HSMM: Hierarchical Synchronized Multimedia Multicast for Heterogeneous Mobile Networks

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Abstract—**For supporting handoff mobile users on heterogeneous wireless networks to synchronously receive and play out multicast multimedia stream data, we propose a two-layer Hierarchical Synchronized Multimedia Multicast (HSMM) architecture to enhance the single-layer Synchronized Multimedia Multicast (SMM) [1]. In HSMM, each wireless network operator can adapt its own management mechanism, such as routing protocol, access control, etc., and further define the range of Guarantee Region (GR) to satisfy different management requirements. Compared to SMM and the traditional Remote Subscription (RS) protocol, HSMM will significantly reduce total amounts of synchronization buffer of foreign agents, join latency and buffer replenishment time of mobile users, and finally achieve a better playback quality.**

Keywords: Sychronized Multimedia Multicast, SMM, HSMM, Herterogeneous wireless networks

I. INTRODUCTION

In recent years, different kinds of wireless networks such as WLAN, GSM, GPRS, 3G cellular network are proliferated for public use, which is gradually formed a heterogeneous wireless environment. It is claimed that the 4G network [8] will build an integrated network among backbone Internet and these different wireless networks. How to support IP multicasting for mobile users in the forthcoming 4G network will be a great challenge [9]. In this paper, based on the single-layer Synchronized Mobile Multicast (SMM) scheme [1], which integrates with Mobile IP [2], CBT v2 [3] for IP Multicasting [4-5] and MPEG-4 *fine granularity scalability* (FGS) compression technique [6], we propose the two-layer *Hierarchical Synchronized Multimedia Multicast (HSMM)* scheme to achieve synchronized multimedia multicast through heterogeneous 4G networks and provide seamless playback of continuous media streams for the mobile receivers (MR) with bounded buffers and join/initial latencies in the handoff Guarantee Region (GR), even when the mobile sender (MS) and MR, hands over to wireless cells within the current multicast tree or not for infinite times, which are advantages that the traditional Home Subscription (HS) and Remote Subscription (RS) schemes [7] cannot support.

This paper is organized as follows. In section 2, the HSMM system architecture and its three operation phases are described. We analyze buffer requirements and join/initial latencies for the mobile to continuously receive multimedia data with SMM and HSMM. Simulations in section 3 exhibit that HSMM is more efficient than SMM to support continuous playback with guaranteed QoS when the MH handover between different wireless networks. Finally, section 4 concludes this paper.

II. HSMM ARCHITECTURE AND OPERATIONS

A. *HSMM Architecture*

The HSMM architecture is shown in Fig. 1. We have made following assumptions: (1) Each layer 2 wireless network can be managed by different network operator to execute SMM inside it and extend capabilities of the Gateway Router (GW) of WLAN or the GGSN of GPRS/3G to work as its layer2 Core Router (CR) which further interconnects with layer1 Internet Backbone. (2) Each GW or GGSN is a multicast-capable router (MCR). It can run as a layer 1 Foreign Agent (FA) and a layer 2 CR simultaneously. (3) End-to-end delay (EED) between layer 2 FA and MH is same. Table I lists notations used in this paper.

