover-based resource allocation policy, which takes into account both the user category (cat) and the class of service differentiation. Thus, it will be designed as 'hybrid' and it will be given the acronym 'HCACH' for 'hybrid CAC scheme for heterogeneous multimedia wireless networks'.

Let B_i, B_c, and C be the bandwidth used by user i connected to the WLAN access point, the bandwidth currently used in the WLAN hotspot and the maximum capacity available in the WLAN hotspot respectively. Define α_j as the percentage of bandwidth assigned to the category j of users, $j = 1, 2, 3$.

We then can define a resource allocation function to which we give the acronym 'RAF'. It combines the user category and the priority of the class of service to which belongs the application currently in use, according to the following algorithm:

$$\mathrm{RAF}_{j,k} = \frac{\alpha_j}{p_k} \tag{1}$$

$$p_k = k, \quad k \in \{1, 2, 3, 4\} \tag{2}$$

where p_k denotes the precedence class. It defines the priority assigned to the class of service in use by the mobile node.

A voice call have the highest priority over all ongoing connections ($p_1 = 1$). However, the WLAN is preferred to be always filled with data calls. The WLAN is then chosen to admit a new voice call only if it is not able to be admitted by the UMTS network. This condition is applied for users initiating their calls within the WLAN coverage area as well as for category 3 of users. Users of this category will have lower priority than users starting new calls within the WLAN cell. Streaming services are very sensitive to access delay and have higher priority over all other ongoing data traffic such as interactive and background.

When a user u, is trying to access the WLAN hotspot and requesting a bandwidth equal to B_{u}, it will be assigned to category j, and given the priority level p_k. The mobile node will be admitted in the WLAN only if the following condition applies:

$$B_c + B_u < \mathrm{RAF}_{j,k} \times C \tag{3}$$

with

$$B_c = \sum B_i, \quad \forall\, i \in \mathrm{WLAN} \tag{4}$$

HCACH is then a multiple bandwidth reservation scheme. The C channels of the access network could be divided into 12 regions by 11 thresholds defined by the fraction α_j/p_k as shown in Figure 2. When $B_{\mathrm{c}} > \mathrm{RAF}_{j,k} \times C$, then only users having a RAF value superior to $\mathrm{RAF}_{j,k}$ are admitted in the WLAN hotspot.

DOI: 10.1002/wcm

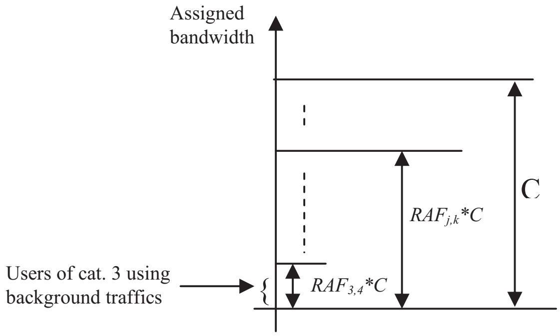

Fig. 2. HCACH multiple bandwidth reservation scheme.

For example, when a user A of category 2 ($\alpha_2 = 0.8$) initiates a voice call and it cannot be admitted in the UMTS network, it will have more priority ($p_k = 1$) than a user B of category 1 ($\alpha_1 = 1$) that requests resources to use the video streaming service ($p_k = 2$).

As HCACH scheme is based on the class of service differentiation, the requests belonging to several mobile stations will be queued according to their class of service. For users of the same category, using the same class of service and, therefore, the same *RAF* value, their requests will be served according to a priority function that we propose. It provides a measure of the priority level, Q_u, given to each user that competes for the resources within the WLAN network. This function is defined as follows:

$$Q_u = \frac{w_p(1/P_u)}{\max((1/P_1)\dots(1/P_n))} + \frac{w_s(S_u)}{\max(S_1\dots S_n)} + \frac{w_f(F_u)}{\max(F_1\dots F_n)} \quad (5)$$

this function is derived from the vertical handoff decision function, denoted 'VHDF', originally developed in Reference [14] to make wiser the handoff decisions. The function presented in Equation (5) depends on three parameters:

