# A Channel-Manageable IP Multicast Support Framework for Distributed Mobility Management

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***Abstract*—As the rapid increase of Internet traffic is becoming a serious problem, mobile Internet networks are moving towards flat architectures. Distributed mobility management (DMM) is expected to be one of the key technologies tackling the problem by distributing the data traffic concentrated on a centralized anchor to different access routers. For deploying IP multicasting on mobile networks, a Multicast Listener Discovery (MLD) Proxy is generally considered due to its lightweight feature compared to multicast routing protocols. Following DMM requirements being defined in IETF, an upstream interface of MLD Proxy on an access router is basically fixed towards mobile node (MN)'s anchor to keep the mobility state with unicast session in the same entity. It causes unnecessary multicast traffic due to multiple tunnels established with several access routers for common multicast channel so that this runs counter to the objective of the DMM. In this paper, we propose a channel-manageable IP multicast framework for distributed mobility management, called (CM-DMM), managing of all the multicast channels on Mobility Access Routers (MARs) and the control of which channel should be local or remote. We confronted the performance of CM-DMM against DMM with fixed MLD upstream decision towards each MN's mobility anchor, in terms of duplicate channels and traffic according to the MNs' movement and channel locality ratio. Simulation results demonstrate that CM-DMM is effective to highly reduce unnecessary multicast traffic relatively to DMM with fixed MLD upstream decision. Additional performance factors of CM-DMM are discussed, as well as considerations for its practical deployment in multicast/broadcast networks.**

***Keywords; IP multicast, distributed mobility management, DMM, channel-manageable IP multicast, multicast/broadcast network***

## I. Introduction

As data traffic on mobile device explosively increases, monthly global mobile data traffic is expected to surpass 10 exabytes in 2016 [1]. Simply extending network capacity does not scale economically, and as thus data offloading is being regarded as one of the potential solutions in novel worldwide wireless system/network [2]. This trend is also reflected in the IP mobility research agenda: flow mobility [3], traffic offload selector [4], and forced handoff [5] are some examples of this. These schemes are effective to disperse traffic load through multiple wireless access networks. As additional efforts, local routing [6] is suggested to provide optimal path between mobile hosts without traversing these anchor nodes, but it is limited to client-to-client communications. There are no easy ways to address the rapidly increasing traffic volumes, because they are based on centralized IP mobility architecture, which uses single anchor node like Home Agent (HA)/Local Mobility Anchor (LMA) in MIP [7]/PMIP [8]. The anchor node performs all the signaling with the access routers or MNs, and manages all MNs' binding information. What is worse, the anchor is required to handle all the packets traversing between MN and correspondent node, and as a consequence, network performance and stability are highly degraded.

To tackle these problems, the concept of distributed mobility management (DMM) has been recently introduced in IETF [9]. The key concept is the distribution of anchor functionality from single anchor to the access routers [10] so that traffic is differently anchored per home network prefix (HNP) assigned from each mobility access router (MAR). All packets towards the MN's HNP assigned from previous MAR (pMAR) are sent to current MAR through the tunnel established between the two MARs. As multimedia traffic is an ever-increasing share of Internet traffic, especially on mobile device, interest in applicable and effective IP multicast network support over network-based mobility architecture is rising along with the advent of DMM [11][12].

For deploying IP multicasting on mobile network, a Multicast Listener Discovery (MLD) Proxy defined in RFC4605 [14] is preferred due to its lightweight feature compared to multicast routing protocols, e.g. an MLD Proxy is installed on the mobile access gateway (MAG) in Base Multicast solution on Proxy Mobile IPv6 (PMIPv6-BM) [13]. Basically, an MLD Proxy instance is required to configure upstream interfaces to join the "upper level" IP multicast router. In PMIPv6-BM, the decision of MLD upstream interface is made on the basis of the MN's associated anchor router, called local mobility anchor (LMA), to keep the mobility state with unicast session in same entity.

