A QOS-BASED BANDWIDTH MANAGEMENT SCHEME IN HETEROGENEOUS WIRELESS NETWORKS

XIN GANG WANG(1), GEYONG MIN(1), JOHN MELLOR(1) and KHALID AL-BEGAIN(2)

(1) Mobile Computing and Networks Research Group
Department of Computing, School of Informatics, University of Bradford, Bradford, BD7 1DP, UK.
E-mail: {X.G.Wang, G.Min, J.E.Mellor}@bradford.ac.uk
(2) School of Computing, University of Glamorgan, Treforest, CF37 1DL, Wales, UK.
E-mail: KBegain@glam.ac.uk

Abstract: Providing a high bandwidth connection for end users anywhere and at anytime is the ultimate goal for the wireless community. Integrating different access technologies is a major step towards such a goal. In a companion paper [Wang et al., 2004], a generic reservation-based QoS framework has been proposed and discussed for integrated cellular and WLAN networks. The bandwidth adaptation algorithm, as the key factor of the proposed framework, decides how to adjust the QoS to maintain ongoing sessions at a satisfactory level with efficient use of the system resources. In this paper we propose a novel QoS management scheme based on per class degradation. Its performance has been compared with the previous proposed adaptation algorithm. The results show that the new scheme generally performs better since it provides better fairness and faster calculation, whereas the previous algorithm, based on per flow, can utilise the system bandwidth more efficiently.

Keywords: WLAN and cellular network integration, QoS management, reservation, bandwidth adaptation

1. INTRODUCTION

The communication systems have been dominated by voice transmission with circuit switching technology [Kleinrock, 2000] for a long time. However, the demand for data communication increased dramatically and drove the development of the Internet, which uses packet switching; an efficient technology for data communication rather than circuit switching. Currently, the mobile communication system is facing the same evolution as the Internet. The network operators are migrating from circuit-switched GSM systems to GPRS and 3G networks [Wisely et al., 2002], which have the packet switched functionality. The ultimate vision is to provide a universal integrated all-IP platform which can provide much richer applications to the end users.

Recent trends indicate that Wireless Local Area Networks (WLAN) based on IEEE 802.11 standards and third-generation (3G) wide area wireless networks such as CDMA2000 and UMTS will co-exist to offer Internet access to end users [Ahmavaara et al., 2003]. It is an important step to build an all-IP platform. It can provide end users with benefits such as lower cost of transmission and higher bandwidth without losing the roaming features or pervasive aspects now emerging. WLAN technology is more likely to be a complimentary access method rather than a competitor to 3G networks because WLAN systems provide high data rates at a relatively low cost compared to 3G networks, but it has a limited coverage area and less support for high speed mobility. WLAN have been widely deployed in places like airports, hotels, and campuses. These places with their Access Points (AP) are called traffic Hot-Spots. Thus interconnecting WLAN radio access networks with 3G cellular networks offers an efficient way to enhance the network operator service and is very appealing to both the vendor and the mobile user community.

To provide end-to-end Quality of Service (QoS) support is one of the key issues in the design of integrated WLAN and cellular networks. Many difficulties emerge when attempting to provide QoS solutions for integrated WLAN and cellular networks owing to the unbalanced capacity of the two systems; issues raised by handover between cells; handover between wireless access points; and handover between WLAN and cells caused by user mobility; as well as the unreliable communication of wireless media. To enable efficient use of the scarce resources provided by the cellular networks while also maintaining strong QoS guarantees, a generic reservation-based QoS model has been proposed [Wang et al., 2004] for the integrated cellular and WLAN network.

A key part of the proposed QoS framework is the adaptation mechanism. In this paper, we propose a new bandwidth adaptation algorithm based on per class degradation and compare its performance with the previous proposed adaptation scheme via simulation. The rest of this paper is organized as follows. Section 2 reviews the adaptive QoS framework. Section 3 presents the desirable features of the flow control algorithms. We introduce and analyze the proposed per class adaptation algorithm in Section 4. Section 5 describes the simulation setups and discusses the performance results. Finally section 6 summarizes this study and gives concluding remarks.

2. THE ADAPTIVE QOS FRAMEWORK

Increasing data service requirements and Internet applications is driving the cellular network to evolve into an IP based packet switching network [Wisely et al., 2002]. Supporting QoS for integrated WLAN and UMTS networks is a challenging task, since there are some fundamental problems that have to be addressed.

