Adaptive QoS-aware Resource Management in Heterogeneous Wireless Networks

I-Shyan Hwang, Bor-Jiunn Hwang*, K. Robert Lai, Ling-Feng Ku, Chien-Chieh Hwang

Department of Computer Engineering and Science,
Yuan-Ze University, Chung-Li, Taiwan, 32026
*Department of Computer and Communication Engineering,
Ming-Chuan University, Tao-Yuan, Taiwan, 33348
E-mail: *ishwang@saturn.yzu.edu.tw*, **bjhwang@mcu.edu.tw, krlai@cs.yzu.edu.tw*, *s939408@mail.yzu.edu.tw*, *s946050@mail.yzu.edu.tw*

Abstract The integration of different IP-based wireless networks, such as WiMAX and WiFi, becomes a 2-tier heterogeneous wireless networks is a more and more popular issue. In order to support multiple types of service with different QoS requirements in heterogeneous wireless networks, efficient resource management, call admission control strategies, mobility management and overflow handoff call are important issues. In this paper, we propose a resource management strategy including the call admission control, resource reservation mechanism for real-time services and Fuzzy controllers are proposed to adjusting bandwidth of real-time service with parameters dynamically. Simulation result shows that the proposed method improves the previous work (non-adaptive bandwidth borrowing reservation methods) and outperforms the traditional CAC in terms of call dropping probability and call blocking probability.

Keywords: WiMAX, CAC, Resource Management, Fuzzy Controller

1. Introduction

With the development of wireless technology, many kinds of wireless access technologies are available to satisfy different needs and requirements of mobile users in the heterogeneous wireless environment, such as WiFi, WiMAX and UTRAN [1,2,3]. The feature of heterogeneous wireless environment is that all users are able to switch different access technologies according to their demands. For example, some users require good mobility support; some users expect high reliability and QoS guarantees [4]. In order to support multiple types of applications with different QoS requirements, efficient resource management and call admission control strategies play an important role [4,5]. Besides, the trend of next generation wireless networks is to provide services anywhere at any time from diverse networks over an IP (Internet Protocol) backbone. For the wireless data network, WiFi and WiMAX are probably two most popular ones. As the density of their deployment is growing higher, the interconnection issues between WiFi and WiMAX are becoming more and more important and urgent. In this paper, we focus the discussion in WiFi technology on the 802.11e instead of 802.11 since 11e standard support Qos facility.

With the combination of call admission control and resource management techniques, systems are able to maintain the delivered QoS to different users at the target level [5]. It is achieved by limiting the number of connections into the networks and controlling the amount of the assigned resources to each user. Therefore, systems are able to balance resource utilization by improving the call blocking probability and handoff dropping probability. In this paper, two QoS-aware resource managements including RMS1 (Resource Management Strategy 1) and RMS2 (Resource Management Strategy 2) are proposed to decrease call blocking probability, handoff dropping probability and make real-time and non-realtime traffic a better resource utilization. The resource management strategies include admission control, resource reservation mechanism for real-time services and the Fuzzy controller. The purpose of Fuzzy controller is to adjust bandwidth of real-time service dynamically and enhance resource reservation mechanism. For example, a real-time service like variable bit rate (VBR) traffic that exhibits highly bursty and non-stationary properties. Inefficient resource allocation may lead to under-utilization of network resources or excessive traffic delay. To prevent more bandwidth being allocated than needed, a Fuzzy bandwidth controller is introduced in the resource management scheme to adaptively adjust the amount of allocated bandwidth for new and handoff calls based on the current network conditions. The status of network always changes from time to time. Therefore, static resource reservation mechanism can not adjust accordingly. Thus, the Fuzzy controller within the resource reservation mechanism alters the parameters dynamically and adaptively.

This paper is organized as follows. Section 2 surveys the related work. Section 3 addresses the system model and introduces the call management flow. The system capacity, the proposed RMS algorithm and Fuzzy controller are described in section 4. In section 5, the simulation model is proposed and simulation results are evaluated and compared. Conclusion and future work are given in section 6.