When applying such a fixed MLD Upstream with an Anchor approach (in short FMUDA) to a DMM, the MAR to which the MN initially attached is used as multicast anchor for the MN so that the MAR forwards the multicast packets to the new MAR where the MN is currently attached through the tunnel established between the two MARs. As DMM was originated and proposed to mitigate traffic burden of the core network, any IP multicast solution should also comply with this objective. Unfortunately, FMUDA, although simple and providing synchronized media delivery during MNs' handoffs, may lead to severe duplication of multicast traffic in case two or more MNs - located at different MARs - with common channel subscription move to the same MAR. Considering IP multicast technique is mainly utilized to deliver large amounts of data packets e.g. multimedia contents, multicast packet duplication to tens or hundreds of multicast channels is much severely regarded to the mobile network operators. In this paper, we propose an effective IP multicast mobility scheme providing a channel-manageable distributed mobility management (CM-DMM), which is able to highly reduce the traffic burden due to duplicate multicast data forwarding over distributed mobility management environments. Specifically, we define a new entity, the channel control server (CCS), which communicates with all the MARs in the DMM domain and manages all the multicast channels (classified as local or remote channels) on each MAR. The MAR receives IP multicast packets from an IP multicast router for local channels, while it receives them from other MARs using bi-directional tunnel for remote channels. To verify how much our scheme can reduce duplicate multicast traffic, a simulator was developed, and results were analyzed in several cases.

The rest of this paper is organized as follows: section II describes the operation of the fixed upstream of MLD Proxy scheme applied to DMM. In section III, we present the CM-DMM and describe its principles of operation. In section IV, we compare and evaluate the network performance of proposed CM-DMM and FMUDA-enabled DMM in terms of duplicate multicast channels and traffic volume under various scenarios. In section V, additional performance factors of CM-DMM are discussed. Finally, we present conclusion in section VI.

## II. IP MULTICAST USE CASES WITH FMUDA OVER DMM

Before checking the IP multicast use cases, generic DMM is defined in this paper as any type of mobility management solution that complies with the following three features:

- The network consists of mobility access routers (MARs), which have both anchor and access router functionalities.
- MNs are mobility-unaware, so it is easy to facilitate enhanced multicast schemes by network operators.
- When the MN attaches to a new MAR, a unique home network prefix (HNP) exclusive to each MAR is assigned to the MN. The MN can use multiple HNPs, assigned from other MARs as necessary.

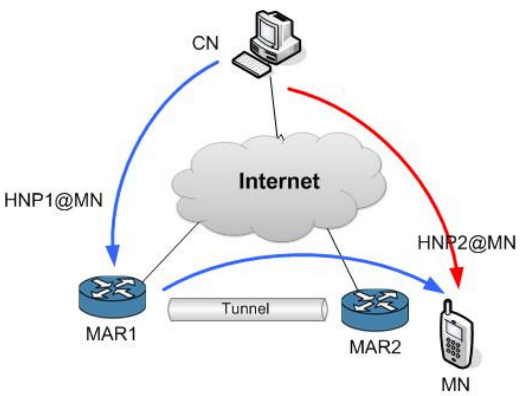



Figure 1. Concept of DMM

Fig. 1 presents a typical scenario with two MARs, and HNP1 and HNP2, assigned to the MN by MAR1 and MAR2, respectively. The packets towards HNP2 are routed directly to the MAR2 while the packets towards HNP1 are routed to MAR2 via MAR1. So, unicast traffic is distributed from MARs having different HNPs.

A method enabling IP multicast into network-based mobility protocols uses PMIPv6-based multicast solution (PMIPv6-BM) [13]. It is assumed that an MLD Proxy or Multicast Router is deployed on an LMA and an MLD Proxy on an MAG. It operates with FMUDA scheme as follows. When the MN attaches to an MAG, the MLD Proxy instance detects a new downstream link and then configures its upstream interface to the MN's associated LMA based on Proxy Binding Update List (PBUL).

When applying the FMUDA scheme used in PMIPv6-BM into DMM architecture, the overall procedures for IP multicast support are as follows. Once the MN attaches to the MAR1, the MAR1 detects the MN, assigns new HNP, and creates a new PBUL. If there's no binding cache entry for the MN, no binding update procedures are generated. While the MN stays at the MAR1, plain IP routing is used for end-to-end communication. For IP multicast support, as illustrated in fig. 2, MAR1 sends an MLD General Query to the MN. The MN transmits an MLD Report message including multicast channel information. Once the MAR1 checks the binding cache, if there is no entry for the MN, it then sends an aggregated MLD Report message to upper IP multicast router. As such, MAR1 receives multicast packets from native IP multicast infrastructure.

