Location Management Area (LMA)-based MBS Handover in Mobile WiMAX Systems

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***Abstract*—Mobile WiMAX aims to provide multimedia multicast/broadcast service (MBS) as well as elastic data service. However, supporting delay sensitive applications like video/audio streaming is still challenging, which requires both efficient handling of link bandwidth and reducing handover delays. To reduce the handover delay in MBS, the IEEE 802.16e standard defines an MBS zone, which is a group of base stations transmitting the same multicast packets. This delay reduction comes at the cost of the high MBS traffic load on Mobile WiMAX networks. In this paper, we propose a location management area (LMA)-based MBS handover, dealing with both the bandwidth usage and service disruption. We develop an analytical model to quantify the handover delay and wireless bandwidth usage. Numerical results reveal that the LMA-based handover scheme achieves bandwidth efficient multicast delivery with a slight increase of the average service disruption.**

I. INTRODUCTION

Recently, a bandwidth-richer fixed wireless network has been specified in IEEE 802.16, which is extended to support mobility, sleep/idle mode, and multicast/broadcast service (MBS) by IEEE 802.16e [1]. As these specifications deal with only the air interface, another industrial forum was launched to promote 802.16-based network deployment and to facilitate service environments, Worldwide Interoperability for Microwave Access (WiMAX). Mobile WiMAX aims at the convergence of mobile and fixed broadband access environments through a flexible network architecture [2]. In particular, Mobile WiMAX is now defining an MBS architecture and its component protocols.

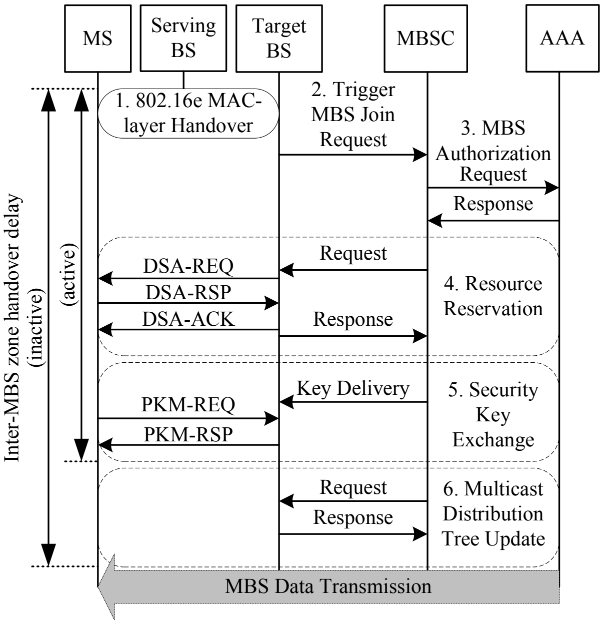
One crucial issue in the MBS architecture is to provide multimedia streaming despite mobility. Mobile WiMAX (or IEEE 802.16e) normally performs hard handovers which break all connections to the serving BS before making new connections to the target BS. As a result, packets on the fly which are to be sent through the serving BS may not be delivered to the MS during the handover process, which is so-called "service disruption". In the case of unicast traffic, packets can be cached and forwarded from the serving BS to the target BS. However, multicast or broadcast packets cannot rely on such techniques since they are destined for multiple receivers and often delay-sensitive. Therefore, the handover delay in MBS should be minimized, so that the disruption in the meantime can be ignorable or tolerable to MSs.

To reduce the handover delay in MBS, the IEEE 802.16e standard defines an MBS zone [1], which is a group of adjacent BSs transmitting the same MBS content such as a video or audio stream. In case of the handover between BSs in the same MBS zone, the handover delay is minimized because the packets of the same MBS content can be received from the target BS right after completing a link-level handover. On the contrary, the handover among BSs crossing the boundary between different MBS zones requires not only link-level handover signaling but also MBS-related signaling, which will take considerable time. Obviously, the larger an MBS zone is, the better quality of MBS will be provided assuming the same level of mobility. However, the handover delay cutback comes at the cost of the amplified MBS traffic, which may waste the link capacity of the air interface because all the BSs in the same MBS zone should broadcast the same MBS packets regardless of the existence of an MBS user. It means that the BSs that do not have a user for a particular MBS content should still transmit the MBS packets because they belong to the same MBS zone. In short, the handover delay and wireless bandwidth usage are two conflicting criteria in MBS services.

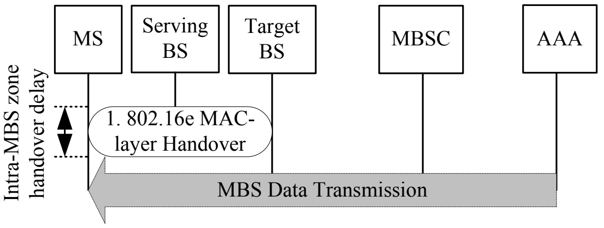
In this paper, we propose a location area management (LMA)-based MBS handover, where an MBS zone is partitioned into multiple LMAs and then packets are transmitted only to the LMAs with MBS users. We evaluate the LMA-based MBS handover in terms of the service disruption time of an MBS session due to handovers and its bandwidth usage considering the user distribution and MBS session popularity. The rest of this paper is organized as follows. The Mobile WiMAX network model and MBS handovers are described in Section II. Section III presents the LMA-based MBS handover and Section IV analyzes the handover delay and bandwidth usage. Section V shows the numerical results and Section VI concludes this paper.

