A Zone-based Bandwidth Allocation Protocol in WiMAX Multi-hop Relay Networks

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***Abstract*—For mobile multi-hop wireless network, IEEE 802.16j/MR network can not only supply large area wireless deployment, but also provide high quality network service to mobile users. In this paper, we will be focusing on QoS supporting for mobile users in the IEEE 802.16-MR network. The probability of a mobile user who visits a RS is known beforehand. With the same visiting probability of each RS and the system-specified size of the range for bandwidth allocation, BS can calculate the required bandwidth to meet the mobile user's demand and allocate appropriate bandwidth for a mobile user includes the user's current relay station and the nearby relay stations. The range of bandwidth allocation for mobile users is called the Zone in this paper; and the proposed scheme is therefore a Zone-based bandwidth allocation protocol. The simulation results demonstrate that Zone-based bandwidth allocation protocol can reduce QoS degradation and bandwidth re-allocation overhead.**

Keywords-component; 802.16, WiMAX, MR, Mobility, QoS

I. INTRODUCTION

IEEE 802.16 working group has launched a standardization process called Wireless Metropolitan Area Network (Wireless MAN[TM]) for Broadband wireless access (BWA). BWA technology based on IEEE 802.16d (802.16-2004) [1] has been developed to achieve high speed mobile wireless network service to mobile users. Considering user mobility, IEEE 802.16e [2], 802.16-2009 [3], had also been completed recently to support wireless access with high mobility. However, IEEE 802.16e/802.16-2009 only provides single-hop wireless connectivity. So the latest version, IEEE 802.16j-2009 [4] proposed for mobile multi-hop relay (MMR) networks. In an MMR network, MSs are allowed to route through intermediate RSs to reach the BS, which differs from the single-hop WiMAX topology. The new MMR network architecture imposes a demanding performance requirement on Relay Stations (RSs). These relays will functionally serve as an aggregating point on behalf of the BS for traffic collection from and distribution to the multiple MSs associated with them. In the standard of IEEE 802.16j-2009, packet construction and delivery mechanism are inherited from IEEE 802.16/16e standard. The new multi-hop wireless network, we also call IEEE 802.16-MR.

IEEE 802.16-MR 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 (WiMAX users, e.g. MS_1, MS_2 in Figure 1) can directly access the network while roaming in the area. IEEE 802.11 access point (Wi-Fi AP) connected to the Relay Station is required for Wi-Fi users (e.g. MH_1, MH_2 in Figure 1) to gain access of the network. In either case of WiMAX or Wi-Fi users, an appropriate bandwidth allocation scheme in the IEEE 802.16-MR network is expected in order to guarantee QoS transmission for mobile users. The issue of QoS supporting for mobile users (also referred as *Mobile QoS*) [5]-[6], has been addressed in the literature for many years. The typical strategy for *Mobile QoS* is to reserve necessary bandwidth at neighboring nodes before the mobile user handoff to the new node, which inevitably results in low bandwidth utilization.

Due to the different nature in network technology, supporting of Mobile QoS in the IEEE 802.16-MR network is worth a second thought. First of all, 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-MR 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* proposed in this 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, whose impact on different performance criteria has been investigated. Simulation study has shown the flexibility as well as the efficiency of the proposed scheme.

The remainder of the paper is organized as follows. Firstly, a survey of research works on the 802.16 QoS and mobile QoS are presented in section 2. The proposed Zone-based bandwidth allocation protocol in the 802.16-MR network is presented in section 3. Simulation study for performance evaluation and comparison is presented in section 4. Finally, section 5 concludes this paper.

II. RELATED WORKS

Since IEEE 802.16-MR network is also multi-hop topology, network utilization, route selection, resource allocation and handoff issue should be discussed. To improve the system utilization, some research works [7]-[9] focus on medium access control (MAC) and radio resource management problems in IEEE 802.16j networks. [10] [11] addressed the path-selection, link scheduling and routing problem in IEEE 802.16j networks considering metrics such as number of Hop count and maximum E2E throughput. Considering QoS supporting and bandwidth allocation, [12] [13] bandwidth allocation schemes were proposed for 802.16-MR networks in order to satisfy traffic demand from different flow requests and guarantee QoS demands of different applications.