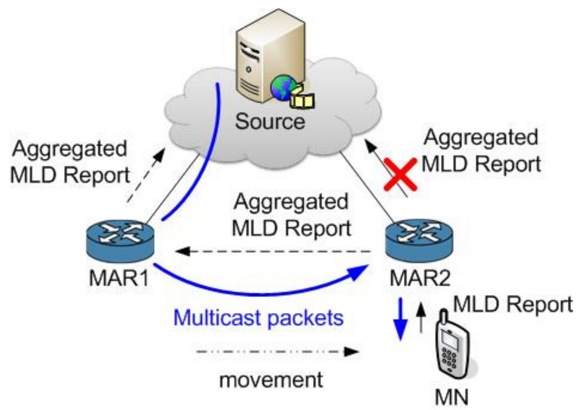



Figure 2. DMM multicast with a fixed MLD upstream decision

When the MN moves to MAR2, the MAR checks the MN ID, assigns a new HNP, creates PBUL for the MN and then sends PBU message to the MAR1[1]. On receiving PBU message, an entry is created in the binding cache for the MN and MAR1 stores the IP address of MAR2 in its binding cache. The MAR1 then sends a PBA message to the MAR2, and bi-directional tunnel is established between MAR 1 and MAR2. MAR1 sends MLD Query message to the MAR2 through the tunnel and

[1] To find the anchors of attached MN, there may be several ways like distributed binding cache sharing among MARs or deploying additional servers to manage MN's cache information. In this paper, this particular issue is out of scope.

MAR2 performs standard MLD Query/Report procedure with newly attached MN and then sends an aggregated MLD Report message to MAR1 based on its PBUL. From this point, MAR2 can receive multicast packets from MAR1 through the established tunnel and transmit them to the MN. Multicast packet flows requested by the MN are not divided over several MARs because a MAR can configure only one upstream interface at a time - either towards an upstream IP multicast router or another MAR - while unicast traffic is divided per HNP.

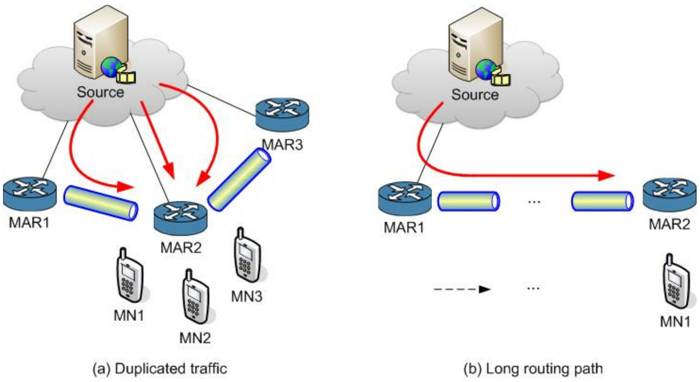



Figure 3. Problem description of fixed MLD upstream decision scheme in DMM

The purpose of DMM is to mitigate traffic convergence to a single anchor, by distributing it to access routers. However, when simply applying this FMUDA scheme in PMIPv6-BM into DMM, severe traffic problems appear, as shown in Fig. 3 (a). In the figure, there are 3 MNs; MN1, MN2, and MN3, which are anchored on MAR1, MAR2, and MAR3, respectively. When MN1 and MN3 move to MAR2 while MN2 keeps static, MN2 receives multicast packets from MAR2 through IP multicast router. From the perspective of MAR2, the same multicast packets are received from MAR1 and MAR3, and as a consequence, two redundant multicast sessions are received. Basically, tunnel-based multicast packet forwarding has a potential issue of duplicate traffic, which can be also found on PMIPv6-BM, the so called tunnel convergence problem. An LMA is a hierarchically upper-level entity so it is expected that the number of LMAs will be much lower than that of MAGs. However, considering DMM multicast, all MARs are access-level entities so it is expected that a MAR can have connections with all MARs except itself. As such, the extent of the duplicate traffic impact on multicast DMM is much worse than that on PMIPv6-BM. Another performance problem of this approach is that it may cause non-optimized tunnel path as shown in Fig. 3 (b) when MN1 moves away from MAR1, which thus acts as its anchor node. Because IP multicast is mainly used as a method to deliver real-time multimedia broadcasting, this long routing path may lead to degradation of users' liveness.

