A New Call Admission Control Scheme for Heterogeneous Wireless Networks

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***Abstract*—Call Admission Control (CAC) between heterogeneous networks, such as an integrated 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) network and a Wireless Local Area Network (WLAN), plays an important role to utilize the system resources in a more efficient way. In this paper, we propose that the preference to the WLAN is determined based on the traffic load in the WLAN and the location of the cellular users. Our analysis relies on a previous study that divides the 3G cellular coverage area into zones based on the amount of resources that are required to support a connection to a mobile user. Using this model, we derive new call blocking and handoff failure probabilities as well as new call and handoff attempt failure probabilities. Through simulations, we investigate proper preference settings by changing the WLAN load in a 3 ring-based sector with a WLAN hotspot.**

***Index Terms*—CAC, Vertical handoffs, Heterogeneous networks, Ring-based model**

I. Introduction

Modern wireless communication systems consist of cellular, WiMAX, and WLAN access networks, co-existing in so-called heterogeneous networks. Multi-mode users can access multiple systems to get ubiquitous access in an efficient way in terms of cost and quality. From the network point of view, it is important to efficiently manage the resources, by considering vertical handoffs (VHOs) and call arrivals in the multiple-coverage area. Recently, the 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) system has gained lots of interest for future broadband wireless networks. Consequently, its integration with Wireless Local Area Networks (WLANs), including seamless/vertical handoffs and Call Admission Control (CAC), have held the spotlight in the heterogeneous networks. Unlike WLANs, where broadband data transmission is available at low cost and features a simple control plane, 3GPP LTE systems can implement more complex resource management schemes to provide more efficient services and better Quality of Service (QoS) with a typical cell radius of less than 300 m [1].

There have been some works in cellular/WLAN integrated networks [4], [5]. A simple admission strategy is to have an unconditional preference to WLANs since WLANs are cheaper and have more bandwidth compared to the early version of 3G networks [4]. However, in 3GPP LTE systems, the bandwidth and cost have become comparable to that of WLANs due to wider bandwidth adoption and flat-rate tariffs. Moreover, WLANs may be over-crowded due to the *WLAN-first* scheme, and thus a large portion of connection attempts to WLANs can fail.

In [5], the authors considered that users with high mobility tend to spend a short time in the double-coverage area and require an *upward VHO* back to the cellular network shortly after a *downward VHO* to the WLAN. This may cause unnecessary VHO processing load in both networks. Therefore, by probabilistically rejecting VHOs for highly mobile cellular users, the VHO processing load and VHO blocking probability can be reduced while maintaining reasonable throughput in the WLAN.

We proposed a ring-based cell model in [2], where the required resources depend on which annular region of the cell the user occupies. Unlike conventional Frequency/Time/Code Division Multiple Access (F/T/CDMA) networks, more resources are allocated to a user farther from the base station (BS) in terms of power, bandwidth, and time slots. We found that the ring-based model allows more accurate analysis of the system performance, especially with respect to handoff and mobility metrics.

It may not be beneficial for the cellular users in the dual-coverage area to have a policy of choosing the WLAN with a fixed probability regardless of the load on the WLAN or the location of the user. For example, it is desirable that a user located farther from the BS access the WLAN since more resources would be released to the cellular network when the user migrates to the WLAN. In this paper, we develop a traffic management policy which sets the probability of migrating to the WLAN based on the traffic load in the WLAN and the location of the user in the cellular system. Using the ring-based model with a single WLAN hotspot, we compute WLAN migration preference values as functions of the blocking and handoff failure probabilities as well as new call/handoff attempt failure probabilities. The network can perform efficient call admission control by adaptively changing the WLAN preference settings in heterogeneous wireless networks in response to changing traffic conditions.

The rest of this paper is organized as follows. In Section II, we describe the system model, where mobility-related parameters are obtained using a ring-based model and system performance is derived based on steady-state analysis. System performances are investigated through intensive simulations in Section III. Finally, we present our conclusions in Section IV.