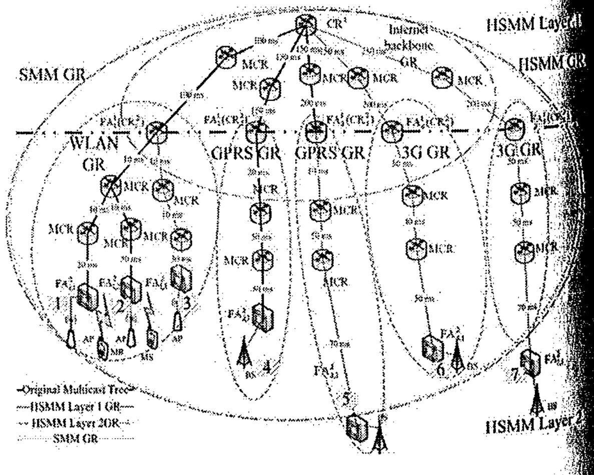

Figure 1. HSMM Architecture

TABLE I. PARAMETER NOTATIONS AND THEIR MEANINGS

Notation	Meaning
$(D^{1}_{CR\_MR})$	Maximal EED from layer 1 CR to any layer 2 MR
$(D^{2}_{CR_i\_FA_{i,j}})$	Maximal EED from layer 2 CR to FA
FA_i	The EED from layer 1 CR to FA
$FA_{i,j}$	The EED from layer 2 CR to FA
MR	The EED from layer 2 FA to MR
[illegible]	Buffer time of the core router synchronization buffer (CRSB) in layer 1 CR
[illegible]	Buffer time of the core router synchronization buffer (CRSB) in layer 2 CR
off	Delay for the MS or MR to complete its horizontal handoff operations.
ndoff	Delay for the MS or MR to complete its vertical handoff operations.
mt	Delay to modify the multicast tree for horizontal handoff of the MR.
mod_mt	Delay to modify the multicast tree when MR performs its inter-network vertical handoff, new GR in layer 1 multicast tree and new FA not in layer 2 multicast tree
mod_mt	Delay to modify the multicast tree when MR performs its inter-network vertical handoff, new GR not in layer 1 multicast tree
[illegible]	Delay to update the routing tables of all multicast routers in the multicast tree when horizontal handoff occurs.
[illegible]	Delay to update the routing tables of all multicast routers in the multicast tree when vertical handoff occurs
[illegible]	Buffer time of the FA synchronization buffer (FASB) in layer 1 FA
[illegible]	Buffer time of the FA synchronization buffer (FASB) in layer 2 FA
MR	Initial buffer time of layer 2 MR
GOP	Duration of a MPEG Group of Picture (GOP)

In the HSMM architecture, layer1 GR is defined as the range from layer1 CR, via layer1 FA, i.e., the CR^2_i of the GR^2_i, which is the GW/GGSN of layer2 wireless network *i*, to the farthest MR with maximal EED $Max(D^1_{CR\_MR})$. Similarly, each layer2 GR is defined as the range from its layer2 CR, via layer2 FA *j* of wireless network *i* ($FA^2_{i,j}$), to the farthest MR with maximal EED $Max(D^2_{CR\_MR})$. For overcoming effects of the versatile EED suffered by the MR when handing over different layer2 wireless networks, HSMM controls transmission of layer1 CR and FAs such that each layer1 FA can synchronously multicast the same multimedia data to its underlying layer2 GR, which in turn synchronously multicasts media data to all layer2 FA and finally to MRs currently inside this layer2 wireless network. In this way, all MRs can play out the same clip of media data simultaneously and continuously, no matter they perform horizontal or vertical handoff operations. Instead of adapting the original SMM on this heterogeneous wireless environment by multicasting media data from the backbone CR, i.e., layer1 CR in HSMM, to the corresponding FA of the MR, through the SMM CBT multicast tree which regards GWs and GGSNs of wireless networks as original MCRs, our 2-layer HSMM architecture has following significant merits: (1) Each layer2 network operator can define its own GR size to meet its policies. (2) Because buffer sizes of CR, FA and MR are directly proportional to the maximal EED of the GR, the HSMM can significantly reduce buffer sizes due to much smaller layer2 GRs than the single huge GR of SMM. (3) Except the first multicast group member, other members only need to join local layer2 multicast tree, which greatly reduces the MR's *join latency (JL)* to continue playback. (4) If the MR horizontally handover within the same layer2 GR, it has to replenish its buffer locally with HSMM, instead of replenishing from layer1 CR with SMM. The buffer replenishment time with HSMM is reduced significantly.

B. *HSMM Operation Phases*

HSMM is composed of Join phase, Multicast phase and Handoff phase. Details of these phases please refer to [1].

1) *Join phase*

The MR sends an *IGMP Membership Report* to its layer2 FA to join a multicast group. Whenever the FA receives IGMP Membership Report, it first checks whether other members in the same FA has joined the same multicast group. If not, it sends *CBT JOIN_REQUEST (CBT_JR)* along the shortest path to the layer2 CR. As soon as the FA receives the *CBT JOIN_ACK (CBT_JA)* from the layer2 CR or an intermediate MCR, it calculates the EED between it and its layer2 CR. At the same time if this CR has not joined layer1 multicast tree, it forward *CBT_JR* to layer1 CR and calculates the EED between it and layer1 CR. After that, the layer1 CR performs the RSVP procedure to reserve network resources on the path to this MR that has joined layer1 and 2 multicast trees.

