Adaptive Zone-Based Bandwidth Management in IEEE 802.16j Multi-Hop Relay Network

Chun-Chuan Yang[1], Yi-Ting Mai[2], Jeng-Yueng Chen[3], I-Wei Lin[1]
[1]Department of Computer Science and Information Engineering, National Chi Nan University, Taiwan
[2]Department of Sport Management, National Taiwan University of Physical Education and Sport, Taiwan
[3]Department of Information Networking Technology, Hsiuping University of Science and Technology, Taiwan
ccyang@csie.ncnu.edu.tw, wkb@wkb.idv.tw, jychen@hust.edu.tw, lewmewmew@yahoo.com.tw

Abstract

By comparing with the characteristics of the traditional mobile Quality-of-Service mechanisms, the idea of zone-based bandwidth allocation for mobile users in the IEEE 802.16j multi-hop relay network (IEEE 802.16-MR) is proposed in the paper. The zone of a mobile user includes the current relay station and its neighboring relay stations within the zone size in hop count. Bandwidth allocation is made for the mobile user roaming within the zone, and calculation of the required bandwidth is presented in the paper. Adaptive selection of the zone size fit for user mobility is the main focus of the paper. Markovian analysis is used to determine the proper zone size. Simulation study has demonstrated the effectiveness of the adaptive zone scheme.

Keywords: IEEE 802.16, Multi-hop relay network, Mobile QoS, Bandwidth management.

1 Introduction

The standard of IEEE 802.16 [1-4], first published in 2001, defines a means for wireless broadband access as a replacement for current cable and DSL “last mile” services to home and business. The adoption of this standard is currently in progress through the use of *WiMAX* (*Worldwide Interoperability for Microwave Access*) Forum certified networking equipment and widespread adoption should appear over the next few years. A series of specifications have been published in the history of IEEE 802.16. *IEEE 802.16d* (802.16-2004) [1] focuses on fixed location wireless access and can support up to 134 Mbps bit rate. *IEEE 802.16e* [2], completed in 2009, was proposed to support wireless access with high user mobility. The latest version of the standard, *IEEE 802.16j-2009* [4] was proposed for mobile multi-hop relay networks, which is denoted by *IEEE 802.16-MR* in this paper [5]. Differing from the single-hop wireless connectivity of IEEE 802.16e, IEEE 802.16 multi-hop relay allows the mobile stations to route through intermediate relay stations (RS) to reach the base station (BS). By adopting the idea of relay stations, IEEE 802.16 multi-hop relay enables fast network deployment in a large area at a lower cost than the traditional wired counterpart.

Mobile users equipped with the IEEE 802.16 interface can directly access the IEEE 802.16 multi-hop relay network while roaming in the network area. The IEEE 802.11 access point connected to the Relay Station is required for Wi-Fi (*Wireless Fidelity*) users to gain access of the network. In either case, an appropriate bandwidth allocation scheme in the IEEE 802.16 multi-hop relay network is expected in order to guarantee QoS transmission. The issue of QoS supporting for mobile users (also referred as *Mobile QoS*, denoted by *MQoS*), has been addressed in the literature for many years. The typical strategy for *MQoS* is to reserve necessary bandwidth at neighboring nodes before the mobile user handoff to the new node, which inevitably results in low bandwidth utilization.

Two important factors make traditional *MQoS* mechanisms inappropriate for *MQoS* support in the IEEE 802.16 multi-hop relay network. Firstly, all relay stations in the network share the same medium (channel), and the bandwidth requirement for a traffic flow depends on (more specifically, is proportional to) its path length (the number of relay stations en route). Therefore, the bandwidth requirement of a mobile user at current relay station is correlated with the bandwidth requirement at neighboring or nearby relay stations. Secondly, the medium in the IEEE 802.16 multi-hop relay network is managed by the base station in a centralized control manner, which provides the feasibility of more sophisticated bandwidth management in the network. The correlation of required bandwidth at nearby relay stations leads to the idea of *zone-based bandwidth allocation* in the paper. The zone of bandwidth allocation for a mobile user includes the user’s current relay station and the nearby relay stations. The number of relay stations in a zone is determined by the zone size in hop count. Adaptive selection of the zone size is the main focus of the paper. Mobility level of the mobile user presents an impact on the zone size. For example, a higher-mobility user deserves a larger zone in order to maintain a certain level of zone stability. Markovian analysis of user mobility in the network is used to determine the proper zone size. Simulation study shows the flexibility as well as the effectiveness of the proposed scheme.

The remainder of the paper is organized as follows. A

*Corresponding author: Yi-Ting Mai; E-mail: wkb@wkb.idv.tw
DOI: 10.6138/JIT.2014.15.2.02

brief survey of IEEE 802.16 and related research work are presented in Section 2. Zone-based bandwidth allocation is presented in Section 3. Markovian modeling and analysis for adaptively selecting the zone size is presented in Section 4. Simulation study is presented in Section 5. Finally, Section 6 concludes the paper.

2 Related Work

IEEE 802.16 is designed to support multimedia service via QoS support of different service types. Currently there are five service types defined in IEEE 802.16, which includes *Unsolicited Grant Service* (*UGS*), *extended real-time Polling Service* (*ertPS*), *real-time Polling Service* (*rtPS*), *non-real-time Polling Service* (*nrtPS*), and *Best Effort* (*BE*). Originally in the standard of IEEE 802.16-2004, two configuration modes were defined: *Point-to-Multipoint* (*PMP*) mode and *Mesh* mode. *PMP* mode consists of a *base station* (*BS*) and a couple of *subscriber stations* (*SS*) that connect to the BS via high-speed wireless link. The BS should act as a gateway of 802.16 domain to the Internet. Legacy LANs or even more complex subnet systems can connect to the 802.16 network via SS. An 802.16 network (including the Legacy LANs that connect to the SS) can cover a large geographical area since the distance between the BS and the SS can be up to 30 miles (in the case of 802.16-2004). On the other hand, as an extension of PMP configuration, the Mesh mode provides that there is no need to have direct link from SSs to the BS and a node can choose the links and path with best quality to transmit data and avoid the congested area. Moreover, the Mesh mode can provide a more flexible and faster approach for network deployment. The idea of the Mesh mode was removed from the standard of IEEE 802.16-2009 [3], since the standard allows only single-hop transmission in the network. However, the design of Multi-hop Relay (IEEE 802.16-MR) in the standard of IEEE 802.16j-2009 has practically brought the idea of the Mesh mode back to the table. Research works on the QoS support for PMP, the Mesh mode, and IEEE 802.16-MR are briefly surveyed in the following.