– *The power consumption* (P): mobile terminals with nearly exhausted battery or equipped with relatively short battery lifetime will have less priority than mobiles with full battery, when they redirect their connections to a higher power consuming network.
– *The security* (S): when the information being exchanged is confidential, a network with high encryption is preferred. Thus, if a WLAN offers a highest encryption performance, mobile nodes exchanging confidential information are given the highest priority.
– *The network performance* (F): mobile terminals with the strongest signal strength have the highest priorities.

w_p, w_s, and w_f are weights for each of the network parameters. The values of these weights are fractions, that is, they range from 0 to 1. Furthermore, all three weights add up to 1.0. Each weight is proportional to the significance of a parameter to the network access. The larger the weight of a specific factor, the more important that factor is to the user and *vice versa*. These weights are obtained from the user *via* a user interface.

Each network parameter has a different unit; this leads to the necessity of normalization. The final normalized equations for n users who tempt to access to the network at the same time are then presented by Equation (5).

In References [14,15], VHDF includes two other parameters relative to the cost of service and the bandwidth availability in the network. Mobile nodes choose the network to which they will be admitted or redirect their connections according to the VHDF-based priority scheme. It gives a priority level value, Q_u, to competing users as follows:

$$Q_u = \frac{w_p(1/P_u)}{\max((1/P_1)\dots(1/P_n))} + \frac{w_s(S_u)}{\max(S_1\dots S_n)} + \frac{w_f(F_u)}{\max(F_1\dots F_n)} + \frac{w_t(1/T_u)}{\max((1/T_1)\dots(1/T_n))} + \frac{w_d(\mathrm{D}_u)}{\max(\mathrm{D}_1\dots \mathrm{D}_n)} \quad (6)$$

where T denotes the cost of service parameter and w_t its weight. Mobile terminals offered a low cost service will have more priority over other ongoing mobile nodes. D defines the network conditions in term of bandwidth availability.

Thus, in resume, for the HCACH handover-based CAC scheme that we propose, the available bandwidth will be shared between users according to their categories that we defined (i.e., depend on call origination point and the anticipated direction) and the application type in use. Users of the same category requiring the same bandwidth will access to the network in an order of priority defined by the function given in Equation (5). In the next section, the performance of this algorithm will be compared to those

DOI: 10.1002/wcm

obtained with a handover-based CAC policy for which mobile nodes access to the networks according to their priority levels given by VHDF.

HCACH allocation scheme could be enhanced by using pre-emption in order to offer better QoS to users of category 1 and using RT services. Thus, lower priority categories with lower priority services can be pre-empted or forced out of the WLAN hotspot. The choice between users with lower priority categories and lower priority services will be done according to their signal strength. Users with the weakest signal strength are selected for pre-emption in first. If enough bandwidth is saved, the pre-emption procedure is stopped. Otherwise, the procedure resumes with the next user in the list. The procedure is repeated until the pre-empted bandwidth B satisfies the following condition:

$$B_c + B_u - B < C \tag{7}$$

This HCACH scheme has the benefits to admit more category 1 users in the WLAN hotspot and thus, limiting the occurrence of costly WLAN–UMTS handovers.

4. Performance Evaluation

In this section, we evaluate the performance of our proposed admission scheme, Hybrid CAC scheme for HCACH. Before proceeding, we first describe the simulation model. We then show simulation results.

4.1. Simulation Model

We evaluate the effect of the HCACH scheme on the IEEE 802.11g and UTRA-TDD networks performance. The performance evaluation is performed using a flexible discrete time simulator based on the programming language C++ that we have developed. It uses as time unit an equal TDMA framework period duration. Both time and spatial dimensions of the traffic variations are taken into account. Time variation of traffic is represented as arrival process, call duration or packet length for various types of services, and spatial variations characterize the user mobility in the cellular area. In order to take into account the users' mobility and the interferences' effects as in a real world environment, 21 micro-cells with 1000 m coverage area serving both packet-switched voice and data calls are considered. The edges of the whole network system are wrapped around such that the 'border effect' is suppressed.

