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Joint Call Admission Control in Integrated Wireless LAN and 3G Cellular Networks

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1. Introduction

The fourth-generation (4G) (Liu, 2004) system is expected to support fully integrated services and ubiquitous access anytime and anywhere. Instead of developing a new uniform standard for all wireless communication systems, some endeavors in 4G research focus on the seamless integration of various existing wireless communication networks, such as integrated Wireless LAN (WLAN) and the third-generation (3G) cellular networks.

3G cellular networks provide wide coverage and universal roaming services with limited data rate up to 2 Mbps (Liu, 2006, 2007). With careful network planning and mature admission control algorithms, the achievable Quality of Service (QoS) level of 3G cellular networks is relatively high. On the other hand, WLANs provide low-cost, high data rate wireless access within limited hotspot-area. Since WLAN is originally designed for best-effort data services with contention-based access, it is difficult to achieve strict QoS provisioning for real-time services, such as voice service (Song et al., 2006).

Due to different network capacities, user mobile patterns, vertical handoffs, and QoS levels, the integrated WLAN and 3G cellular networks require a new call admission control scheme to provide QoS provisioning and efficient resource utilization. Currently there are three major architectures for internetworking between 3G cellular cellular networks and WLAN (Ahmavaara et al., 2003). But they are all lack of joint resource management and admission control schemes in integrated environment. Previous research work on admission control in homogeneous cellular networks and heterogeneous integrated networks are investigated with technical descriptions on their pros and cons. It is shown that more endeavors are needed on joint congestion control, load balance, and high-level QoS provisioning in integrated networks.

In this chapter, a novel joint call admission control (CAC) scheme is proposed to support both voice and data services with QoS provisioning. Due to different network service characteristics, 3G cellular network is defined to be a voice-priority network where voice services have higher priority for resource allocation than data services, while WLAN is defined as data-priority network where data services have higher priority than voice services. A joint call admission policy is derived to support heterogeneous network architecture, service types, QoS levels, and user mobility characteristics. Furthermore, to relieve traffic congestion in cellular networks, an optimal channel searching and replacement algorithm and related passive handoff techniques are further developed to balance total system traffic between WLAN and 3G cellular network, as well as to reduce average system QoS cost, such as system blocking probability. A one-dimensional Markov model for voice service is also developed to analyze interworking system performance metrics. Both theoretical analysis and simulation results show that average system QoS costs, such as overall blocking and dropping probabilities, are reduced, and our scheme outperforms both traditional disjoint static CAC scheme and joint CAC without optimization.

2. Technical background

This section briefly describes concepts, architecture and vertical handoffs in integrated WLAN and cellular networks.

2.1 Architecture of integrated WLAN and 3G cellular networks

Driven by the anywhere and anytime mobile service concept, it is expected that 4G wireless networks will be heterogeneous, integrating different networks to provide seamless Internet access for mobile users. The integrated WLAN and 3G cellular network takes advantage of the wide coverage and almost universal roaming support of 3G cellular networks and the high data rates of WLANs.

Currently, there are three major architectures for internetworking between 3G Universal Mobile Telecommunications System (UMTS) cellular networks and IEEE 802.11 WLAN. These are Open Coupling, Tight Coupling, and Loose Coupling (Liu, 2006). The Open Coupling architecture specifies an open standard and is used for access and roaming between 802.11 WLAN and UMTS networks. In this approach, both networks are considered as two independent systems that may share a single billing scheme between them. An 802.11 WLAN is connected to the Internet through a Gateway Router, and UMTS network, is connected to the Internet through a Gateway GPRS Support Node (GGSN). Open Coupling scheme is lack of supports for mobility, resource management, QoS provisioning, and security in integrated environment.

As a direct integration scheme, Tight Coupling connects the WLAN network to the rest of the core network in the same manner as other cellular radio access technologies (Liu & Zhou, 2005a, 2005b; Liu, 2006). As shown in Fig. 1, the WLAN gateway router hides the details of the WLAN from the 3G UMTS core network by adding a new component, SGSN emulator, into WLAN. The SGSN emulator connects the gateway router in the WLAN to the IP core network. It interconnects the UMTS core network at the $\mathbf{G_n}$ interface (Liu, 2006), and implements all UMTS protocols required in a 3G radio access network. In terms of UMTS protocols, the WLAN service area works like another SGSN coverage area to the UMTS core network. As a result, all the traffics, including data and UMTS signaling, generated in the WLAN are injected directly into the UMTS core network through the SGSN emulator. This increases the traffic load of the UMTS core network. If the operators of the WLAN are different from those of UMTS network, the new interface between the UMTS and the WLAN can cause security weaknesses. In addition, the WLAN cards in client devices must incorporate the UMTS protocol stack, and Universal Subscriber Identity Module (USIM) authentication mechanism must be used for authentication in the WLAN (Liu & Zhou, 2005a).

In contrast to high cost of Tight Coupling, the Loose Coupling is an IP-based mechanism, and approach separates the data paths in the 802.11 WLAN and 3G cellular networks (Liu, 2006). The 802.11 WLAN gateway routers connect to the Internet, and all data traffic is

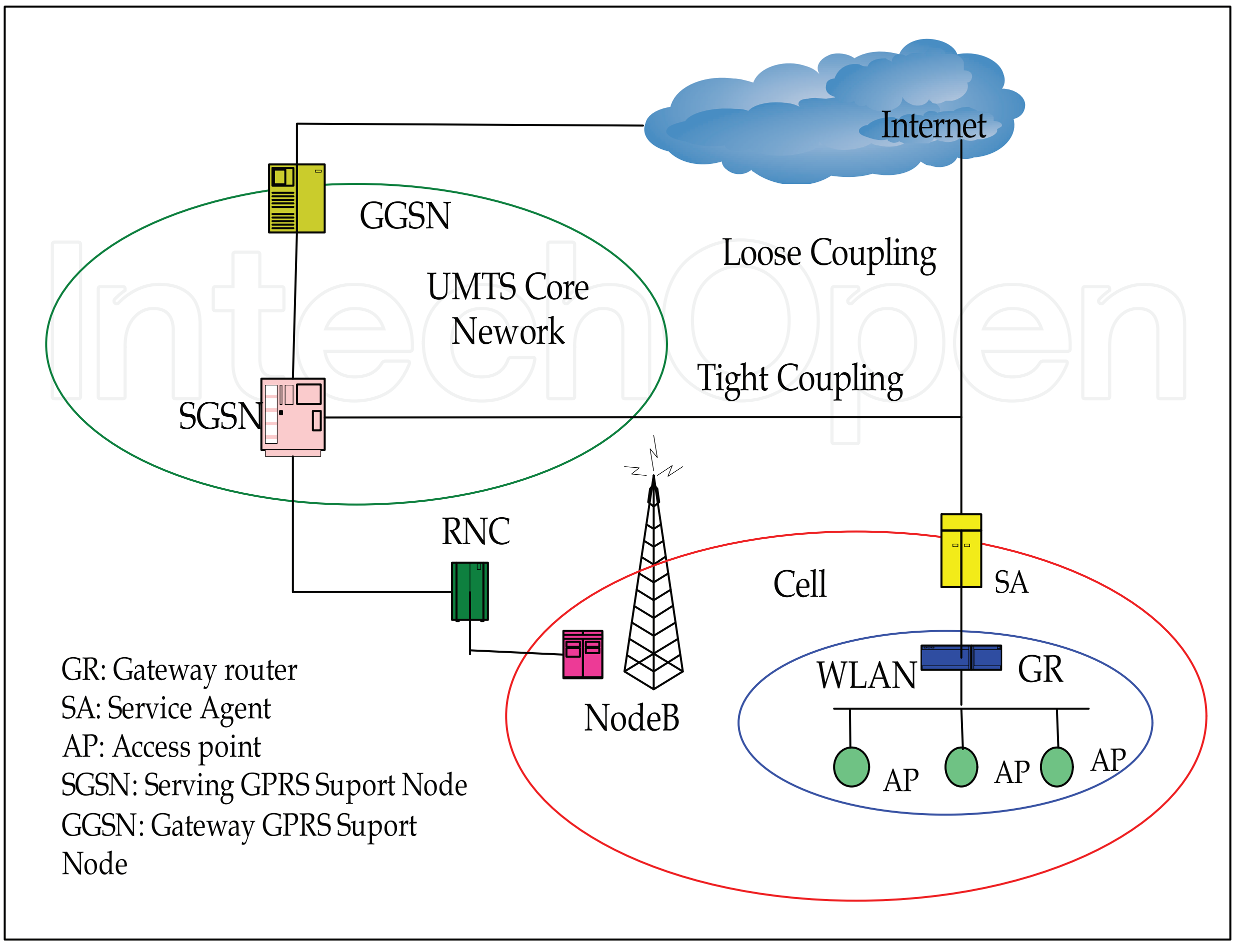

Fig. 1. Tight coupling and loose coupling

routed to the core Internet, instead of to the cellular core network. To the core network of the UMTS for example, the 802.11 WLAN appears like a visiting network. The gateway of the 802.11 WLAN can be connected to a Service Agent (SA), a combined SGSN/GGSN emulator, which provides not only internetworking protocol for signaling between the 802.11 WLAN and the UMTS 3G core network, but also an interface for data traffics between the WLAN and IP networks. If the 802.11 WLAN is deployed by the same UMTS operator, the SA may interface directly to the UMTS Core Network for signaling. Otherwise, the SA is interfaced to the IP network for both signaling and data traffic. Compared to open or tight coupling architectures, loose coupling implements the independent deployment and traffic configuration of both the 802.11 WLAN and UMTS networks. In addition, loose coupling architecture allows a mobile operator to provide its own private 802.11 WLAN "hotspots" and interoperate with public 802.11 WLANs and UMTS operators via internetworking agreements. So generally speaking, loose coupling is most preferable for integrated WLAN/Cellular network, due to the simplicity and less reconfiguration work.

