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A Design of Network-based Flow Mobility based on Proxy Mobile IPv6

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Abstract—**Supporting flow mobility is an emerging challenge in today mobile networks. This paper introduces a network-based solution to support flow mobility. It requires minimum modification at the mobile node. All signaling processes are performed by the network. The mobile node can seamlessly switch flow over multiple access technologies while maintaining ongoing connections.**

PMIPv6, network-based flow mobility, logical interface

I. INTRODUCTION

The number of mobile subscribers today is increasing rapidly. The traffic demand of mobile subscribers now is not only for voice and SMS service but also for the high-speed internet access services such as Video streaming, IPTV, and Game … To adapt with this exponential growth of traffic demand, operators are looking for a solution to extend the network capacity. Since the WiFi hotspots, a cheap access technology, is available everywhere and co-existing with other expensive access networks such as 3GPP, LTE and WiMax, the cheapest way is to comprise WiFi with various heterogeneous access networks to realize global accessibility and converge diverse networking resources together to satisfy the mobile subscribers' traffic demands.

Most of the mobile nodes today are equipped with multiple interfaces using different access technologies such as WiFi, WiMax, and LTE … To best utilize this capacity the network should be extended to support simultaneous connections from multiple interfaces of the mobile node. It also has to be able to optimize the data distribution over multiple interfaces. For example, mobile node equipped with two interfaces using two different access technology, 3GPP and WiFi. At the beginning it is walking in the 3GPP zone and using voice and video streaming services [fig.1.a]. Then it moves to an overlapping zone of the 3GPP and WiFi networks [fig1.b]. Since the WiFi can support higher bandwidth, the operator decides to seamlessly move the video streaming from 3GPP to WiFi network to provide better connection for video traffic and also to reduce the traffic load on 3GPP network.

Several solutions are proposed to gain this goal. The 3GPP released 8 introduces a client-server based protocol to enable seamless handover between 3G and WiFi. It was developed basing on Dual Stack Mobile IP, which is a mobility protocol specified in the IETF RFC5454. The QUALCOMM enhances this solution by providing flow mobility capability [10]. The IETF Mobile Extension (MEXT) working group is now also finalizing a flow binding protocol for MIPv6 [8].

All of the above solutions are host-based protocol. They require the mobile node to be modified to involve in mobility management process. A massive amount of software logic and system resources are required on the mobile node which has a limitation energy and resource. To avoid this limitation, the network-based mobility management, Proxy Mobile IPv6 (PMIPv6) [1] is a better choice since it has many advantages as analyzed in [11].

In this paper we focus on network-based flow mobility solutions. First we analyze the technical challenges to support flow mobility and show the limitations of existing solutions. Then we introduce our novel solution with performance evaluation results.

II. PROBLEM STATEMENTS

A. *Network-based flow mobility*

Flow mobility is an extension of IP mobility, a well known IETF standard communication protocol [7]. It allows moving selected flows from one network to another in mid-session without any interruptions while keeping the other flows on the current network. Figure 1 shows an example in which the mobile node equipped with two interfaces, WIFI and 3GPP. At first time the mobile user transfer both voice and video flow via 3GPP interfaces. When the mobile user moves from 3GPP service area to the overlapping area of 3GPP and WIFI network, the video flow can be moved to WIFI interface in order to get higher bandwidth while the voice flow is still transferred via 3GPP interface. The key advantage of network-based mobility management is that it does not require any modification of the MN. The network will perform mobility management on behalf of the mobile node. The client just involves in minimal proportions. This design results in a simple mobile device with minimal software requirements. It was standardized by IETF in PMIPv6 [1], and also adopted in 3GPP and WiMAX architecture. There was many extensions of the network-based mobility management are being planned. One of them is the network-based flow mobility management stated in the re-charter of the NETEXT working group

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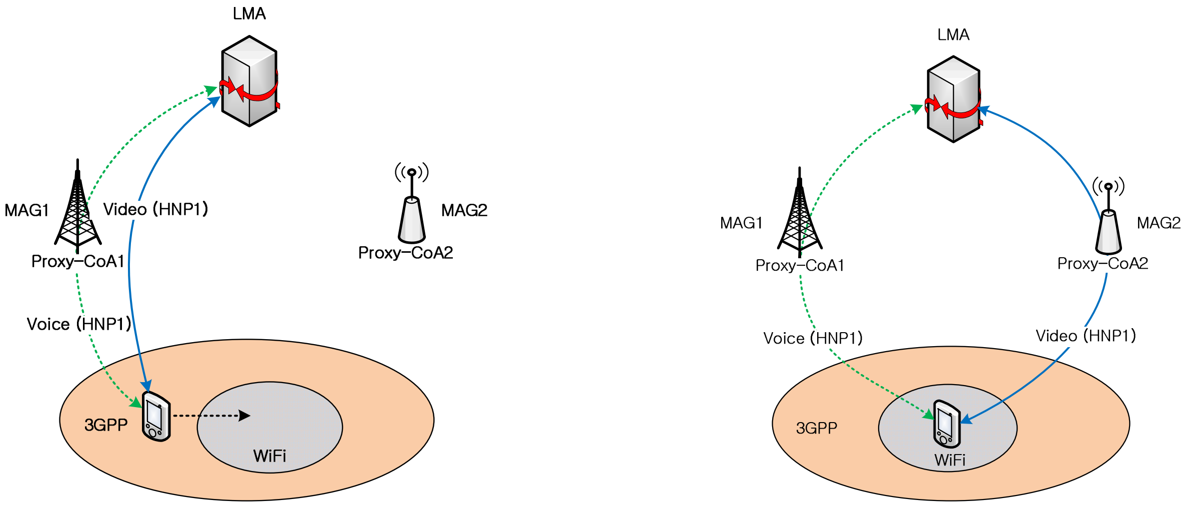