## III. PROPOSED IP MULTICAST FRAMEWORK

We developed our proposed IP Multicast framework with concerns above mentioned, and guided by a set of large design principles.

### A. Design Principles

- Minimized duplicate multicast traffic: the proposed scheme should minimize the occurrence of duplicate multicast traffic, made by multiple tunnels established between multiple MARs in DMM architecture.
- Centralized channel management: the proposed scheme should support centralized channel control framework to facilitate effective multicast traffic distribution. To apply a variety of requirements into operators' networks, a policy-based channel control management should be possible. This policy would then depend on the operators' network environments.
- Network-based channel management: the channel management, regarding on where should be upper multicast delivery router for requested multicast channel, should be determined without MN's involvement. This decision should be made based on channel lists received from a channel control server.
- Shortest multicast routing path: in order to provide reliable streaming performance and liveness i.e. to reduce the time difference of multicast data receiving among multicast listeners, a long routing should be avoided.

### B. Multicast Operation in CM-DMM

Our solution is a channel-manageable distributed mobility management (CM-DMM). Compared to DMM architecture, a channel control server (CCS) is here added. The utilization of a MLD Proxy on an MAR is also assumed. The CCS communicates with a channel enforcement function (CEF) integrated on MAR and provides channel lists classified by 'L' or 'R', representing which channel should be locally or remotely supported.

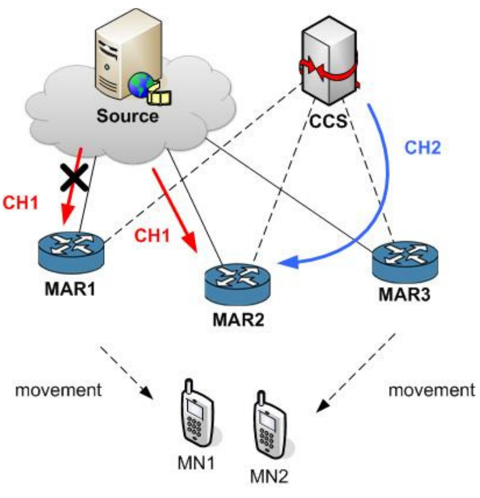



Figure 4. Multicast data forwarding per channel in CMM-DMM

Once an MN attaches to a MAR, the direction of upstream interface is set based on the received policy from the CCS. For example, as shown in Fig. 4, MN1 and MN2 that were listening to CH1 and CH2 at MAR1 and MAR3, respectively, move to MAR2. The channel policy on MAR2 defines CH1 as local only and CH2 as remote, allowing tunnel establishment to other MARs. Following the channel policy, MAR2 will not transmit an MLD Report message to MAR1 although MAR1 is MN1's anchor, but the message is directly routed to an upstream IP multicast router. As a result, an MLD Report message for CH2 is transmitted towards MAR3 so that MAR2 receives the multicast packets through the tunnel established between MAR2 and MAR3.

The meaning of "local channel" is valid in the perspective of receiving multicast packets. If MAR2 is asked to forward CH1 packets to other MARs, it adds a new downstream interface to the corresponding MLD Proxy instance towards requesting MAR. These channel policy decisions can be made by the operators. For example, in the case of a worldwide popular sports game, the operator can make the channel supported through direct routing at every MAR while unpopular channels are allowed through both routing mechanisms, therefore a huge amount of reduced traffic is expected. In addition, improved liveness representing the transmission delay between source and listener may be also expected according to the channel configuration.