QoS-related issues in PMP were extensively investigated in the literature, which mainly focused on the scheduling mechanism, bandwidth management, and admission control. Based on the connection-oriented concept, the admission control scheme [6-7] must be properly designed to decide whether a new request of traffic flow can be granted or not. The new request is granted only when the bandwidth requirement of the request can be satisfied and none of the quality of the existing traffic flows is violated. Some research papers [8-9] proposed scheduling mechanisms for bandwidth allocation in PMP. The common idea of these scheduling mechanisms is to dynamically allocate time slots according to the service type of the traffic flows for higher network utilization. To integrate IP layer scheduling (L3) and IEEE 802.16 scheduling (L2) in PMP, some researches [10-13] proposed the idea of multi-layer QoS scheduling support by assigning different scheduling algorithms in L3 and L2 for different combinations of L3 and L2 service types.

QoS support is affected by the basic type of scheduling in the Mesh mode. There are two basic mechanisms to schedule data transmission in the Mesh mode: *centralized and distributed* scheduling. In centralized scheduling, the BS works like the cluster head and determines time slot allocation of each SS. In order to transmit data packets, the SS is required to submit the request packet (Layer 2 frame namely *BW_REQ*) to the BS via the control channel. The BS grants the access request by sending the slot allocation schedule called *UL_MAP* (*uplink* map for slot access) to all SS nodes. Since all the control and data packets need to go through the BS, the scheduling procedure is simple, however a longer path in the mesh network is inevitable. On the other hand, in distributed scheduling, every node competes for channel access using an election algorithm based on the scheduling information of the two-hop neighbors. Distributed scheduling is more flexible in terms of route selection (e.g., shortest path route can be used) at the cost of higher signaling overhead for the exchange of scheduling information.

Most of the research work in the Mesh mode focused on the centralized scheduling for better bandwidth management. Different variations[14-18] of scheduling and routing mechanisms were proposed to improve the performance by lowering the interference of routes and reducing the congestion near the hotspot of the BS. Some other research works [19-22] focused on the construction of virtualization network or the routing tree based on different QoS types. In Distributed scheduling, each node competes for channel access using a pseudorandom election algorithm based on the scheduling information of the two hop neighbors. However, the complicated behavior of Distributed scheduling makes it difficult to provide precise bandwidth allocation, which also makes it inappropriate in QoS support [23].

Similar to the Mesh mode, IEEE 802.16-MR is a multi-hop configuration. Issues of network utilization, route selection, resource allocation and handoff in IEEE 802.16-MR were investigated in the literature. To improve system utilization, some research works [24-26] focused on medium access control (MAC) and radio resource management problems in IEEE 802.16-MR. By considering performance metrics such as the number of hop count and E2E (*End-to-end*) throughput, the problem of path selection, link scheduling and routing were addressed in some research papers [27-28]. Some bandwidth allocation schemes [29-30] were proposed in order to satisfy the traffic demand from different flow requests and guarantee QoS requirement of different applications.

The authors have also been involved in the research of IEEE 802.16 QoS supporting for some years. In our previous work, two QoS frameworks each for PMP and the Mesh mode respectively have been proposed. The PMP framework [31] focused on the cross-layer design that integrating L3 and L2. A BS-controlled and delay-sensitive scheduling/routing scheme was proposed in the framework for the Mesh mode [32]. Associated mechanisms including admission control, flow setup and link state monitoring were also proposed. Simulation study has demonstrated that the average delay as well as the delay jitters in the proposed scheme is smaller than that of the standard distributed scheduling and much smaller than that of the standard centralized scheduling. The proposed mechanisms in the Mesh framework could also achieve higher throughput than the contrasts and generate much smaller signaling overhead, making the proposed framework a promising scheme for multimedia support in the IEEE 802.16 mesh network.

QoS support for mobile users was not addressed in most of the previous works in IEEE 802.16, let alone Mobile QoS (MQoS) support in IEEE 802.16-MR. Extension of RSVP (Resource Reservation Protocol) was adopted in traditional MQoS mechanisms, such as *Mobile RSVP* [33] and *Hierarchical Mobile RSVP* [34]. It is worth to clarify that traditional RSVP based mechanisms for Mobile QoS are Internet wide and operate above the IP layer. It is extremely challenging to allocate bandwidth for mobile users since QoS must be achieved over the E2E path in the presence of handoff. On the other hand, the IEEE.802.16-MR network is operating under the IP layer, which classifies the handoff within the IEEE 802.16-MR network as the case of micro mobility. Therefore, the issue of MQoS in IEEE 802.16-MR considered in this paper is also in the realm of micro mobility.

3 Zone-Based Bandwidth Allocation

3.1 Basic Idea

The motivation of zone-based bandwidth allocation is to reserve appropriate amount of bandwidth used for a mobile user at all RSs within the zone such that bandwidth re-allocation is not necessary for handoffs of the user among the RSs of the same zone. The size of a zone (denoted by Z_{size}) is defined to be the hop count of the most distant RS from the initial (center) RS as displayed Figure 1. Following assumptions are made for better understanding zone-based bandwidth management.

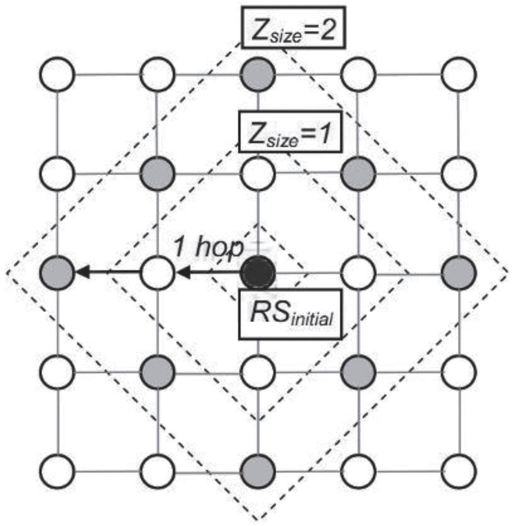


Figure 1 Zone with Different Z_{size}

(1) All RSs in the network share the same medium without *spatial reuse* in medium access, i.e., two or more RSs cannot access the medium at the same time.
(2) BS is fully in charge of medium access control and is responsible for bandwidth allocation by using fields like UL_MAP and *DL_MAP* (*downlink* map for slot access) in the control sub-frame. Details of the signaling procedure and the exchange of control messages are not presented in the paper.
(3) Although the proposed scheme can be applied to other types of network topology, a chessboard like topology as displayed in Figure 1 is used for modeling the IEEE 802.16-MR network, in which BS is located at the upper-left corner, and the correspondent node (CN) outside the network. The proposed scheme only considers bandwidth allocation within the network.
(4) The visiting probability of the mobile user at each RS is assumed to be obtainable either by the user profile data or network modeling techniques. The visiting probability of the mobile user at RS $RS_{i,j}$ is denoted by $P_{RS_{i,j}}$.
(5) The applications are assumed to be adaptable to bandwidth adjustment. The satisfaction rate for the required bandwidth, denoted by S, is defined as the ratio of the allocated bandwidth over the required value. The mobile user provides the flow data rate (denoted by *BW*) as well as the threshold of the satisfaction rate (denoted by *S_TH*) for bandwidth allocation.