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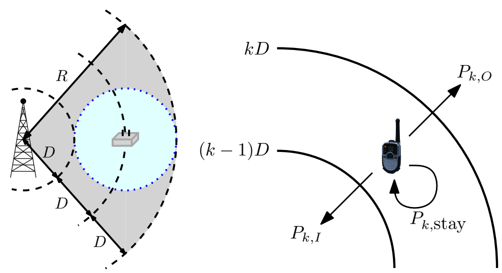
II. System Modeling

We begin our analysis by modifying the ring-based model from [2] to include sectors and a WLAN hotspot[1]. A cell has three sectors and each sector is divided into K concentric rings, each of whose width is D m. Fig. 1(a) shows an example sector with 3 rings, where a single WLAN AP, whose coverage radius is D m, is located $2D$ m from the BS. In the double-coverage area, a cellular user can access either the cellular network or a WLAN [4], and can perform handoffs to move from one to the other. These vertical handoffs (VHOs) can be categorized into downward VHOs and upward VHOs [5]. The downward VHO is a handoff from the cellular network to the WLAN; the upward VHO is a handoff in the opposite direction.

A. Modified ring-based model



(a) A sector divided into rings, K=3, with a WLAN hotspot

(b) Transition probabilities in the kth ring

Fig. 1. System model

Let n_k be the number of mobile users in the kth ring in the cellular network, for $k = 1, \ldots, K$. n_{K+1} is the number of cellular users being serviced in the WLAN. The system state S is denoted as $(n_1, \ldots, n_K, n_{K+1})$. A_c is the area covered by a 3G sector, and $A_{c,k}$ is the area of the kth ring of a sector and $A_{w,k}$ is the area of the WLAN that overlaps the kth ring, $k = 1, \ldots, K$. We can define $P_{c,k}$ and $P_{w,k}$ as the probabilities that a user lies in the kth ring excluding the region of overlap with the WLAN and in the intersection of the kth ring and the WLAN, respectively. Assuming a uniform mobility[2], these probabilities can be written as

$$
\begin{aligned}
P_{w,k} &= \frac{A_{w,k}}{A_c} &(1)\\
P_{c,k} &= \frac{A_{c,k} - A_{w,k}}{A_c}, &(2)
\end{aligned}
$$

for $k = 1, \ldots, K$. $P_w = \sum_{k=1}^{K} P_{w,k}$ and $P_c = \sum_{k=1}^{K} P_{c,k}$ and therefore, $P_w + P_c = 1$..

Let λ_c be the new call arrival rate in a sector for the cellular network and λ_h be the handoff rate of users into the sector. And the average call holding time for a user is denoted as $1/\mu_c$. Since WLAN users tend to remain stationary, it is assumed that there is no handoff request for WLAN users. In the WLAN, all users are assumed to require the same amount of resources for simplicity [5]. For the cellular network, however, a user's required resources vary depending on its distance from its BS, and guard channels are reserved for handoff and mobility [2]. In this paper, we consider CBR traffic for simplicity but extending the analysis to multiple traffic types is straightforward. When a call arrives in the kth ring in the cellular network, it requires r_k resources, while a user in the WLAN requires r_w resources. C_c and C_w are the capacities of the cellular network and the WLAN, respectively, and C_g is the amount of guard resources reserved by the cellular network. A fixed amount of resource, n_w is allocated to the WLAN users and the remaining resource of $C_w - n_w$ can be assigned for the cellular users who request connections to the WLAN.

$R_c(S)$ and $R_w(S)$ are the total resources being used in the cellular network and the WLAN, respectively, when the system is in state S. They are denoted by

$$
\begin{aligned}
R_c(S) &= \sum_{k=1}^{K} n_k r_k &(3)\\
R_w(S) &= (n_{K+1} + n_w) r_w. &(4)
\end{aligned}
$$