2) *Multicast phase*

Fig. 2 illustrates the HSMM multicast flow. The MS is located within some layer2 GR and unicasts media data to its layer2 CR, then finally multicasts to all MRs through layer1 and 2 CBT multicast trees at normal playback rate of the MR.

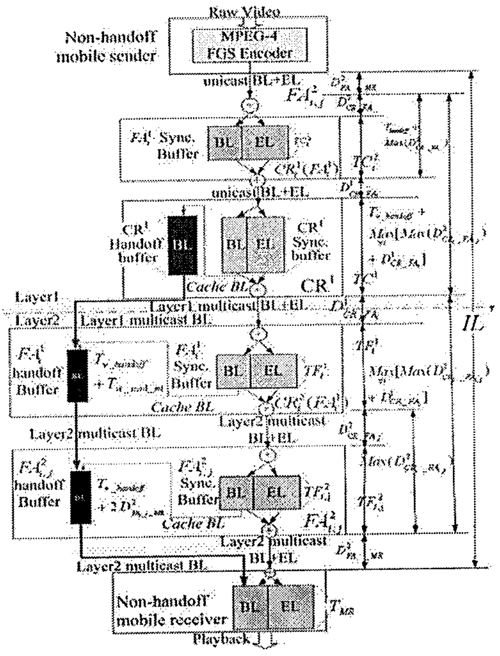

Figure 2. HSMM multicast flow

a) From the MS to the layer1 CR : To guarantee the MR can continuously receive the multimedia data as the MS handover, HSMM allocates the *CR synchronization buffer (CRSB)* in all layer1 and 2 CR to cache the initial data sent from the MS, instead of multicasting them to all MRs immediately. If the MS hands over in the same layer2 GR, the layer2 CR must cache the missed data for the duration formulated by (1). If the MS hands over across two different layer2 GRs, the layer1 CR must cache the missed data for the duration formulated by (2).

$$TC_i^2 = T_{handoff} + Max(D^2_{CR_i\_FA_{i,j}}) - D^2_{CR_i\_FA_{i,j}} \tag{1}$$

$$\begin{aligned} TC^1 = T_{v\_handoff} + \underset{\forall i}{Max}[(Max(D^2_{CR_i\_FA_{i,j}}) + D^1_{CR\_FA_i}] \\ - Max(D^2_{CR_k\_FA_{k,j}}) - D^1_{CR\_FA_k} \end{aligned} \tag{2}$$

b) From layer1 CR to FA (layer2 CR) and from layer2 CR to FA: For avoiding the playback interruption that results from different EEDs before and after the MR handover, HSMM allocates the *FA synchronization buffer (FASB)* in all layer1 FAs and layer2 FAs of the MR to cache the multicast data sent from the layer1 CR and FA (layer2 CR), respectively. The layer2 FA has to cache data for the duration calculated by (3). HSMM controls all layer2 FAs in all GRs to send media data to MRs at the same time. It is equal to the size of HSMM GR, i.e., the maximal total delays which consist of propagation delay from layer1 CR to FA and cache delay of layer1 FA which is calculated by (4), propagation delay from layer2 CR to FA and the cache delay of layer2 FA for all GR *i*.

$$TF^2_{i,j} = Max(D^2_{CR_i\_FA_{i,j}}) - D^2_{CR_i\_FA_{i,j}} \tag{3}$$

$$\begin{aligned} TF^1_i = \underset{\forall i}{Max}[(Max(D^2_{CR_i\_FA_{i,j}}) + D^1_{CR\_FA_i}] \\ - Max(D^2_{CR_i\_FA_{i,j}}) - D^1_{CR\_FA_i} \end{aligned} \tag{4}$$

3) Handoff phase

For supporting infinite times of the MS or MR handoffs, HSMM replenishes buffers with minimal extra bandwidth by employing the MPEG-4 fine granularity scalability (FGS) approach to encode the video into the *base layer (BL)* and *enhancement layer (EL)* streams. The BL can be decoded alone to show a video with the poorer quality and the EL is only used to combine with the BL to enhance the quality. There are five types of handoffs, which corresponding buffer replenishment processes are discussed below.