3.2 Bandwidth Allocation

Given the flow data rate *BW*, the satisfaction threshold *S_TH*, the zone size Z_{size}, and the initial location of the mobile user $RS_{initial}$, we are showing the calculation of the allocated bandwidth. First of all, all RSs in the zone must be identified according to the value of Z_{size} as follows.

$RS_{i,j} \in$ Zone if the hop count $(RS_{i,j}, RS_{initial)} \leq Z_{size}$

Secondly, by normalization of the visiting probability at all RSs in the network, the visiting probability for each RS in the zone (denoted by P_{RS}^{Zone}) can be obtained.

$$P_{RS_{i,j}}^{Zone} = \frac{P_{RS_{i,j}}}{\sum_{\forall \text{ RS in the Zone}} P_{RS}}$$

If we assume the bandwidth allocated in the zone is $N*BW$, the satisfaction rate S for the allocation can be calculated as follows

$$S = \sum_{\forall \text{ RS in the Zone}} \left[Min\,(1, \frac{N*BW}{HC_{RS_{i,j}} * BW}) \right] * P_{RS_{i,j}}^{Zone} \qquad (1)$$

where $HC_{RS_{i,j}}$ is the hop count between BS and $RS_{i,j}$.

Note that the satisfaction rate at each RS should be no larger than 1. This is the reason why the *Min* operator is placed in the above equation.

Finally, the allocated bandwidth is determined by the minimum value of N which makes the value of S in Equation (1) larger than (or equal to) the threshold of the satisfaction rate *S_TH*.

For example, given $S\_TH = 0.95$, $RS_{initial} = RS_{5,5}$, flow date rate *BW*, the hop count from the BS to each RS, and the same visiting probability for all RSs, Figure 2 is used as an illustration for zone-based bandwidth calculation. For the case of $Z_{size} = 0$ (i.e., only $RS_{5,5}$ in the zone), in order to make user satisfaction rate larger than *S_TH*, N must be equal to or larger than 9.5. For the case of $Z_{size} = 1$ (5 RSs in the zone as shown in the figure), user satisfaction rate becomes 0.935 if N is still 9.5, as calculated as follows:

$$S = Min\,(\frac{9.5*BW}{9*BW}) * \frac{2}{5} + Min\,(1, \frac{9.5*BW}{10*BW}) * \frac{1}{5} + Min\,(1, \frac{9.5*BW}{11*BW}) * \frac{2}{5} = 0.935$$

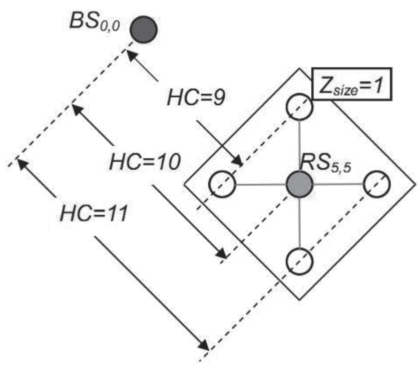


Figure 2 Example of Bandwidth Calculation

That is, for the case of $Z_{size} = 1$, $N = 9.5$ is not enough to meet user satisfaction requirement *S_TH*. A proper value of N is 9.8, which makes user satisfaction rate 0.952.

Admission control for a new mobile user is simply by checking if current available bandwidth is enough for the calculated value of bandwidth allocation. Moreover, by introduction the idea of zone, two types of handoff between RSs are defined, *intra-zone handoff* and *inter-zone handoff*. Bandwidth re-allocation is only triggered by inter-zone handoffs, and the RS triggering bandwidth re-allocation becomes the initial RS of the new zone. Notations used in zone-based bandwidth management are summarized in Table 1.

Table 1 Summary of Notations

Notation	Description	Remark
S_TH	Threshold of the satisfaction rate	User parameters
BW	Flow data rate	
$RS_{initial}$	Initial RS for bandwidth allocation	
Z_{size}	Zone size	System parameters
S	Satisfaction rate for the required bandwidth	
$P_{RS_{i,j}}$	Visiting probability at the RS	
P_{RS}^{Zone}	Normalized visiting probability at the RS in the zone	
$HC_{RS_{i,j}}$	Hop count between BS and RSi,j	

4 Adaptive Selection of Zone Size

As mentioned in Section 1, the mobility level of the user imposes some impact on selecting a proper zone size. In this paper, user mobility in the network is modeled by the probability moving out of the current RS, denoted by P_{move}, and moving into any of the neighboring RS with equal probability. The discrete-time Markov chain modeling user mobility in the chessboard-like network is displayed in Figure 3. Our goal is to find a large enough zone to make

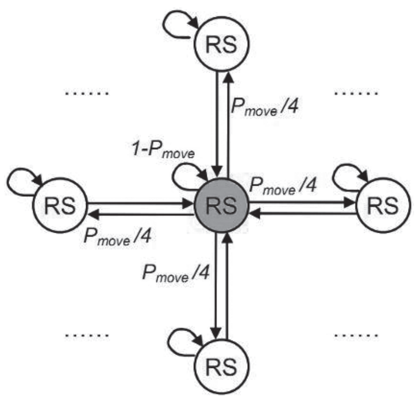


Figure 3 Modeling User Mobility

the stay probability of the mobile user in the zone larger than the pre-defined threshold (denoted by $P_{stay}TH$, 0.8 is used in the simulation). Two factors must be considered in the calculation of the stay probability in the zone. First, the stay probability should not include the case that the mobile user moving out of the zone and into the zone again, since a new zone should be initiated when the user moving out of the zone. Second, in the practical sense, the stay probability should be associated with a certain number of transitions. Therefore, the stay probability, denoted by $P_{stay}(k)$, is defined as the probability of the mobile user never leaving the zone within *k* transitions.

In order to reduce the number of states in the discrete-time Markov chain, RSs with the same hop count from the initial RS are treated as a single state, denoted by *Ring*(*L*) as displayed in Figure 4(a), in which *L* indicates the hop count. The new Markov chain of *Ring* states is displayed in Figure 4(b). The approximation of modeling is reasonable since the transition probability from the initial RS to each of its neighboring nodes is the same. Transition probability from *Ring*(*L*) to *Ring*(*L-1*) is calculated by the following equation. An example of calculating $P_{Ring(2) \rightarrow Ring(1)}$ is given in Figure 5.

$$P_{Ring(L) \rightarrow Ring(L-1)} = \frac{\text{Summation of all transition prob. from } Ring(L) \text{ to } Ring(L\text{-}1)}{\text{Total number of nodes in } Ring(L)} \quad (2)$$

Expansion of the states is used to compute the probability of each *Ring* state after *k* transitions. An example of the *Ring* states after 5 transitions is displayed in Figure 6, in which the transition probability between Ring states can be obtained by Equation (2) (Note that $P_{Ring(L) \rightarrow Ring(L+1)} = P_{move} - P_{Ring(L) \rightarrow Ring(L-1)}$ for L > 0). The probability of the mobile user staying in states *Ring*(*0*) ~ *Ring*(*5*) is calculated from the root state *Ring*(*0*) (the initial state with probability 1) following all possible paths until the 5th transition. For a given zone size, e.g., Z_{size} = 2, the staying probability of the mobile user in the zone within 5 transitions, $P_{stay}(k = 5)$, is the summation of the staying probability of *Ring*(*0*), *Ring*(*1*), and *Ring*(*2*) at the 5th transitions in Figure 6. Unfortunately, a computer program is required to calculate $P_{stay}(k)$ since the closed form for the probability is difficult to find.