### C. *Multicast Function on MAR*

Fig. 5 shows multicast function inside the MAR, indicating how local/remote channel settings can be handled. Basically, an MLD Proxy on a MAR follows the operations of MLD Proxy [14] so that it detects newly attached downstream link from an MN and configures appropriate upstream interface to receive multicast packets. In CM-DMM, we employ the channel enforcement function (CEF) communicating with the CCS and receiving channel bitmap information represented with the form of channel number and bit that indicate that which channel is supported as local or remote. The CEF writes the information into local/remote channel list. Based on the lists, the upstream interface of the MLD Proxy to the requested channel is determined. The CEF periodically sends status reports based on forwarding lists to the CCS. The reports can be used to check channel popularity and traffic intensity and other management functions.

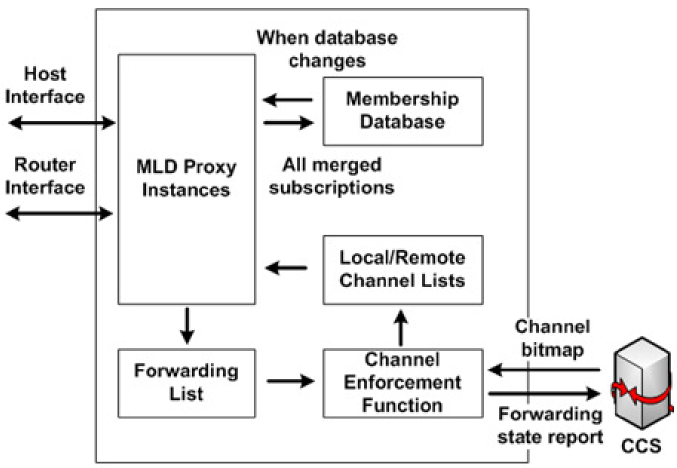
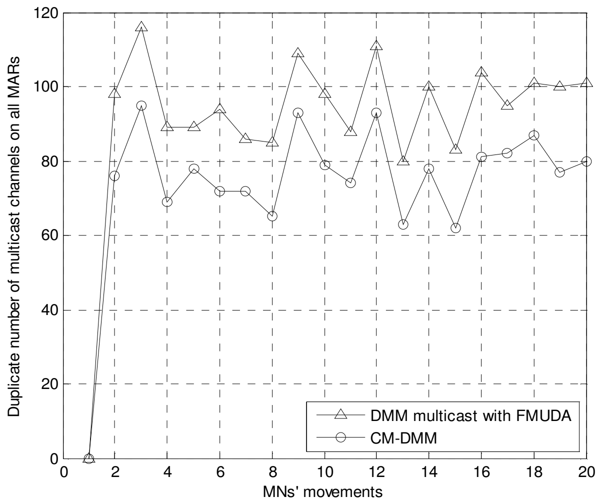



Figure 5. Multicast function structure on MAR

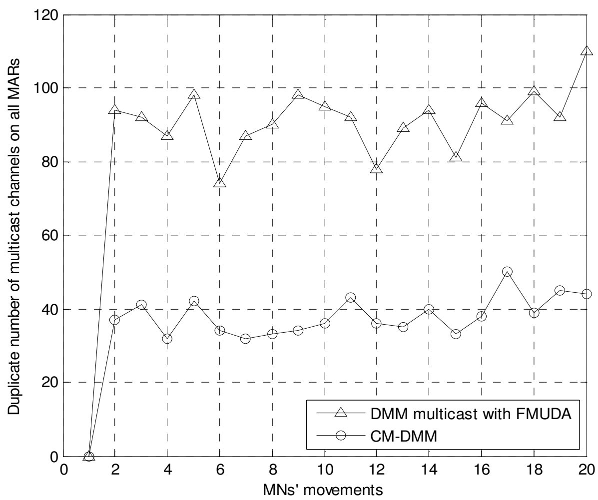
## IV. SIMULATION

In this section, we simulate the schemes of the CM-DMM and DMM multicast with FMUDA using a custom built MATLAB simulator [15].

The conditions of the simulated environment are as follows. Each MAR may establish a bi-directional tunnel with any MAR where the MN stayed before handoff. At the initial time, each MAR has an equal number of MNs within its area. Every MN randomly moves to a MAR with a designated number of handoff times. The next MAR is chosen regardless of its neighborhood. Every handoff, duplicate channels and amounts of traffic on MAR are examined. Local channel is not statically but dynamically configured on each MAR. Several simulations were made with the number of MARs, MNs, the number of local channels and the number of handovers. It is assumed that multicast data is transmitted between MARs with 500kbps rate.