II. MBS HANDOVER IN MOBILE WIMAX SYSTEMS

Mobile WiMAX consists of three logical entities: mobile station (MS), access service network (ASN), and connectivity service network (CSN) [2]. The BS performs radio-related functions, which is located in the ASN. The CSN provides IP connectivity services to MSs and performs administrative functions such as authentication, authorization, and accounting (AAA), and admission control for WiMAX operators. To provide MBS, a new functional entity, multicast and broadcast service controller (MBSC), is introduced, which is typically



(a) Inter-MBS zone handover



(b) Intra-MBS zone handover

Fig. 1. MBS zone handover.

located in the CSN. An MBS session refers to a single logical multicast connection established between the MSs and the MBSC. The MBSC performs service provisioning and delivery functions for MBS and serves as an entry point for multimedia contents providers. That is, when a multimedia stream is ready, the MBSC initiates the corresponding MBS session by performing resource reservation for data path and then forwards the multimedia stream over the WiMAX network.

The handover delay of an MBS session includes two types of delay: 1) the delay due to the link level messages during the IEEE 802.16e handover; and 2) the delay due to the MBS signaling messages. The former occurs whenever an MS with an ongoing MBS session switches to the new BS. Fig. 1(a) depicts how the MBS signaling messages are exchanged after the MAC layer handover. As IEEE 802.16 is connection-oriented, every connection between a BS and an MS has its own connection identifier (CID). To facilitate MBS, all BSs in the same MBS zone have the same multicast connection identifier (MCID) and the same security key for MBS data packets. In other words, whenever an MS moves from one MBS zone to another (i.e., *inter-MBS zone handover*), a new connection is needed, which is triggered by MBS join, Step 2 in Fig. 1(a). After the MBS authorization procedure (Step 3) is done, the resource reservation (Step 4), security key exchange (Step 5), and multicast distribution tree update (Step 6) for the new connection will be performed. On the other hand, if the MS moves from one BS to another within the same MBS zone (i.e., *intra-MBS zone handover*), no further processing is required except for the IEEE 802.16e MAC-layer handover (Step 1), as shown in Fig. 1(b).

In case of the inter-MBS zone handover, the multicast distribution tree update (Step 6) may not be necessary depending on the existence of users of the same MBS session in the target MBS zone. MBS zones in which MBS users currently reside are called *active* MBS zones, whereas others in which no users for the MBS session reside are called *inactive* MBS zones. If an MS enters a new MBS zone which is inactive, the MS will be the first user in the MBS zone. Then, the signaling messages of Steps 4-6 should be exchanged with all the other BSs in the MBS zone as well as the target BS. On the other hand, if the target MBS zone is active (i.e., there is already an MBS user receiving the same multicast packets), the multicast distribution tree update is not needed.

III. LMA-BASED MBS HANDOVER

To meet quality of service (QoS) requirements in real-time multimedia services, it is critical to reduce the MBS handover delay. To this end, the inter-MBS zone handover should be avoided as much as possible by planning the MBS zone appropriately. To make the best use of the intra-MBS zone handover, the MBS zone should be designed as large as possible. However, as the size of an MBS zone increases, the number of BSs which have no user but send multicast packets may increase. Accordingly, the waste of wireless link bandwidth increases.

In this paper, we propose that an MBS zone is partitioned into multiple location management areas (LMAs) and then MBS data packets are transmitted only to the LMAs in which MBS users currently reside. An LMA is a set of geographically adjacent BSs. Typically, an LMA is larger than a single BS, and smaller than a whole MBS zone.

Managing MBS users in each LMA is embodied by the current standard WiMAX framework on location management. In IEEE 802.16e, a paging group [1] which is a specified set of adjacent cells is used to track the locations of MSs. A paging controller (PC) manages the up-to-date information as to which MSs are located in which paging groups.

The location of an MS in normal mode is tracked by the PC at the level of BSs. Whenever the IEEE 802.16 MAC-layer handover is performed, the target BS reports this event to the PC. Thus, the PC keeps track of the current BS and the current PG of an MS in normal mode. On the other hand, the location of an MS in idle mode[1] is handled at the more coarse level. Each time an MS in idle mode crosses a paging group boundary, it informs the PC of the new paging group.