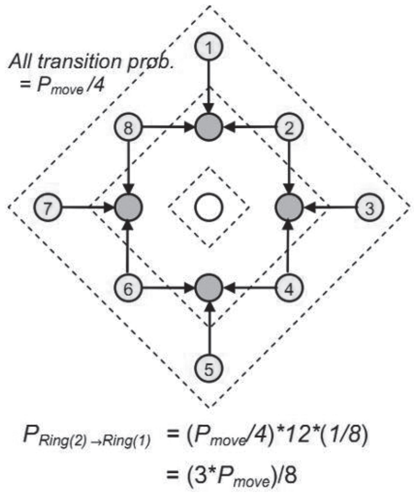
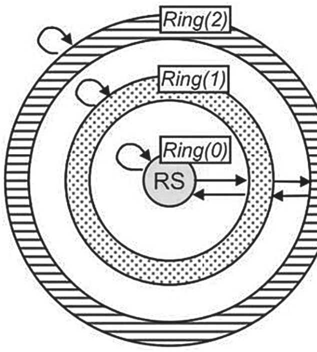
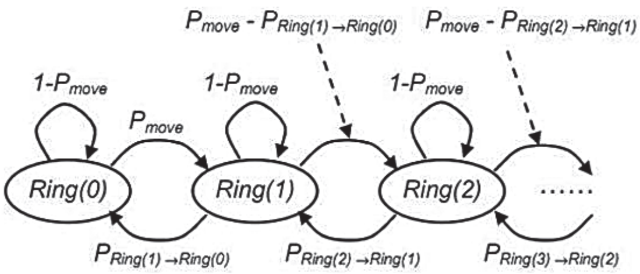


Figure 5 Calculation of $P_{Ring(2) \rightarrow Ring(1)}$



(a) The Idea of *Ring*



(b) New Markov Chain of *Ring*

Figure 4 Reducing the Number of States by the Idea of *Ring*

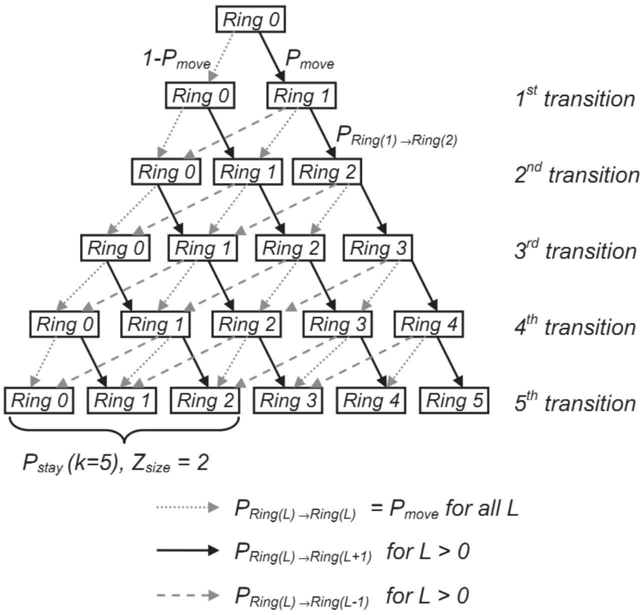


Figure 6 Expansion of Ring State for 5 Transitions

Simulation programs were conducted to evaluate the accuracy of the calculation of $P_{stay}(k)$. Figure 7 displays the simulation result as well as the analytical result in the case of $Z_{size} = 2$ and $P_{move} = 0.5$. Closeness of the two curves in the Figure 7 demonstrates the feasibility of the above Markovian analysis. Finally, for a given value of k, the proper zone size for the mobile user is set as the smallest value of Z_{size} to make $P_{stay}(k) \geq P_{stay}TH$. Figure 8 displays some results of zone size selection for the case of $P_{stay}TH = 0.8$ with different values of k (5, 10, 15, 20). For example, for the case of $P_{move} = 0.5$, the size of the zone should be 4 for $k = 10$. Figure 9 summarizes the process of zone size selection, and Figure 10 summarizes the overall idea of adaptive zone-based bandwidth management in this paper.

5 Performance Evaluation

5.1 Simulation Environment

Simulation study has been conducted to evaluate the performance of the adaptive zone scheme. An 11 × 11 chessboard-like network is used to simulate the IEEE 802.16-MR network, in which the BS is located at the upper-left corner and the CN is located outside the network. A discrete-time model is used to simulate user mobility. The initial position of a mobile user is randomly selected from the RSs in the network. Each mobile user leaves its current RS and moves to one of its neighboring RSs with probability P_{move} at each transition time. Considering the regular service range of an RS is about 1 km and the highest speed of the mobile user is 90 km per hour, the average staying time at an RS is about 1 minute, which maps to one transition time unit in the Markovian analysis in Section 3. Simulation parameters are listed in Table 2.

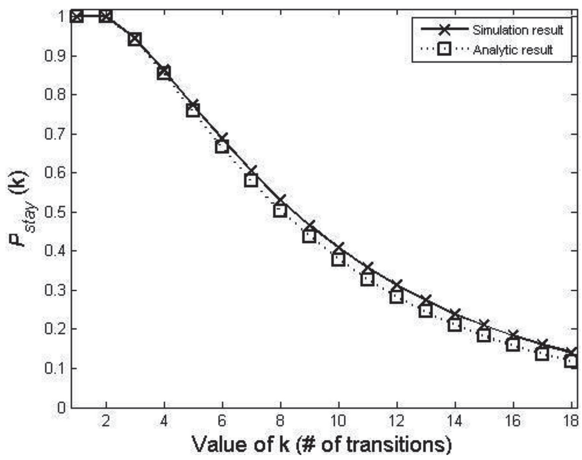


Figure 7 Analytic vs. Simulation for $P_{stay}(k)$

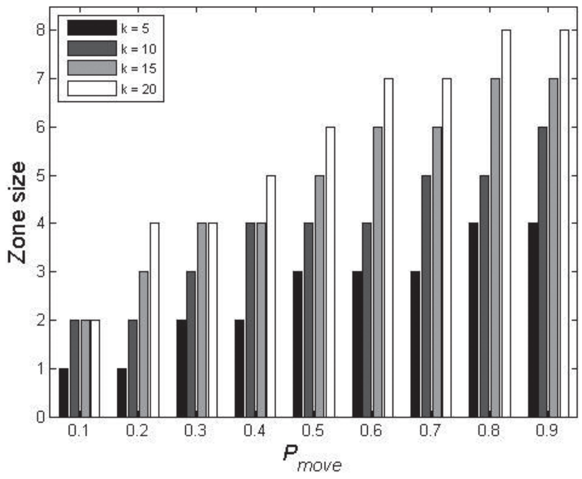


Figure 8 Selection of Zone Size ($P_{stay}TH = 0.8$)