2. Related Work

In recent years, varieties of call admission control (CAC) and resource reservation schemes have been proposed to provide QoS guarantees for multimedia applications in wireless networks. The central role the CAC plays is the QoS provisioning in terms of signal quality, CBP, CDP, packet delay and loss rate and transmission rate. A number of surveys classified the CAC schemes into different design choices and approaches [6,7,8,9,10]. Several adaptive resource reservation schemes, CAC and bandwidth control mechanisms have been proposed to cope with the complex wireless network dynamically [11,12,13,14,17]. In [15,16] a dynamic admission control for WiMAX networks and a handoff algorithm for the hybrid network of WiFi and WiMAX are proposed. The former proposed a static reservation scheme for UGS flows and a degradation model for nrtPS flows in order to have more UGS, ertPS and nrtPS connections in the system. The later proposed a scheme to make vertical handoff between 802.16a and 802.11n to cope with the challenge in heterogeneous networks.

Hwang et al. [17] proposed a resource reservation scheme with reserved resource in neighboring cells which introduced the impact on system performance. The behavior of the mobile user handoff to each of neighboring cells is haphazard. Our proposed resource management strategy is similar to [17] except the differences are that one. For RT-VR traffic we adapt Fuzzy bandwidth controller to adaptively allocate reserve bandwidth for VBR traffic to get better resource utilization, 2. By considering uplink bandwidth in WiMAX system, when there is no sufficient downlink bandwidth for resource reservation, we can borrow from uplink bandwidth.

3. System Model

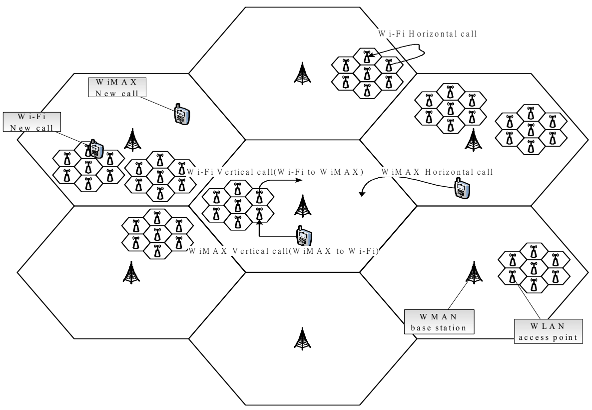


Figure 1 System model.

Figure 1 illustrates a heterogeneous network architecture, where a macrocell (WiMAX cell) is an overlay of several microcells (WiFi cells). The mobile users can access the resources by WiFi or WiMAX. Both the WiMAX and WiFi cells contain new calls, vertical handoff calls and horizontal handoff calls.

New calls event means if the mobile users request new call, the system start the resource management strategy to evaluate sufficient bandwidth for new call; in handoff calls if the mobile user discovers the received signal strength indicator (RSSI) from target cell is weaker than neighboring cell, it notifies the system to start the resource management strategy to evaluate sufficient bandwidth for handoff call. Besides, when the vertical handoff call is initiated, there exists a traffic mapping mechanism between WiMAX and WiFi 802.16e network. The traffic mapping rule works as follow: UGS and ERT-VR maps to VO, RT-VR maps to VI, NRT-VR maps to BK and BE maps to BE, and vice versus.

4. Resource Management Strategy

This section describes how resources are allocated and reserved for new and handoff calls, respectively. Two resource management strategies are proposed in this paper to compare with each other. The system capacities considered in the system are active capacity and passive capacity [13], the system downlink residual capacity can be obtained by the following. $C_{down\_resi} = C_{down} - C_{down\_a} - C_{down\_p}$. Similarly, the system uplink residual capacity can be obtained by the following. $C_{up\_resi} = C_{up} - C_{up\_a} - C_{up\_p}$.

4.1 RMS1

For a mobile user, dropping of an on-going call is generally more unacceptable than blocking a new call request and in order to meet the QoS requirement of real-time service; the wireless network usually needs resource reservation mechanism. Figure 2 shows the algorithms of the proposed RMS 1 for a WiMAX new calls, WiMAX horizontal handoff calls, WiMAX vertical handoff calls, and WiFi vertical handoff calls. As for WiFi new calls, WiFi horizontal handoff calls, we adopt the methods from [18].