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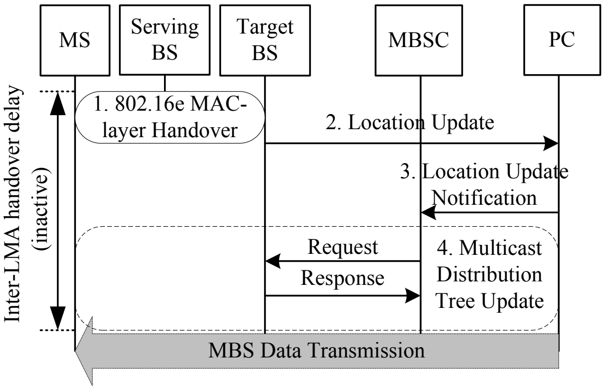
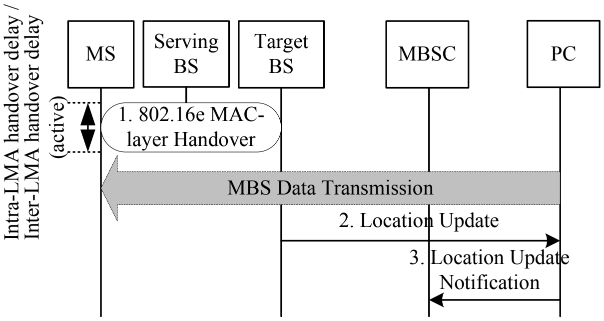
[1] This mode is defined in IEEE 802.16e to conserve power and network resources. An MS in idle mode performs no handover when it crosses the cell boundary but can receive MBS packets [1].



(a) Inter-LMA handover to an inactive LMA



(b) Inter-LMA handover to an active LMA and intra-LMA handover

Fig. 2. LMA-based handover.

Hence, the PC keeps track of the current PG of an MS in idle mode. Since the MBSC controls which LMAs will multicast packets, it is assumed to receive the location information of MBS users from the PC.

In LMA-based MBS handover, the intra-MBS zone handovers are subclassified into: intra-LMA handovers and inter-LMA handovers. The former is caused by the movement between BSs in the same LMA whereas the latter is a handover between BSs in different LMAs. Fig. 2 depicts how the signaling messages of an inter-LMA handover are exchanged. LMAs in which users of a particular MBS session currently reside are called *active* LMAs, whereas the others are called *inactive* LMAs with respect to the MBS session. The MBSC can distinguish active LMAs in an MBS zone based on the location information of MBS users. The PC maintains the up-to-date location information of an MBS user by the location update or the MAC-layer handover to the target BS (Steps 1-2). The PC informs the MBSC of the location update of an MS, so that the MBSC can decide whether the MS crosses an LMA boundary or not[2] (Step 3). If the MS moves into an inactive LMA, the multicast distribution tree update (Step 4) is performed. Otherwise (i.e., moving to an active LMA), Step 4 is not needed since all the BSs in the target LMA are already transmitting MBS packets. In other words, the packets can be received right after completing the MAC-layer handover. Hence, time for Steps 2 and 3 does not constitute the handover delay. Therefore, the delay of an inter-LMA handover moving to an active LMA is the time to finish Step 1 only.

The delay of the intra-LMA handover is equivalent to that of the intra-MBS zone handover, as shown in Fig. 2(b). As similar to the inter-LMA handover moving to an active LMA, Steps 2 and 3 in Fig. 2(b) can be performed, which does not affect MBS packets reception delay.

IV. PERFORMANCE ANALYSIS

In this section, we analyze the total disruption time during an MBS session both in the original MBS zones (dubbed MZ) and the LMA-based MBS zones (dubbed LMA), which considers the MBS user distribution and mobility. In addition, the MBS session popularity is taken into account. We have the following assumptions and notations for the performance comparison.

- The MBS session duration time follows an exponential distribution with mean $1/\lambda_s$.
- The residence times in an MBS zone, an LMA, and a cell follow exponential distributions with mean $1/\lambda_z$, $1/\lambda_l$, and $1/\lambda_c$, respectively ($1/\lambda_z \geq 1/\lambda_l \geq 1/\lambda_c$).
- Let S be the total number of MBS sessions on the air. All sessions are ranked depending on their popularity. Let β_i be the conditional probability that the arriving request is made for i-th rank session for a given join request ($i = 1, 2, ..., S$). Then, β_i is drawn from a cut-off Zipf-like distribution [4], and is given by

$$\beta_i = \frac{\Omega}{i^\alpha}, \qquad \text{where } \Omega = \left(\sum_{i=1}^{S} \frac{1}{i^\alpha} \right)^{-1}, \quad 0 < \alpha < 1. \tag{1}$$

- The user spatial distribution follows a two-dimensional Poisson distribution with net rate λ^*, which is defined as the average number of users per unit area. From (1), the average number of users per unit area for the i-th popular session is

$$\lambda_i = \beta_i \lambda^*. \tag{2}$$

- Let Z, L and C be the random variables for the numbers of MBS zone crossings (i.e., inter-MBS zone handovers) per session, LMA crossings (i.e., inter-LMA handovers) per session, and cell crossings (i.e., the total number of handovers) per session, respectively.