B. Mobility-related parameters

First, we consider the mobility of users between neighboring rings. When a mobile enters a given ring, it is assumed to reside there for an exponentially distributed residual time whose mean is $1/\gamma$. At the end of that time period, a user in the kth ring may move to the $(k-1)$th or $(k+1)$th rings with probabilities of $P_{k,I}$ or $P_{k,O}$, respectively (see Fig. 1(b)). Or the user may stay within the kth ring with probability $P_{k,\mathrm{stay}}$, which can be equivalently seen as the user moves within the ring after a certain residual time. Assuming a user's direction of movement is uniformly distributed, we can obtain that $P_{k,\mathrm{stay}} = P_{k,I} + P_{k,O} = \frac{1}{2}$. $P_{k,I}$ and $P_{k,O}$ are determined in terms of the inner and outer circumferences of the kth ring, $l_{k,I}$ and $l_{k,O}$. For $k > 1$, the parameters are given by

$$
\begin{aligned}
P_{k,I} &= \frac{1}{2} \frac{l_{k,I}}{l_{k,I} + l_{k,O}} &(5)\\
P_{k,O} &= \frac{1}{2} - P_{k,I}. &(6)
\end{aligned}
$$

These results agree with those in [2], where the probabilities $\{P_{k,I}\}_{k=2}^{K}$ and $\{P_{k,O}\}_{k=2}^{K}$ have been calculated by using the balance equations to satisfy the condition that the average inward-rate should be equal to the average outward-rate at each ring boundary. Exceptionally for the innermost "ring" (i.e., $k = 1$), a user always moves out of the ring after a certain residual time, so $P_{1,O}$ is always 1 and other probabilities become 0.

[1]Extending to include more than one WLAN hotspots is rather straightforward. However, the system state has more dimensions according to the number of WLAN hotspots and the state transitions should be modified together with relevant parameters.

[2]In a model without uniform mobility, $P_{w,k}$ and $P_{c,k}$ will depend on the model or measurements taken from an actual network. For example, we could have users tend to remain in the WLAN for longer periods of time. This extension is left for a future work

Now we consider the probabilities of moving between the cellular and WLAN areas. When a user moves out of the WLAN's coverage, it may move to the kth ring in the sector or it may move to neighboring cells. The corresponding probabilities are denoted as β_k and β_{K+1}. Assuming the mobile's direction is uniform over $[0, 2\pi]$, these probabilities are respectively proportional to the length of the WLAN's boundary that lies within the kth ring or neighboring cell. Generally, we require a degree of margin in the received signal strength (RSS) for handoff to prevent ping-pong effects. Assuming a margin of ξ_{th} dB, β_1 and β_{K+1} can be calculated assuming a given path loss. That is, for the first ring and the Kth ring, if a user leaves the WLAN and the path loss difference from the WLAN boundary to the corresponding sector/ring boundary is less than the margin, then the user moves to the first ring or to a neighboring cell. For example, we consider a simple 3-ring case with D = 100 m, where the path loss (in dB) is given by $39.95 + 43.375 \log_{10} \frac{d}{10}$ (d in meters) and ξ_{th} = 1 dB. Then, $\beta_1 = 0.11$, $\beta_2 = 0.31$, $\beta_3 = 0.37$, and $\beta_4 = 0.21$.

We next consider the balance equations between the cellular network and the WLAN. The users in the kth ring moves into the WLAN with a probability of α_k. On the boundary of the WLAN coverage within each of the K rings, the average move-in rate from the cellular network to the WLAN should be equal to the average move-out rate from the WLAN to the cellular network, i.e.,

$$P_{c,1}\gamma_1\alpha_1 = P_w\gamma_w\beta_1 \quad (7)$$
$$P_{c,2}\gamma\alpha_2 = P_w\gamma_w\beta_2 \quad (8)$$
$$\vdots$$
$$P_{c,K}\gamma\alpha_K = P_w\gamma_w\beta_K \quad (9)$$
$$\gamma_R\alpha_{K+1} = P_w\gamma_w\beta_{K+1}, \quad (10)$$

where $1/\gamma_w$ and $1/\gamma_1$ are the mean residual times in the WLAN and in the innermost ring, respectively[3]. α_{K+1} is the probability that a handoff call from a neighboring cell requests a VHO to the WLAN. The residual time is assumed to be proportional to the size of the region [2], [3], i.e., $1/\gamma_R = \alpha R$, $1/\gamma_1 = \alpha D$, and $1/\gamma = \alpha \frac{D}{2}$, where $1/\gamma_R$ is the mean residual time in a sector, R is the cell radius, and α is a constant determined by the mobility characteristics of the users.