Firstly, WLAN and UMTS networks have different transmission capacities, therefore handoff between the two systems makes the maintenance of a QoS connection very hard. One has to consider the significant difference in transmission capacity between the two systems especially when user handoff takes place. The second constraint is that WLAN operates on a free ISM band and has a lot of uncontrollable interference (i.e. microwave), although some techniques like spread spectrum are used to reduce the interference. Such problems are beyond engineering control and hard QoS guarantee is very difficult or even impossible to achieve. To support QoS in packet switching networks there has to be some mechanisms to control network load, to keep it under a threshold, so that the system can achieve a satisfactory performance. The third problem is that the achievable QoS levels in WLAN and 3G cellular networks do not match each other. 3G cellular networks are very well designed with careful network planning and mature admission control algorithms. Therefore, the achievable QoS level is relatively high, while 802.11e WLAN works within a less controlled environment and it is difficult to achieve hard QoS, although some form of admission control [802.11e/D4.3, 2003] has been provided for HCF in the IEEE 802.11e standard. Even the EDCF (enhanced distributed coordination function) can only provide Differential of Service (DoS).

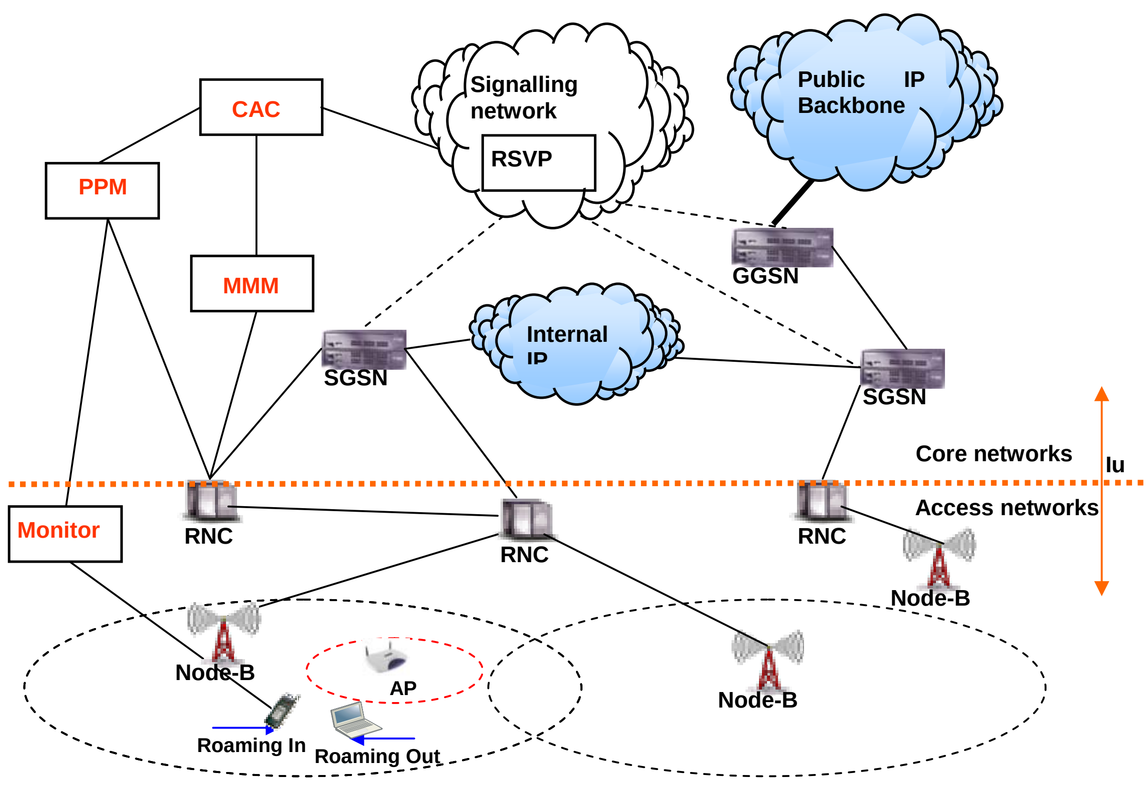

Figure 1: The adaptive QoS framework

We previously proposed a QoS framework [Wang et al., 2004] based on an adaptive approach for integrated WLAN and cellular networks, which addresses the above issues and also provides practical and user-satisfied QoS. The overall architecture is shown in Figure 1. It is well known that the Internet has some fundamental scalability limitations [WelzlMuhlhauser, 2003] when it comes to the management of individual traffic flows using the reservation-based approach. Its successor, the prioritization approach addresses the scalability problem at the cost of coarser service granularity. To enable efficient use of scarce resources provided by cellular networks while also maintaining strong service guarantees, we adopt the reservation-based approach [Barzilai et al., 1998]. In WLAN the reservation is achieved by using the HCF and in UMTS it is achieved by the functionality provide by BS. The other components of the framework are defined below:

- *A Policy Provisioning Module (PPM)*
  The PPM is responsible for mapping actual user QoS profiles with their subscription information and decides the traffic classes for the user traffic flows. Then these QoS parameters can be handed to Admission Control Module (CAC) module to process.
- *A Connection Admission Control Module (CAC)*
  The CAC is to admit the number of flows that can be served and allocates bandwidth to them through signalling to all the network nodes along the traffic path. It also needs to maintain the QoS requirements of existing connections.
- *A QoS Mobility Management Module (MMM)*
  The MMM decides whether terminals are detached, connected or idle from the network and also monitors active nodes moving at high speed.
- *A QoS Monitoring Module (Monitor)*
  The Monitor continuously measures whether the QoS merits of mobile nodes have been satisfied.

The components illustrated are viewed as logical entities. These components can be actually implemented combined with realistic network components or in an independent location.

- **QoS Class Mapping**

To provide unified QoS traffic classes, the QoS traffic classes from UMTS and WLAN are mapped in a new set of QoS traffic classes namely: Broadband conversational (B-conversational), Broadband streaming (B-streaming), Narrowband conversational (N-conversational), Narrowband streaming (N-streaming), interactive and background. Their mapping relationships are shown in Table 1.

Table 1: QoS classes mapping table

Class	Integrated Network	WLAN	UMTS
1	B-conversational	Voice	-
2	B-streaming	Video	-
3	N-conversational	-	Conversational
4	N-streaming	Video Probe	Streaming
5	Interactive	-	Interactive
6	Background	Best Effort	Background

- **Degradation Profile**

The negotiation of established QoS connection is allowed through the degradation profile. It defines the minimum network resource needed for certain traffic flows or certain traffic class. When a user requests to establish a QoS call, certain network resources need to be admitted from the integrated networks. The requested QoS has to be allocated when the connection is set up. If certain conditions change over the activation time, a negotiation procedure is called.

3. DESIRABLE CHARACTORISTICS FOR FLOW CONTROL SCHEMES

One of the reservation approach advantage is that we can establish a streaming flow to individual applications and the performance in terms of delay and loss should be guaranteed by means of flow control schemes [Oliveira et al., 1998; Ramanathan et al., 1999]. In this section, we discuss some of the most important desirable characteristics of the flow control schemes.

- **Fairness**

When offered traffic load must be cut back in our adaptive approach, it is important to do so fairly. There are many notions of fairness by the presence of different session priorities and service requirements. In general, cooperation is required among the flows to allow equal access to network resources and those who are using up the recourse more than its share should be cut off. We use an index [Wang et al., 2004] to measure the fairness among different flows. It is defined as:

$$FairnessIndex = \frac{(\sum_{i=1}^{N} T_i)^2}{N\sum_{i=1}^{N} T_i^2} \quad (1)$$

where N is the number of flows, T_i is the throughput of flow i. The higher the fairness index (up to 1) the better fairness the system can gain.

- **Scalability**

To reserve the necessary resource, a signalling protocol has to store some state information into the routers memory along the data path. Each of the flow's reservation needs to be classified, policed and queued in the router. When the size of the network grows, it generates a huge amount of calculation demands. The scalability concern has prevented widespread of the reservation approach in the Internet community. Therefore to make a flow control scheme more attractive, one has to consider the scalability problem.

- **Robustness**

Data communication is different from the voice communication and it is bursty in nature. The bandwidth requirement for many applications is not a single number and it varies constantly sometimes. Take video application for example, the bits per second generated from a rapidly moving scene is much more than when it is still or slow moving. Just knowing the long-term average bandwidth is not enough. The beauty of the Internet is it can cope with robust requirements. When we design some flow control schemes, we should also bear in mind that the robustness of the application's.

4. A DYNAMIC BANDWIDTH MANAGEMENT SCHEME

Applying QoS means treating some traffic in preference to others, and this implies the ability to reject traffic. Especially in wireless mobile communication networks, uncontrolled error rate and users' mobility make us have to look for adaptation solutions. The use of degradation profile provides us a gradation between different QoS merits; therefore, negotiation between different network flows is an effective way to improve the overall system performance. The bandwidth adaptation algorithm as the key factor of the proposed framework decides how to adjust the QoS connections since mobile users should be able to seamlessly maintain their ongoing sessions at a satisfied level.