A. Disruption Time in MZ

Let Z_1 and Z_2 be the numbers of inter-MBS zone handovers to inactive MBS zones and to active MBS zones, respectively. In addition, let Z_3 be the number of intra-MBS zone handovers. Then, $E[Z] = E[Z_1] + E[Z_2]$ and $E[C] = E[Z] + E[Z_3]$. The average service disruption time for an i-th popular session in MZ can be obtained from

$$T_{MZ,i} = E[Z_{1,i}] \cdot D_{Z1} + E[Z_{2,i}] \cdot D_{Z2} + E[Z_{3,i}] \cdot D_{Z3} \tag{3}$$

where D_{Z1}, D_{Z2}, and D_{Z3} are unit handover delays of the inter-MBS zone to an inactive MBS zone, inter-MBS

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[2] An LMA may be typically equal to a paging group or multiple paging groups, but it is not a requirement.

zone handover to an active MBS zone, and intra-MBS zone handover, respectively.

Let t_s, t_z, and t_c be the random variables for the session duration time, MBS zone residence time, and cell residence time, respectively. Then, the MBS zone crossing probability per session, P_Z, and the cell crossing probability per session, P_C, can be computed as [5]

$$P_Z = \Pr(t_s > t_z) = \frac{\lambda_z}{\lambda_z + \lambda_s} \tag{4}$$

and

$$P_C = \Pr(t_s > t_c) = \frac{\lambda_c}{\lambda_c + \lambda_s}. \tag{5}$$

Then, the probability mass functions of Z and C are derived using (4) and (5), and they are respectively given by [5]

$$\Pr(Z = n) = P_Z^n \cdot (1 - P_Z) \tag{6}$$

and

$$\Pr(C = n) = P_C^n \cdot (1 - P_C). \tag{7}$$

Let $p(k, i, R)$ denote the probability that there are k users subscribing the i-th popular session in an area A. We have

$$p(k, i, A) = \frac{(\lambda_i A)^k e^{-\lambda_i A}}{k!}. \tag{8}$$

Then, the probability that there is no user subscribing the ith most popular session in an MBS zone with area A_z is given by

$$p\left(0, i, A_z\right) = e^{-\lambda_i A_z}. \tag{9}$$

Let $\Pr(Z_1 = j|Z = n)$ be the conditional probability that there are n inter-MBS zone handovers, among which j handovers are for inactive MBS zones. Then, $\Pr(Z_1 = j|Z = n)$ follows a Bernoulli distribution and it is computed as

$$\Pr(Z_1 = j|Z = n) = \binom{n}{j} \left[p\left(0, i, A_z\right)\right]^j \left[1 - p\left(0, i, A_z\right)\right]^{n-j}. \tag{10}$$

From (4), (6), (9), and (10), the average number of inter-MBS zone handovers to inactive MBS zones for session i (i.e., $E[Z_{1,i}]$) can be reduced as

$$\begin{aligned} E[Z_{1,i}] &= \sum_{n=0}^{\infty}\sum_{j=0}^{n} j \cdot \Pr(Z_1 = j|Z = n) \cdot \Pr(Z = n) \\ &= \frac{\lambda_z}{\lambda_s} e^{-\lambda_i A_z}. \end{aligned} \tag{11}$$

Similarly, the average number of inter-MBS zone handovers to active MBS zones (i.e., $E[Z_{2,i}]$) can be computed as

$$\begin{aligned} E[Z_{2,i}] &= \sum_{n=0}^{\infty}\sum_{j=0}^{n} j \cdot \Pr(Z_2 = j|Z = n) \cdot \Pr(Z = n) \\ &= \frac{\lambda_z}{\lambda_s}\left(1 - e^{-\lambda_i A_z}\right). \end{aligned} \tag{12}$$

On the other hand, from (5) and (7), the average number of cell crossings is given by

$$E[C] = \sum_{n=0}^{\infty} n \cdot {P_C}^n (1 - P_C) = \frac{\lambda_c}{\lambda_s} \tag{13}$$

Then, since $E[Z_3] = E[C] - E[Z]$ and $E[Z] = E[Z_1] + E[Z_2]$, the average number of intra-MBS zone handovers (i.e., $E[Z_{3,i}]$) is given by

$$E[Z_{3,i}] = \frac{\lambda_c - \lambda_z}{\lambda_s}. \tag{14}$$

Using (3), (11), (12), and (14), we have

$$\begin{aligned} T_{MZ,i} &= \frac{\lambda_z}{\lambda_s}\left[e^{-\lambda_i A_z} \cdot D_{Z1} + \left(1 - e^{-\lambda_i A_z}\right) \cdot D_{Z2}\right] \\ &+ \frac{(\lambda_c - \lambda_z)}{\lambda_s} \cdot D_{Z3}. \end{aligned} \tag{15}$$