C. Call admission control scheme

In the WLAN, a fixed amount of resource, n_w is allocated for WLAN users and the WLAN's remaining resource, $C_w - n_w$ can be assigned to cellular users that newly appear in the double-coverage area or that request downward VHOs. For the cellular network, however, the resources that are used by a mobile depend on the mobile's location, and guard resources are reserved to support handoff and mobility [2].

When a new call appears in the intersection of the WLAN coverage area and the kth ring, it is serviced by the cellular network with a probability of $1 - w_k$. With probability w_k, a new call attempts to connect to the WLAN. If no resources are available in the WLAN, the mobile tries to connect to the cellular network; the call is blocked only when resources are not available in the cellular network and the WLAN.

[3]The mean residual time in the WLAN is also assumed to be exponentially distributed for analytical simplicity.

For downward VHO requests by mobiles in the kth ring, they are processed in the WLAN with probability w_k. The call continues to be serviced in the cellular network without requesting a VHO with probability $1 - w_k$. When the call is successfully handed off to the WLAN, r_k resources are released by the cellular network and r_w resources are occupied in the WLAN. If $\Delta r = r_k - r_w > 0$, it is beneficial to initiate VHOs to reduce the overall resource usage. Larger Δr values indicate more efficient resource usage due to VHOs. Users from neighboring cells enter the double-coverage area with a probability of α_{K+1} and request downward VHOs to the WLAN with a probability of w_K. If no resources are available in the WLAN, their requests are rejected and they try to access the cellular network.

We measure the system performance using the call blocking probability P_B and handoff failure probability P_f [2]. The new call may be blocked in the cellular network or the WLAN with probabilities $P_{B,c}$ and $P_{B,w}$, respectively, and $P_B = P_{B,c} + P_{B,w}$. Similarly, $P_f = P_{f,c} + P_{f,w}$, where $P_{f,c}$ and $P_{f,w}$ are the probabilities of handover failure to the cell and WLAN, respectively. The goal of the CAC is to find the optimum value for the vector of WLAN choice probabilities, which we call the WLAN preference settings, $W = [w_1, \ldots, w_K]$, so that P_B and P_f are minimized. We introduce two new probabilities, P'_B and P'_f, as cost measures. P'_B is the new call attempt failure probability, and P'_f is the handoff attempt failure probability. When a new call or VHO call attempts to connect to the WLAN, its attempt fails if no resources are available in the WLAN. However, it is not blocked or lost unless there are no resources available in the cellular network as well. These attempt failures result in wasted resources in the control plane; thus it is also important to reduce these failure probabilities to minimize cost and complexity.

D. Steady-state analysis

The state transitions are investigated as follows;

- New call arrivals outside the WLAN: When a call arrives in the non-overlapped kth ring at a rate of $\lambda_{c,k} = \lambda_c P_{c,k}$, $n_k \to n_k + 1$ if $R_c(S) + r_k \leq C_c - C_g$. Otherwise, it is blocked.
- New call arrivals in the double-coverage area: When a new call appears in the kth ring at a rate of $\lambda_c P_{w,k}$, it attempts to connect to the WLAN or the cellular network with probabilities of w_k or $1 - w_k$, respectively. When the new call uses the WLAN, $n_{K+1} \to n_{K+1} + 1$ if $R_w(S) + r_w \leq C_w$. Otherwise, $n_k \to n_k + 1$ if $R_c(S) + r_k \leq C_c - C_g$.

When a call terminates, its resources are released to the cellular network or the WLAN as follows.

- When a call terminates in the kth ring with a rate of $n_k\mu_c$, $n_k \to n_k - 1$ for $k = 1, \ldots, K$.

- When a call terminates in the WLAN with a rate of $n_{K+1}\mu_c$, $n_{K+1} \rightarrow n_{K+1} - 1$.