a) Intra-network horizontal handoff, new FA in Layer2 multicast tree: In this case, the handoff MR only connects to the new layer2 FA without modifying the multicast tree. Based on SMM, HSMM allocates the *FA handoff buffer (FAHB)* to cache one copy of the missed BL data for the duration of handoff and two times of the EED from layer2 FA to MR, as soon as the layer2 FA starts to multicast media data from the FASB to its MRs when the FASB is full. For replenishing buffers of all handoff MRs with the missed data, HSMM allocates extra (BL+EL) bandwidth for local multicasting the cached BL data in the FAHB to concatenate the BL data left in the handoff MR's buffer for the $\sum_{k=1}^{\infty}\left[\left(T_{handoff} + 2\times D^2_{FA^2_{i,j}\_MR}\right)\times Q^k\right] = \left(T_{handoff} + 2\times D^2_{FA^2_{i,j}\_MR}\right)\times \frac{Q}{1-Q}$ duration, where *Q* denotes the quotient of the BL bandwidth over the (BL+EL) one. The MR after its handoff suffers BL video quality for the $\left(T_{bandoff} + 2\times D^2_{FA^2_{i,j}\_MR}\right)\times \frac{1}{1\ \ Q}$ duration.

b) Intra-network horizontal handoff, new FA not in Layer2 multicast tree: In this case, the new layer2 FA has to join the layer2 multicast tree. Therefore, the MR must spend extra time to modify the multicast tree, which is formulated in (5). In addition, the missed data during the MR handoff cannot be replenished from the new FA such that HSMM allocates the *CR handoff buffer (CRHB)* in all layer2 CRs to cache one copy of the BL data when the layer2 CR multicasts media data to other FAs from its CRSB for the duration of handoff and modify multicast tree. As the MR's CBT_JR is reached the layer2 CR, the layer2 CR simultaneously multicasts the new media data to all FAs and multicasts the cached BL data in the CRHB to the new layer2 FAHB with the extra (BL+EL) bandwidth and immediately pipelines to the MR's buffer with local multicast bandwidth. After that, the new FA follows the operations mentioned in case *a* to replenish the MR's buffer.

$$T_{mod\_mt} = 2\times[Max(D^2_{CR_i\_FA_{i,j}}) + D^2_{FA_{i,j}\_MR}] + T_{mt} \tag{5}$$

c) Inter-network vertical handoff, new GR in Layer1 multicast tree and new FA in Layer2 multicast tree: This case is similar as case *a,* except the size of the layer2 FAHB must be able to cache one copy of the BL data for the duration of vertical handoff and two times of the EED from layer2 FA to MR and replenish the vertical handoff MR's buffer for the $\sum_{k=1}^{\infty}\left[\left(T_{v\_handoff} + 2\times D^2_{FA^2_{i,j}\_MR}\right)\times Q^k\right] = \left(T_{v\_handoff} + 2\times D^2_{FA^2_{i,j}\_MR}\right)\times \frac{Q}{1-Q}$ duration.

d) Inter-network vertical handoff, new GR in Layer1 multicast tree and new FA not in Layer2 multicast tree: This case is similar to case *b,* except that the CRHB in the new layer2 CR has to cache one copy of the BL data for the duration of handoff and modify multicast tree. At the worst case, the MR must spend extra time to modify the multicast tree, which is formulated in (6).

$$T_{vi\_mod\_mt} = 2\times \underset{\forall i}{Max}[(Max(D^2_{CR_i\_FA_{i,j}}) + D^2_{FA_{i,j}\_MR}] + T_{mt} \tag{6}$$

e) Inter-network vertical handoff, new GR not in Layer1 multicast tree: In this case, the MR has to modify the multicast trees, which is formulated in (7). In addition, the missed data during the MR handoff cannot be replenished from the new layer1 and 2 FA such that HSMM allocates the CRHB in the ayer1 CR to cache one copy of the BL data when the layer1 R multicasts media data to other layer1 FA from its CRSB duration of handoff and modify multicast tree. After the ayer1 FA has buffered for the duration, it begins to multicast media data to all layer2 FA in this new GR and caches one opy of sent data in its FAHB. As soon as layer2 FA receives cached BL data which is first from the layer1 CR to the ayer2 CR and then to it, it immediately pipelines the BL data MR's buffer with local multicast bandwidth, which is shown Fig. 3.