In order to achieve QoS support in IEEE 802.16 network, both 802.16 layer and upper layer QoS should be considered. Cross-layer QoS frameworks for IEEE PMP [14] and Mesh [15] were proposed respectively in our previous work. Higher throughput, lower access delay and less signaling overhead can be achieved in the frameworks. QoS supporting for mobile users is not addressed in most of the previous works on IEEE 802.16 QoS, let alone mobile QoS supporting in the IEEE 802.16-MR network. Traditional networks generally require the use of RSVP to reserve bandwidth for users. Some research paper [16] [17] applied the *RSVP* concept for E2E QoS reservation in IEEE 802.16 Mesh network. However, it hasn't been noted yet that the mobility of MHs and cannot support MHs handoff frequently. *Mobile RSVP (MRSVP)* [5] is an extension of *RSVP* that distinguishes between two kinds of reservations - the active and passive reservations. *Hierarchical Mobile RSVP (HMRSVP)* [6] integrates *RSVP* with *Mobile IP* regional registration protocol [18]. The *RSVP* session between the MH and the CN is split into 2-tier group.

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 Micro-Mobility. Resources management in IEEE 802.16-MR is centrally controlled by the BS. As illustrated in Figure 2, in the case of the same hop count before and after handoff, the BS only needs to re-assign the Minislots used by the RSs on the old path to the RSs on the new path without triggering bandwidth re-allocation. In general case, the BS has to ensure there is enough bandwidth for handoff, which leads to the idea of zone-based bandwidth allocation in the paper.