Handoffs from adjacent cells can be categorized into two cases. A handoff to a neighboring cell that arrives outside that cell's embedded WLAN occurs with a probability of $1-\alpha_{K+1}$; a handoff to a neighboring cell's double-coverage area occurs with a probability of α_{K+1}. The mobile that is handing off to the double-coverage area requests a VHO with probability ω_K. Otherwise, there is a horizontal handoff, which occurs with probability $1 - \omega_K$.

- Handoff calls move into the cellular-only area at a rate of $(1 - \alpha_{K+1})\lambda_h$; when a handoff of this type happens, $n_K \rightarrow n_K + 1$ if $R_c(S) + r_K \leq C_c$.
- Calls perform VHOs to the WLAN in the double-coverage area with a rate of $\omega_K \alpha_{K+1}\lambda_h$; when this happens, $n_{K+1} \rightarrow n_{K+1} + 1$ if $R_w(S) + r_w \leq C_w$, or $n_K \rightarrow n_K + 1$ if $R_c(S) + r_K \leq C_c$.
- Calls perform horizontal handoffs to the cellular network from the double-coverage area at a rate of $(1 - \omega_K)\alpha_{K+1}\lambda_h$; when one of these occurs, $n_K \rightarrow n_K + 1$ if $R_c(S) + r_K \leq C_c$.

During a downward VHO, a call in the kth ring attempts a VHO to the WLAN with a probability of w_k. We must have $R_w(S) + r_w \leq C_w$ in the WLAN, after accepting the request. After the VHO completes, r_k resources are released in the cellular network. Therefore, the larger Δr is, the greater w_k should be. For upward VHOs, r_w resources are released in the WLAN and r_k resources are occupied in the sector.

- Calls in the kth ring ($k = 2, ..., K$) moves to the double-coverage area at a rate of $n_k \alpha_k w_k \gamma$ and change S as follows: $n_k \rightarrow n_k - 1$ and $n_w \rightarrow n_w + 1$, if $R_w(S) + r_w \leq C_w$.
- Calls in the first ring move to the double-coverage area at a rate of $n_1 \alpha_1 w_1 \gamma_1$, changes in S are the same as above.
- Calls move out to the kth ring at a rate of $n_{K+1}\gamma_w \beta_k$, $k = 1, \ldots, K$, and S changes as follows: $n_{K+1} \rightarrow n_{K+1} - 1$ and $n_k \rightarrow n_k + 1$, if $R_c(S) + r_k \leq C_c$.
- Calls are handed off to neighboring cells at a rate of $n_{K+1}\gamma_w \beta_{K+1}$, and S changes as follows: $n_{K+1} \rightarrow n_{K+1} - 1$.

When a user moves outward or inward between rings in the cellular network, it requires more resources or fewer, respectively [2].

- When a user in the kth ring ($k = 1, \ldots, K-1$) moves outward, it requires more resources and the state S changes as $n_k \rightarrow n_k - 1$ and $n_{k+1} \rightarrow n_{k+1} + 1$ with a rate of $n_1\gamma_1$ for the first ring and $n_k P_{k,O}\gamma$ for the other rings, respectively. If $R(S) + \delta r_k \geq C_c$, the user can maintain its connection, where $\delta r_k = r_{k+1} - r_k$ is the additional resources required by the user. In the outmost ring (the Kth ring), the user can be handed off to a neighbor cell, i.e., $n_K \rightarrow n_K - 1$ with a rate of $n_K P_{K,O}\gamma$.
- For a ring ($k = 2, \ldots, K$), when a user moves inward, $n_{k-1} \rightarrow n_{k-1} + 1$ and $n_k \rightarrow n_k - 1$ with a rate of $n_k P_{k,I}\gamma$.

The state transition rates can be obtained from the above investigation. And then, the steady-state probabilities, denoted as $\pi(S)$, can be obtained with the normalization condition $\sum_{\text{all } S} \pi(S) = 1$.