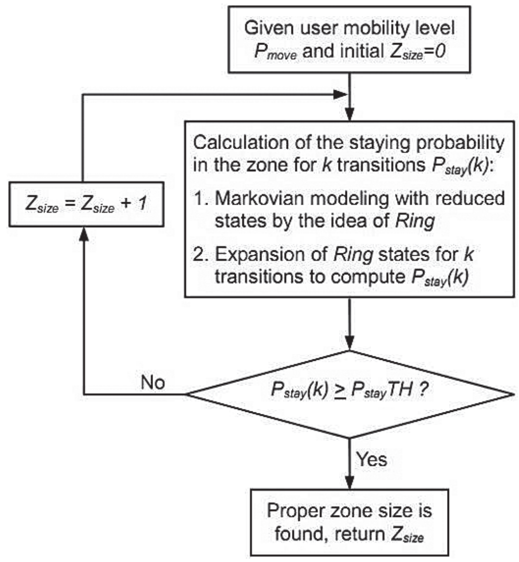


Figure 9 Process of Adaptive Zone Size Selection

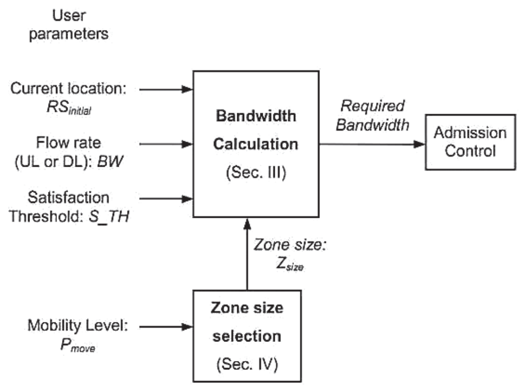


Figure 10 Adaptive Zone-Based Bandwidth Management

5.2 Results and Discussion

Simulation results of some performance criteria are presented in the paper.

(1) *Handoff call degradation ratio* is defined as the ratio of the case that the required bandwidth cannot be met after handoff. A lower Handoff call degradation ratio implies better service quality for handoff calls.

Table 2 Summary of Simulation Parameters

Parameter	Value
Topology size	11 × 11
Link capacity	70 Mbps
Value of *k* for *Pstay*(*k*)	5 transitions
$P_{stay}TH$	0.8
P_{move}	0.1 ~ 0.9
S_TH	1.0
Flow data rate (*BW*)	14 Kbps
Flow type	UGS
# of mobile users	100 ~ 700

(2) *New call blocking ratio* is defined as the ratio of which new calls are rejected due to the failure of meeting the required bandwidth in admission control.

(3) *Bandwidth allocation* is defined as the amount of allocated bandwidth for each flow in the IEEE 802.16-MR network.

(4) *Bandwidth utilization* is defined as the amount of allocated bandwidth for total flows in the IEEE 802.16-MR network.

(5) *Throughput* is defined as the amount of receiving data for total MSSs in the IEEE 802.16-MR network.

Figure 11 displays the result of *Handoff call degradation ratio* in the case of P_{move} = 0.5. The curve of Z_{size} = 0 in the figure presents the case of no pre-reservation of bandwidth for handoff, which inevitably increases the likelihood of failing to meet the bandwidth requirement as the load (# of flows) increases. Figure 11 also shows that a larger zone results in a lower *Handoff call degradation ratio* under heavy load (# of flows > 400). It's due to the reason that more RSs and also more handoff cases are covered by a larger zone, and degradation of a handoff call only occurs in the case of inter-zone handoff.

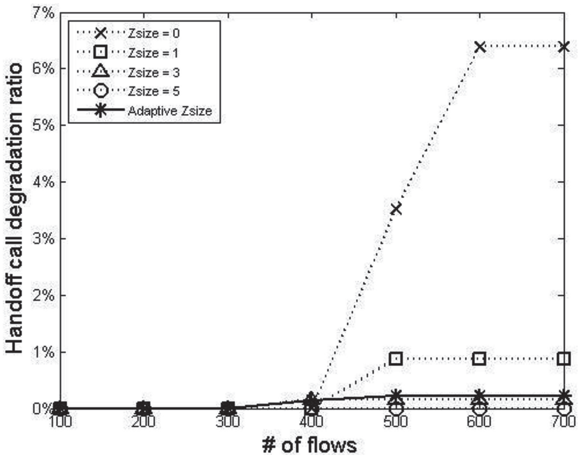


Figure 11 Handoff Call Degradation Ratio, P_{move} = 0.5

The result of *New call blocking ratio* is shown in Figure 12 indicating that larger zone size results in higher *New call blocking ratio*, since a larger zone requires more bandwidth allocation as displayed in Figure 13. In other words, in order to cover all possible movements in a zone, an accepted call with a larger zone is allocated with more bandwidth, which in turn reduces available bandwidth for the new calls. In addition, a new call with a larger zone also requires more bandwidth such that the blocking probability for the new call is inevitably increased.

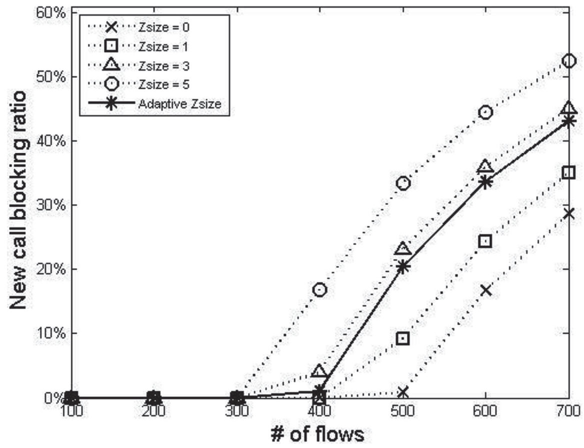


Figure 12 New Call Blocking Ratio, P_{move} = 0.5

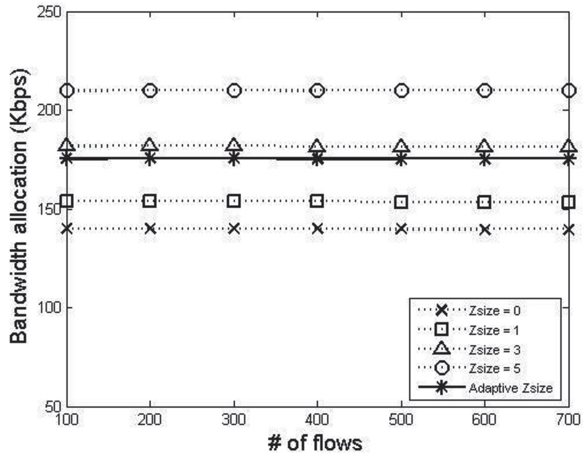


Figure 13 Bandwidth Allocation, P_{move} = 0.5

Figure 14 shows *Bandwidth utilization* under different zone sizes as the number of flows increases. The figure shows that a larger zone results in lower *Bandwidth utilization* under the same number of flows (e.g., 500). The reason is due to the fact that a larger zone requires more bandwidth as mentioned in the last paragraph, and thus fewer flows can be accepted resulting in lower utilization of bandwidth.