$$_{mod\_mt} = T_{v\_mt} + 2\times \underset{\forall i}{Max}[(Max(D^2_{CR_i\_FA_{i,j}}) + D^2_{FA_{i,j}\_MR} + D^1_{CR^1\_FA^1_i}] \tag{7}$$

When the MR suffers the case *e* handoff, the MR must wait the *Join Latency (JL)* formulated in (8), to resume eiving the media data such that HSMM must allocate buffer the MR for the T_{MR} =[($T_{v\_handoff} + T_{vo\_mod\_mt}$)+ 1GOP] ation, assuming the video player of the MR has to buffer at st one MPEG *Group of Picture (GOP)* data to decode the deo data and start the playback. As shown in Fig. 2, HSMM *itial Latency (IL)* can be calculated by (9).

$$\begin{aligned} JL &= T_{v\_handoff} + T_{vo\_mod\_mt} \\ &2\times \underset{\forall i}{Max}[(Max(D^2_{CR_i\_FA_{i,j}}) + D^2_{FA_{i,j}\_MR} + D^1_{CR^1\_FA^1_i}] + T_{v\_mt} \end{aligned} \tag{8}$$

$$\begin{aligned} IL &= T_{v\_handoff} + \underset{\forall i}{Max}[(Max(D^2_{CR_i\_FA_{i,j}}) + D^1_{CR\_FA_i}] \\ &\underset{\forall i}{Max}[(Max(D^2_{CR_i\_FA_{i,j}}) + D^1_{CR\_FA_i}] + D^2_{FA_{i,j}\_MR} + T_{MR} \\ &2\times T_{v\_handoff} + 4\times \underset{\forall i}{Max}[(Max(D^2_{CR_i\_FA_{i,j}}) + D^1_{CR\_FA_i}] \\ &3\times D^2_{FA_{i,j}\_MR} + T_{v\_mt} + 1GOP \end{aligned} \tag{9}$$

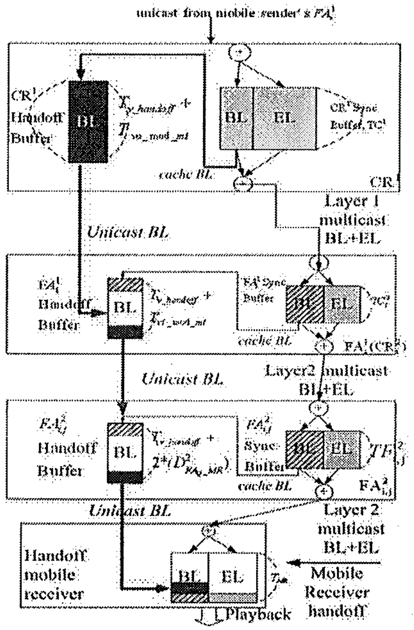

Figure 3. The buffer replenishment process when MR Inter-network vertical handoff, new GR not in Layer1 multicast tree