Though promising, loose coupling have several technical open issues to be addressed before successful integration, such as integrated location management, seamless vertical handoff, common QoS provisioning, unified Authentication, Authorization and Accounting (AAA), joint call admission control and so on. As a part of resouce management, joint call admission control tightly interacts with vertical handoff and QoS provisioning schemes in integrated WLAN and 3G cellular networks.

2.2 Vertical handoff

In integrated networks, there are two types of handoff: intra-technology handoff and inter-technology handoff (Lampropoulos et al., 2005; Shafiee et al., 2011). The intra-technology handoff is traditional Horizontal Handoff (HHO) in which mobile terminals handoff between two adjacent base stations or access points using same access technology. In contrast, inter-technology handoff is called Vertical Handoff (VHO), and happens when mobile terminals roam between two networks with different access technologies, for example, between WLAN and 3G UMTS network.

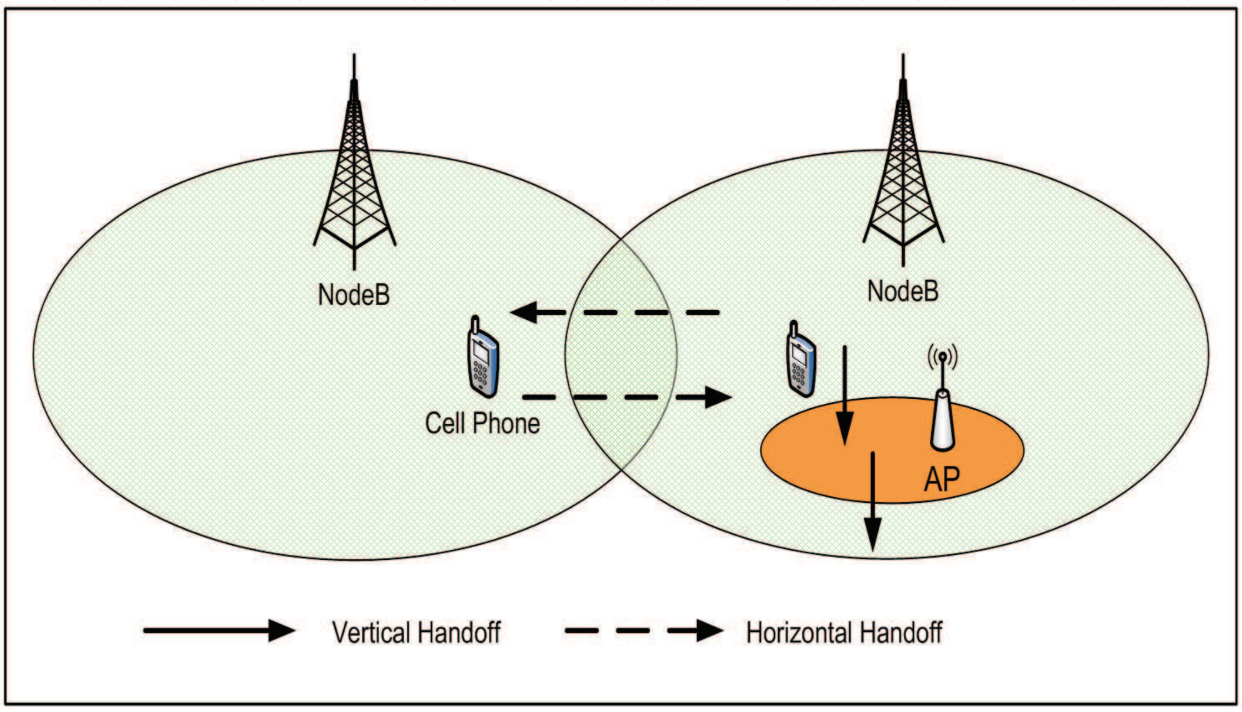

Fig. 2. Handoffs in integrated WLAN and UMTS cellular networks

Vertical handoffs in integrated WLAN / UMTS networks have two scenarios: a mobile terminal moves out of a WLAN to a UMTS cellular network, and moves from UMTS cellular network into a WLAN. Considering different service coverage area, the vertical handoff from WLAN to Cellular network is normally triggered by signal fading when a user moves out of the service area of the WLAN. However, the vertical handoff from cellular network to WLAN is regarded as a network selection process, because mobile terminals are in a wireless overlay area where both cellular access and WLAN access are available to mobile terminals at same time.

Seamless vertical handoffs face challenges caused by the gap between different QoS levels in cellular network and in WLAN (Liu, 2006; Shafiee et al., 2011): UMTS cellular networks provide wide coverage with high QoS provisioning for voice service, but limited-rate data service. However, WLANs support high-rate data service, but lack of universal roaming ability and suffer from low QoS level for voice service, due to their original real-time constraints. Furthermore, call admission control has been implemented in cellular network to ensure low call dropping probability in system by assigning voice horizontal handoffs with a higher priority for resource than new voice and data call requests, while WLANs only support coarse packet-level access without considering handoffs priorities. So in integrated WLAN and 3G cellular networks, seamless vertical handoffs and call admission control must be considered as dependent and joint mechanisms to ensure both high-level call service quality and efficient resource utilization in interworking environment.

3. Call admission control and previous work

In communication system, the call admission control scheme is a provisioning strategy for QoS provisioning and network congestion reduction (Ahmed, 2005). Arriving calls are granted or denied based on predefined system criteria. Due to limited spectrum resource and growing popularity of usage in wireless cellular networks, CAC has been receiving a lot of attentions for QoS provisioning, and its main features are extended to cover signal quality, blocking probability of new call, handoff dropping probability, data rate, etc. The next-generation integrated WLAN and 3G cellular networks pose a great challenge to the CAC design due to heterogeneous network features, such as varied access techniques, resource allocation priorities, QoS provisioning levels, vertical handoffs, etc.

3.1 Call admission control in cellular networks

Extensive research work has been done on the CAC schemes in homogeneous cellular networks (Ahmed, 2005). They can be classified based on various design focuses and algorithms, and each algorithm has its own advantages and disadvantages. Generally, CAC in 3G cellular networks give higher priority for voice service than data services for resource allocation, and higher priority for handoff calls than new call requests. We classify previous work on CAC into five major categories: signal quality based CAC, guard channel reservation based schemes, queuing methods, QoS estimation methods, and bandwidth degradation approaches.

Signal quality based CAC: signal quality in the physical layer is used as a criterion of admission control (Ahmed, 2005; Liu & Zarki, 1994). Some research work use power level of received signals or signal-to-noise-ratio (SIR) threshold as call admission requirements (Liu & Zarki, 1994). An optimal CAC scheme is proposed to minimize the blocking probability while keeping a good signal quality to reduce the packet error (Ahmed, 2005). However, all the above schemes only check the signal characteristics in the physical layer without considering technical features in other layers and service priorities. Furthermore, there are different criteria for the measurement of signal quality in integrated networks. So it is difficult for implement a CAC in an interworking environment based on a uniform criterion.

Guard channel reservation based schemes: To prioritize handoff calls over new calls, a number of channels, guard channels, in each cell are reserved for exclusive use by handoff calls, while the remaining channels are shared by both new calls and handoff calls. To decrease the handoff call dropping probability, which is at the cost of increasing the new call blocking probability, the guard channel must be chosen carefully and dynamically adjusted so that the dropping probability of handoff call is minimized and the network can support as many new call requests as possible (Fang & Zhang, 2002; Ahmed, 2005). However, the intensities of new call requests and handoff requests are time-variant, and it is difficult to assign appropriate guard channel timely. So the guard channel will reduce the efficiency of system resource utilization, and may not be suitable for heterogeneous network environment.

Queuing methods: When there is no channel for incoming call requests, either handoff call requests are put into a queue while new call requests are blocked, or new call requests are put into a queue while handoff calls are dropped (Lau & Maric, 1998; Ahmed, 2005). Although queuing schemes can avoid high blocking probability or dropping probability due to increased call intensity for a short period, it is not realistic in a practical system in which a handoff call may not hold in a queue for a long time because of fast signal fading, and new calls will leave the queue system due to users' impatience.