E. Performance measures

The new call blocking probabilities for the WLAN and the cell, $P_{B,w}$ and $P_{B,c}$ can be expressed as

$$P_{B,w} = \sum_{k=1}^{K} \sum_{S\in\Omega\cap\Omega_k} \pi(S) P_{w,k} \tag{11}$$

$$P_{B,c} = \sum_{k=1}^{K} \sum_{S\in\Omega_k} \pi(S) P_{c,k}, \tag{12}$$

where

$$\begin{aligned} \Omega &= \{S | R_w(S) + r_w > C_w\} \\ \Omega_k &= \{S | R_c(S) + r_k > C_c - C_g\}. \end{aligned}$$

The overall blocking probability P_B is $P_{B,c} + P_{B,w}$. The handoff failure probability in the WLAN is

$$\begin{aligned} P_{f,w} &= \sum_{k=1}^{K} \sum_{S\in\Gamma_k} \pi(S) P_w \beta_k \\ &\quad + \sum_{S\in\Gamma_K} \pi(S) P_w \beta_{K+1}, \end{aligned} \tag{13}$$

where $\Gamma_k = \{S | R_c(S) + r_k > C_c\}$. Similarly, the handoff failure probability in the cellular network is

$$\begin{aligned} P_{f,c} = &\sum_{S\in\Gamma_K} \pi(S) \big\{(1 - \alpha_{K+1}) + \alpha_{K+1}(1 - w_K)\big\} \\ &+ \sum_{S\in\Omega\cap\Gamma_K} \pi(S)\alpha_{K+1} w_K, \end{aligned} \tag{14}$$

and $P_f = P_{f,c} + P_{f,w}$.

A new call attempts to connect to the WLAN with a probability of w_k when it arrives in the double-coverage area. Its attempt can fail when there are not enough resources available in the WLAN, though the call may be serviced in the cellular network if r_k resources are available. The new call attempt failure probability, P'_B, is

$$P'_B = \sum_{k=1}^{K} \sum_{S\in\Omega} \pi(S) P_{w,k} w_k. \tag{15}$$

A downward VHO attempt to the WLAN fails when not enough resources are available in the WLAN. It should be noted that the call requesting a VHO is not forced to be terminate if its VHO attempt fails. An upward VHO attempt to the cellular network can fails and the call terminates when there are not enough resources in the target ring to support the call, i.e., at least r_k resources for the kth ring. The handoff attempt failure probability, P'_f, is

$$\begin{aligned} P'_f = &\sum_{k=1}^{K} \sum_{S\in\Omega} \pi(S) P_{c,k} \alpha_k w_k \\ &+ \sum_{k=1}^{K} \sum_{S\in\Gamma_k} \pi(S) P_w \beta_k + \sum_{S\in\Gamma_K} \pi(S) P_w \beta_{K+1}. \end{aligned} \tag{16}$$

A call may be dropped when moving within a sector since a call moving outward requires more resources. When a user moves inward, there is no blocking because the amount of resources required by the user decreases. As shown in [2], the call dropping probability due to mobility (P_D) can be kept low when the reserved resources C_g can be assigned to outward-moving calls as well as handoff calls, so we do not examine P_D here.

III. Simulations and Numerical Results

As shown in Fig. 1(a), a WLAN AP is located 200 m apart from the BS and its coverage radius is 100 m. The radius of coverage of the cellular network is set to 300 m and the cell coverage area is divided into three rings.

A. Effective resources

In order to get the required resources in each ring, the same assumptions have been used as in [2]. The path loss in dB at a distance d m from the BS is $39.95 + 43.375\log_{10}\frac{d}{10}$. A frequency selective fading channel is considered according to a 3GPP typical case for an urban area with a receiver with 6 taps [6]. Simulation parameters are based on the 3GPP LTE system: A 5 GHz band contains 25 resource blocks (RBs), where each RB consists of 12 subcarriers with a spacing of 15 kHz. Total transmit power at the BS is 43dBm and the target BER is 0.1%. The data rate at RB j of user i is given by $R_{i,j} = 12\log_2(1+\beta\text{SNR}_{i,j})$, where 12 is the number of subcarriers in an RB, $\beta = \frac{1.5}{-\ln(5\text{BER})}$, and $\text{SNR}_{i,j}$ is the SNR averaged over 12 subcarriers in RB j of user i. The noise power density N_o is -174 dBm/Hz. The target data rate is 10 kb/s with single antenna configurations for both BS and User Equipment (UE).