The result of the total *Throughput* in the network is displayed in Figure 15. It is shown in the figure that the maximum throughput of a smaller zone (e.g., Z_{size} = 1) is

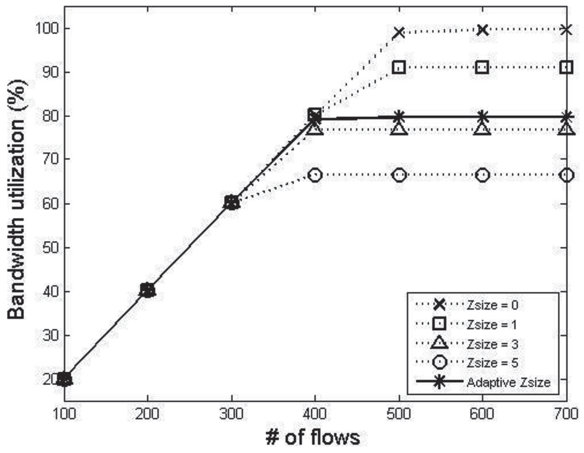


Figure 14 Bandwidth Utilization, P_{move} = 0.5

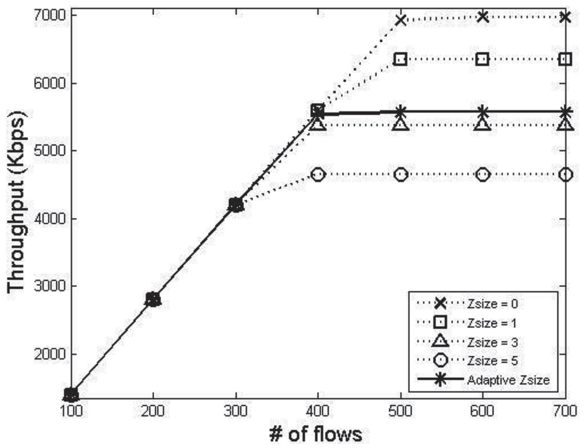


Figure 15 Throughput, P_{move} = 0.5

higher than the maximum throughput of a larger zone (e.g., Z_{size} = 3). The reason is due to the fact that less bandwidth is required for a smaller zone so that more flows can be accepted into the network and thus more throughput can be achieved.

According to the observation from Figure 11 ~ Figure 15 presented above, we conclude that a larger zone can achieve better quality of handoff calls at the expense of higher bandwidth allocation and higher new call blocking probability, which also leads to lower utilization and throughput. Moreover, Figure 11 ~ Figure 15 has also demonstrated the goal of the proposed adaptive zone scheme in seeking for a good balance between the service quality of handoff calls and new calls, and bandwidth allocation in the adaptive zone scheme is moderate in comparison with the scheme of fixed zone size.

In order to investigate the effectiveness of the zone size, one more performance criterion namely *Zone effectiveness* is defined as $\frac{Assigned\_Z_{size}+1}{Ideal\_Z_{size}+1}$, where the assigned zone size is the actual zone size in the schemes (fixed or adaptively selected), and the ideal zone size is defined as the average distance of the mobile user for 5 consecutive transitions. Closeness of *Zone effectiveness* to 100% implies the zone size is more effective. *Zone effectiveness* higher than 100% implies the waste of bandwidth allocation, while *Zone effectiveness* under 100% implies lower quality of service. As shown in Figure 16, the adaptive scheme is more effective in zone size selection for different move probabilities.

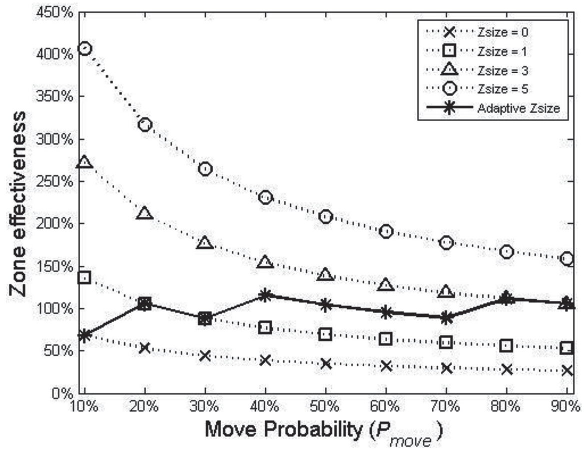


Figure 16 Zone Effectiveness

Lastly, the impact of the total number of flows and the level of move probability (P_{move}) on "*Handoff call degradation ratio*" is investigated. Figure 17 displays the result for the case of P_{move} = 0.5 under different number of flows. As shown in Figure 17, *Handoff call degradation ratio* decreases for all schemes as the number of flows increases in the same total system load. The reason behind is as the number of flows increases, the number of handoff flow at the same time also increases which enlarges the gain of multiplexing in bandwidth allocation. Similarly, as displayed in Figure 18, *Handoff call degradation ratio* decreases for all schemes as the value of P_{move} increases.

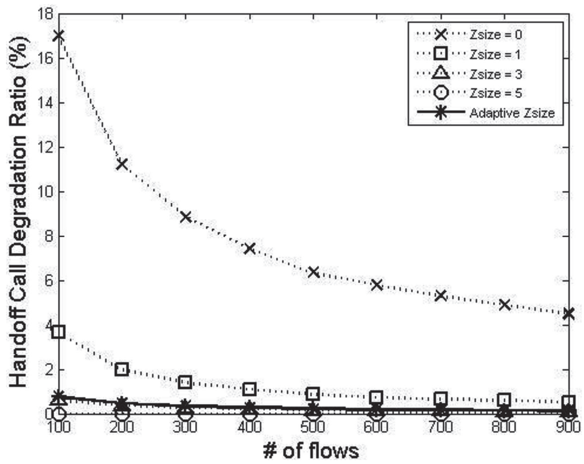


Figure 17 Impact of # of Flow on Handoff Calls, P_{move} = 0.5

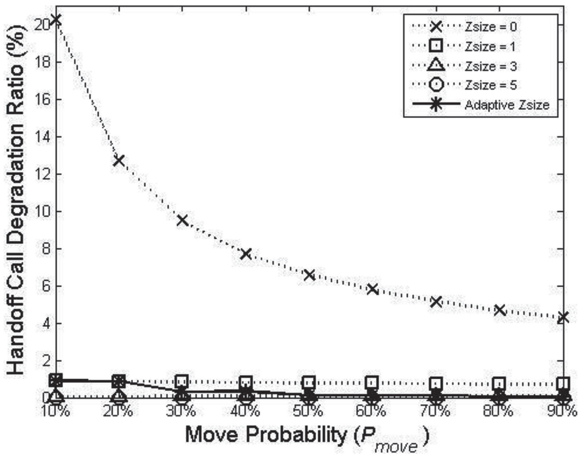


Figure 18 Impact of P_{move} on Handoff Calls, *# of flow = 500*

Handoff call degradation ratio of the proposed adaptive zone scheme in both figures is smaller than other schemes demonstrating the benefit of adaptive zone-based bandwidth management.