For WiMAX new calls shown in Fig. 2(a), if it is the UGS or ERT-VR traffic, the strategy first verifies that the WiMAX cell has enough capacity (C_{down_resi} and C_{up_resi}) to support the traffic QoS requirement. If not, the new connection is blocked; otherwise, the new call is accepted and allocated with desired amount of bandwidth. In the case that the system has enough capacity but reservation fails in one of six neighboring cells, the new call is also blocked, and so does in RT-VR traffic. For the RT-VR traffic, since this kind of VBR traffic exhibits highly bursty and stationary properties, the effective bandwidth allocation must be designed to handle the worst-case input scenario in order to avoid excessive delay or even the call is dropped. This implies that the system must support the minimum required bandwidth in order to guarantee the maximum tolerable end-to-end delay. If the desired amount of bandwidth can be provided and succeed in the resource reservation, the new call is accepted and allocated with desired amount of bandwidth. At the same time, a fuzzy bandwidth controller adjusts the allocated bandwidth to the target RT-VR traffic based on the system state: residual bandwidth and dropping probability. As for the NRT-VR traffic, it is accepted as long as residual capacity is greater than or equal minimum amount of resource requested in the target cell. For the BE traffic, it is accepted as long as there is available resource in the target cell. We provide no resource reservation for these kinds of traffic due to nonreal-time packets or data packets which can tolerate longer transmission delay and packet loss.

For a WiMAX new call
IF UGS or ERT-VR traffic type
  IF $C_{down\_resi} \geqq$ desired amount of downlink bandwidth
  AND $C_{up\_resi} \geqq$ desired amount of uplink bandwidth
    Allocate desired amount of bandwidth
    Resource Reservation
  ELSE
    Call blocked
IF RT-VR traffic type
  IF $C_{down\_resi} \geqq$ desired amount of downlink bandwidth
  AND $C_{up\_resi} \geqq$ desired amount of uplink bandwidth
    Fuzzy Bandwidth controller
    Resource Reservation
  ELSE
    Call blocked
IF NRT-VR traffic type
  IF $C_{down\_resi} \geqq$ minimum amount of downlink bandwidth
  AND $C_{up\_resi} \geqq$ minimum amount of uplink bandwidth
   Balance mechanism
  ELSE
   Call blocked
IF BE traffic type
  IF $C_{down\_resi} \geqq 0$ AND $C_{up\_resi} \geqq 0$
   Balance mechanism.
  ELSE
   Call blocked

Figure 2(a) RMS 1 for WiMAX new calls.

The real-time traffic type in WiMAX new call procedure, WiMAX horizontal handoff call procedure, WiFi horizontal handoff call procedure and WiFi vertical handoff call procedure all are needed to reserve resource resulted in higher threshold of admission control for real-time traffic type. On the contrary, our proposed strategy adopts lower threshold of admission control for nonreal-time traffic and it maybe introduces higher blocking or dropping probability for real-time traffic. To avoid this, the balance mechanism is proposed in next section.

For the WiMAX horizontal handoff call (from WiMAX to WiMAX), it is similar to WiMAX new call.

For the WiFi vertical handoff calls, if the traffic type is real-time type (i.e., VO, VI), and available resource in target cell is greater or equal than the desired amount of bandwidth and succeeds in resource reservation, then the call is accepted and allocated with desired amount of resource. Otherwise, the call is dropped even if available resource in target cell is enough. If it is the BK traffic type, and the target cell has enough capacity to satisfy the minimum amount of resource, then the call is accepted and allocates the minimum amount of resource. If it is BE traffic type, and the target cell has available capacity, then the target cell accepts this call. The detail of the proposed RMS 1 for WiFi vertical handoff calls is described in Fig. 2(b).

IF VO traffic type
 IF $C_{resi} \geqq$ desired amount of bandwidth
    Allocated desired amount of bandwidth.
    Resource Reservation
  ELSE
    Call dropped
Update P_D
IF VI traffic type
  IF $C_{resi} \geqq$ desired amount of bandwidth
    Allocated desired amount of bandwidth.
    Resource Reservation
  ELSE
    Call dropped
Update P_D
IF BK traffic type
  IF $C_{resi} \geqq$ minimum amount of bandwidth
  Balance mechanism
 ELSE
    Call dropped
Update P_D
IF BE traffic
 IF $C_{resi} \geqq 0$
    Balance mechanism
 ELSE
      Call dropped
Update P_D

Figure 2(b) WiFi vertical handoff calls.