Consider an integrated UMTS–WLAN (IEEE 802.11g) network consisting of a set of UMTS cells and a number of WLAN spots located inside each cell. Assume that all the UMTS cells and underlying WLANs are stochastically identical, so we can focus our analysis on one UMTS cell and two underlying WLANs as shown in Figure 1.

WLAN coverage area is 100 m radius circle. The performance evaluation is performed only for mobile nodes operating within only one UMTS cell. In this system the delays introduced by the information exchanges either between the access point and the stationary server or between the base station and the stationary server are neglected.

All users are pedestrians. They move across cells at the velocity of 3 km/h, crossing cells boundaries impacting on the quality of received signal of their resident cell. For simplicity, we consider that within the UMTS and WLAN networks, the radio propagation is performed considering the free space model [16] which characterizes the main effects impacting the mobile radio channel: path loss, fast fading, and shadowing. It aims mainly at estimating CIR ratio for each communicating mobile terminal. For the division of slots within a frame in the UMTS network, we have chosen the combination of 8/7 for downlink (DL)/uplink (UL). The power control procedure and the handover management are performed every 0.5 s which acts as the mobility time unit [17]. For users of category 1 and 2 that are redirecting their connections to the UMTS network, an interference-based CAC scheme is used to control their admission. In such network, each new call increases the interference level of all other ongoing calls, affecting their quality [18]. For each class of service, the interference parameter taken into consideration when the access to the network is controlled varies along simulation and is maintained under defined static threshold. For each UE reaching the UMTS network, the energy per bit to spectral noise density ratio target is computed as the following:

$$\left(\frac{E_b}{N_0}\right)_u = \left(\frac{W}{\mathrm{D}_u}\right) \times \left(\frac{G_0 P_u^0}{\gamma \times \left(G_0 \times \sum_{i \neq u} P_i^0\right) + \sum_{j=1}^{6} Gj \times P^j}\right) \tag{8}$$

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where W is the WCDMA chip rate, P_u^0 ($u = 1, \ldots, 6$) the transmit power from the current base station, D_k the transmission rate, γ the orthogonality factor and G_j ($j = 0, \ldots, 6$) is the signal attenuation between user and the current base station (Node B), computed using the three-stage propagation model [16].

G_0 is defined as the signal impairment between the user and the current base station.

The inter-cells interference can be approximated by $G \times P_n$, where G is the signal attenuation between the current and the interferer base stations, and P_n is the maximum transmit signal power of all base stations. The formula (8) becomes:

$$\left(\frac{E_b}{N_0}\right)_u = \left(\frac{W}{D_u}\right) \times \left(\frac{G_0 P_u^0}{\gamma \times G_0 \times (N-1) \times P_u^0 + G \times P_n}\right) \tag{9}$$

For each type of service, the maximum number of users depends on the energy per bit to noise density threshold $(E_b/N_0)_{\text{threshold}}$. It is defined by

$$N_{\max} = \left\lceil \frac{1}{\gamma + \left(\frac{G}{G_0}\right)} \times \left(\gamma + \left(\frac{W}{D}\right) \times \left(\frac{E_b}{N_0}\right)^{-1}_{\text{Threshold}}\right) \right\rceil \tag{10}$$

The notation $\lceil x \rceil$ designates the whole part of the variable x. If the number of admitted users becomes over $N_{\max}$, the connection will be rejected.

The traffic generated by each user in the system can be of the following types: voice, video streaming, www traffic (web browsing), and E-mail. They are modeled respectively as a conversational, real-time streaming, interactive, and background traffics as outlined in References [18,19]. The first three types of services are mapped over guaranteed services (GS), while the E-mail application is best effort (BE) traffic having no delay constraint. In the presented simulation campaigns the system is loaded by the heterogeneous traffic according to the following percentages: voice, 35%; video streaming, 20%; www (web browsing), 20%, and E-mails, 25%.

Since we use a discrete time simulator, the new packet-switched calls are generated with *Bernoulli* distributed process either in the WLAN network or in UMTS. It is equivalent to a *Poisson* process in continuous time simulation, adopted in most of the traffic models.