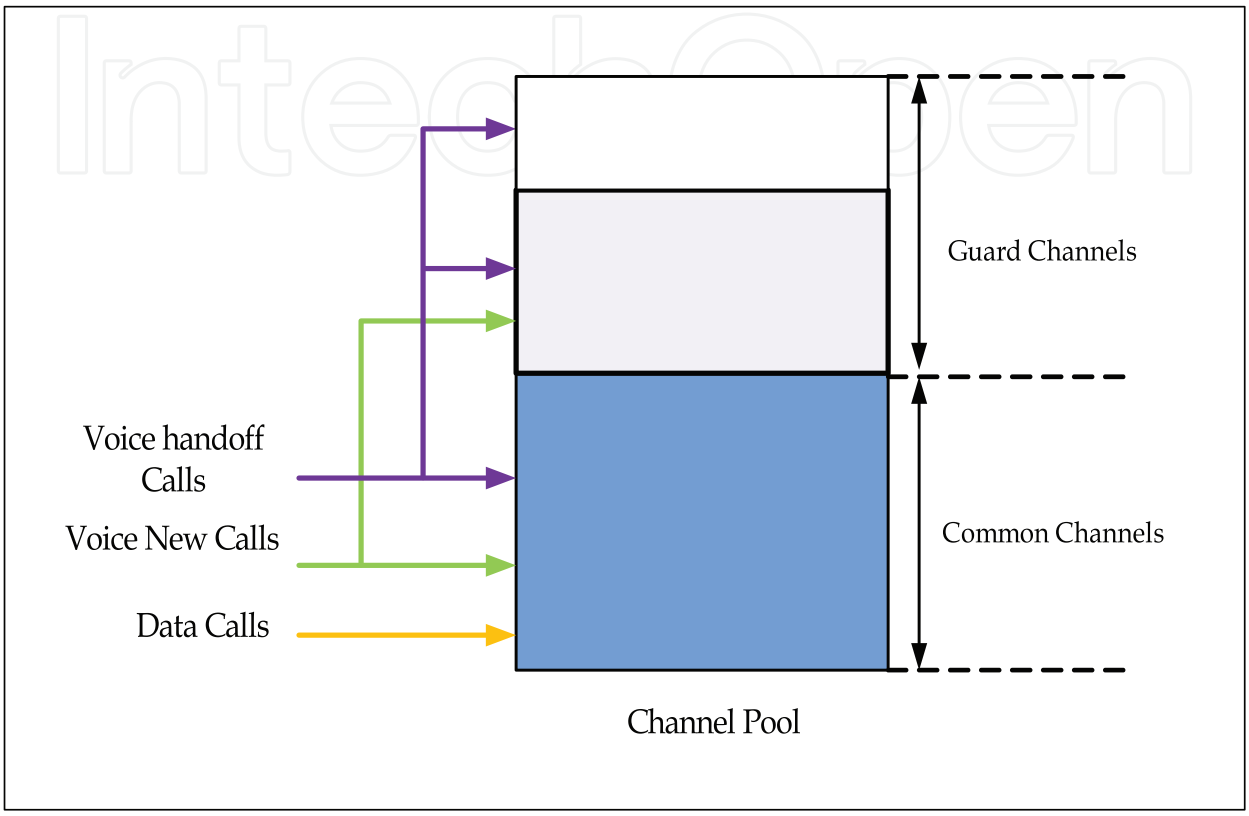

Fig. 3. Guard channel reservation based scheme for voice and data services

QoS estimation based approaches: CAC in cellular networks calculates the future resource requirements for new calls and handoff calls based on user mobility and call intensity estimation (Zhao et al., 2003; Koodli & Puuskari, 2001). A weighted overall handoff failure probability for all cells is calculated as an indicator for long-term statistics of successful call completion. The suggested schemes take the overall weighted handoff failure probability as the criterion for new call admission. Although those schemes can improve the efficiency of admission control and resource utilization, they cause nontrivial calculation complexity, and too many real-time control messages among cells may incur large signaling traffic and communication overhead. Furthermore, rough estimation techniques used in these schemes may cause erroneous decisions for call requests in a real world scenario, which will deteriorate the QoS level in the system.

Bandwidth degradation CAC: Some methods are proposed to degrade some connections adaptively when there are no more resources available for incoming new calls or handoff calls. For example, longest calls in the system are degraded to free resource for handoff calls (Jia & Mermelstein, 1996). Another proposal includes an algorithm in which each admitted connection degrades to a lower bandwidth level according to weights (Ahmed, 2005). Other proposals reduce the bandwidth of latest admitted connections. However, bandwidth degradation can only reduce the bandwidth of varied-bit-rate (VBR) and non-real-time (NRT) services for each individual, and is not suitable for constant-bit-rate (CBR) connections. Furthermore, though these schemes can reduce the blocking probability, the QoS level in the network cannot avoid deteriorating after degradation, and the overall utilization ratio may not be improved.

3.2 Call admission control in integrated WLAN and 3G cellular networks

There have been some works on call admission control in integrated WLAN and 3G cellulr networks. Most significant ones are WLAN-first approaches, mobility based algorithms and policy based CAC schemes.

WLAN-first approaches: If mobile terminals locate in a WLAN service area, both new voice and data calls first request admission to the WLAN. If rejected, the calls overflow to 3G cellular network. If mobile terminals with on-going voice and data calls move into the WLAN, the calls always try to handoff to WLAN (Song et al., 2006; Song et al., 2007a). This unconidional preference to WLAN aims to take advantage of cheaper and higher bandwidth in WLAN, compared to 3G cellular network. However, these approaches may cause an over-crowded traffic situation in WLAN, without load balance in both networks. Since user mobility is not covered in these approaches, frequent handoff requests will happen around the WLAN boundary, which may cause "Ping-Pong" effects for too many vertical handoffs with extra large sigaling traffics generated into networks.

Mobility based algorithms: Some research works consider users with different mobility speeds and apply different CAC and vertical handoff algorithms for them. Some authors probabilistically reject vertical handoff requests to WLAN for highly mobile cellular users (Lampropoulos et al., 2005; Klein & Han, 2004), to reduce unnecessary handoffs. In this scheme, the processing load and new call blocking probability can be reduced while maintaining reasonable throughput in the WLAN. A mobility-based predictive call admission control technique has been proposed for the 4G wireless heterogeneous networks (Rashad, 2006). In this scheme, local and global mobility profiles for the mobile terminals are generated and used for call admission decision. However, since randomness of user mobility, it may be difficult for such algorithms to getting speed estimation timely and concisely. Besides handoff management based on mobility information, more works are needed for considering service differentiations, QoS cost, and user preference, to provide global optimization for resource utilization in integrated networks.

Policy Based CAC Schemes: Some solutions follow policy framework defined by IETF, and combine call admission control and vertical handoff management together. They use a mobile-assisted scheme, in which system functionality is controlled by a network policy engine and a mobile policy engine (Zhuang et al., 2003). As shown in Fig. 4, a pairing of a policy decision point (PDP) and policy enforcement point (PEP) exist in both engines, along with policy repositories. PEP is responsible for the execution of a policy that is decided by PDP, and the policy repositories define the policies that must be followed for a proper handover decision (Zhuang et al., 2003; Guerrero & Barba 2008). In the call admission control procedure, PEPs in the mobile terminals consult a PDP residing at the network for available resources. The PDP will make a decision on call admission, based on network capacities, QoS level, call types, user preferences as well as estimations on current network load and performances. This approach gives flexibility to the terminal and the network to make the best possible handover decision, and implements load balance. However, there are several drawbacks of this policy method, such as high latencies to fetch context information during the candidate access point classification procedure, and no optimization policy is defined for resource allocation in integrated networks.

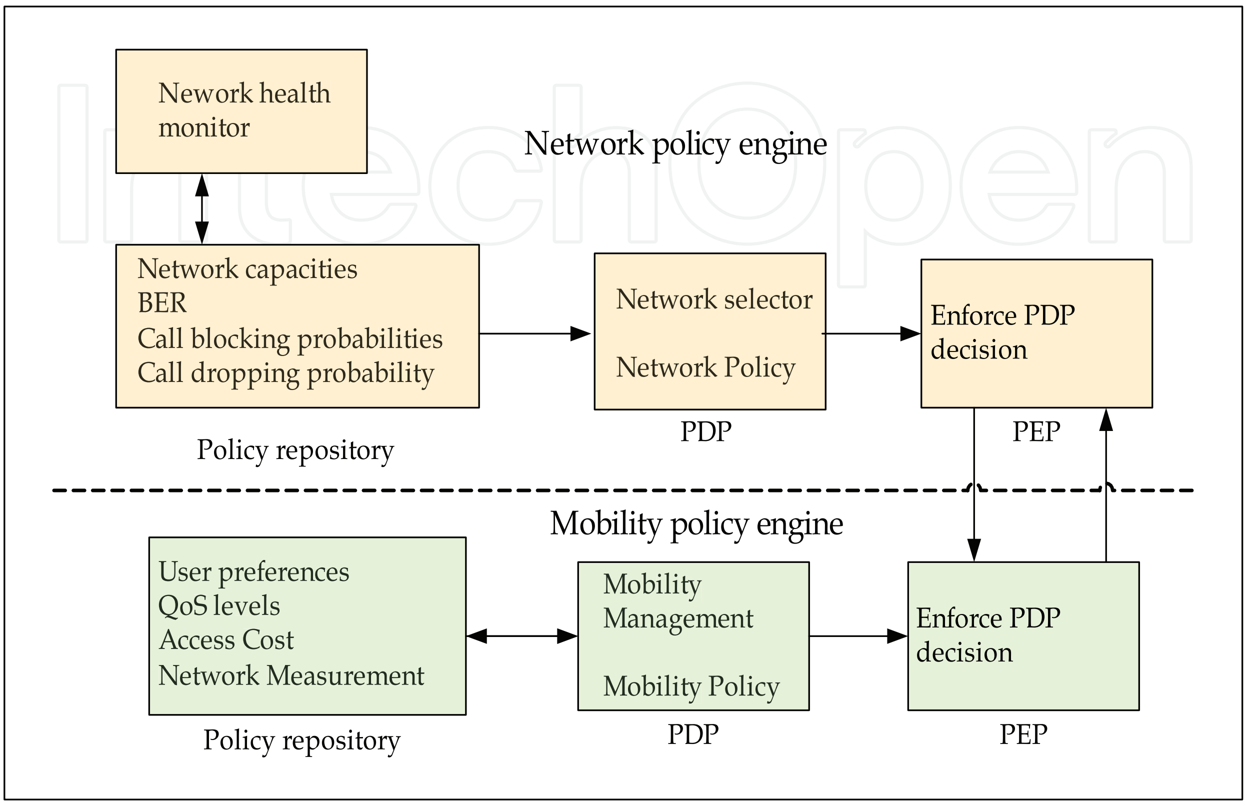

Fig. 4. Policy-based admission control framework

4. A novel joint call admission control scheme

In this section, a novel joint call admission control scheme is proposed for both voice and data services with QoS provisioning in integrated WLAN and 3G UMTS cellular networks. Due to different network service characteristics, UMTS network is defined to be a Voice-Priority network where voice services have higher priority for resource allocation than data services, while WLAN is defined as Data-Priority network where data services have higher priority than voice services. Instead of using WLAN-first schemes, a novel joint call admission policy is derived to support heterogeneous network architecture, service types, QoS levels, mobility characteristics, and user network preferences. Based on the policy, a channel searching and replacement algorithm (CSR) is designed to relieve traffic congestion in UMTS cellular network. CSR searches idle channels in WLAN and replacement channels among mobile terminals based on their location and passive vertical handoffs, and therefore implements load balance between UMTS networks and WLAN. A one-dimension Markov model is further developed to compare system performance metrics, such as new call blocking probability and dropping probability of voice handoff, between the proposed algorithm and normal disjoint guard channel reservation based scheme.
The CSR algorithm is further improved by considering congestion scenarios in both the WLAN and UMTS cellular networks. Specifically, a system cost function is derived and