When the target data rate can be supported with a partial use of an RB, the RB doesn't need to be used continuously in the time domain. The system can use time sharing in this case; the amount of resources for a user can be less than one and the remaining can be assigned to other users. Scheduling is based on the heuristic max-min method [7]. The required resources are measured by the portion of an RB required to support the target data rate, assuming an equal power distribution over the frequency band since it has been shown that water-filling has an insignificant impact after multi-user scheduling. As found in [2], r_k is independent of the traffic load and cell size, and depends on the target data rate. Interestingly, if r_1 is normalized to be one, $R = (r_1, r_2, r_3)$ can be approximated as $(1, 1.5, 2)$, i.e., a user in the 3rd ring may require twice the resources of a user in the innermost ring.

B. Performance evaluation

We use $R = (1, 1.5, 2)$ and set $r_w = 1$[4]. We consider three cases for comparison as shown in Table I. The capacity of the cellular network (C_c) is 15 and C_g is 2. The available

[4]The assumption of $r_1 = r_w$ may not be simply interpreted as "a user in the innermost ring of the cellular network requires the same amount of *physical* resource as a user in the WLAN does". Different systems may have different costs per unit resource depending on, e.g., the capital expenditures (CAPEX) and operating expenses (OPEX) for the system.

TABLE I
THREE CASES

Case	C_c	C_g	$C_w - n_w$
1	15	2	0
2	15	2	8
3	15	2	2

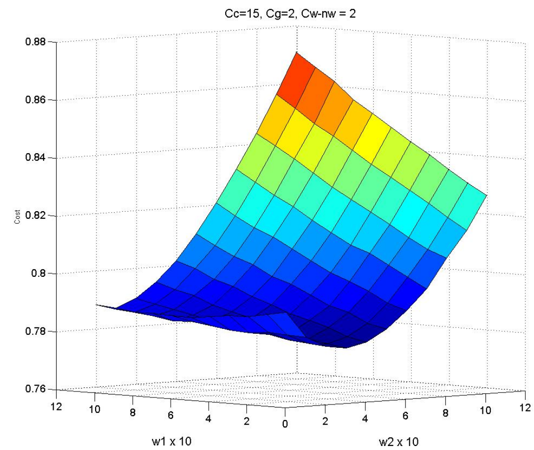


Fig. 2. Cost vs. preferences w_1 and w_2 (C_c = 15, C_g = 2, $C_w - n_w$ = 2).

resources for the cellular users in the WLAN, $C_w - n_w$, is varied. The preference w_3 is set to 1 so that the call requiring the most resources in the cellular network always prefers the WLAN over the cellular network. w_1 and w_2 are each varied in the range $[0, 1]$. When there is no WLAN, P_B = 0.14, P_f = 0.04 and their ratio, P_B/P_f, is 3.5. The mean call duration $1/\mu_c$ is set at 100 s.

For Case 1, P'_B increases as w_2 increases and converges to $\frac{1}{3}$ which corresponds to P_w. P'_f increases as well but is kept low due to guard resources. For Case 2, there are sufficient resources in the WLAN; P'_B and P'_f are kept very small e.g., less than 10^{-3} and P'_f decreases as (w_2, w_3) approaches $(1, 1)$. In this case, it is best to accommodate as many cellular users as possible in the WLAN, i.e., P_B and P_f are minimized when $W = [111]$. It should be noted that P_B and P_f are always smaller when a WLAN overlaps the cell. Finally, if the available resources in the WLAN are small as in Case 3, P'_B and P'_f become significant and they increase as $W \rightarrow [1\,1\,1]$ unlike in Case 2.