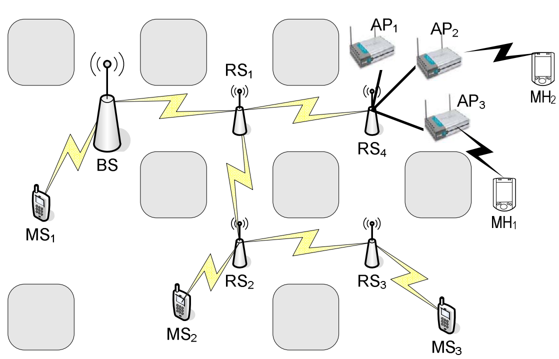

Figure 1. Integrated wireless network topology in IEEE 802.16-MR network

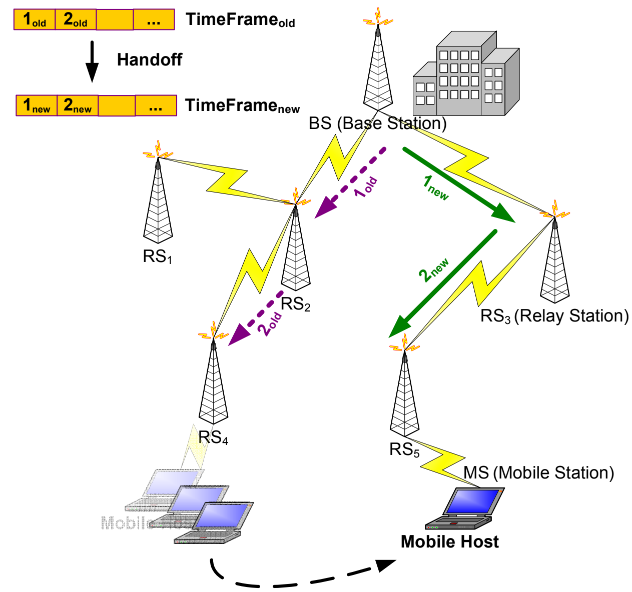

Figure 2. Resource Re-allocation in IEEE 802.16-MR Network

III. ZONE-BASED BANDWIDTH ALLOCATION PROTOCOL

A. *Basic Idea and Notations*

The motivation of zone-based bandwidth allocation is to reserve appropriate amount of bandwidth used for a mobile user at all relay stations within the zone such that bandwidth re-allocation is not necessary for handoffs of the user among the relay stations of the same zone. The size of a zone is defined to be the Hop count of the most distant relay station from the initial (center) relay station. For more general purpose to cover different network sizes, a system parameter L, whose value is in-between 0 ~ 1, is defined for zone size in the paper. Assuming the size of the IEEE 802.16-MR network in Hop count is HC_{MAX}, zone size L means the Hop count of the most distant relay station from the initial relay station ($RS_{initial}$) is $\lceil L*HC_{MAX} \rceil$ as illustrated in Figure 3. Therefore, the zone only includes the initial relay station for $L=0$, and all relay stations in the network for $L=1$. Following assumptions are made for better understanding the proposed scheme.

(1) All relay stations in the network share the same medium without *spatial reuse* in medium access, i.e. two or more relay stations 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* in the control sub-frame. Details of the signaling procedure as well as the exchange of control messages are not presented in the paper.
(3) Although the proposed scheme can be applied to other types of topology, a chessboard like topology as displayed in Figure 3 is used for modeling the network. BS is located at the upper-left corner. The correspondent node (CN) for the mobile user is located outside the network. The proposed scheme

only considers bandwidth allocation within the IEEE 802.16-MR network.

(4) The visiting probability of the mobile user at each relay station is assumed to be obtainable either by user profile data or network modeling techniques. The visiting probability of the mobile user at relay station $RS_{i,j}$ is denoted by $P_{RS_{i,j}}$.

(5) The applications adopting the proposed scheme 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 rate (denoted by *BW*) as well as the threshold of the satisfaction rate (denoted by *S_TH*) for bandwidth allocation.

Notations used in the paper are summarized in TABLE I.

TABLE I. SUMMERY OF NOTATIONS

Notation	Description	Type
L	Zone size	System parameters
S	Satisfaction rate for required bandwidth	
HC_{MAX}	Hop count of 802.16-MR	
$P_{RS_{i,j}}$	Visiting probability at $RS_{i,j}$	
$P^{Zone}_{RS_{i,j}}$	Normalized visiting probability at $RS_{i,j}$ within the zone	
$HC_{RS_{i,j}}$	Hop count between BS and *RSi,j*	
S_TH	Threshold of the satisfaction rate	User parameters
BW	Flow data rate	
$RS_{initial}$	The initial RS of the zone for bandwidth allocation	

B. Bandwidth Allocation

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

$$RS_{i,j} \in Zone_{RS_{initial},L}$$

$$\text{as long as the hop count between } RS_{i,j} \text{ and } RS_{initial} \le \lceil HC_{MAX} * L \rceil$$

Secondly, by normalization of the visiting probability at all relay stations in the network, the visiting probability for each relay station in the zone (denoted by $P^{Zone}_{RS_{i,j}}$) can be obtained as follows.

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

$P^{Zone}_{RS_{i,j}}$ is the visiting probability of the mobile user at $RS_{i,j}$ in the case of the user not moving outsize of the zone. If we assume the bandwidth allocated in the zone is *N*BW*, the satisfaction rate *S* for the allocation can be calculated as follows.

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

where $HC_{RS_{i,j}}$ is the Hop count between BS and $RS_{i,j}$. Eq-1

Note that the satisfaction rate at each relay station (calculated by $\frac{N * BW}{HC_{RS_{i,j}} * BW}$) should be no larger than 1. This is 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 Eq-1 larger than (or equal to) the threshold of the satisfaction rate *S_TH*.