minimized by admitting passive vertical handoffs with a probability, and it is proven that there exists at least one optimal value for the target passive handoff probability. In this way, the total traffic is balanced in the interworking environment as well as the resource utilization is optimized. A linear programming solution is proposed for searching the optimal admission probability for passive vertical handoff, with performance comparsion to the traditional disjoint guard channel CAC. Numerical and simulation results demonstrate that the optimal CSR (oCSR), outperforms disjoint guard channel CAC and original CSR algorithms in both QoS provisioning and system resource utilization.

4.1 System model

Our system model is based on the loose coupling achitecture in which WLAN is connected to cellular networks through Internet. All traffics in WLAN are routed to Internet through gateway routers. Since the coverage area of a UMTS cell is normally much larger than WLAN area, the cellular cell is called a "macro-cell," while the WLAN region is regarded as a "micro-cell" inside (Liu et al., 2007). The overlaid service area between the "macro-cell" and the "micro-cell" provides mobile terminals with opportunities to connect to either UMTS network or the WLAN, as shown in Fig. 5.

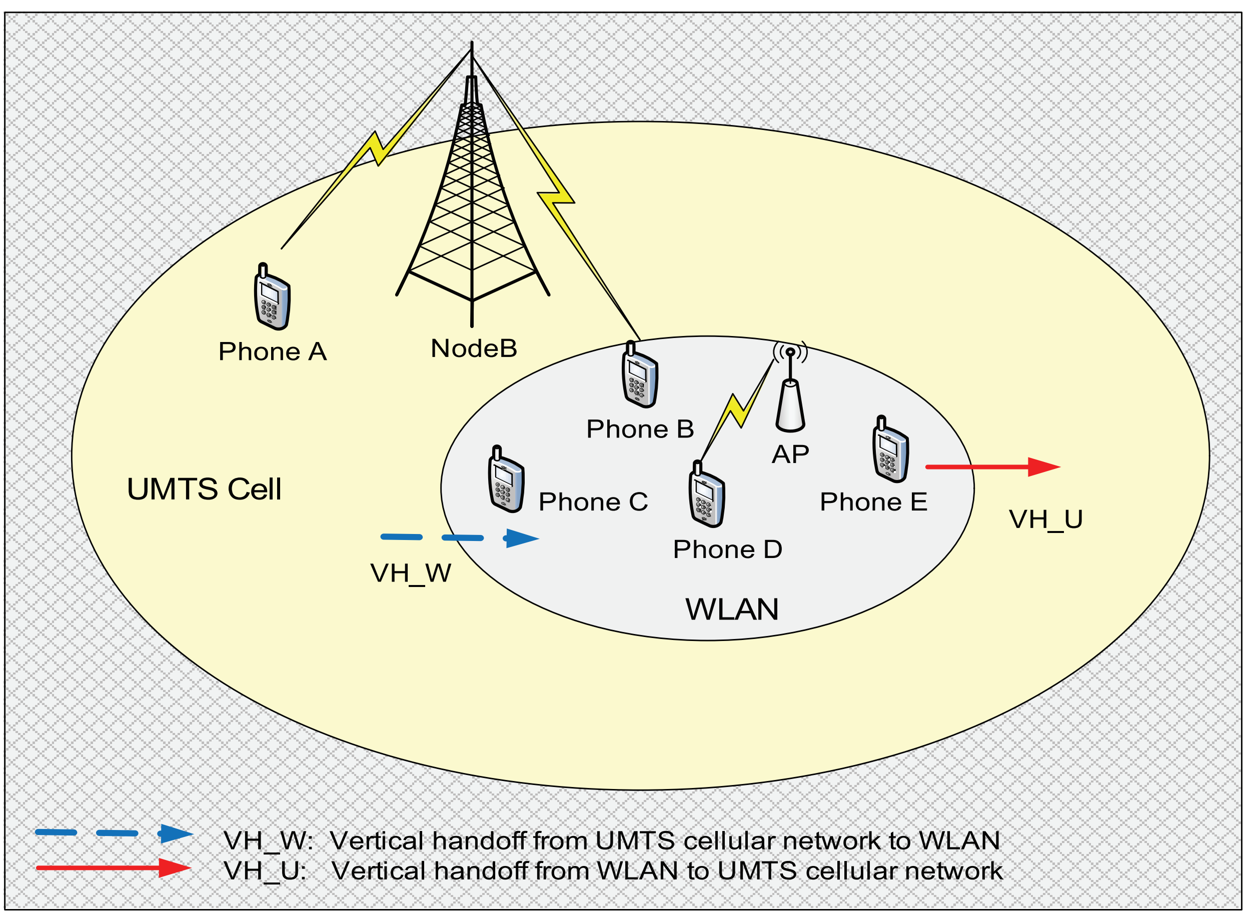

Fig. 5. System model for integrated UMTS cell and WLAN

There are one class of voice service and N classes of data service considered in the integrated networks. Since voice is sensitive to the transmission delay, the QoS requirement for voice service is represented as an average voice packet generation rate b_v and the maximum tolerable transmission delay D_v. On the other hand, QoS constraint for data service i is mainly defined as the minimum throughput Ti, since data services are assumed as best effort services and not sensitive to the transmission delay.

With careful network planning and mature admission control algorithms, the UMTS network is assumed to support both voice and data services with QoS provisioning. However, due to limited bandwidth and high cost per bit, voice calls are assigned with higher priority than data services in cellular networks, and data services are regarded as best-effort services. So we set the proportion Rc ($0< Rc < 1$) as the maximum ratio of resource usage assigned to all data services in the cellular network.

On the other hand, the traditional WLAN is designed to support only best-effort data services. To match the QoS difference between the cellular network and the traditional WLAN, we assume that the IEEE 802.11e WLAN standard is adopted and our polling algorithm named IIT (Liu & Zhou, 2006) is used to guarantee bandwidth and delay requirements for voice services in WLAN while enhanced distributed coordination function (EDCF) to support data services. Since normally mobile users connect to WLAN for high-speed data transmission with low cost, we assume that data services in WLAN have higher priority than voice services. Compared to cellular network, the proportion Rw ($0 < Rw < 1$), is set as the maximum ratio of resource usage assigned to all voice services in the WLAN.

Based on user mobility characteristics, voice call requests in a UMTS cell can be classified into the following two categories: vertical handoffs from the overlaid WLAN to the UMTS, which is denoted as *VH_U*, and new calls from this UMTS cell. Since a WLAN network is assumed to be overlaid by a UMTS cell, there are also two categories in admission requests: new call requests for WLAN access, and vertical handoffs from the surrounding UMTS cell, denoted as *VH_W*, as shown in Fig. 5. To reduce complexity, the horizontal handoffs from nearby cellular cells to the target cell are assumed to be equal to horizontal handoffs out of the cell to neighbor cells so that we do not consider horizontal handoffs in this work. We further assume that QoS level in the integrated networks are mainly bottlenecked by the total bandwidth in the integrated networks. Therefore, the QoS performance considered in this work includes blocking probability of new call requests and dropping probability of handoff call requests.

4.2 Call admission control flow and policy

The admission control flow for the integrated networks is classified into two sub-schemes according to the types of call requests, as shown in Fig. 6. If the call request is a new call and mobile terminal is out of the WLAN service area, the mobile terminal will send the new call request to the UMTS base station directly. On the other hand, if the call is a new call and mobile terminal is in the WLAN area, the mobile terminal will first send a new call request to the WLAN as the first choice, since the WLAN is much less expensive per call. The new call request will be handled by the CAC in the WLAN. If the WLAN cannot accommodate the new call request, the request will be forwarded to the UMTS base station.

The situation becomes complex when we consider vertical handoff call requests. Since voice service is real-time service, a user is much more sensitive to voice dropping than dropping of data service during vertical handoff. So voice vertical handoff from WLAN to UMTS cellular network should be assigned a higher priority than new call requests and data vertical handoff from WLAN to UMTS, to avoid possible voice dropping in the cellular service area. Here, we adopt guard channel scheme (Fang & Zhang, 2002) to reserve some bandwidth for voice *VH_U* handoff. However, for any data *VH_U* handoff, no matter how high data rate it gets in WLAN, it become best-effort service when the user move from WLAN to cellular network. So data *VH_U* is assigned same priority as any new call requests is in cellular network.