This can be done in two ways. One is to adapt a flow to its corresponding level, when it migrates from one system into another. Ideally each call in the system should be allocated the maximum allowable bandwidth. However, WLAN and cellular networks have different transmission capacity; a session that consumes a moderate amount of bandwidth in WLAN system can be greedy and therefore could be rejected in the cellular networks. A connection switched from cellular networks to WLAN needs to level up its bandwidth otherwise it will lose the meaning of the integration. The other way is to adapt flows to use the system resource more efficiently in a single system or both to accommodate more new arrivals and handoff calls.

The method used in [Wang et al., 2004] degraded the longest calls in the system based on their state information with a good hope that those flows have a bigger probability to quit the system and leave fewer degraded connections in the system. The management of the algorithm can be very complex as the CAC will need to search for the call each time. It can create unfairness because if the system state does not change frequently, you can have some connections degraded for long time while others are going at full or at least high speed.

The new bandwidth adaptation scheme is based on per class degradation. When a new user arrives and there are no enough resources in the system, the system should ask all connections in the lowest priority level to degrade until they reach their minimum acceptable level and if the resources are still not enough continue with the next priority level (class). If all connections that have lower or equal priority to the new connection have degraded to their minimum and still there is no enough resource, this new connection will be rejected. By using this method would give better fairness between the connections of the same class and give high priority to the more sensitive classes so that their performance would not be affected by the lower priority classes. The above idea also can improve the scalability of the scheme and reduce the computation complexity. The pseudo code of the adaptation algorithm is described in Table 2, where B_i represents the required bandwidth for each flow and D_i denotes the minimum bandwidth request defined in the connection degradation profile.

Table 2: Pseudo code for the adaptation algorithm

New Call Arrivals

IF (New Requested Bandwidth B_i < system available bandwidth)
    assign B_i;
ELSEIF (New Requested Band D_i < system available bandwidth)
    assign D_i;
ELSE
    WHILE (undegraded class exists AND D_i > system bandwidth)
    {degrade lowest priority class;
    IF (D_i < system available bandwidth)

assign D_i and exit;}
IF (D_i > system available bandwidth)
reject the call;

Handoff Call Arrivals

IF (Handoff Requested Bandwidth B_i < system available bandwidth + guard bandwidth)
assign B_i ;
ELSEIF (Handoff Requested Band D_i < system available bandwidth + guard bandwidth)
assign D_i ;
ELSE
WHILE (undegraded class exists AND D_i > system available bandwidth + guard bandwidth)
{degrade lowest priority class;
IF (D_i < system available bandwidth)
assign D_i and exit;}
IF (D_i > system available bandwidth)
reject the call;

Departures

WHILE (system available bandwidth > threshold)
allow highest priority class use more bandwidth;

5. PERFORMANCE ANALYSIS

5.1 The Simulation Model

This section uses simulation experiments to validate the proposed scheme. Following the assumptions widely used in previous studies, [Oliveira et al., 1998; Chen et al., 2002; El-Kadi et al., 2002] the call arrivals in our simulation follow an independent Poisson process and the session time of each connection is exponentially distributed. We assume that QoS bottleneck is in the access network and we do not consider core network and routing problem.

It is well known that dropping an established communication is worse than rejecting a new call. Therefore cellular systems reserve a guard bandwidth for the handoff calls in order to reduce the handoff dropping probability. The reserved guard bandwidth can be either static or dynamic [Oliveira et al., 1998; Ramanathan et al., 1999; ChoiShin, 2002]. The dynamic approach often outperforms the static one at the expense of generating more control overheads [Wisely et al., 2002]. However, the static approach is often attractive in practice owing to its design simplicity. In our simulation, a static guard bandwidth (i.e., 5% of the system capacity) is employed to deal with handoff calls.