For example, given the following parameters, *S_TH = 0.8*, *Zone size = 3*, $RS_{initial} = RS_{5,5}$, the Hop count of each RS in the zone as displayed in Figure 4, and the same visiting probability for all RSs, the value of satisfaction rate S ≈ *0.784* for *N = 9*and *S≈0.828* for *N = 9* according to the calculation of Eq-1. Bandwidth allocation for the zone of the case should be *9*BW* to make value of *S* greater than *S_TH*.

Admission control for the 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 relay stations are defined, *intra-zone handoff* and *inter-zone handoff* as illustrated in Figure 5. Bandwidth re-allocation is only triggered by inter-zone handoffs, and the relay station triggering bandwidth re-allocation becomes the initial relay station of the new zone.

IV. PERFORMANCE EVALUATION

A. Simulation Environment and Performance Criteria

Simulation study has been conducted to evaluate the performance of zone-based bandwidth management. The IEEE 802.16-MR network is an 11x11 chessboard-like topology as the one in Figure 3. The BS is located at the upper-left corner, and the CN is outside the network. Link capacity of the network is 20 Mbps. The visiting probability at all RSs in the network is assumed to be the same in the simulation. Parameters used in the simulation are displayed in TABLE II. Some criteria are defined for performance evaluation.

(1) *Bandwidth Allocation* is defined in the unit of Hop count, since the flows in the simulation are all UGS flows with same data rate of *BW*.

(2) *Average Satisfaction* is the average ratio of allocated bandwidth over required bandwidth. *Standard Deviation of Satisfaction* is used to evaluate the fluctuation of the allocated bandwidth.

(3) *Handoff Call Degradation Ratio* is the ratio of the case that the required bandwidth can not be met after handoff.

(4) *Bandwidth Re-allocation Ratio* is the ratio of the case that bandwidth re-allocation is triggered over the total number of handoff.