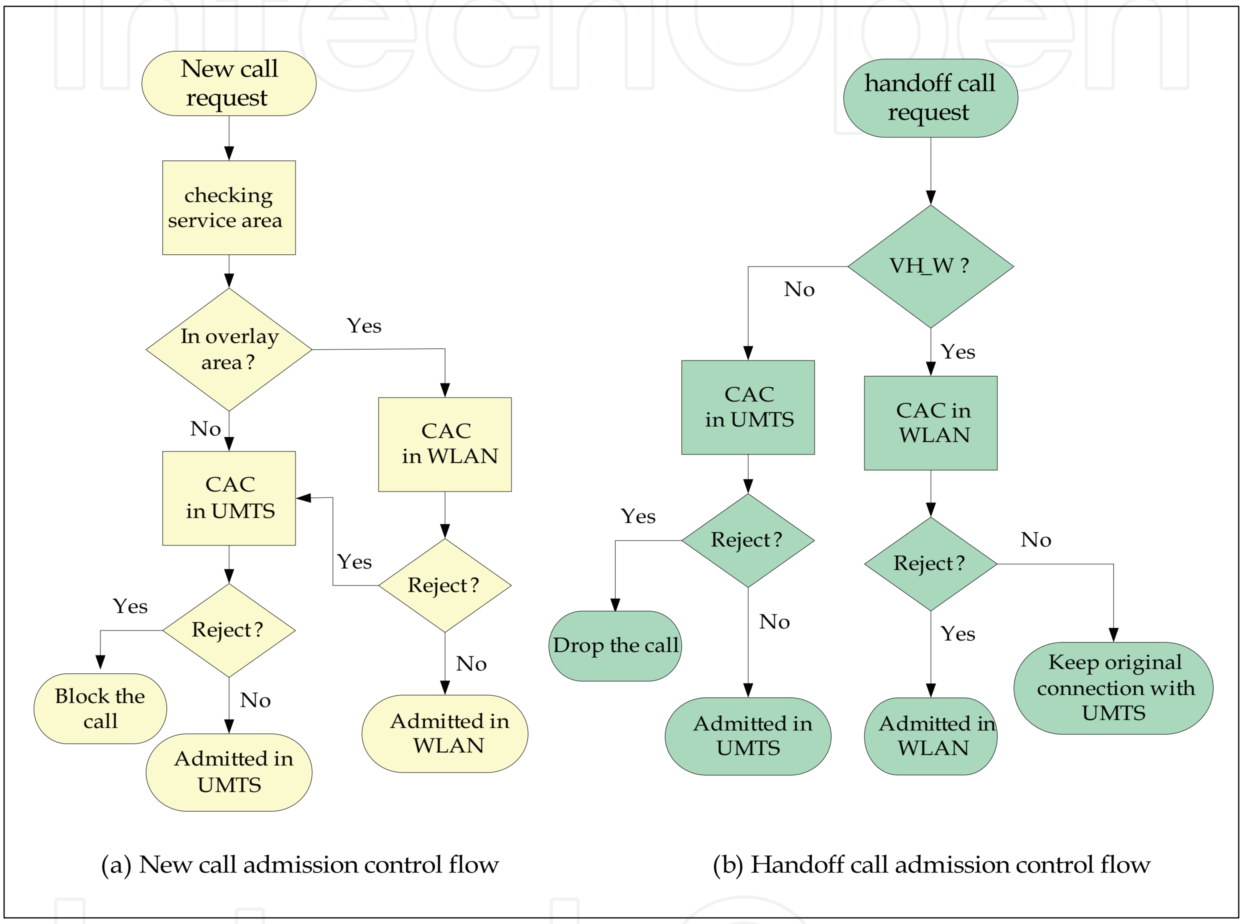

Fig. 6. Call admission control flow

Furthermore, for all *VH_W* handoff requests from cellular to WLAN, users can still keep original connections with the cellular network even when the handoff request is denied by the WLAN. Since there is no real connection dropping for *VH_W* handoffs, both *VH_W* and new calls in the WLAN are assigned the same priority in our system.
Based on the above analysis of user mobility and service characteristics, the pseudocode of proposed admission policy for interworking system are developed in Fig. 7. We assume total bandwidth in cellular network and WLAN as *Bc* and *Bw*, respectively. The numbers of admitted voice call in WLAN and cellular network are denoted as *Vw* and *Vc*, respectively. The guard channel in cellular network is set as *Gc*. The number of admitted data service of class-*i* is denoted as *Di*. When WLAN receive a call request, the average throughput, t_i, for current WLAN can be calculated based on enhanced DCF mode method (Liu & Zhou, 2006).

Notations :

Vw: number of admitted voice calls in WLAN;
Vc: number of admitted voice calls in cellular network;
Bw: total bandwidth of WLAN;
Bc: total bandwidth of cellular network;
Gc: Guard channel reserved for handoff in cellular network;
D_i: number of admitted data calls of service i in cellular network;
T_i: minimum throughput requirement of data service i;
t_i: current throughput of data service i in WLAN;
Rv: maximum ratio of bandwidth assigned to voice in WLAN;
Rc: maximum ratio of bandwidth assigned to data services in cellular;
bv: average voice generation rate;

Admission Policy:

Switch (Call request type in WLAN)
  Case (voice new call or voice handoff from cellular)
    if ($(Vw+1)\cdot bv \le Bw\cdot Rv$) & ($t_i \ge T_i$ for all Data classes)
    admit the call; ***else*** *transfer call to cellular;*
  Case (data new call | data handoff from cellular)
    if ($t_i \ge T_i$)
    admit the call; ***else*** *transfer call to cellular;*
end

Switch (Call request type in cellular network)
  Case (data new call in cell | data handoff from WLAN)
    if ($\sum_i (D_i+1)\cdot T_i \le Bc\cdot Rc$) & ($Vc\cdot bv+\sum_i (D_i+1)\cdot T_i \le (Bc-Gc)$)
    admit the call; ***else*** *reject the call request;*
  Case (voice new call in cell)
    if ($(Vc+1)\cdot bv+\sum_i D_i\cdot T_i \le (Bc-Gc)$)
    admit the call; ***else*** *reject the call request;*
  Case (voice handoff call from WLAN)
    if ($(Vc+1)\cdot bv \le Bc$)
    admit the call; ***else*** *transfer call to cellular;*
end

Fig. 7. Call admission control policy

4.3 Channel searching and replacement (CSR) algorithm

Although the above proposed CAC can handle call requests in both WLAN and cellular networks, all admission decisions are made based on the situation of each individual network. To improve the whole system performance, we propose a channel searching and replacement (*CSR*) algorithm based on passive vertcial handoff to implement joint resource management.

Due to different capacities and user densities, the traffic intensities and QoS levels are often unbalanced in the WLAN and overlaid cellular network. When WLAN becomes congested, the traffic will be routed to the cellular network automatically. On the other hand, when the 3G cellular network has no resource available for an incoming call requests, our CSR algorithm is used to find available resources in the WLAN by switching some 3G

connections staying in WLAN area to the WLAN, as shown in Figure 8. Specifically, if there exists an ongoing cellular connection and the mobile terminal residing in the WLAN area, and there is still bandwidth available in the WLAN at the same time, the cellular connection will be switched to the WLAN by vertical handoff, and then the incoming call request will take the released bandwidth in cellular network to avoid being blocked or dropped. This kind of vertical handoff is called "passive" because it is initiated by the system resource management instead of by users or signal fading.
To achieve the fairness among different service connections, *CSR* checks the difference of QoS provisioning in both networks before switching a cellular connection to WLAN. If there is no QoS degradation during switching and WLAN can guarantee QoS provisioning for all existing ongoing calls, then the bandwidth or channel is released.
Considering the CSR algorithm may increase the blocking probability in the WLAN (i.e., deteriorate the QoS in the WLAN by forwarding more traffics from the cellular network to WLAN). We further assume that there is a call admission probability for passive vertical handoff, which is determined by the system status of cellular network and WLAN, and QoS levels. The pseudocode of the *CSR* is shown in Fig. 8.

```
switch (call request in cellular network)
case (data-call-arrival):
    if (CAC for data::admitted) & (QoS provisioning )
       admit the call;
    else if (Channel_Searching() == 1) & (No degradation)
        switch the cellular connection to WLAN;
        admit the call request & assign a channel with a probability P;
    else { reject the call request;}
          break;
 case (voice-call-arrival):
    if (CAC for voice::admitted) & (QoS provisioning )
        admit the call ;
    else if (Channel_Searching() == 1) & (No degradation)
        switch the cellular connection to WLAN;
        admit the call request & assign a channel with a probability P;
    else { reject the call request; }
          break;
 default: break;
 end
-----------------------------------------------------------------------
#Channel_searching() :
Search for cellular connections but mobile terminal staying in WLAN;
if (at least one cellular connection in WLAN) & (QoS provisioning in
WLAN ) { return 1; }
else { return 0; }
```

Fig. 8. Channel searching and replacement (CSR) algorithm

4.4 Analysis and comparsion

In this section, the proposed CSR algorithm is compared with traditional disjoint guard channel (DGC) scheme with system performance metrics, including new call blocking prabability and handoff dropping probability. To reduce the complexity, we focus on voice services in the integrated WLAN and 3G UMTS cellular networks, with fixed total channels in UMTS cell and bandwidth in WLAN.