In our assumption, WiFi is overlapped by WiMAX and a mobile user can access WiMAX and WiFi networks in the WiFi coverage. For the WiMAX vertical handoff calls, because in the overlap area the mobile user can access two wireless technologies, so when the mobile user approaches the overlap area, the WiFi AP estimates the dwelling time of the mobile user with "Renewal Process", if the dwelling time is greater or equal than the dwelling time threshold, and the residual system capacity is enough to support the QoS requirement, then the handoff call is accepted. Because it is difficult for WiFi AP to reserve bandwidth due to the MAC behavior of CSMA/CA, therefore, RMS 1 only hands this call to WiFi cell when there has enough bandwidth in WiFi cell.

4.2 Balance Mechanism

In our proposed strategy, it adopts higher threshold of admission control for real-time traffic type. In order to avoid higher CBP and CDP of real-time traffic type as a result of higher threshold of admission control, our proposed strategy provides a balance mechanism. The resource reservation mechanism records the CBP and the CDP of real-time traffic type that the handoff calls are blocked or dropped as a result of a fail in reserving resource, $P_{fail\_reserving}$. The details of balance mechanism are described in Fig. 3.

IF CBP of nonreal-time traffic type + CDP of nonreal-time traffic type $< P_{fail\_reserving}$ ||
CBP of real-time traffic type = 0 && CDP of real-time traffic type = 0
  Call is blocked or dropped
ELSE IF
  Call is accepted
  IF NRT-VR or BK traffic type
    Allocated minimum amount of bandwidth
  IF BE traffic type
    Allocated bandwidth

Figure 3 Balance mechanism.

<u>**For a WiMAX new call**</u>
IF UGS or ERT-VR traffic type
  IF C_{down_resi} desired amount of downlink bandwidth
  AND C_{up_resi} desired amount of uplink bandwidth
    Allocate desired amount of bandwidth.
    Resource Reservation
   IF There is enough passive resource capacity to be shared
   Fuzzy Ratio controller
   ELSE
    Call blocked
IF RT-VR traffic type
  IF C_{down_resi} desired amount of downlink bandwidth
  AND C_{up_resi} desired amount of uplink bandwidth
   Fuzzy Bandwidth controller
   Resource Reservation
  ELSE
    Call blocked
IF NRT-VR traffic type
  IF $C_{down\_resi} \geq$ minimum amount of downlink bandwidth
  AND $C_{up\_resi} \geq$ minimum amount of uplink bandwidth
    Allocate desired amount of bandwidth.
  ELSE
   Call blocked
IF BE traffic type
  IF $C_{down\_resi} \geq 0$
  AND $C_{up\_resi} \geq 0$
    Balance mechanism.
  ELSE
   Call blocked

Figure 4 RMS 2 algorithm.

4.3 RMS2

The reservation scheme can reduce the handoff dropping probability, but it comes to increase the new call blocking probability. The purpose of sharing mechanism can share some passive capacity to provide new calls with real-time traffic type with resource. Therefore, the purpose of sharing mechanism is to provide better QoS guarantees and to reduce the blocking probability for real-time new calls.

In WiMAX cell, if a new call of real-time traffic type arrives and the target cell or neighboring cells do not have enough capacity to support traffic QoS requirements. The target cell is allowed to "share" some of the bandwidth from the passive capacity (reserved capacity for handoff calls) to improve the call blocking probability performance.

For a real-time new call, the RMS 2 works as follows. First, the RMS 2 is verified if $C_{down\_resi}+C_{down\_s}$ and $C_{up\_resi}+C_{up\_s}$ are sufficient for the call. If they are able to support the traffic QoS requirement and the resource reservation succeeds, the new call is accepted and reserves bandwidth in ε neighboring cells. If either reservation failed or the available capacity is not enough for the call, the call is blocked. As for a nonreal-time new call, it is blocked as long as no enough residual capacity available for this call. The proposed RMS 2 is shown in Fig. 4.