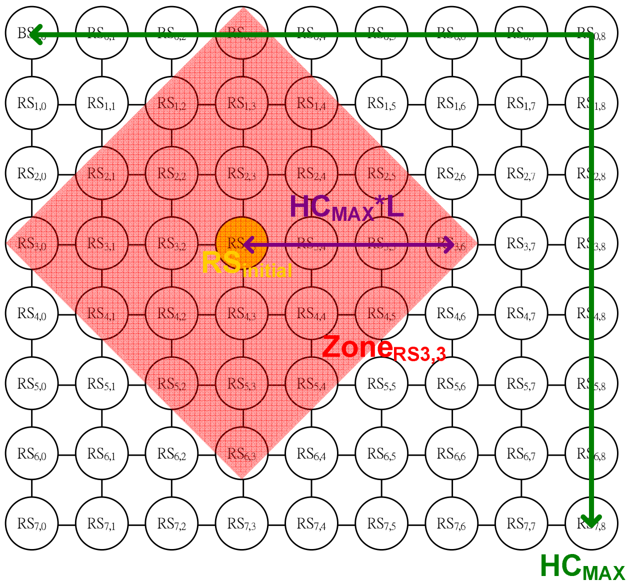

Figure 3. Zone coverage area of parameter L

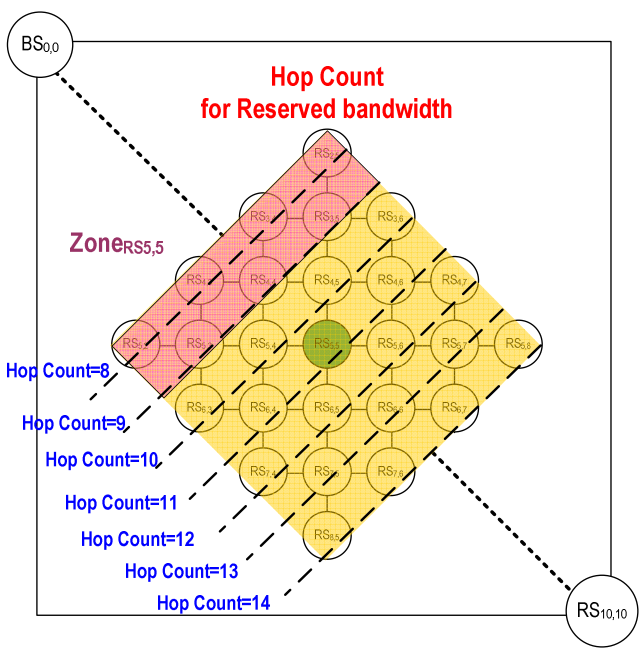

Figure 4. Example of reserved bandwidth

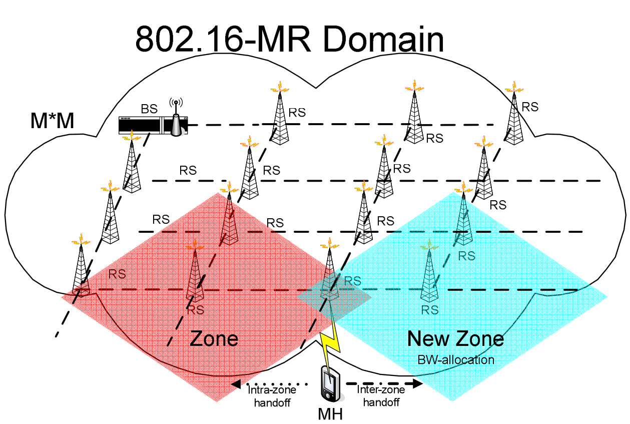

Figure 5. Intra-zone and Inter-zone handoff

TABLE II. SIMULATION PARAMETERS

Description	Value
Topology Size	11*11 Mesh
System Bandwidth	20 Mbps
Time Frame	10 ms
# of Minislot in Time Frame	500
Simulation Time	100 s
Flow Type	UGS
Flow Rate	3.65 Kbps
Flow Life Time	50 s
Number of Flow	100 ~ 1000

B. *Simulation Results*

The impact of *S_TH* and *L* on *Bandwidth Allocation* is illustrated in Figure 6. To reach a higher satisfaction rate (above 90%) with a higher zone size *L*, it needs to reserve more bandwidth. However, if fewer than 90% satisfaction rate is acceptable, *Bandwidth Allocation* can be greatly reduced as low as 60% (N/HC_{MAX}). Simulation result of *Average Satisfaction Rate* is displayed in Figure 7, which demonstrates the user requirement (*S_TH* = 0.9) can be achieved by the proposed zone-based scheme. As shown in Figure 8, a larger zone might increase *Standard Deviation of Satisfaction* due to larger roaming area for MHs movement. Figure 9 displays the result of *Handoff Call Degradation Ratio*, which is reducing as the zone size increases. However, it surely increases the likelihood of failing to meet the bandwidth requirement as the load (# of flows) increases. *Bandwidth Re-allocation Ratio* for different zone sizes is displayed in Figure 10. In summary, a larger zone can reduce *Handoff Call Degradation Ratio*, and *Bandwidth Re-allocation Ratio*, at the cost of more *Bandwidth Allocation*. To enlarge zone size is inevitably raising *Standard Deviation of Satisfaction*.

V. CONCLUSION

IEEE 802.16 (WiMAX) Wireless Network technology is a popular research issue in recent years. It provides wider coverage of radio, faster wireless access, and the Quality of Service plays an important role as the standard in assessing this technology. For mobile multi-hop wireless network, IEEE 802.16j/MR network can not only supply large area wireless deployment, but also provide high quality network service to mobile users. In this paper, a novel Zone-based bandwidth allocation protocol is proposed to maintain mobile users in the IEEE 802.16-MR network. Based on our proposed protocol, mobile users can choose an appropriate Zone size depending on their QoS satisfaction and requirement in the IEEE 802.16-MR network. Simulation result has demonstrated our proposed protocol can meet user's requirement. The larger zone size can effectively reduce QoS degradation and bandwidth re-allocation overhead but decreases bandwidth utilization. Our future work will try to design an adaptive Zone size scheme to select the appropriate zone size for mobile users with different mobility distribution characteristic.