(a) Duplicate number of multicast channels
(when # of local channel is managed with 10 among 50)




(b) Duplicate number of multicast channels
(when # of local channel is managed with 30 among 50)

Figure 6. Duplicate multicast channel numbers on MARs

### A. Comparison of duplicate channels

Fig. 6 shows the duplicate multicast channel whenever MNs move to new MARs, where the deployed number of MARs and MNs is 100 and 1000, respectively. The total number of channels is considered to be 50. In the perspective of a MAR, duplicate channels are counted whenever handoff event occurs. Comparing Figs. 6 (a) and (b), we can see that the number of duplicate multicast channels in CM-DMM is highly reduced compared with the DMM-based multicast scheme when multicast channels are partially allowed to be local on MARs during 20 times handoff event.

Fig. 7 shows the cumulative number of multicast channels according to MNs' movements. Two different values for the number of local channels were considered: 10 and 30. When comparing CM-DMM (10) with CM-DMM (30), we can see the difference is proportional to the extent of local channel configuration. As expected, the less the number of remote channels, the more efficient the IP multicast distribution is.

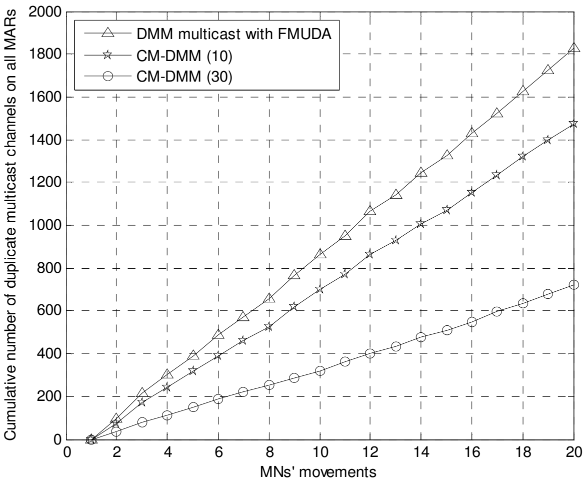



Figure 7. Cumulative number of multicast channels (when the number of local channels is managed with 10 and 30 among 50)

### B. Amounts of duplicate multicast traffic vs. Channel Locality Ratio (CLR)

To check the traffic effects according to the number of channel numbers, we use the channel locality ratio (CLR), defined as the ratio of local channel numbers ($n$) over the totally available channel numbers ($N$). It is assumed that the MN subnet residence time follows a general distribution with mean $1/\mu_s$ [16]. The average residence time is assumed to be 60 seconds. As the CLR decreases, duplicate multicast traffic increases due to establishing more tunnels between each MAR. On the contrary, as the CLR increases, the amounts of duplicate multicast traffic on MAR highly decrease, and the effect of reduced multicast traffic is better improved. As shown in Fig. 8, the larger the total number of available channels is, the smaller the chance of establishing and using tunnels decreases for common multicast channel. Fig. 8 (a) shows the average duplicate traffic on each MAR as the CLR increases when the number of total channels is fixed with 100, while Fig. 8 (b) uses 50 channels. When we see the differences of duplicate traffic, 3 times more traffic occurs when the number of MNs is changed from 500 to 1000 and from 1000 to 2000 because MNs may not equally be distributed to all MARs so that situation can be worsened depending on MNs' handoffs. Consequently, the channel configuration needs to be adjusted with consideration of the number of MNs in services.

These results do not mean that every channel should be local, and that cannot be made because the channel can be configured depending on the region. As the benefits of tunnel-based forwarding introduced before, it is effective to provide synchronized media delivery without special treatment such as context transfer scheme, and it enables continuous media access without any hindrance, regardless of whether current channel is supported or not at the visited domain. This decision may be related to operators' policies so it should be carefully configured based on network situations, including the load on the core network.

## V. DISCUSSION

### A. Requirements on MN

An MN is assumed to have normal IPv6 node with IP multicast client capability. No further protocols are required for proposed framework.