4.4.1 DGC algorithm

First the traditional DGC algorithm is considered. Assume that the arrival process for both new calls and vertical handoff follows Poisson distributions, and the channel holding time for both vertical handoffs and new calls are exponentially distributed. Let λ_n and $1/\mu_n$ denote the arrival rate and the average channel holding time for new voice call in the UMTS cell, respectively. Let λ_v and $1/\mu_v$ denote the the arrival rate and average channel holding time for voice vertical handoff from WLAN to UMTS cell, respectively. The arrivals of new calls and vertical handoffs are independent of each other. To simplify, assume the avarage channel holding time for both new voice call and handoff call are same: $\mu_n = \mu_v$.
Assume total C available channels in UMTS cellular network for voice service. An approximate one-dimension Markov model (Fang & Zhang, 2002; Liu et al., 2007) is derived to present state transitions in UMTS network, as shown in Fig. 9(a). The state space in cellular network can be denoted as $\{(m,n) \mid 0 \le m+n \le C\}$, where m and n are the numbers of admitted new calls and admitted vertical handoffs in the cell, respectively. The traffic intensity of vertical handoffs ω_v and traffic intensity of new calls ω_n are specified as $\omega_v = \lambda_v/\mu_v$ and $\omega_n = \lambda_n/\mu_n$, respectively.
Based on the stationary state distribution, the vertical handoff dropping probability P_v and new call blocking probability P_n, for disjoint guard channel scheme can be expressed as follows,

$$P_v = \pi_c(C) = \frac{\dfrac{(\omega_n+\omega_v)^G \cdot (\omega_v)^{C-G}}{C!}}{\sum_{i=0}^{G}\dfrac{(\omega_n+\omega_v)^i}{i!} + \sum_{i=G+1}^{C}\dfrac{(\omega_n+\omega_v)^G(\omega_v)^{i-G}}{i!}} \tag{1}$$

$$P_n = \sum_{i=G}^{C}\pi_c(i) = \frac{\sum_{i=G}^{C}\dfrac{(\omega_n+\omega_v)^G \cdot (\omega_v)^{i-G}}{i!}}{\sum_{i=0}^{G}\dfrac{(\omega_n+\omega_v)^i}{i!} + \sum_{i=G+1}^{C}\dfrac{(\omega_n+\omega_v)^G(\omega_v)^{i-G}}{i!}} \tag{2}$$

where $\pi_c(i)$ represents the stationary state of occupied channel i. The detailed derivations for above equations are shown in our previous work (Liu & Zhou, 2007).

4.4.2 CSR algorithm

In the proposed CSR scheme, the total number of occupied channels in the cell and the idle channels in the WLAN are the keys to deciding whether a new voice calls or a vertical handoffs need intersystem channel switching through a passive handoff to the WLAN. When the total channel number i in the cell is larger than Gc, an incoming new call request can get admission if there is an ongoing cellular connection residing the WLAN and there is still bandwidth available in the WLAN. When the total occupied UMTS channel number equals to C, an incoming vertical handoff from WLAN can also be admitted in cellular network if there is a successful channel replacement in the WLAN. To avoid over-utlization on WLAN, it is assumed that a call request can get admission with probability δ that is determined by the total number of occupied channels in the cell, the probability for mobile terminals using ongoing cellular connection while located in the WLAN, and the state of current occupied channels in the WLAN. Based on the above descriptions, we can get a Markov chain model for the cellular network, shown in Fig 9(b).

Using CSR, call request blocking or dropping in a cellular network will happen in following two scenarios:

Scenario 1: There is no idle channel available in cellular network, and no cellular connections residing in the WLAN;

Scenario 2: There is no idle channel available in cellular network, and no channel within the WLAN, although there is a cellular connection residing in the WLAN.

So Let P_f be the probability of an ongoing cellular call remaining in a WLAN, which is assumed to be determined by a user's preference for vertical handoff and mobility velocity. Let $\psi_c(i)$ be the probability that there is no cellular connection within the WLAN when the number of total occupied channels in the cellular network is i.

$$\psi_c(i) = \binom{i}{0} \cdot (p_f)^0 \cdot (1 - p_f)^i \tag{3}$$

If the probability for finding a cellular connection staying in the WLAN is set as 1, which means always finding available cellular connection successfully, the traffic intensity in the WLAN depends on not only original traffic inside, but also on passive handoffs from the cell. So the traffic intensity $\rho(i)$ in the WLAN is a function of state i in UMTS cell and can be expressed as,

$$\rho(i) = I_1(i) \cdot (\rho_n + \rho_v) + I_2(i) \cdot (\rho_n + \rho_v + \omega_n) + I_3(i) \cdot (\rho_n + \rho_v + \omega_n + \omega_v) \tag{4}$$

where ρ_n is original traffic intensity of new call requests in WLAN, ρ_v is original call intensity of vertical handoff requests from UMTS to WLAN. $I_i()$ are state indicator functions: $I_1(i)$ equals to 1 when state i smaller than guard channel Gc, otherwise equals to zero. $I_2(i)$ equals to 1 when state i larger than Gc-1 and smaller than total channels C in UMTS cell, otherwise equals to zero. $I_3(i)$ equals to 1 when state i equals to total channels C in UMTS cell, otherwise equals to zero.

Since in WLAN vertical handoffs and new calls are assigned with same priorities for resource, the blocking probability of new call is same to dropping probability of vertical handoffs. Considering voice service, the blocking probability p_b^w in WLAN is determined by incoming traffic intensity $\rho(i)$, which is affected by traffic intensities in both UMTS cell and WLAN, the probability of an ongoing cellular call remaining in a WLAN, as well as admission probability of passive handoffs.

According to above definitions of the two scenarios, the blocking probability for new call requests and dropping probability for vertical handoffs from WLAN to cellular network can be approximated as,

$$P_n = \sum_{i=G}^{C} \left\{ \psi_c(i) + \left[1 - \psi_c(i)\right] \cdot p_b^w(i) \right\} \cdot \pi_c(i) \tag{5}$$

$$P_v = \left\{ \psi_c(C) + \left[1 - \psi_c(C)\right] \cdot p_b^w(C) \right\} \cdot \pi_c(C) \tag{6}$$

where $\pi_c(i)$ represents the stationary state of occupied channel *i* in UMTS cell.
Since probability that there is no cellular connection within the WLAN is alway smaller than 1, and same for blocking probability p_b^w in WLAN, it is proved (Liu & Zhou, 2007) that value of blocking probability for new call requests and dropping probability of vertical handoffs in UMTS cell through CSR algorithm are both smaller than the probability values using disjoint guard channels shown in equations (1) and (2).

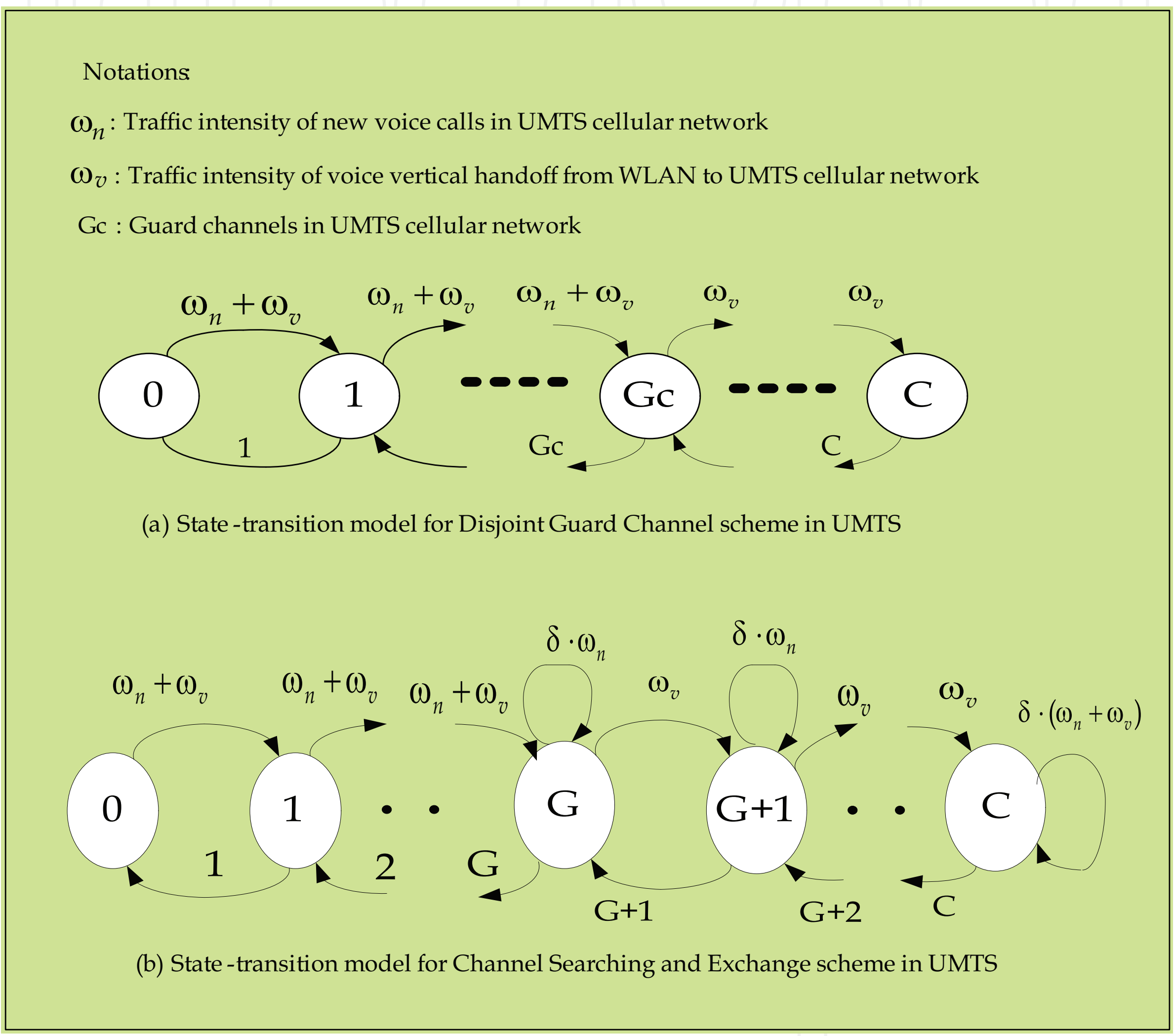

Fig. 9. State-transition diagram for DGC and CSR algorithms

4.5 Optimization on joint call admission control

Although the blocking probability of new calls and dropping probability of handoff calls in UMTS cellular network get reduced by using CSR algorithm, the cost is load balance traffics to WLAN and therefore may deteriorate QoS in WLAN, such as increasing blocking probability in WLAN. So the joint call admission control needs to be optimized to achieve the minimum blocking probability per Erlang in the integrated networks.
A weitghted system cost function is derived based on blocking probability, dropping probability, call intensities, and probability of passive vertical handoffs. Our goal is to