B. Disruption Time in LMA

Let L_1 and L_2 be the numbers of inter-LMA handovers to inactive LMAs and to active LMAs without changing MBS zones, respectively. Let L_3 be the number of intra-LMA handovers. Since both the inter-LMA handovers and intra-LMA handovers belong to the intra-MBS zone handovers, we have $E[Z_3] = E[L_1] + E[L_2] + E[L_3]$. From (3), the average service disruption time for an i-th popular session in LMA can be expressed as

$$\begin{aligned} T_{LMA,i} &= E[Z_{1,i}] \cdot D_{Z1} + E[Z_{2,i}] \cdot D_{Z2} + E[L_{1,i}] \cdot D_{L1} \\ &+ E[L_{2,i}] \cdot D_{L2} + E[L_{3,i}] \cdot D_{L3} \end{aligned} \tag{16}$$

where D_{L1}, D_{L2}, and D_{L3} are unit handover delays of the inter-LMA handover to an inactive LMA, inter-LMA handover to an active LMA, and intra-LMA handover, respectively.

Recall that L is the random variable for the number of LMA crossings, which is equal to $E[Z] + E[L_1] + E[L_2]$. By similar derivations in (4) and (5), the LMA crossing probability per session P_L is given by $\frac{\lambda_l}{\lambda_l + \lambda_s}$. In addition, the probability mass function of L can be obtained from $\Pr(L = n) = P_L^n \cdot (1 - P_L)$. Then, the average number of LMA crossings is given by $E[L] = \sum_{n=0}^{\infty} n \cdot {P_L}^n (1 - P_L) = \frac{\lambda_l}{\lambda_s}$. Since $E[L_1] + E[L_2] = E[L] - E[Z]$, the average number of inter-LMA handovers without changing MBS zones is given by $E[L] - E[Z] = \frac{\lambda_l - \lambda_z}{\lambda_s}$. On the other hand, the probability that there is no user for session i in an LMA with area A_l is $p\left(0, i, A_l\right) = e^{-\lambda_i A_l}$. Finally, $E[L_{1,i}]$, $E[L_{2,i}]$, and $E[L_{3,i}]$ are derived as follows:

$$\begin{aligned} E[L_{1,i}] &= (E[L] - E[Z]) \cdot p\left(0, i, A_l\right) \\ &= \frac{(\lambda_l - \lambda_z)}{\lambda_s} e^{-\lambda_i A_l} \end{aligned} \tag{17}$$

$$\begin{aligned} E[L_{2,i}] &= (E[L] - E[Z]) \cdot \left(1 - p\left(0, i, A_l\right)\right) \\ &= \frac{(\lambda_l - \lambda_z)}{\lambda_s}\left(1 - e^{-\lambda_i A_l}\right) \end{aligned} \tag{18}$$

$$E[L_{3,i}] = \frac{\lambda_c - \lambda_l}{\lambda_s}. \tag{19}$$

TABLE I
PARAMETER VALUES USED IN NUMERICAL ANALYSIS

Unit Transmission Delay (ms)					Mac-layer Handover Delay (ms)
T_{BS-MS}	$T_{BS-MBSC}$	T_{BS-PC}	$T_{MBSC-AAA}$	$T_{MBSC-PC}$	T_{ho}
5	5	5	5	5	50

Unit Processing Delay (ms)						
P_{auth}	P_{conn}	P_{key}	$P_{mu(MBSC)}$	$P_{mu(BS)}$	$P_{lu(MBSC)}$	$P_{lu(PC)}$
1	1	1	1	1	1	1

Using (11), (12), (16), (17), (18), and (19), we have

$$\begin{aligned} D_{LMA,i} &= \frac{\lambda_z}{\lambda_s}\left[e^{-\lambda_i A_z}\cdot D_{Z1} + \left(1-e^{-\lambda_i A_z}\right)\cdot D_{Z2}\right] \\ &+ \frac{(\lambda_l-\lambda_z)}{\lambda_s}\left[e^{-\lambda_i A_l}\cdot D_{L1} + \left(1-e^{-\lambda_i A_l}\right)\cdot D_{L2}\right] \\ &+ \frac{(\lambda_c-\lambda_l)}{\lambda_s}\cdot D_{L3}. \end{aligned} \tag{20}$$

V. NUMERICAL RESULTS

In this section, we analyze the performance improvement of LMA compared to MZ in terms of the service disruption time and wireless link bandwidth usage. We have the following notations.

- T_{A-B}: The average time required to send a message between nodes A and B.
- T_{ho}: The average time required to complete an IEEE 802.16e MAC-layer handover.
- P_{auth}: The average processing time to perform the MBS Authorization at AAA.
- P_{conn}: The average processing time to establish a multicast connection at MS.
- P_{key}: The average processing time to set up a security key at MS.
- $P_{mu(A)}$: The average processing time to perform a multicast distribution update at node A.
- $P_{lu(A)}$: The average processing time to perform a location update at node A.