4.4 Fuzzy Bandwidth Controller

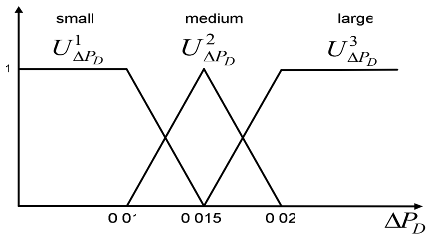


Figure 5 Membership function for ΔP_D.

The fuzzy bandwidth controller adjusts the allocated bandwidth to the target RT-VR traffic based on system state, e.g. residual bandwidth and call dropping probability. The system residual bandwidth can be derived, and recall the bandwidth management strategy, every time a handoff call is accepted or dropped, system call dropping probability P_D is updated. When P_D reaches or exceeds the target dropping probability P_{D_tar} , the system calculates the dropping probability change ΔP_D, current residual capacity C_{resi} are derived, the fuzzy bandwidth controller is initiated. $\Delta P_D = | P_D - P_{D\_tar} |$.

Fuzzification is the process that translates the real number inputs of each feedback into linguistic terms. Fig. 5

shows the dropping probability change ΔP_D , three linguistic terms are defined as {low, medium, high} of each of them with corresponding membership function.

After the linguistic terms are generated through the membership functions in the Fuzzifier, the Inference Engine performs the logic inference according to the Fuzzy Rule Base. In our case, the Fuzzy Rule Base is expressed as the following format:

Rule i:

IF C_{down_resi} is $U^m_{C_{down\_resi}}$ and ΔP_D is $U^m_{\Delta P_D}$

Then decrease the RT-VR traffic by δ_i of the desired amount of bandwidth. m = 1, 2, 3.

4.5 Fuzzy Ratio Controller

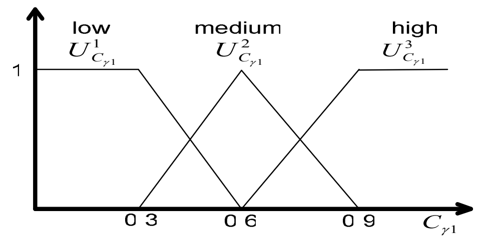


Figure 6 Membership function for $C_{\gamma 1}$.

RMS2 adopts sharing-resource method to decrease call blocking/dropping probability. For the ratio of total WiMAX uplink bandwidth to WiMAX uplink passive bandwidth, three linguistic terms are defined as $U^m_{C_{\gamma 1}}$ = {low, medium, high}, with corresponding membership function shown in Fig. 6. After the linguistic terms are generated through the membership functions in the Fuzzifier, the Inference Engine performs the logic inference according to the Fuzzy Rule Base. In our case, the Fuzzy Rule Base is expressed as the following format:

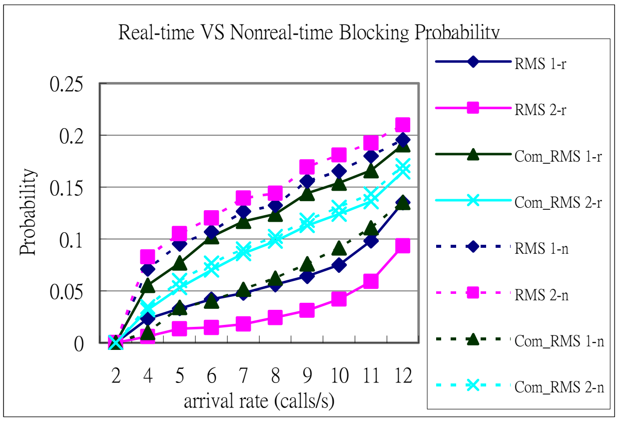
Rule i:

IF $C_{\gamma 1}$ is $U^m_{C_{\gamma 1}}$ and P_D is $U^m_{P_D}$

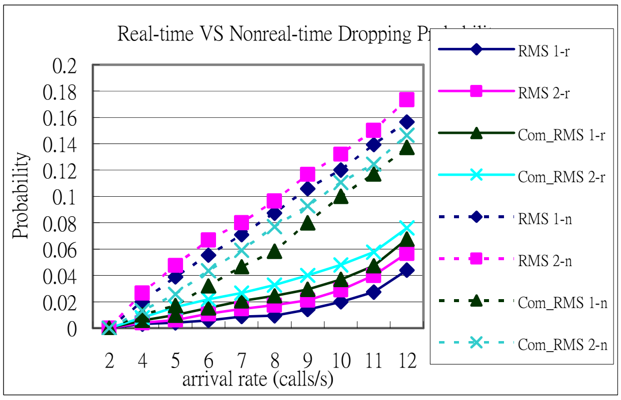
Then set the ρ for τ . m = 1, 2, 3.

5. Simulation Results

Six types of calls are considered in the simulation in terms of WiMAX new calls, WiFi new calls, WiMAX horizontal handoff calls, WiFi horizontal handoff calls, WiMAX vertical handoff calls, and WiFi vertical handoff calls. Traffics are generated following Poisson distribution with average arrival rates. The call holds duration for data, voice, and video traffic are exponentially distributed. The value of target dropping probability P_{D_tar} is set to 0.02 [11,12]. The threshold of dwelling time of a mobile user staying in a cell is estimated periodically by using the dwelling time statistics that is updated.



(a)



(b)

Figure 7 (a) Call blocking probability of Real-time vs. Nonreal-time, (b) Call dropping probability of Real-time vs. Nonreal-time.

The CBP and CDP are evaluated for each strategy, and the proposed RMS1 and RMS2 is compared with two resource management methods in [17], called Com_RMS 1 and Com_RMS 2, respectively. Figure 7(a) shows the CBP. The CBP of real-time traffic of the proposed RMS1 and RMS2 is smaller than Com_RMS 1 and Com_RMS 2 since RMS1 and RMS2 adopt fuzzy bandwidth controller for VBR traffic resource reservation. Besides, newly arriving calls are allowed to share capacity to improve the performance in RMS2, thus the CBP is reduced. The CBP reduction in RMS 1 has 55% improvement compared with Com_RMS1 and the RMS2 is 76% compared with Com_RMS2. For nonreal-time calls, the reason that nonreal-time CBP increase rapidly as the arrival rate increases is due to real-time traffic. Since the call duration of a real-time call is relatively long (180 secs for voices calls, 360 secs for video calls) when compared to nonreal-time calls, more capacity will be occupied by a real-time calls (64kbps~384kbps for video calls). As the arrival rate increases, more real-time calls are accepted to enter into the system leading to the increase of nonreal-time CBP.

Figure 7 (b) shows that the CDP of real-time traffic of the proposed RMS1 and RMS2 is smaller than Com_RMS 1 and Com_RMS 2. The real-time CDP of the RMS 2 is slightly larger than the RMS 1 but still smaller than Com_RMS 1 and Com_RMS 2. It is due to some of the passive capacity is "shared" by real-time new calls so less reserved capacity is available for real-time handoff calls. Fuzzy ratio controller dynamic modifying uplink bandwidth when there is no sufficient downlink bandwidth for reservation. The reductions of RMS1 and RMS2 compared with Com_RMS1 and Com_RMS 2 are 46% and 55%, respectively. For increasing CDP in nonreal-time calls, the reason is the same as we depicted in 7(a).

6. Conclusion

In this paper, two resource management strategies are proposed in heterogeneous wireless network. The proposed strategy adopts resource reserving mechanism, thus, it is more efficient. Simulation results show that the real-time CDP and CBP of the proposed RMS1 and RMS2 are smaller than Com_RMS 1 and Com_RMS 2 due to the mobile users' fuzzy controller. Nevertheless, the non-real-time CBP and CDP of the proposed RMS1 and RMS2 are higher than Com_RMS 1 and Com_RMS 2. Future work will be emphasized on how to fine tune the membership function and discuss which fuzzy model fits in non-real-time traffic.

References

[1] IEEE Std 802.16-2004 (Revision of IEEE Std 802.16-2001), "IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems," Oct. 2004.