Table I. Voice traffic parameters.

Voice parameters	Distribution	Mean/value
Inter-arrival of calls (s)	Bernoulli	0–120
Duration of calls (s)	Bernoulli	120
Mean talk spurt duration(s)	Geometric	1.35
Max throughput (kbps)		12.2
In UMTS		
Codes		2 (SF 16)
Bits per code		61
$(E_b/N_0)_{\text{target}}$		3.8

In Table I we summarize the simulation parameters of the voice traffic.

Internet packet data service traffic is based on the model outlined in Reference [19]. The traffic model is intended to represent HTTP browsing session by user. And as we are interested only in the uplink, calls represent the pages downloading requests. The packet data traffic parameters are exhibited in Table II.

Video streaming model represents an MPEG-4 streaming data. The service bearer is modeled as a constant bit rate circuit switched data service with 100% activity. The packet sizes vary depending on the type of video frame. There are three types of frames, namely I, P, and B frames. The frames are produced periodically and in the deterministic IBBPBBPBBPBBPBB sequence (15 frames per second). Frame generation is done according to Reference [20] and the video streaming parameters are based on a statistical survey of frame statistics [21]. We assume that the size of the video pictures is: QCIF 176×144 pixels. The relative parameters are depicted in Table III.

The parameters of the E-mail traffic are presented in Table IV.

Table II. www Traffic parameters.

www Parameters	Distribution	Mean/value
Inter-arrival of calls (s)	Bernoulli	0–120
UL request size (bytes)	Geometric	180
Packet size (bytes)	Geometric	480
Number of HTML pages per session	Geometric	5
Reading time (s)	Neg. exponential	12
Datagrams inter-arival time (ms)	Neg. exponential	10.4
Max throughput (kbps)		64
Max packet delay (s)		2
In UMTS		
Codes		5 (SF 16)
Bits per code		128
$(E_b/N_0)_{\text{target}}$		3.3

DOI: 10.1002/wcm

Table III. Video traffic parameters.

Frame type	Distribution	Mean (bytes)	Variance
I-frame	Log-normal	775	97 656
P-Frame	Log-normal	100	4727
B-Frame	Log-normal	63	1405
Max. throughput (kbps)		115.2	
Max packet delay (s)		0.25	
In UMTS			
Codes			Max 8 (SF 16)
Bits per code			144
$(E_b/N_0)_{\text{target}}$			1.4

4.2. Simulation Results

As RT services are very sensitive to delay, we compare the performance of the handover-based HCACH scheme with those of VHDF-based CAC scheme [14] that we have simulated for RT video streaming service.

To show the advantages of HCACH, we evaluate the performance of this algorithm for category 1 users which move from WLAN1 to WLAN2 and try to redirect their connections to the access point AP2.

The simulations were performed while neglecting the users power consumptions and the security of the information being exchanged by giving the same weights to all users or simply by considering $w_p = w_s = 0$. As we are investigating the performance of the proposed algorithm only for the video streaming service, we consider that the cost of service will be also the same for all competing users. Thus, this parameter could be neglected in this case of simulation. The two remaining parameters in the VHDF function are then the user required bandwidth and the signal strength. As video steaming is bandwidth hungry, that is, bandwidth must be the most significant parameter, users will be given a weight $w_d = 0.9$. The weight w_f relative to the network performance is, therefore, equal to 0.1. In this investigation, the quality measures reported are the percentage of satisfied RT users and the blocking probability. Users of video streaming application are satisfied if packets are received in less than 250 ms during 95% of the session duration. In all experiments, the simulation run takes duration of about ($10^6 \times$ simulation time unit) to achieve a confidence level of 95%. Beyond this time of simulation, the confidence level remains the same. In addition, in all curves the arrival rate of voice and data users is varied to study the heterogeneous system under increasing load conditions.

Table IV. Model parameters of the E-mail application.