ACKNOWLEDGMENT

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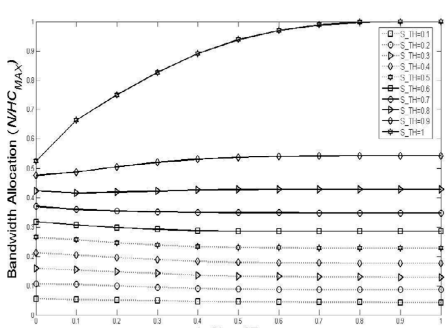

Figure 6. Average Bandwidth allocation

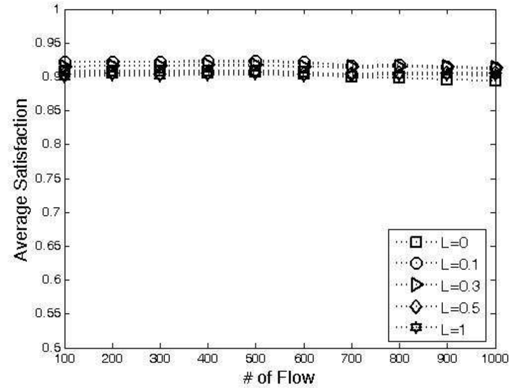

Figure 7. Average Satisfaction with *S_TH=0.9*

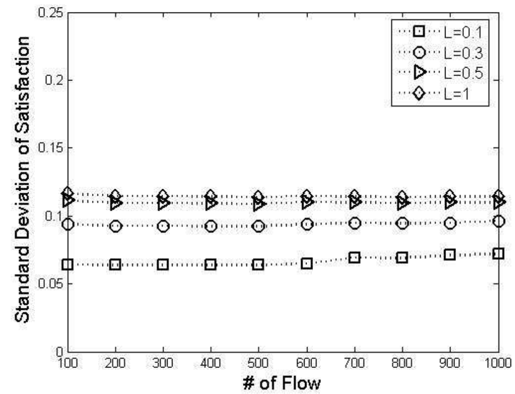

Figure 8. Standard Deviation of Satisfaction with *S_TH=0.9*

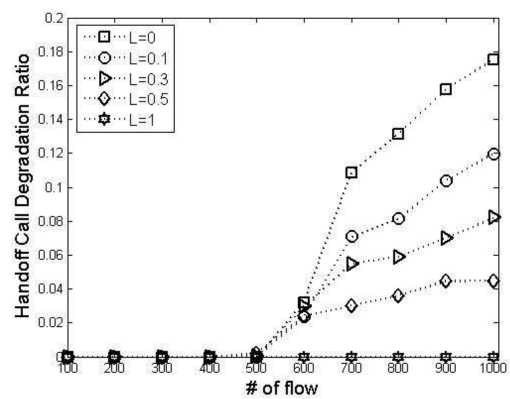

Figure 9. Handoff Call Dropping Probability with *S_TH=0.9*

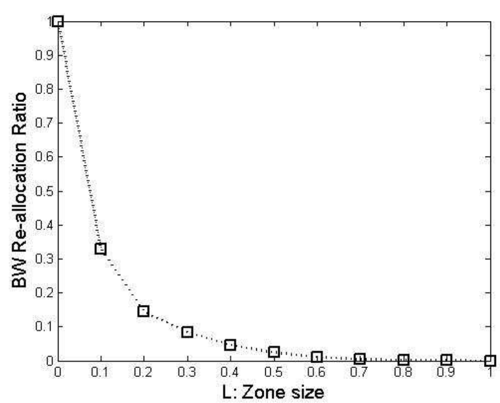

Figure 10. Bandwidth Re-allocation Ratio