Table I lists parameter values for transmission and processing delays. Since Mobile WiMAX mostly uses a 5-ms time division duplex (TDD) frame [3], T_{BS-MS} is set to 5 ms. In addition, $T_{BS-MBSC}$, T_{BS-PC}, $T_{MBSC-AAA}$, and $T_{MBSC-PC}$ set to 5 ms. The service disruption time during an IEEE 802.16e MAC-layer handover is reported to be between 4 to 20 TDD frames depending on physical parameters and the level of handover process optimization [1]. We assume that T_{ho} is 50 ms and all processing delays are set to 1 ms, which is typical in the literature [6]. Using these values, we can derive the delays of the MBS handover types from the message flows in Figs. 1 and 2, as functions of transmission and processing delays. D_{Z1}, D_{Z2}, D_{Z3} are summarized in Table II, and D_{L1}, D_{L2}, D_{L3} are summarized in Table III.

TABLE II
THE DELAYS OF INTER/INTRA-MBS ZONE HANDOVERS

Delay		Expression
Type	Step	
D_{Z1}	1	T_{ho}
	2	$T_{BS-MBSC}$
	3	$2T_{MBSC-AAA} + P_{auth}$
	4	$2T_{BS-MBSC} + 2T_{BS-MS} + P_{conn}$
	5	$T_{BS-MBSC} + 2T_{BS-MS} + P_{key}$
	6	$2T_{BS-MBSC} + P_{mu(MBSC)} + P_{mu(BS)}$
D_{Z2}	1	T_{ho}
	2	$T_{BS-MBSC}$
	3	$2T_{MBSC-AAA} + P_{auth}$
	4	$2T_{BS-MBSC} + 2T_{BS-MS} + P_{conn}$
	5	$T_{BS-MBSC} + 2T_{BS-MS} + P_{key}$
D_{Z3}	1	T_{ho}

TABLE III
THE DELAYS OF INTER/INTRA-LMA HANDOVERS

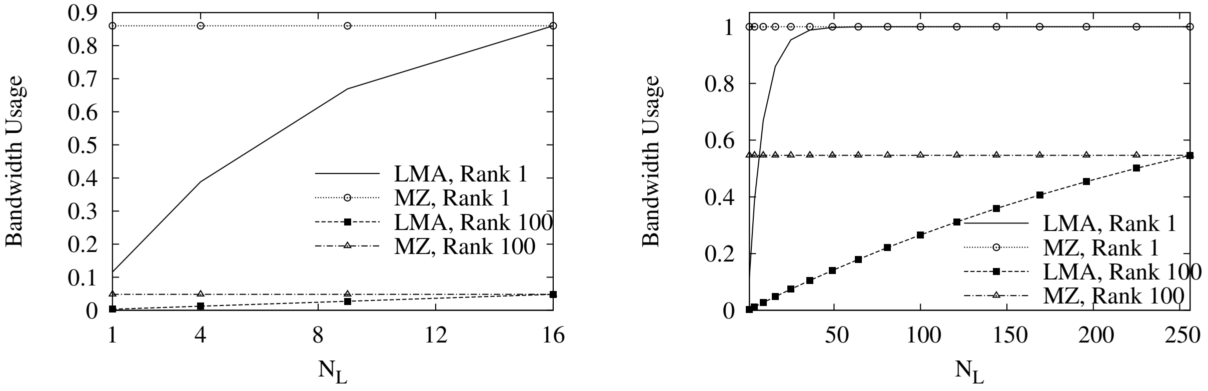
Delay		Expression
Type	Step	
D_{L1}	1	T_{ho}
	2	$T_{BS-PC} + P_{lu(PC)}$
	3	$T_{MBSC-PC} + P_{lu(MBSC)}$
	4	$2T_{BS-MBSC} + P_{mu(MBSC)} + P_{mu(BS)}$
D_{L2}	1	T_{ho}
D_{L3}	1	T_{ho}

For the sake of simplicity, we suppose that MBS zones, LMAs, and cells are square-shaped where there are N_Z cells in an MBS zone and N_L cells in an LMA. Then, by the fluid flow mobility model [7], the cell boundary crossing rate can be expressed as $\lambda_c = (16v)/(\pi l)$, where v is the average velocity of MSs and l is the perimeter of a cell. In addition, λ_z and λ_l can be approximated to $\lambda_c/\sqrt{N_Z}$ and $\lambda_c/\sqrt{N_L}$, respectively [7]. The average session duration time, $1/\lambda_s$ is set to 60 minutes, and the total number of MBS sessions, S is set to 100.