[2] IEEE 802.16e-2005, "Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems – Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands," Feb. 2006.

[3] N. Nasser, A. Hasswa and H. Hassanein, "Handoffs in fourth generation heterogeneous Networks," *IEEE Communication Magazine*, vol. 44, issue 10, Oct. 2006, pp. 96-103.

[4] S. Xu and B. Xu, "A fair admission control scheme for multimedia wireless network," *International Conference on Wireless Communications, Networking and Mobile Computing*, vol. 2, Sept. 2005, pp. 859-862.

[5] I.S Hwang, S.N. Lee and I.C. Chang, "Performance Assessment of Fuzzy Logic Control Routing Algorithm with Different Wavelength Assignments in DWDM Networks", *Journal of Information Science and Engineering*, vol. 22, no. 2, Mar. 2006, pp. 461-473.

[6] I.S Hwang, I.F Huang and S.C. Yu, "Dynamic Fuzzy Controlled RWA Algorithm for IP/GMPLS over WDM Networks", *Journal of Computer Science and Technology*, vol. 20, no. 5, Sept. 2005, pp. 717-727.

[7] M.H. Ahmed, "Call admission control in wireless communications: a comprehensive survey," *IEEE Communication Surveys*, vol. 7, no. 1, First Quarter 2005, pp. 50-69.

[8] J. Soldatos, E. Vayias and G. Kormentzas, "On the building blocks of quality of service in heterogeneous IP networks," *IEEE Communication Surveys*, vol. 7, no. 1, First Quarter 2005, pp. 70-89.

[9] J. Diederich, M. Zittebart, J. Diederich and M. Zittebart, "Handoff prioritization schemes using early blocking," *IEEE Communication Surveys*, vol. 7, no. 2, Second Quarter 2005, pp. 26-45.

[10] D. Niyato and E. Hossain, "Call admission control for QoS provisioning in 4G wireless networks: issues and approaches," *Special Issue of IEEE Network on 4G Network Technologies for Mobile Telecommunications*, vol. 19, no. 5, Sept.-Oct. 2005, pp. 5-11.

[11] C. Oliveira, J.B. Kim and T. Suda, "An adaptive bandwidth reservation scheme for high-speed multimedia wireless networks," *IEEE J. Select. Areas Commun.*, vol. 16, no. 6, Aug. 1998, pp. 858-874.

[12] Y. Wu, A. Hu and G. Bi, "A dynamic connection admission control scheme for wireless multimedia communication networks," *International Conference on Communication Technology* (*ICCT'2003*), Beijing China, Apr. 2003, vol. 2, pp. 901-904.

[13] B.J. Hwang, J.S. Wu and Y.C. Nieh, "Improving the performance in a multimedia CDMA cellular system with resource reservation," *IEICE Trans. on Communications*, vol. E84-B, no. 4, Apr. 2001, pp. 727-738.

[14] P. Siripongwutikorn, S. Banerjee and D. Tipper, "A survey of adaptive bandwidth control algorithms," *IEEE Communication Surveys*, vol. 5, no. 1, Third Quarter 2003, pp. 14-26.

[15] H. Wang, W. Li and D.P. Agrawal, "Dynamic admission control and QoS for 802.16 wireless MAN," *Wireless Telecommunications Symposium*, Pomona, California, Apr. 28-30, 2005, pp. 60-66.

[16] J. Nie, J.C. Wen, Q. Dong and Z. Zhou, "A seamless handoff in IEEE 802.16a and IEEE 802.11n hybrid networks," *International Conference on Communication, Circuits and Systems*, *Hong Kong*, May 27-30, 2005, vol. 1, pp. 383-387.

[17] I.S. Hwang, B.J. Hwang and L.F. Ku, "Adaptive resource management in two-tier wireless networks", *International Computer Symposium,* vol. 2, pp. 634-639, Taipei, Taiwan, Dec. 4-6, 2006.

[18] A. Palmieri and F. Sigona, "A QoS management system for multimedia applications in IEEE 802.11 wireless LAN," *ACM International Conference on Mobile and ubiquitous multimedia*, Dec. 2006, vol. 193.