minimize average weighted system cost with constraint on probability of passive vertical handoffs, as shown in follows:

$$\textbf{Minimize}\ P_{ave} = \frac{W_1 \cdot P_n \cdot \omega_n + W_2 \cdot P_v \cdot \omega_v + W_3 \cdot P_b^w \cdot (\rho_n + \rho_v)}{\omega_n + \omega_v + \rho_n + \rho_v}$$

s.t. $0 \le \delta \le 1$

where W_1, W_2, and W_3 are cost weights for the blocking probability in the cellular network, the dropping probability in cellular network, and the blocking probability in the WLAN, respectively.

It is easy to prove that blocking probability in WLAN is a monotonically increasing continuous function of δ, while blocking probability and dropping probability in UMTS cell are continuous decreasing functions over δ in the interval between zero and one. So the weighted cost function is also a continuous function over the same interval. According to the Extreme Value Theorem, target cost function has a minimum and a maximum value over the interval $0 \le \delta \le 1$. So it is feasible to find out a optimal admission probability for passive handoff which minimizes the integrated system cost with linear programming. Here we should notice that there may be more than one optimal value for the admission probability.

5. Numerical and simulation results

In this section, the performances of CSR are testified through numerical results and simulations. Referred from (Fang & Zhang, 2002; Liu, 2006; Liu et al., 2007), the system parameter values are shown in Table 1, and results are shown as below. We focus on voice service and assume that the traffic intensity of data service in both WLAN and cellular network are kept constant. The step searching method of linear programming (Liu, 2006) is used to find the optimal admission probability for passive vertical handoff.

Bc	Bw	Gc	bv	Rc	Rw	p_f	W_1	W_2	W_3	Ti
20	30ms	18	30kb	0.2	0.2	0.3	1.0	2.0	1.0	30kb

Table 1. System parameters

Fig. 10 shows the changes in the optimal admission probability for passive vertical handoff as handoff intensity in the cell varies. We set new call intensity in UMTS cell ω_n = 10, new call intensity in WLAN ρ_n = 10, vertical handoff intensity ρ_v = 5. Since the weight of handoff dropping is larger than both the weights of blocking calls in cellular network and in WLAN, the optimal admission probability increases quickly for W3 = 1.3 and W3 = 2.0, and is 1 when the handoff intensity is larger than 45. In other words, the integrated system attempts to allocate each idle resource in the WLAN to handoff in cellular network to avoid larger system cost caused by dropping probability.

In contrast, when new call intensity ρ_n in the WLAN increases (ω_v is set as 5), the admission probability for W3 = 2.0 and W3 = 1.3 is reduced to zero, but remains 1 for W3 = 1, as shown in Figure 11. Again, it is shown that CSR can adjust the traffic intensity among the two networks to avoid overloaded situation in the WLAN. For W3 = 1.0, since the cost for blocking a passive handoff is no more than the costs of blocking a new call or dropping a connection in cellular network, the passive handoff always get an admission into the WLAN.

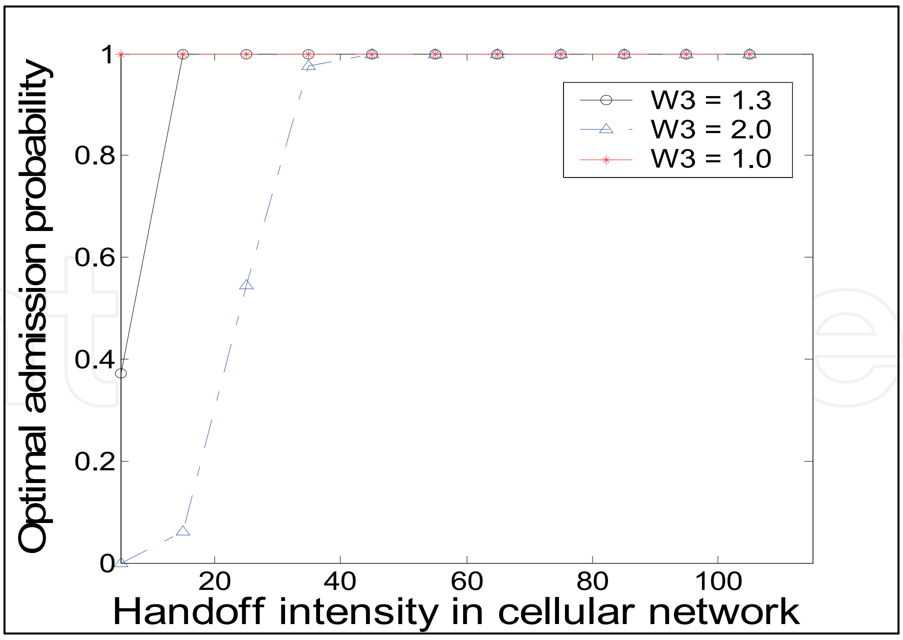

Fig. 10. Optimal admission probability for passive handoff vs handoff intensity in cellular

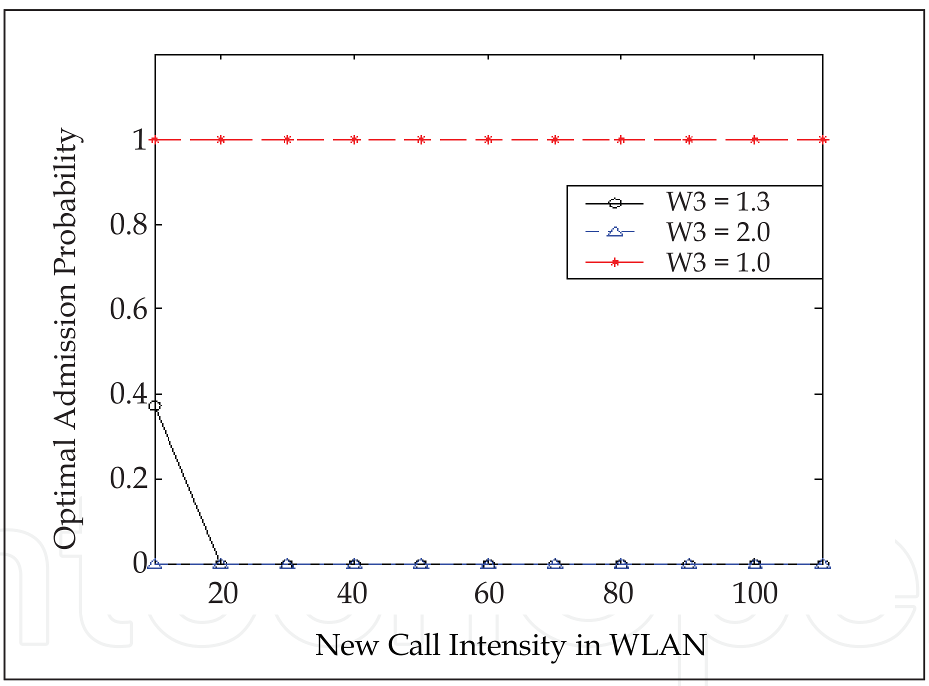

Fig. 11. Optimal admission probability for passive handoff vs new call intensity in WLAN

To validate the analytical results, simulations were performed based on the OPNET tool, an efficient discrete event-driven simulator. Fig. 12 shows the average system cost for DGC, CSR, and optimal CSR (oCSR), when new call intensity in UMTS, ω_n, is set as 30. In this case, the optimal admission probibility for passive handoff δ can be obtained as 0.078. DGC has the highest system cost due to its disjoint resource allocation, while oCSR can achieve the optimal resource allocation with minimum average system cost. Since the cost of oCSR is less than that of CSR, original CSR in UMTS cellular network is a sub-optimal solution for the overall resource allocation for integrated networks.