E-mail parameters	Distribution	Mean
Inter-arrival of calls (s)	Bernoulli	0–120
E-mails mean size (bytes)	Geometric	18 944
Max packet delay (s)		60
Max throughput (kbps)		64
In UMTS		
$(E_b/N_0)_{\text{target}}$		1.2

In Figure 3 and for two scenarios of bandwidth reservation ($\alpha_1 = 1$, $\alpha_2 = 0.8$, $\alpha_3 = 0.6$, and $\alpha_1 = \alpha_2 = \alpha_3 = 1$), we compare the blocking probabilities for each class of service used by the mobile nodes that redirect their connections to WLAN2 while performing HCACH. Although category 1 users have always the highest priority, this figure shows that instead of confounding themselves, a little gap separates the two blocking probability curves relative to each scenario for the video application users ($p_k = 2$). This gap is due to the fact that in some cases, the $\text{RAF}_{i,j}$ value assigned to category 2 mobile terminals using voice calls may be higher than the value assigned to video streaming users of category 1. And then, more users of category 2 will be admitted in WLAN while reducing the number of admitted video streaming users of category 1. More α_2 is higher; more the blocking probability of category 1 users is higher. Users of the BE traffic (E-mail) have the highest blocking probability since they are assigned the lowest percentage of bandwidth and have the lowest priority.

Figure 4 exhibits the blocking probabilities of category 1 users and those performing handoffs from AP1 to AP2 while performing respectively the HCACH algorithm and the VHDF-based CAC policy. Figure 5 reports the rates of satisfied users while

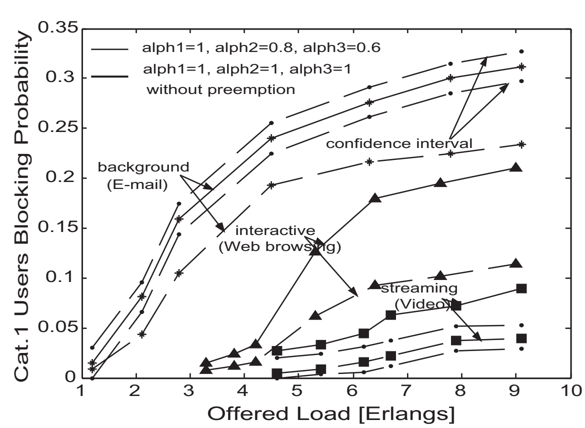

Fig. 3. Performance evaluation of HCACH for multimedia users.

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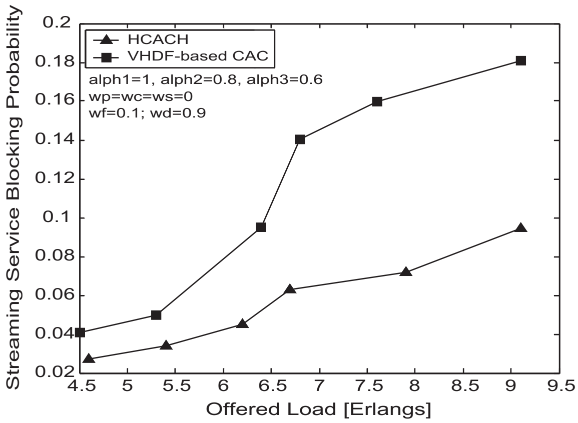

Fig. 4. Impact of the HCACH on the RT streaming users—a comparison with VHDF-based CAC scheme.

performing the two algorithms. The exhibited results show clearly that HCACH enhances the rates of satisfied users by giving more priority to mobiles nodes coming from other WLAN and, therefore, accepting fewer users of other categories in the cell. This means less hard WLAN–UMTS handoffs and less congestion. When HCACH policy is performed, the rate of satisfied users remains over 95% if the system load is below 7.5 Erlangs.