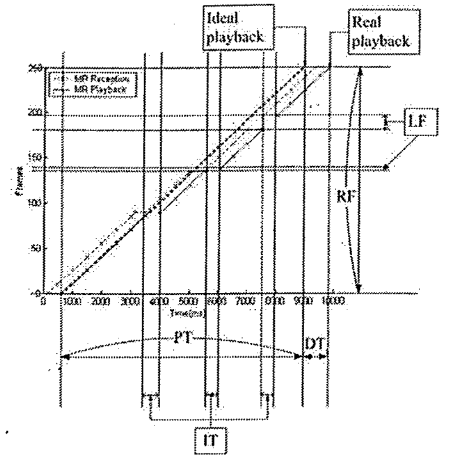

Figure 4. Relation of the MR reception and playback behavior

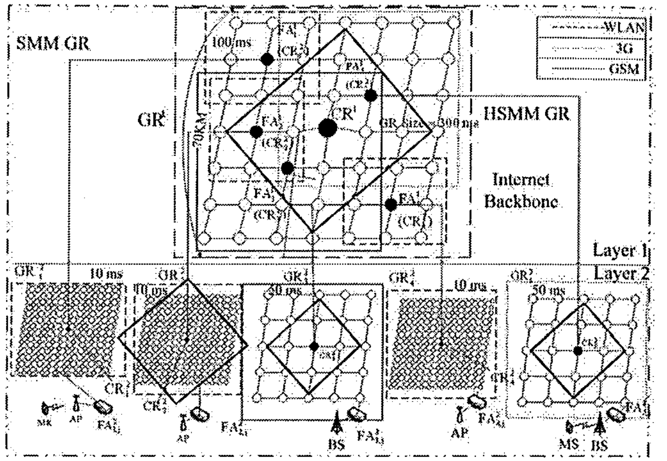

Figure 5. The heterogeneous meshed multicast environment used in simulation when the GR size is 300ms.

III. SIMULATION RESULTS

In this section, we evaluate performances of RS, SMM and HSMM in terms of three QoS parameters for a MPEG-4 FGS coded video with respect to different handoff interval times. The bandwidth requirements of the BL and the EL data are 256kbps and 768kbps such that the value of Q is equal to (256)/(256+768)=0.25. We also assume the processing and queuing delays of each node are zero. Based on the duration of common MPEG video GOP sequence *IBBPBBPBBPBBPBB*, the duration of a GOP is 500ms. According to the results in our previous work [10], relation of the MR reception and playback behaviors can be depicted by Fig. 4. In the ideal case, the multimedia data should be continuously played without any interruption after the initial latency. However, the multimedia playback in the real case may suffer from the delayed and lost frames whenever the MS or MR handover to a new cell, which in turn degrades the multimedia QoS significantly.

In this simulation, we adopt the 7x7 meshed MRTs in Fig. 5 as the layer 1 multicast backbone [11] and 15×15 WLAN, 5×5 3G and 5×5 GPRS as three types of layer 2 meshed wireless networks. We assume communication delays between two directly connected MRTs in layer 1 backbone, in layer 2 WLAN, 3G and GPRS networks are 100ms, 10ms, 50ms and 50ms, respectively. Each CR is located at the center of its mesh. GR sizes adopted in the simulation are 200, 300, 400, 500 and 600ms. GRs of layer 1 backbone and layer2 wireless networks are drawn as diamonds. As shown in Fig. 5 when the GR size is 300ms, GR sizes of layer 2 are 0ms, 100ms, 100ms, 0ms and 100ms for layer2 GR from network 1 to 5, respectively. Initially, MRs are uniformly distributed over cells that are controlled by corresponding layer 2 FAs and their MRTs. The average number of the MR per square kilometers in a cell, i.e., the *MR density*, is assumed to be 0.01, 0.07, 0.13, 0.19 and 0.25 where 0.01 and 0.25 denote each cell owns at least one MR respectively. Mobile nodes could freely move to one of the four neighboring cells of the four MRTs that are directly connected to the current MRT with equal probabilities. If the neighboring cell is not covered by the current layer 2 wireless network of the MR, the MR has to perform the inter-network vertical handoff; otherwise, it only executes the intra-network horizontal handoff. We further assume the inter-handoff time of the MS or MR is uniformly distributed with the average value as $T_{handoff}$. Besides, the simulation duration is the time for the MR to perform one hundred times of handoffs. In this paper, we define these three QoS parameters as the *average loss* ratio, the *average delay ratio* and the *average playback interruption ratio*, respectively. Legends used in simulation results are illustrated in Table II.

A. *Average frame loss ratio (ALR)*

As shown in Fig. 4, the frame loss ratio of MR_i is computed as the fraction of total lost frame (LF_i) in the real case over total playback frames (RF_i) in the ideal case. The average loss ratio is further computed by averaging loss ratios of all N MRs with (10).

$$Average\ Loss\ Ratio = \frac{1}{N} \times (\sum_{i=1}^{N} \frac{LF_i}{RF_i}) \qquad (10)$$

B. *Average frame delay ratio (ADR)*

We define the time difference between the time to play out the last frame in the ideal case and that in the real case as the real delay time (DT). The average delay ratio is computed by averaging delay ratios, i.e., the fraction of the DT over the ideal playback duration (PT), of all N MRs, which is listed in (11).

$$Average\ Delay\ Ratio = \frac{1}{N} \times (\sum_{i=1}^{N} \frac{DT_i}{PT_i}) \qquad (11)$$