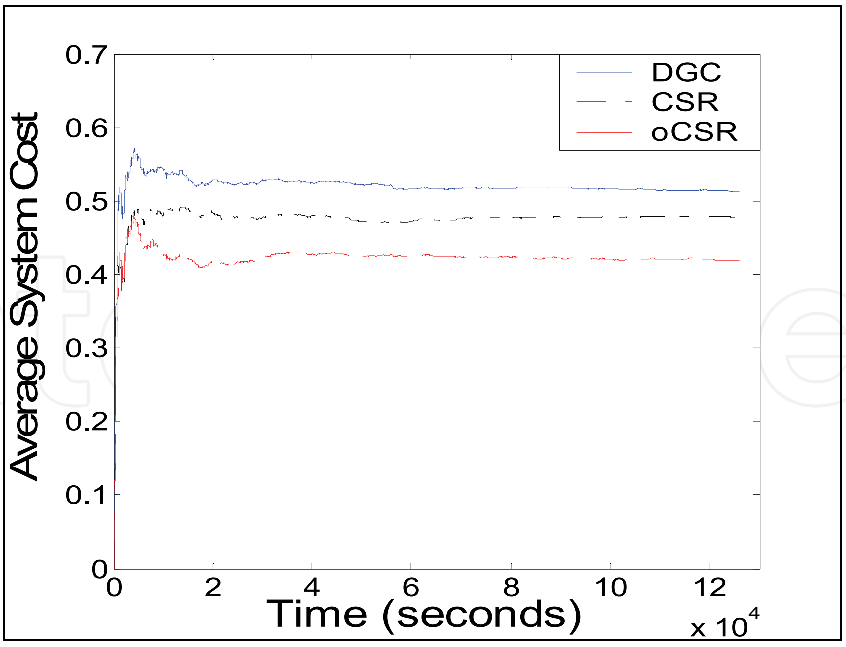

Fig. 12. System cost of DGC, CSR, and optimal CSR

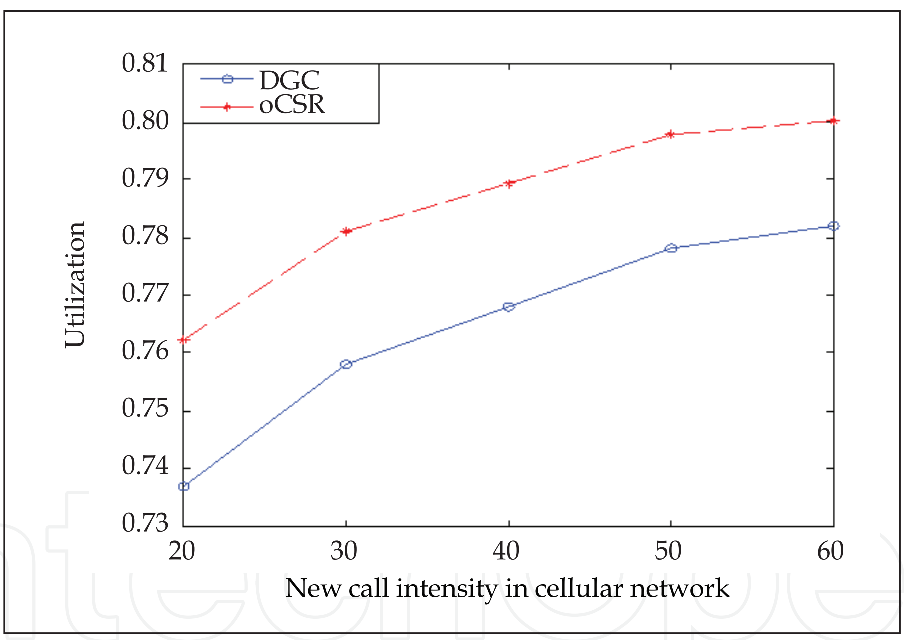

Fig. 13. Utilization with new call intensity in UMTS

Similarly, Fig. 13 shows the simulation result of utilization of system resource as new call requests ω_n in cellular network increases. We can see that optimal CSR has larger resource utilization than DGC does because optimal CSR uses idle resource in each network when traffic intensity in a network increases.

Fig. 14 shows the blocking probability when new call intensity in cellular network increases. When ω_n equals 20, 30, 40, 50, and 60, the optimal admission probability for passive handoffs are 0.496, 0.302, 0.216, 0.167, and 0.136, respectively. It is shown that the blocking probability of new call of oCSR scheme is always less than in the DGC scheme, due to optimal passive handoffs in oCSR scheme.

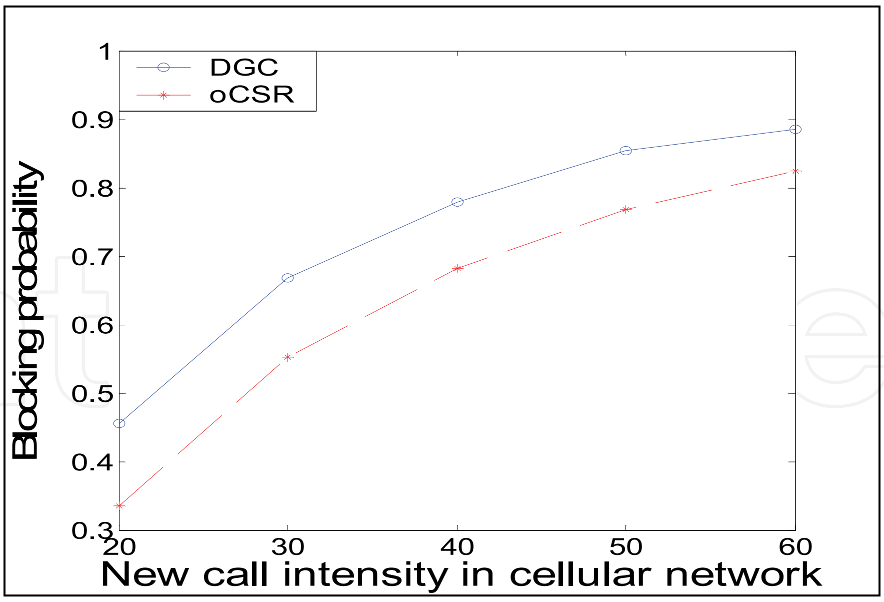

Fig. 14. Blocking probability with optimal CSR and DGC

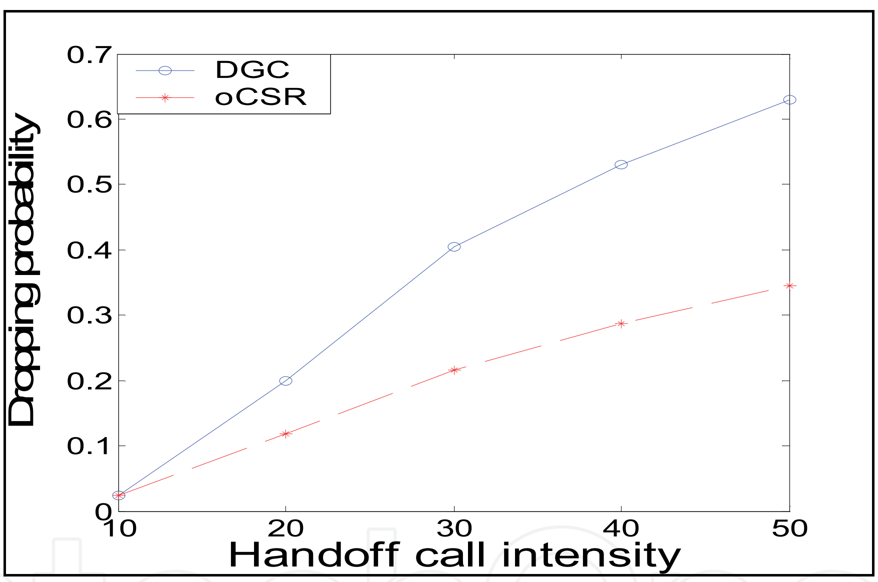

Fig. 15. Dropping probability with optimal CSR and DGC

Similarly, Fig. 15 shows the handoff dropping probability in the cell as the handoff intensity increases. Due to limited resources in the cellular network, both dropping probabilities increase. However, the dropping probability of the DGC is always greater than the dropping probability of the oCSR, since some handoffs are transferred to the WLAN, except in the case vertical handoff equals to 10. Since the optimal admission probability is equal to zero when $\omega_v = 10$, there is no passive handoff from the cellular network to the WLAN and both dropping probabilities are the same.

6. Conclusion

In this chapter, we introduce the next-generation call admission control schemes in integrated WLAN / 3G cellular networks. Technical background and previous works on call admission control in homogeneous and heterogeneous networks are investigated. Then a novel joint call admission control scheme is proposed to support both voice and data services with QoS provisioning in next-generation integrated WLAN / 3G UMTS networks. A joint admission policy is first derived with considering heterogeneous network architecture, service types, QoS levels, and user mobility characteristics. To relieve traffic congestion in networks, a channel searching and replacement algorithm, CSR, is further developed and optimized to balance total system traffics between WLAN and 3G cellular network, as well as to reduce average system QoS cost. A one-dimensional Markov model for voice traffic is further developed to analyze interworking system performance metrics. Both theoretical analysis and simulation results show that our scheme outperforms both traditional disjoint guard channel scheme and non-optimized joint call admission control scheme.

Our feature work will focus on more real-time services, such as video services, and investigate interactions between resource management and user mobility in integrated WLAN / 3G cellular networks.

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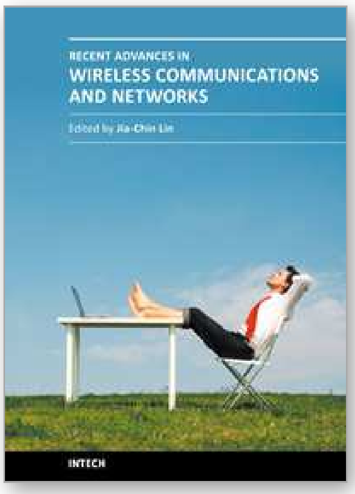

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