6 Conclusion

By comparing the characteristics of the traditional Internet-based network environment with IEEE 802.16-MR, the authors concluded that traditional mechanisms for mobile QoS cannot fit well in IEEE 802.16-MR, and the idea of zone-based bandwidth management is proposed. Bandwidth allocation is made for the mobile user roaming within the zone, which is defined to include the current RS and its neighboring RSs within the zone size in hop count. The required bandwidth and the service level provided are affected by the size of the zone. A larger zone requires more bandwidth but can provide better quality of service for handoff. Markovian analysis for adaptively selecting the zone size based on user mobility is proposed in the paper. Simulation study has demonstrated the effectiveness of the adaptive zone scheme. The mobility model in the paper assumes equal probability to neighbors for movement. The future work of the research is to target on a more general model for user mobility such as directional mobility.

References

[1] *IEEE standard for local and metropolitan area networks -- Part 16: Air interface for fixed broadband wireless access systems*, October, 2004. IEEE Std. 802.16-2004.

[2] *IEEE standard for local and metropolitan area networks -- Part 16: Air interface for fixed and mobile broadband wireless access systems -- Amendment for physical and medium access control layers for combined fixed and mobile operation in licensed bands*, February, 2006. IEEE Std. 802.16e-2006.

[3] *IEEE standard for local and metropolitan area networks part 16: Air interface for broadband wireless access systems*, May, 2009. IEEE Std. 802.16-2009.

[4] *IEEE standard for local and metropolitan area networks part 16: Air interface for broadband wireless access systems amendment 1: Multiple relay specification*, June, 2009. IEEE Std 802.16j-2009.

[5] Steven W. Peters and Robert W. Heath, Jr., *The Future of WiMAX: Multihop Relaying with IEEE 802.16j*, *IEEE Communications Magazine*, Vol.47, No.1, 2009, pp.104-111.

[6] Haitang Wang, Bing He and Dharma P. Agrawal, *Admission Control and Bandwidth Allocation above Packet Level for IEEE 802.16 Wireless MAN*, *Proc. 12th International Conference on Parallel and Distributed Systems (ICPADS 2006)*, Minneapolis, MN, July, 2006, doi:10.1109/ICPADS.2006.22.

[7] Liping Wang, Fuqiang Liu, Yusheng Ji and Nararat Ruangchaijatupon, *Admission Control for Non-preprovisioned Service Flow in Wireless Metropolitan Area Networks*, *Proc. 4th European Conference on Universal Multiservice Networks (ECUMN 2007)*, Toulouse, France, February, 2007, pp.243-249.

[8] Alexander Sayenko, Olli Alanen, Juha Karhula and Timo Hämäläinen, *Ensuring the QoS Requirements in 802.16 Scheduling*, *Proc. 9th ACM International Symposium on Modeling Analysis and Simulation of Wireless and Mobile Systems (MSWiM 2006)*, Torremolinos, Spain, October, 2006, pp.108-117.

[9] Xiaofeng Bai, Abdallah Shami, Khalim Amjad Meerja and Chadi Assi, *New Distributed QoS Control Scheme for IEEE 802.16 Wireless Access Networks*, *Proc. IEEE Global Telecommunications Conference (GLOBECOM 2006)*, San Francisco, CA, November, 2006, pp.1-5.

[10] Jianfeng Chen, Wenhua Jiao and Qian Guo, *An Providing Integrated QoS Control for IEEE 802.16 Broadband Wireless Access Systems*, *Proc. IEEE 62nd Vehicular Technology Conference (VTC-2005-Fall)*, Dallas, TX, September, 2005, pp.1254-1258.

[11] Yen-Wen Chen, I-Hsuan Peng and Shiu-Tsuen Guan, *Dynamic Bandwidth Management for Handoffs with RSVP in 802.16/WLAN Environment*, *Proc. Advanced Information Networking and Applications Workshops, 2007 (AINAW 07)*, Niagara Falls, Canada, May, 2007, pp.243-248.

[12] Der-Jiunn Deng, Li-Wei Chang, Tin-Yu Wu and Chia-Cheng Hu, *Guaranteed QoS Provision Scheduling Mechanism for CBR Traffic in IEEE 802.16 BWA Systems*, *Journal of Internet Technology*, Vol.9, No.4, 2008, pp.403-409.

[13] Fei Yin, Guy Pujolle, Jong Hyuk Park and Han-Chieh Chao, *Performance Optimization with Efficient Polling Mechanism in IEEE 802.16 Network with Cross-Layer Consideration*, *Wireless Personal Communications*, Vol.51, No.3, 2009, pp.635-665.

[14] Bo Han, Fung Po Tso, Lidong Ling and Weijia Jia, *Performance Evaluation of Scheduling in IEEE 802.16 Based Wireless Mesh Networks*, *Journal of Computer Communications*, Vol.30, No.4, 2007, pp.782-792.

[15] M. Peng, Y. Wang and W. Wang, *Cross-Layer Design for Tree-Type Routing and Level-Based Centralised Scheduling in IEEE 802.16 Based Wireless Mesh Networks*, *IET Communications*, Vol.1, No.5, 2007, pp.999-1006.

[16] Mehmet S. Kuran, Gürkan Gür, Tuna Tugcu and Fatih Alagöz, *Cross Layer Routing Scheduling in IEEE 802.16 Mesh Networks*, *Proc. 1st International Conference on MOBILe Wireless MiddleWARE, Operating Systems, and Applications (MOBILWARE'08)*, Innsbruck, Austria, February, 2008, Article No.47.

[17] Rung-Shiang Cheng and Whe Dar Lin, *A Centralised Transmission Tree Scheduling Algorithm for IEEE 802.16 Mesh Networks*, *International Journal of Ad Hoc and Ubiquitous Computing*, Vol.9, No.4, 2012, pp.250-257.

[18] Yi-Ting Mai, Chun-Chuan Yang, Jeng-Yueng Chen and Cheng-Jung Wen, *Design of Multi-hop QoS Scheduling for IEEE 802.16 Networks*, *TELKOMNIKA Indonesian Journal of Electrical Engineering*, Vol.11, No.12, 2013, pp.7715-7726.