C. *Average playback interruption ratio (APIR)*

This value is computed by averaging playback interruption ratios, i.e., the fraction of the total interruption time (IT) in the real case over the ideal playback time (PT) of each MR, for all N MRs. The APIR is calculated by (12). Note that the IT of an MR may be larger than its DT because the IT consists of both the delayed and lost frames.

$$Average\ Playback\ Interruption\ Ratio = \frac{1}{N} \times (\sum_{i=1}^{N} \frac{IT_i}{PT_i}) \qquad (12)$$

In Fig. 6 and 7, ALR, ADR and APIR simulation results of each scheme with different handoff times are presented. As mentioned above, packet losses would occur as the MR hands over from a cell with a larger EED to a new cell with a smaller EED. We can observe the following ALR behaviors from these results. First, with a larger MR density, initial multicast tree covers more cells, which reduces the probability of moving to a cell not in the tree and the corresponding handoff delay. Hence, ALR values of each scheme decrease as the MR density raises. Second, as the GR size grows, the MR has higher probability to handover to a new cell that is already within the GR to replenish buffers rapidly, which results in a smaller ALR. Third, HSMM achieves the smallest ALR than SMM and RS, which results from its two-layer architecture that can fast replenish buffers from layer2 CR at some handoff scenarios, instead of always replenishing them from layer1 CR with SMM. Oppositely, RS has no buffer replenishment mechanisms, which results in the highest ALR which is 5% higher than SMM200 when handoff times are 1000ms. As mentioned above, packet delays occur as the MR hand over from a cell with a smaller EED to a new cell with a larger EED. Similar to ALRs, ADRs also decrease as the MR density raises. Under same simulation parameters, HSMM also achieves the smallest ADR than SMM and RS due to its fast replenishment process with layer2 CR at some handoff scenarios.

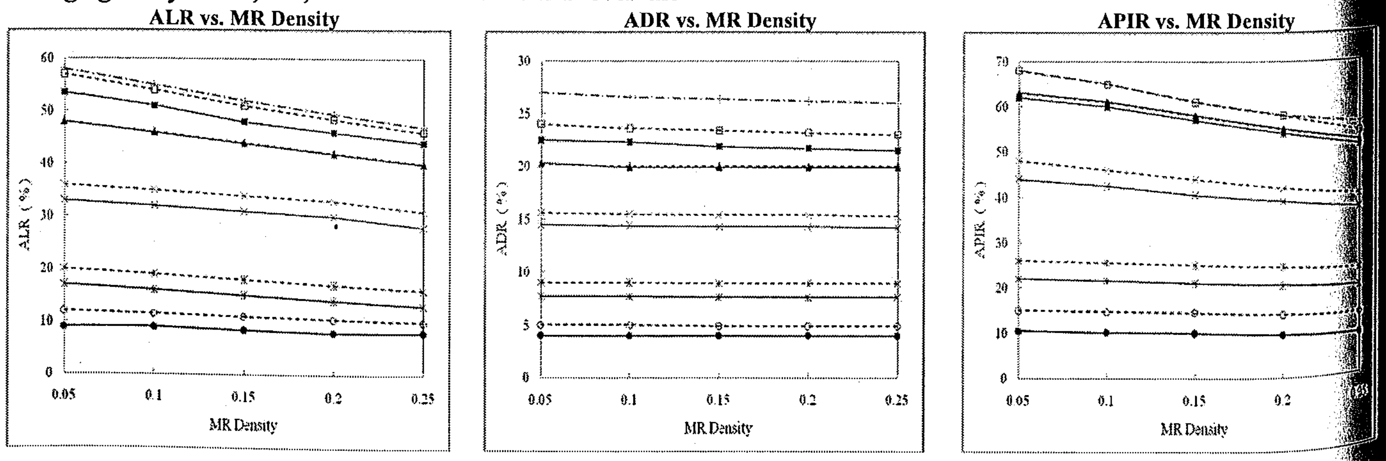

Figure 6. ALR, ADR and APIR when MS Handoff Interval=1000ms, MR Handoff Interval=1000ms