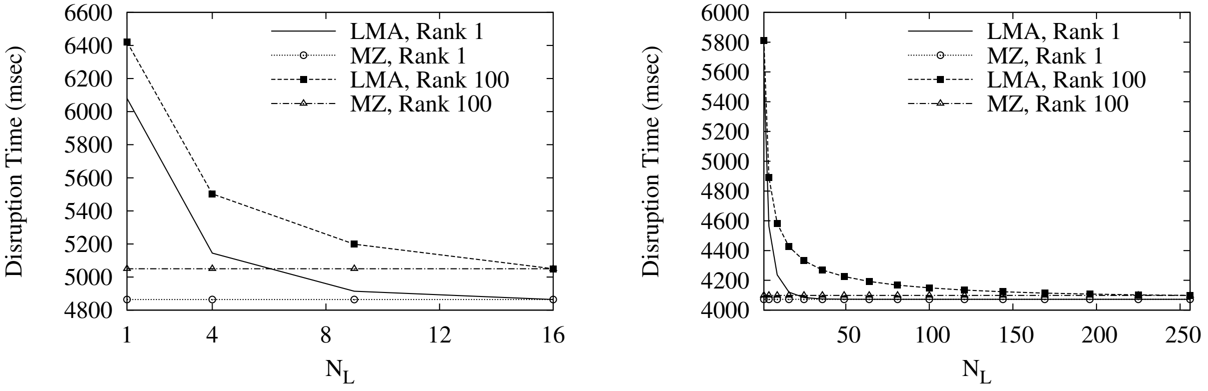
A. *Effect of N_Z and N_L*

The wireless link bandwidth usage is defined as the ratio of the number of cells transmitting multicast packets of an MBS session to the total number of cells in the network. Let $U_{MZ,i}$ and $U_{LMA,i}$ be the bandwidth usages in MZ and LMA, respectively. Then, $U_{MZ,i}$ and $U_{LMA,i}$ can be expressed as $U_{MZ,i} = (1 - p(0,i,A_z))$ and $U_{LMA,i} = (1 - p(0,i,A_l))$, respectively.

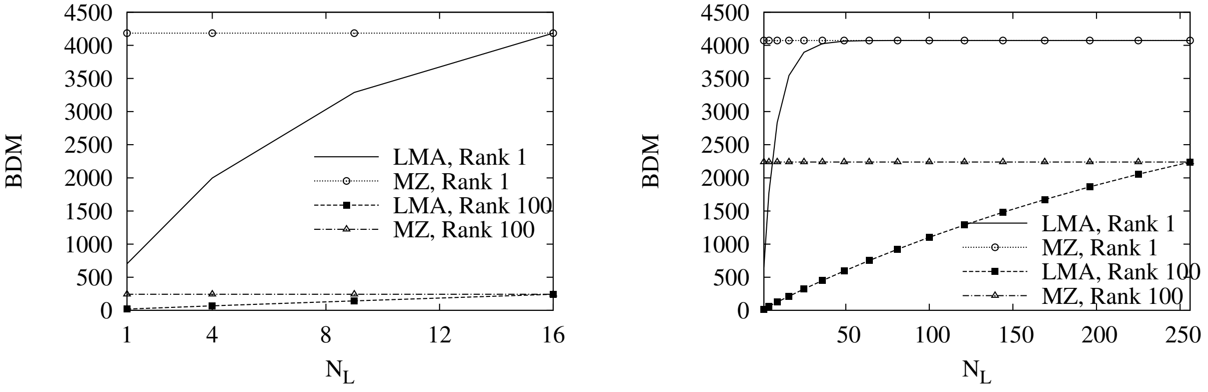
Figs. 3(a) and 3(b) show $U_{MZ,1}$, $U_{LMA,1}$, $U_{MZ,100}$, and $U_{LMA,100}$ as a function of N_L. It can be seen that $U_{LMA,1}$ and $U_{LMA,100}$ increase as N_L increases and become equal to $U_{MZ,1}$ and $U_{MZ,100}$ when N_L reaches N_Z, respectively. This implies that the small-sized LMA outperforms MZ in terms of the bandwidth usage. Obviously, the higher rank session consumes more bandwidth than the lower rank session. In addition, a small value of N_Z saves more bandwidth than a large value of N_Z; $U_{MZ,1}$, $U_{LMA,1}$, $U_{MZ,100}$, and $U_{LMA,100}$ in Fig. 3(a) are always lower than those in Fig. 3(b) for every N_L. In particular, $U_{LMA,1}$ significantly outperforms $U_{MZ,1}$



(a) Bandwidth usage (N_Z=16) (b) Bandwidth usage (N_Z=256)



(c) Disruption time (N_Z=16) (d) Disruption time (N_Z=256)



(e) BDM (N_Z=16) (f) BDM (N_Z=256)

Fig. 3. Effect of N_Z and N_L (α=0.8, λ^*=1 user/cell, and v=60 km/h).

in Fig. 3(a), while $U_{LMA,100}$ and $U_{MZ,100}$ have comparable performance. On the other hand, $U_{LMA,100}$ significantly outperforms $U_{MZ,100}$ in Fig. 3(b), while $U_{LMA,1}$ and $U_{MZ,1}$ have similar performance. To conclude, the bandwidth usage is generally reduced as both N_Z and N_L decrease. Furthermore, the bandwidth usage of LMA is more reduced for the higher rank session with small values of N_Z, and for the lower rank session with large values of N_Z.