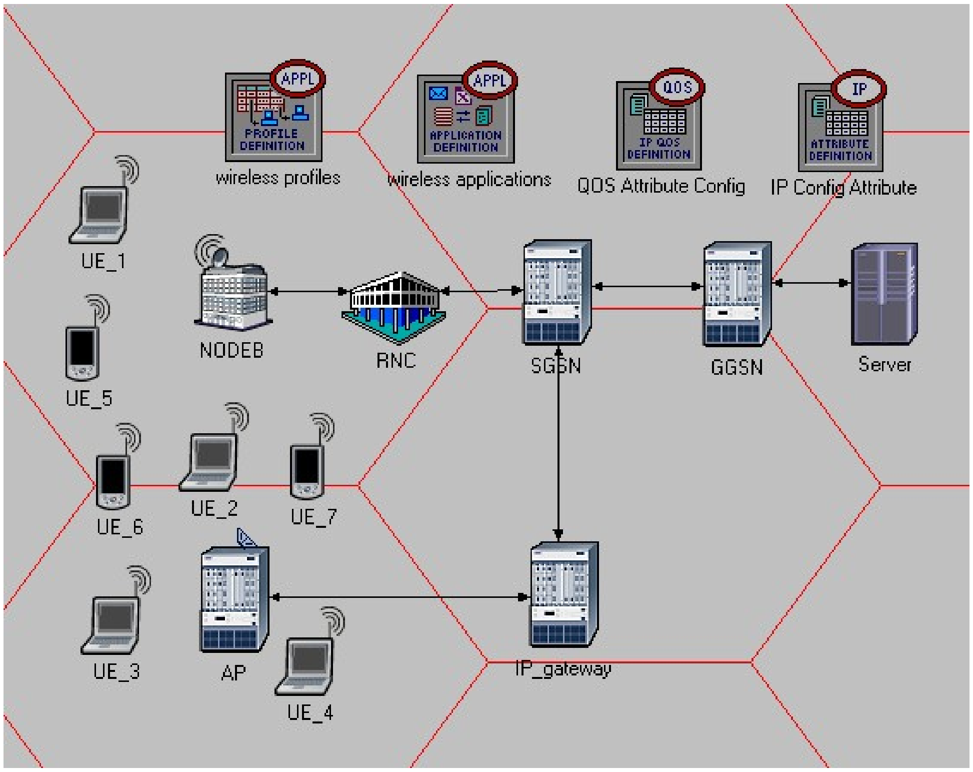

Figure 2: Simulation topology

Without loss of generality, the integrated network in the simulation consists of one cellular network and one WLAN hotspot. The simulation topology is shown in Figure 2. Since WLAN has a higher capacity and is cheaper than UMTS, we assume the handoff probability from UMTS to WLAN is 5 times as much as that from WLAN to UMTS. The system capacity for UMTS and WLAN is 2 mb/s and 11 mb/s respectively. The bandwidth requirement for each of four QoS classes $\{B_1, B_2, B_3, B_4\}$ and their acceptable degradation level defined in degradation profile are assumed to be a portion of the system capacity listed in Table 3. The reservation signaling cost before the establishment of each new or handoff connection is set to a fixed value. For the sake of clarity, all the relevant simulation parameters are summarized in Table 3.

Table 3: Simulation parameters

Parameter	Value	Parameter	Value
UMTS Capacity (U)	2 mb/s	Session time	Exp(50)
WLAN Capacity (W)	11 mb/s	Guard Band	5%
UMTS to WLAN Handoff	0.05	$\{B_1, B_2, B_3, B_4\}$	{5%*W,3%*W,5%*U,3%*U}
WLAN to UMTS Handoff	0.01	$\{D_1, D_2, D_3, D_4\}$	{4%*W,2%*W,4%*U,2%*U}
Reservation signaling cost	1%*W	Simulation Time	1000s

The level of the performance degradation of the overall systems is critical information to the network operators. If this happens frequently in a certain area, a new base station or a new access point may be installed to solve the problem permanently. For this purpose, a new performance merit called system degradation degree was defined in [Wang et al., 2004]. The higher values of the system degrade degree means the deeper the system has been degraded.

5.2 The Experiment Results

This section presents the simulation results to demonstrate the effectiveness of the proposed scheme. To do so, we assign the same traffic loads to two systems working under the normal operation condition and under the proposed framework, respectively. We also compare the performance of the new adaptive algorithm with the previous one. Each simulation experiment was run until the system reached its stable state. To measure the system performance merits, we first examine the normalized system utilization defined as the amount of data transmitted in the unit time normalized with the system capacity. We then consider QoS parameters: the call blocking probabilities and handoff dropping probabilities. Finally, the fairness index and the overall system degradation are calculated.

Figure 3 compares the bandwidth utilization supported among the two adaptive schemes in the integrated network and that without the adaptive scheme. From this diagram, we can observe that the utilization increases as traffic loads increase. Under all the system traffic loads, the adaptive strategy uses the system recourses more efficiently than non-adaptive connections. When the traffic load becomes higher, the advantage is more evident. The reason that adaptive connections can better utilize the system bandwidth is that the proposed scheme allows the network to intelligently adjust each admitted QoS connection by its degradation profile and give sufficient resources for the new or handoff calls. We can also observe that at the low and moderate traffic load the per-flow method uses the bandwidth more efficient than the per-class method, because where per-flow method only degrades one or several flows to release some bandwidth and per-class degrades all the flows in the lower priority class. However, per-class method made the trade off for its computation simplicity and therefore is faster than that per class method.