Intuitively, users of category 1 in the WLAN2 network will have the lowest blocking probability since they have the highest priority over categories 2 and 3. Figure 6 reports that by choosing a multiple bandwidth reservation for the different categories (for example: $\alpha_1 = 1$, $\alpha_2 = 0.8$, $\alpha_3 = 0.6$) the overall blocking probability in WLAN2 is higher than the blocking probability obtained for one bloc bandwidth

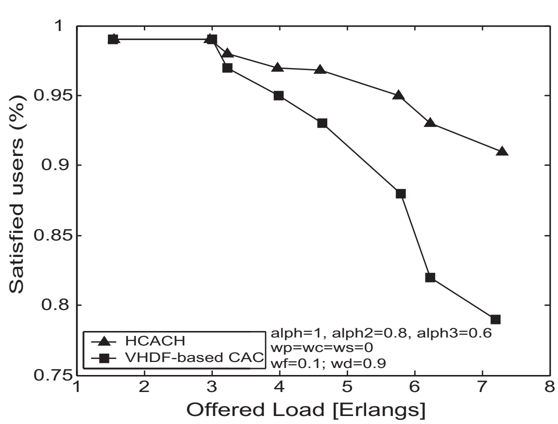

Fig. 5. Impact of the HCACH on the satisfied users' percentage—a comparison with VHDF-based CAC scheme.

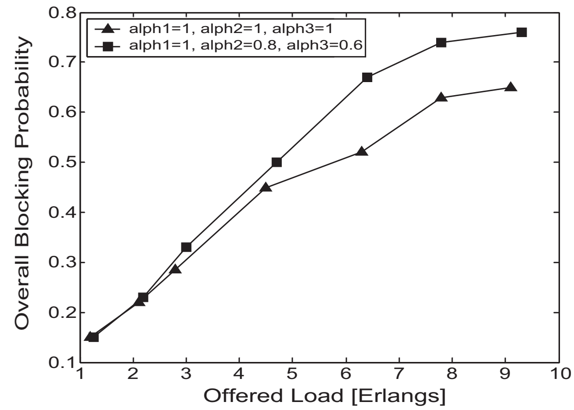

Fig. 6. Impact of the HCACH on the overall blocking probability.

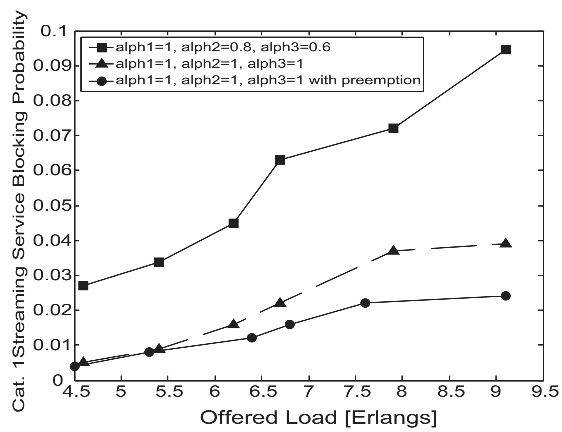

Fig. 7. Enhancement of HCACH using a pre-emptive mechanism.

scheme ($\alpha_1 = \alpha_2 = \alpha_3 = 1$). This is because of limitation of the bandwidths assigned for categories 2 and 3. The overall rate of blocked background users in WLAN2 which belong to lower categories will grow up when they are pre-empted by users of category 1.

In Figure 7 we report only the gain obtained for the category 1 streaming RT traffic when lower categories are pre-empted by category 1 mobile nodes. At a load of 9 Erlangs, for example, the blocking probability decreases from about 3.9–2.4%.

5. Conclusion

The integration of different wireless access technologies will characterize the NGWNs and the connection admission control constitutes a fundamental techni-

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que for QoS provisioning. In this paper, an efficient hybrid adaptive QoS oriented CAC function has been proposed for WLAN–UMTS handovers especially for subscribers using real-time applications. It is based on the service class differentiation, on a vertical decision function and on the anticipated direction and the originating point of a handover that can occur between UMTS and WLAN cells. The performance evaluation has shown that the proposed scheme, called HCACH, provides better service to accepted RT connections. Its QoS performances are shown under real world heterogeneous wireless network traffic conditions. Future work includes performance analysis of the proposed scheme while taking into account in the simulations the power consumption and the security level of information being exchanged.

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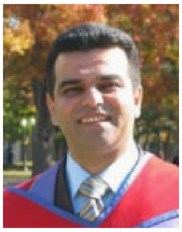

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DOI: 10.1002/wcm