[19] Harish Shetiya and Vinod Sharma, *Algorithms for Routing and Centralized Scheduling to Provide QoS in IEEE 802.16 Mesh Networks*, *Proc. 1st ACM Workshop on Wireless Multimedia Networking and Performance Modeling (WMuNeP 2005)*, Montreal, Canada, October, 2005, pp.140-149.

[20] Spyros Xergias, Nikos I. Passas and Apostolis K. Salkintzis, *Centralized Resource Allocation for Multimedia Traffic in IEEE 802.16 Mesh Networks*, *Proceedings of the IEEE*, Vol.96, No.1, 2008, pp.54-63.

[21] Jung-Shyr Wu, Yen-Chieh Cheng and Shiann-Tsong Sheu, *Memorised Carrier Sense Multiple Access with Collision Avoidance (MCSMA/CA) Protocol for IEEE 802.11p*, *International Journal of Internet Protocol Technology*, Vol.7, No.1, 2012, pp.52-61.

[22] Jeng-Yueng Chen, Chun-Chuan Yang and Yi-Ting Mai, *Design of Multi-RAT Virtualization Architectures in LTE-Advanced Wireless Network*, *ICIC Express Letters*, Vol.8, No.5, 2014, pp.1519-1529.

[23] Yan Zhang, Honglin Hu and Hsiao-Hwa Chen, *QoS Differentiation for IEEE 802.16 WiMAX Mesh Networking*, *Mobile Networks and Applications*, Vol.13, No.12, 2008, pp.19-37.

[24] Dusit Niyato, Ekram Hossain, Dong In Kim and Zhu Han, *Relay-Centric Radio Resource Management and Network Planning in IEEE 802.16j Mobile Multihop Relay Networks*, *IEEE Transactions on Wireless Communications*, Vol.8, No.12, 2009, pp.6115-6125.

[25] Shun-Ren Yang, Chien-Chi Kao, Wai-Chi Kan and Tzung-Chin Shih, *Handoff Minimization through a Relay Station Grouping Algorithm with Efficient Radio-Resource Scheduling Policies for IEEE 802.16j Multihop Relay Networks*, *IEEE Transactions on Vehicular Technology*, Vol.59, No.5, 2010, pp.2185-2197.

[26] D. Satish Kumar and N. Nagarajan, *A New Adaptive Model for Throughput Enhancement and Optimal Relay Selection in IEEE 802.16j MMR Networks*, *Scientific Research and Essays*, Vol.6, No.29, 2011, pp.6227-6242.

[27] Bo Wang and Matt Mutka, *Path Selection for Mobile Stations in IEEE 802.16 Multihop Relay Networks*, *Proc. International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM)*, Newport Beach, CA, June, 2008, doi: 10.1109/WOWMOM.2008.4594865.

[28] Sojeong Ann, Kyung Geun Lee and Hyung Seok Kim, *A Path Selection Method in IEEE 802.16j Mobile Multi-hop Relay Networks*, *Proc. IEEE International Conference on Sensor Technologies and Applications (SENSORCOMM'08)*, Cap Esterel, France, August, 2008, pp.808-812.

[29] Liu Erwu, Wang Dongyao, Liu Jimin, Shen Gang and Jin Shan, *Performance Evaluation of Bandwidth Allocation in 802.16j Mobile Multi-hop Relay Networks*, *Proc. IEEE 65th Vehicular Technology Conference (VTC-2007-Spring)*, Dublin, Ireland, April, 2007, pp.939-943.

[30] Anas F. Bayan and Tat-Chee Wan, *A Scalable QoS Scheduling Architecture for WiMAX Multi-hop Relay Network*, *Proc. 2nd International Conference on Education Technology and Computer (ICETC)*, Shanghai, China, June, 2010, pp.326-331.

[31] Yi-Ting Mai, Chun-Chuan Yang and Yu-Hsuan Lin, *Design of the CrossLayer QoS Framework for the IEEE 802.16 PMP Networks*, *IEICE Transactions on Communications*, Vol.E91B, No.5, 2008, pp.1360-1369.

[32] Chun-Chuan Yang, Yi-Ting Mai and Liang-Chi Tsai, *Design of the QoS Framework for the IEEE 802.16 Mesh Networks*, *International Journal of Communication Systems*, Vol.22, No.12, 2009, pp.1543-1562.

[33] Anup Kumar Talukdar, B. R. Badrinath and Arup Acharya, *MRSVP: A Resource Reservation Protocol for an Integrated Services Network with Mobile Hosts*, *Wireless Networks*, Vol.7, No.1, 2001, pp.5-19.

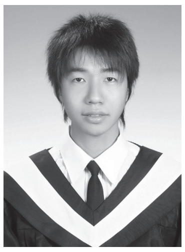
[34] Chien-Chao Tseng, Gwo-Chuan Lee, Ren-Shiou Liu and Tsan-Pin Wang, *HMRSVP: A Hierarchical Mobile RSVP Protocol*, *Wireless Networks*, Vol.9, No.2, 2003, pp.95-102.

Biographies

Chun-Chuan Yang received his BS degree in computer and information science from National Chiao-Tung University, Taiwan, in 1990 and PhD degree in computer science from National Taiwan University in 1996. He joined the Department of Computer Science and Information Engineering, National Chi Nan University (NCNU), Puli, Taiwan, as an assistant professor in 1998. Since February 2008, he has been a full professor. His research area of interests includes mobile networking, QoS supporting, power saving, and 4G LTE/LTE-A.

Yi-Ting Mai received his BS degree in Department of Science Education from National Hualien University of Education, Hualien, Taiwan, in 1998 and MS degrees in Department of Information Management from Chaoyang University of Technology, Taichung, Taiwan, in 2004. He got PhD degree in Department of Computer Science and Information Engineering, National Chi Nan University (NCNU), Puli, Taiwan, in 2008. He joined the Department of Information and Networking Technology, Hsiuping University of Science and Technology, Taichung, Taiwan, R.O.C., as an assistant Professor in 2008. He is currently an associate professor in the Department of Sport Management, National Taiwan University of Physical Education and Sport, Taichung, Taiwan, R.O.C. His current research topics include wireless networks, QoS, power saving, multimedia network protocols, and 4G LTE/LTE-A.

Jeng-Yueng Chen received his PhD degree in Computer Science and Information Engineering from National Chi Nan University in 2009. Currently, he is an assistant professor of Department of Information Networking Technology at Hsiuping University of Science and Technology. His research interests cover routing, mobile computing, network management SIP-based applications, and 4G LTE/LTE-A.



I-Wei Lin received his BS degree in department of computer science from I-Shou University, Taiwan, in 2008 and MS degree in computer science from National Chi Nan University, Puli, Taiwan, in 2010. His current research topic includes broadband wireless access network protocols.