### B. Deployment of CCS

In mobile operator network, CCS may be centrally-managed entity or BM-SC defined in 3GPP multicast/broadcast service (MBMS). CM-DMM presents overall concept to provide operator-driven effective mobile multicast framework. To apply architectural concept of CM-DMM into 3GPP MBMS, appropriate interfaces and signaling should be considered.

### C. Additional performance consideration

#### 1) Signaling overhead

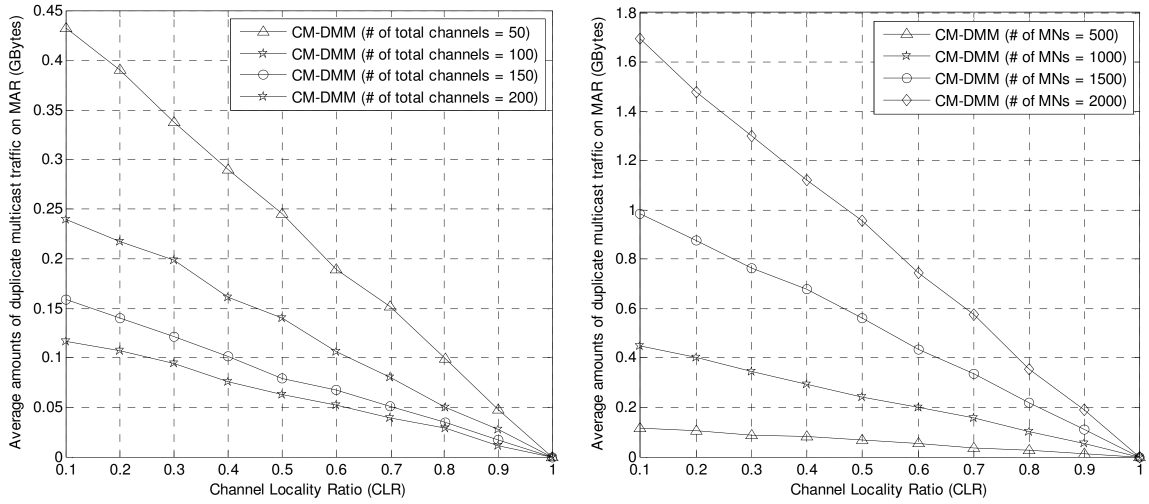
Every CEF should send channel status report to CCS periodically so it might cause signaling overhead. However, signaling transmission for new channel configuration is sent only when channel management policy is changed in CCS. And the channel update is limited to particular MAR.

#### 2) Service latency

This architectural framework is based on a network-based mobility approach so that improved handover performance is basically expected to be similar with that of PMIPv6-BM. However, it may cause service latency when receiving multicast packet sequence is not synchronized on new MAR due to multicast path change i.e. from tunnel-based data forwarding to direct multicast routing or vice versa. It will be shown through additional simulation as further work.

#### 3) Packet routing delay

Deciding upstream router to receive multicast packet affects packet routing delay. CM-DMM does not directly consider shortest multicast routing path. However, when there is locally available multicast channel on MAR, tunnel-based forwarding mechanism is deprecated. Ultimately, CM-DMM achieves shorter routing path. It will be also demonstrated in further work.




(a) when the number of MNs is fixed with 1000

(b) when the number of channel is fixed with 50

Figure 8. Effects on channel locality ratio

## VI. CONCLUSION

Due to rapidly increasing Internet traffic, research directions of mobile Internet are moving towards flat architectures. With this research trend, distributed mobility management concepts are expected to be one of the future network solutions. It is effective to reduce traffic and processing burden concentrated on centralized anchors but this concept still fails to avoid unnecessary multicast traffic volume when a traditional fixed MLD upstream decision is used. In this paper, a channel-manageable IP multicast framework for distributed mobility management was proposed. It manages all the multicast channels on MARs and controls which channel should be local or remote for the requested channel. This provides also an added value for enhanced control, since this management can be decided by operator policies. Through simulation results, we confirmed that duplicate traffic is highly reduced relatively to FMUDA-enabled DMM and that results will depend on the operators' policies. As further work, we will present a wide range of performance results using additional simulation studies.


## ACKNOWLEDGMENT

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