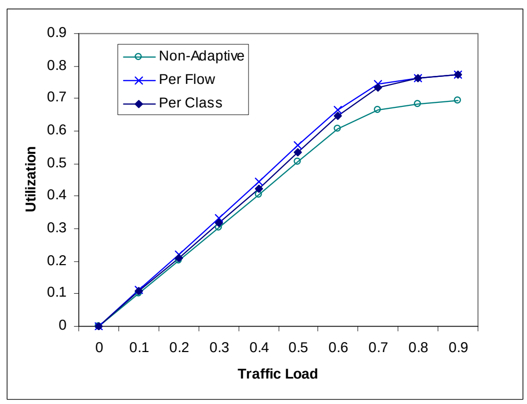

Figure 3: System utilization

Figure 4 depicts the call blocking probability versus the traffic load. From the diagram, we can observe that there is no call blocking probability for any of the methods with light traffic load. Particularly, we start to see the call blocking probability when the traffic loads reached 0.4 under non-adaptive situation and for the adaptive conditions we start to observe the call blocking probability at 0.5 traffic load. This clearly demonstrated the effectiveness of the proposed mechanism. With further increment of the traffic load, the call blocking probability increases, since channel became more and more crowded. The figure also reveals that the adaptive approach reduces the call blocking probability compared to the non-adaptive approach. The per flow method and the per class method made no difference to provide more bandwidth for the new arrivals, since in the congested scenario they both degraded to the maximum allowable degree.

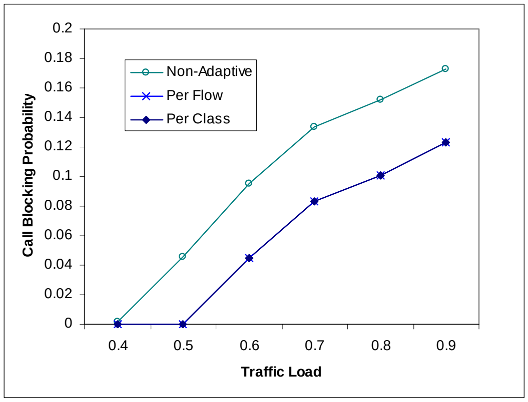

Figure 4: Call blocking probability

Figure 5 further evaluates the handoff dropping probability in the integrated network. From the figure, we can observe that the handoff dropping probabilities increase as the system traffic loads increase. The handoff dropping probability for adaptive connections is much less than that for non-adaptive connections at the same traffic load condition. When the traffic load becomes higher, the trend is more evident. Under the adaptation system, we barely see the handoff dropping calls. It reveals that the proposed approach reduces a great number of handoff dropping calls for the integrated WLAN and cellular system, which is often a disturb event in cellular networks. Again since the per flow method and per class method both degrade to their maximum degree, they show the same trend in the graph.

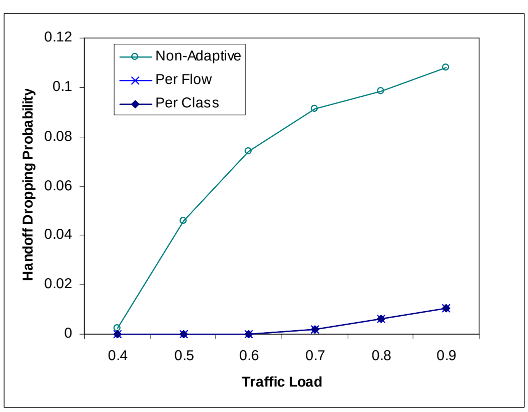

Figure 5: Handoff dropping probability

Figure 6 shows the degree of overall system degradation. This designed parameter can act as indicator to the network operators. When the overall system degradation parameter stays high for a certain period time, the network operator should think of installing more base stations or access point. From the figure, we observe that the degradation degree for per flow method and per class method increases nearly linearly with the increment of traffic loads, since with more users wanting to use the channel, the system has been adapted deeper to its capacity. As traffic load increases, the dividend between per flow method and per class method is more evident, since per class method degrades all flows in a certain class where per flow method degrades one or a few necessary flows.