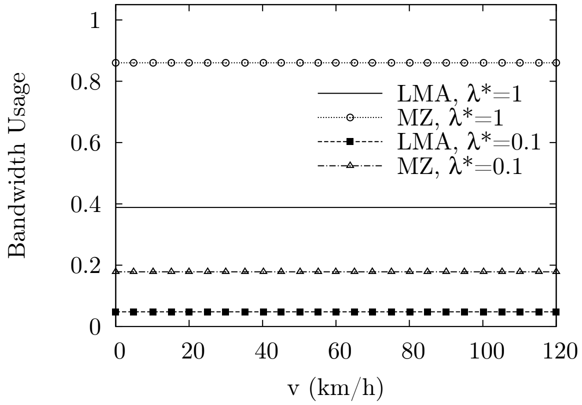
Figs. 3(c) and 3(d) show the $T_{MZ,1}$, $T_{LMA,1}$, $T_{MZ,100}$, and $T_{LMA,100}$ as a function of N_L. It can be shown that MZ outperforms LMA in terms of the disruption time. As N_L decreases, the average disruption time increases. That is because the number of crossing LMAs during a session for small LMAs increases. For the smallest LMA (N_L=1), $T_{LMA,1}$ and $T_{LMA,100}$ increase up to 25% and 27% compared to those of MZ in Fig. 3(c), and up to 37% and 42% in Fig. 3(d), respectively. As N_L increases, the disruption time of LMA approaches that of MZ. Additionally, the disruption time of the higher rank session is shorter than that of the lower rank session, and it also decreases as N_Z increases.

To consider both the bandwidth usage and service disruption time jointly, we define a new metric, bandwidth delay metric (BDM), which is the product of the bandwidth usage and the average disruption time during an MBS session and is expressed as $BDM_{MZ,i} = U_{MZ,i} \times T_{MZ,i}$ and $BDM_{LMA,i} = U_{LMA,i} \times T_{LMA,i}$. Figs. 3(e) and 3(f) show $BDM_{MZ,1}$, $BDM_{LMA,1}$, $BDM_{MZ,100}$, and $BDM_{LMA,100}$ as a function of N_L. It can be found that LMA generally exhibits the lower BDM than MZ. This is because the impact of reducing bandwidth usage is greater than that of increasing delay, which is highlighted when N_L becomes smaller.

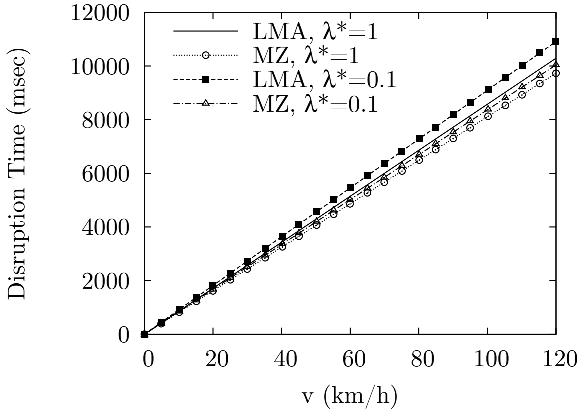
B. *Effect of* v

Fig. 4 shows the bandwidth usage and average service disruption time of the most popular session (i.e., i=1). Since the bandwidth usage is dependent on not v but user distribution (λ^* users/cell), Fig. 4(a) shows that the bandwidth usage with the larger population (λ^*=1) is greater than that with the smaller population (λ^*=0.1). It can be shown that $U_{LMA,1}$ is about 45% of $U_{MZ,1}$ for λ^*=1 and 27% of $U_{MZ,1}$ for λ^*=0.1.

Fig. 4(b) shows that the disruption time of the most popular session linearly increases as v increases. This is because the higher average velocity of users implies that the more frequent handovers are expected during the session. In contrast to bandwidth usage, the disruption time of LMA is slightly worse than that of MZ; The delay increases of $T_{LMA,1}$ over $T_{MZ,1}$ for λ^*=1 and λ^*=0.1 are 6% and 9%, respectively. Moreover, $T_{MZ,1}$ and $T_{LMA,1}$ with the larger population (λ^*=1) are shorter than those with the smaller population (λ^*=0.1), since an MBS user is more likely to perform a handover to active MBS zones and LMAs, respectively.



(a) Bandwidth usage



(b) Disruption time

Fig. 4. Effect of v (N_Z=16, N_L=4, α=0.8, and i=1).

VI. CONCLUSION

In this paper, we proposed LMA-based MBS handover and evaluated its performance in terms of both the bandwidth usage and disruption time. The numerical results reveal that LMA reduces substantially the bandwidth usage compared to MZ, while the service disruption time increases slightly. The performance gain of LMA is increased as the rank of an MBS session becomes higher when MBS zones are small. For large MBS zones, the lower rank session highlights the advantages of LMA compared to MZ. In the future work, we will investigate the optimal LMA and MBS zone planning for satisfying delay and bandwidth usage requirements.

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