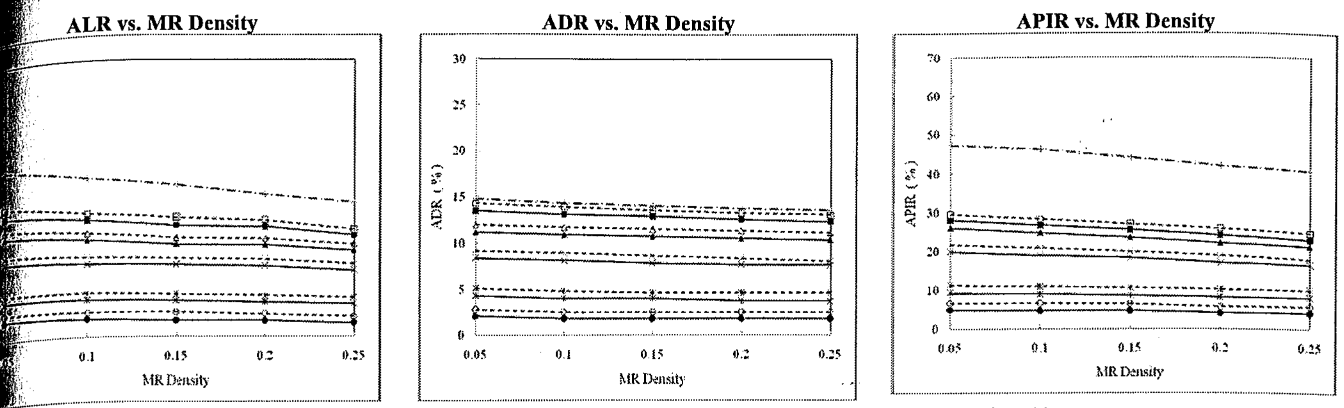

Figure 7. ALR, ADR and APIR when MS Handoff Interval=5000ms, MR Handoff Interval=5000ms

TABLE II. LEGENDS USED IN THE SIMULATIONS

Scheme	Legend	Description
RS	—·+·–	Remote Subscription
SMM200	--⊡--	SMM GR Size = 200ms
SMM300	--△--	SMM GR Size = 300ms
SMM400	--×--	SMM GR Size = 400ms
SMM500	--✳--	SMM GR Size = 500ms
SMM600	--○--	SMM GR Size = 600ms
HSMM200	—■—	HSMM GR Size = 200ms
HSMM300	—▲—	HSMM GR Size = 300ms
HSMM400	—×—	HSMM GR Size = 400ms
HSMM500	—✳—	HSMM GR Size = 500ms
HSMM600	—●—	HSMM GR Size = 600ms

However, RS suffers the largest ADR, which is 4% higher than SMM200 when handoff times are 5000ms. Because the IT includes interruption times introduced by packet losses and delays, APIRs are higher than its corresponding ALR and ADR ones and also decrease as the MR density raises. Similar to ALRs and ADRs, HSMM also achieves the smallest APIR than SMM and RS due to its fast replenishment process with layer2 CR at some handoff scenarios. However, RS still suffers the largest APIR, which is 8% higher than SMM200 when handoff times are 1000ms. Moreover, as handoff intervals grow, MRs can receive more packets between two consecutive handoffs such that ALR, ADR and APIR decrease accordingly.

IV. CONCLUSIONS

In this paper, we have proposed a two-layer HSMM architecture under 4G heterogeneous wireless network environment to support synchronized multicast with less amounts of buffer, higher quality media playback and faster buffer replenishment for infinite numbers of handoff than SMM. Wang et al. [12] proposed a QoS manager (QM) with RSVP extension to manage the mobility of MNs and make the resource pre-reservation or conventional reservation for MNs. Belhoul et al. [13] proposed a classification mechanism for RSVP. Let the crossover router (COR) can detect the changed portion of the end-to-end RSVP session and confine RSVP signaling to it. Yi et al. [14] proposed a Fast RSVP scheme, divided handover process with QoS guarantees into 2 stages. After resources are successfully reserved on the optimized route, the sessions between MN and CN are smoothly switched from the reservation tunnel to the new optimized route. Our future works will focus on apply those proposed fast and mobile RSVP mechanisms in HSMM to support fast and seamless handoffs, which in turn reduces loss, delay and interruption ratios and buffer consumptions of HSMM.

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