Generally, the consequences of a handoff failure are worse than those of a new call blocking. We introduce an outage probability for all connections,

$$P_{out} = P_B + 3.5 \cdot P_f, \tag{17}$$

where we use the weighting factor of 3.5 since P_B is 3.5 times higher than P_f without the WLAN. Similarly, the new connection attempt failure probability, P'_{out}, can be defined with P'_B and P'_f in the same way. Then, we define the overall cost as

$$Cost = P_{out} + f \cdot P'_{out},$$

where f is the weighting factor for the new connection attempt failure probability. Fig. 2 shows $Cost$ versus w_1 and w_2 with

TABLE II
PREFERENCE SETTINGS TO MINIMIZE THE COST WITH VARIOUS VALUES FOR THE WEIGHTING FACTOR f (w_3 =1).

f	0	2	4	6	8	10	12	14	16
w_1	0	0	0	0	0	0	0.5	0.7	0.7
w_2	0	0	0.4	0.7	0.9	1.0	1.0	1.0	1.0
$\frac{C_{min}}{C_{1,1}}$	0.33	0.78	0.91	0.96	0.98	0.99	1	1	1

$f = 3.5$ for Case 3. $W = [0\ 0.3\ 1]$ minimizes the cost for this case. The cost increases most rapidly with respect to w_2, and $W = [1\,1\,1]$, i.e., unconditional preference to the WLAN by users in every ring, pays the largest cost. Thus, as the remaining resources in the WLAN decrease, it is better to for the WLAN to give higher preference to the users who requiring the most resources in the cellular network.

To further investigate the impact of the weight f, Table II shows the optimum preference settings as well as the ratio of the minimum value of $Cost$ over the value of $Cost$ when $W = [111]$. With a small value of f, it is beneficial not to allow the cellular traffic to perform VHOs to the WLAN. Increasing f reflects greater importance of the effect of new connection attempt failures. In such a situation, more cellular traffic is allowed to attempt to move to the WLAN, i.e., $W \to [1\,1\,1]$. We also note that in the considered scenario, w_1 has an insignificant impact on the gain in $Cost$ and can be set to 0.

IV. CONCLUSIONS

We have proposed a new call admission control scheme for heterogenous networks, where the users' relative preference for the WLAN changes adaptively based on the available resources in the WLAN and the location distribution of the cellular users. By modifying our ring-based model of the cell, we derived performance measures such as call blocking/handoff failure probabilities as well as new call/handoff attempt failure probabilities. We investigated the effect of WLAN preference settings with various WLAN loading and cost weighting factors in a sector with 3 rings and a WLAN hotspot. Using the proposed CAC scheme the system cost can be greatly decreased with respect to the case where users always prefer the WLAN (i.e., $W = [1\,1\,1]$).

REFERENCES

[1] D. Astély, E. Dahlman, A. Furuskär, Y. Jading, M. Lindström, and S. Parkvall, "LTE: the evolution of mobile broadband," IEEE Commun. Mag., pp. 44-51, Apr. 2009.

[2] D. K. Kim, D. Griffith, and N. Golmie, "A novel ring-based performance analysis for call admission control in wireless networks," IEEE Commun. Letters, vol. 14, no. 4, pp. 324-326, Apr. 2010.

[3] D. K. Kim and D. K. Sung, "Characterization of soft handoff in CDMA systems," IEEE Trans. Veh. Technol. vol. 48, no. 4, pp. 1195-1202, Jul. 1999.

[4] W. Song, H. Jiang, and W. Zhuang, "Performance analysis of the WLAN-first scheme in cellular/WLAN interworking," IEEE Trans. on Wireless Commun., vol. 6, no. 5, pp. 1932-1943, May 2007.

[5] S. Lee, K. Kim, K. Hong, D. Griffith, Y. H. Kim, and N. Golmie, "A probabilistic call admission control algorithm for WLAN in heterogeneous wireless environment," IEEE Trans. on Wireless Commun., vol. 8, no. 4, pp. 1672-1676, Apr. 2009.

[6] 3GPP TS45.005 v8.3.0, "Radio Access Network; Radio transmission and reception (Release 8)," Nov. 2008.

[7] M. Tao, Y. C. Liang, and F. Zhang, "Resource allocation for delay differentiated traffic in multiuser OFDM systems," IEEE Trans. Wireless Commun., vol. 7, no. 6, pp. 2190-2201, Jun. 2008.