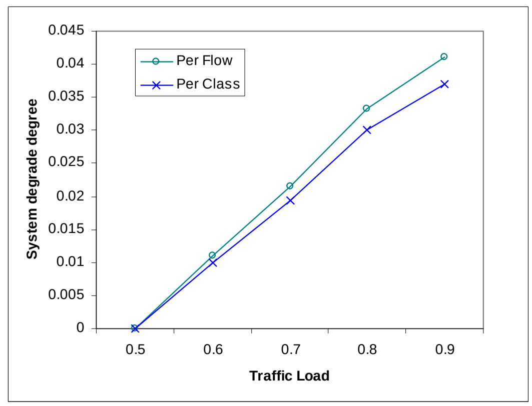

Figure 6: System degrade degree

Figure 7 shows that the fairness index for the per flow method and per class method. We can observe that per flow method is more fair than the per class, since it degrades all the flow in a class and per flow method only degrades those needed. With more flows are degraded in the per flow method, it reduces the difference between flows and it becomes fairer for the per flow method.

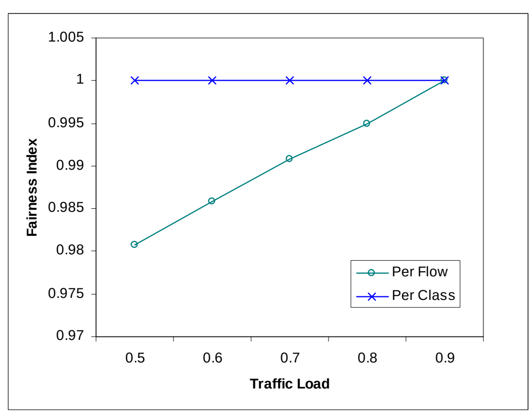

Figure 7: Fairness index

6. CONCLUSIONS

To design of a network architecture that can efficiently integrate WLAN and cellular networks with QoS support is a challenging task. We proposed a generic reservation-based QoS model for the integrated cellular and WLAN networks in the previous study. The key part of the framework is the dynamic bandwidth adaptation mechanism. In this paper, we propose a new bandwidth adaptation algorithm based on per class degradation. We have compared the performance of the new approach with that of the adaptation method used in the previous study via simulation experiments. The results show that there are some tradeoffs between the two methods. The per class method generally performs better than the per flow method, since it degrades all the flows in certain class and thus has better fairness than the per flow method. It also provides computation simplicity and executes faster, which is important to the admission control component. However, the per flow method can use the system resources more efficiently than the per class method. Simulation experiments also indicate that the adaptive multimedia framework outperforms the non adaptive approach in terms of lower handoff dropping probability and call blocking probability while still maintaining acceptable QoS to the end users.

REFERENCES:

IEEE 802.11e/D4.3, I. 2003. "Draft Supplement to STANDARD FOR Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Part 11: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications: Medium Access Control (MAC) Enhancements for Quality of Service (QoS)".

Ahmavaara, K., H. Haverinen and R. Pichna 2003. "Integration of wireless LAN and 3G wireless - Interworking architecture between 3GPP and WLAN systems." Communications Magazine, IEEE 41(11): 74-81.

Barzilai, T. P., D. D. Kandlur, A. Mehra and D. Saha 1998. "Design and implementation of an RSVP-based quality of service architecture for an integrated services Internet." IEEE Journal on Selected Areas in Communications 16(3): 397-413.

Chen, C. L. P., Y. Xiao and B. Wang 2002. "Bandwidth degradation QoS provisioning for adaptive multimedia in wireless/mobile networks." Computer Communications 25(13): 1153-1161.

Choi, S. and K. G. Shin 2002. "Adaptive bandwidth reservation and admission control in QoS-sensitive cellular networks." IEEE Transactions on Parallel and Distributed Systems 13(9): 882-897.

El-Kadi, M., S. Olariu and H. Abdel-Wahab 2002. "A rate-based borrowing scheme for QoS provisioning in multimedia wireless networks." IEEE Transactions on Parallel and Distributed Systems 13(2): 156-166.

Kleinrock, L. 1997. "Nomadicity: anytime, anywhere in a disconnected world." Mobile Networks and Applications 1(4): 351-357.

Kleinrock, L. 2000. "On some principles of nomadic computing and multi-access communications." IEEE Communications Magazine 38(7): 46-50.

Oliveira, C., J. B. Kim and T. Suda 1998. "Adaptive bandwidth reservation scheme for high-speed multimedia wireless networks." IEEE Journal on Selected Areas in Communications 16(6): 858-874.

Ramanathan, P., K. M. Sivalingam, P. Agrawal and S. Kishore 1999. "Dynamic resource allocation schemes during handoff for mobile multimedia wireless networks." IEEE Journal on Selected Areas in Communications 17(7): 1270-1283.