(a) (b)

Figure 1: IP flow mobility

B. *Technical challenges*

The PMIPv6 [1] allows mobile nodes to connect to the network through multiple interfaces for simultaneous access. The Mobile Node (MN) can send and receive simultaneously packets to the PMIPv6 domain over multiple interfaces. However it cannot performs flow mobility due to some limitations:

- *The PMIPv6 can only support IP mobility:* In PMIPv6, when the mobile node performs handover from a network to another, all of the IP flows are moved to the new network. However, the flow mobility requires to support moving just some of the selected flows to the new network, while the other flows are kept transmitting on the old one.
- *The PMIPv6 can only support unique prefix(es) per interface model:* Basically, a home network prefix (HNP) can only be assigned to a single interface at one time. However in a real system, multiple flows can be associated with a HNP. When the flow mobility occurs, some of these flows are moved to a new interface, while the other flows are kept transmitting via the old interface. To keep the sessions continuing the HNP should be preserved during the movement of the flows. It means that the HNP should be able to be assigned simultaneously to multiple interfaces.
- *The PMIPv6 does not support flow-based routing:* Normally, the network can only route a packet at IP-based level. However to route packet at flow-based level it should be able to classify the packets at flow level and then apply the same policy to the packets that has the same flow information

C. *Related works*

To support flow mobility in PMIPv6, the re-charter of the IETF NETEXT working group allows the mobile node to use logical interface to hide the actual usage of physical interface from the IP layer. An informational document [2] was approved as working group document to provide a detailed description of the logical interface. It will be used by the mobile node to support network-based flow mobility.

The important work left is how to extend the PMIPv6 to support shared-prefix model and flow-based routing capability. Some solutions [3-6] were proposed for these technical requirements. The internet draft [4], a combined version of [5] and [6], specified a protocol between the Local Mobility Anchor (LMA) and Mobile Access Gateways (MAGs) for distributing specific traffic flows on different interfaces. The authors considered two possible scenarios. Based on that, they specified the signaling messages for each scenario to support flow mobility. In this document the author did not specify the procedure for the LMA to support shared-prefix model. In addition, they requested the LMA to send the flow policy to the MAG. It was considered as a redundant action since the MAG is only hosting the prefixes that the LMA intends to assign to the MN. It has no control on the MN. All of the flows forwarding decisions are decided by the LMA.

III. PROPOSED SOLUTION

In this paper we solve the limitations of the existing solutions by providing solutions for supporting shared-prefix model and flow-based routing at the network side. The proposed solutions did not require the LMA to send any flow policies to the MAG. The proposed scheme also adopted the flow binding results in MEXT WG [8] to enable the LMA to support flow-based routing without any complicated requirement at both MN and network side.

A. *Shared-prefix model support*

In shared-prefix model, a HNP can be assigned simultaneously to multiple interfaces. To do that the PMIPv6 can be extended in two ways, proactive and reactive signaling approaches.

1) *Pro-active signaling*

To support flow mobility, HNP is shared across attachments immediately when it is assigned to the MN. When the LMA assigns a new HNP to the MN, it will immediately signal this HNP to the entire MAGs to which the MN attaches.

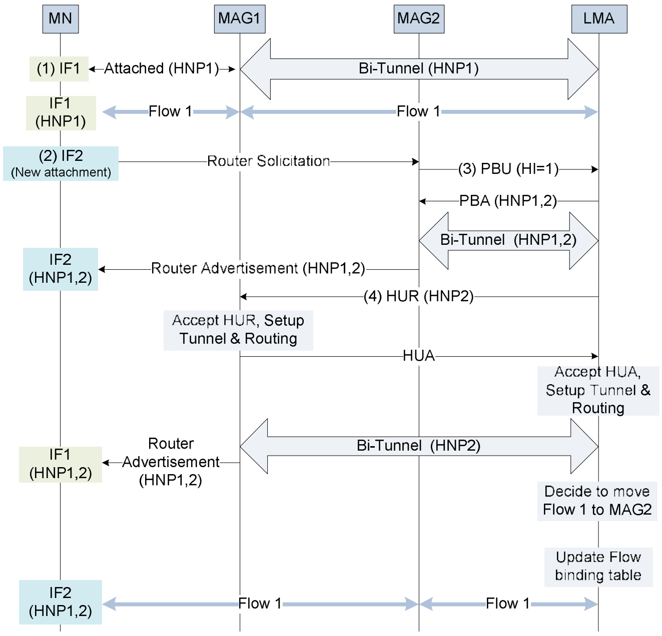

Figure 2: Call flow of pro-active signaling

By doing this, the HNPs assigned to the MN are always shared across its attachments in advance. Therefore the LMA can move flows from an attachment to another in a free manner without any extra signaling messages.