Wang, X. G., G. Min, J. E. Mellor, K. Al-Begain and L. Guan 2004. "An Adaptive QoS Framework for Integrated Cellular and WLAN Networks." Elsevier Journal on Computer Networks.

Wang, X. G., G. Min, J. E. Mellor and L. Guan 2004. "Maximizing Transmission Time (MTT): A New Distributed MAC Scheme for Enhancing Wireless LAN Performance." Mobile Networks and Applications Journal (MONET).

Welzl, M. and M. Muhlhauser 2003. "Scalability and quality of service: a trade-off?" Communications Magazine, IEEE 41(6): 32-36.

Wisely, D., P. Eardley and L. Burness 2002. IP for 3G, John Wiley.

BIOGRAPHIES:

Xin Gang Wang received his 1st B.Sc. degree in Computer Science from the Heilongjiang University, P.R.China, in 2001. He is currently a Ph.D. student in the computing department, University of Bradford. His research interests include performance modeling of the mobile networks, IEEE 802.11 WLAN networks and future wireless networking technologies.

Geyong Min received the PhD degree in computing science from the University of Glasgow, United Kingdom, in 2003, and the BSc degree in computer science from Huazhong University of Science and Technology, China, in 1995. He is currently a lecturer in the Department of Computing at the University of Bradford, United Kingdom. His research interests include Performance Modelling/Evaluation, Parallel and Distributed Systems, Mobile Computing, Computer Networks, Multimedia Systems.

Dr. Min is the founding co-chair of the International Workshop on Performance Modelling, Evaluation, and Optimisation of Parallel and Distributed Systems (PMEO-PDS) held in conjunction with IEEE/ACM-IPDPS. He is the guest editor of the journals *Computation and Concurrency: Practice and Experience*, *Future Generation Computer Systems*, and *Supercomputing*. He has served on the program committees of a number of international conferences. He is a member of the IEEE Computer Society.

John Mellor has worked in the modelling and simulation of communication networks for 25 years. Early work included dynamic alternate routing and the application of learning automata to routing strategies in circuit and packet switched networks. Collaboration with a Cambridge UK company led to the development of a LAN protocol which consistently outperformed Ethernet. He was sent as a government expert to study the Manufacturing Messaging protocol in the USA and Japan. He later became a technical expert consultant on the application of European Directives within manufacturing industry. A foray into radio frequency identification tags resulted in the development of a novel protocol that was exploited by a major vehicle component manufacturer. He now finds himself involved in wireless protocols with researchers working on WiFi (802.11) and on security aspects of mobile commerce. John is leader of the Mobile Computing and Networks Research Group at the University of Bradford and course tutor to three innovative advanced MSc. courses in mobile computing, applications and security.

Khalid Al-Begain is Professor of Mobile Networking and Head of the Mobile Computing and Networking Research Centre at the School of Computing of the University of Glamorgan in Cardiff/Wales/UK. He received his High Diploma (1986), the Specialisation Diploma of Communication Engineering (1988) and his Ph.D. degree in Communication Engineering (1989) from the Technical University of Budapest in Hungary.

From 1990 to 1996, he held the position of a Assistant Professor at the Department of Computer Science of the Mu'tah University in Jordan. Then he became an Associate Professor at the same university. In 1997 he moved to the Department of Computer Science at the University of Erlangen-Nuremberg in Germany as Alexander von Humboldt research fellow. Later, he spent one year as Guest Professor at the Chair of Telecommunications, Dresden University of Technology, Germany. From 2000-2003, he has been Senior Lecturer and Director of Postgraduate Research in the Department of Computing of the University of Bradford, UK before moving to Glamorgan. He co-authored the book "Practical Performance Modelling" published by Kluwer Academic Publishers in Boston and more than 100 refereed journal and conferences papers. He also served/serves as Guest Editor for several special issues of the International Journal of Simulation on Analytical and Stochastic Modelling Techniques. He is UNESCO Expert in networking, UK Representative to EU COST Action 290 Management Committee, senior member of the IEEE and many other scientific organisations. Since 2003, he became the Conference Chair for the annual ASMTA (Analytical and Stochastic Modelling Techniques and Applications) Conference (ASMTA'03 in Nottingham, UK and ASMTA'04 in Magdeburg, Germany). He also manages several research projects funded by the EPSRC and EU.

His research interests include performance modelling and analysis of computer and communication systems, modelling and design of wireless mobile networks and multicast routing in mobile IP networks. He is also interested in Mobile Computing research.