Figure 2 shows signaling call flow of the proactive signaling approach.

- *Step 1:* The MN attaches to the MAG1 using the physical interface IF1. The network assigns HNP1 to the IF1.
- *Step 2:* The MN performs new attachment via the physical interface IF2.
- *Step 3:* The MAG sends a Proxy Binding Update (PBU) message with the handoff indicator (HI) value of 1 to inform the LMA. If the LMA recognizes that the MN can support flow mobility, it will assign both the new HNP2 and the old HNP1 to the new attachment. Upon accepting this PBU message, the LMA sends a Proxy Binding Acknowledgement (PBA) message including both of the HNP1 and HNP2 to the MAG2.
- *Step 4:* The LMA signals MAG1 to update with the new HNP2 by sending a Home Network Prefix Update Request (HUR) to the MAG1. When receiving the HUR message, the MAG1 setups a tunnel and a routing path for the HNP2 and sends back a Home Network Prefix Update Acknowledgement Message (HUA) to inform the LMA that it is ready to forward the packets of the HNP2.

After the above steps, both MAG1 and MAG2 can forward any packets of flows associated with the HNP1 as well as HNP2. Therefore the LMA can move flows between two attachments freely without any extra signaling messages. For example the LMA can move the flow 1, which uses HNP1, from MAG1 to MAG2 immediately because the MAG2 is already enabled to forward the packets of the HNP1.

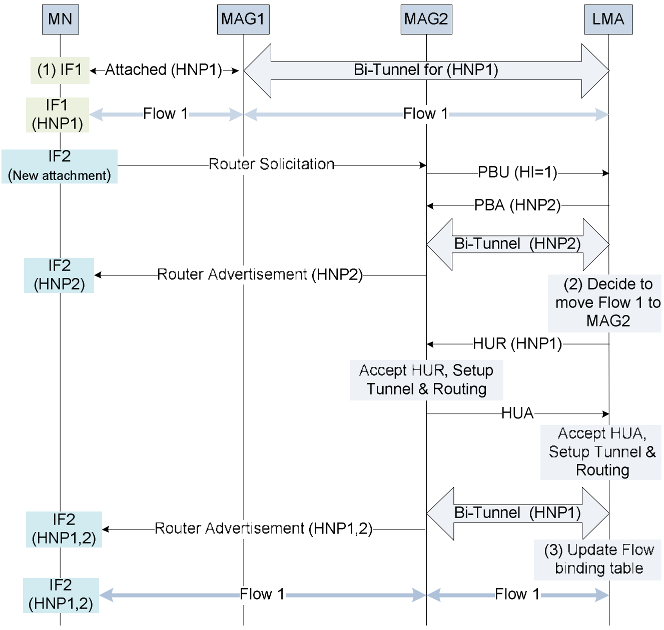

Figure 3: Call flow of re-active signaling

With this approach, the implementations need two extensions:

- Extend the PBA message to include both the new HNP assigned to new attachment and the old HNP that are already assigned to the current MN's attachments.
- Extend the MAG and LMA to enable them to exchange HUR and HUA.

2) *Re-active signaling*

With the re-active signaling approach, an HNP is shared with another attachment only when a flow is moved to an attachment which the HNP associated to that flow is not valid. When the LMA decides to move a flow and realizes that the HNP used by that flow is not valid on the destination MAG, it will signal the HNP to that MAG. By doing this, an HNP will be shared on the destination MAG only when the flow associating with it is moved to a destination MAG that it is not valid. Figure 3 shows the signaling call flow of re-active signaling approach.

- *Step 1:* The MN attaches to the network using 2 interfaces, IF1 and IF2. The network assigns HNP1 to the IF1 and HNP2 to the HNP2. The flow 1 is forwarded by the MAG1 and uses HNP1.
- *Step 2:* The LMA decides to move flow 1 to the MAG2, and signals MAG2 to update with the HNP1 by sending a HUR message to the MAG2. On receiving the HUR message, the MAG2 setups a routing path for the HNP1 and sends back a HUA message to inform the LMA that it is ready for forwarding the packets of HNP1.
- *Step 3:* After receiving HUA from the MAG2, the LMA updates the flow binding table to move the flow 1 from MAG1 to MAG2.

BID	MN-ID	ATT	HNP	Proxy-CoA
1	MN1	3GPP	HNP1	IP1 (MAG1)
2	MN1	WiFi	HNP2	IP2 (MAG2)

(a) The MN attaches with MAG using two interfaces

BID	MN-ID	ATT	HNP	Proxy-CoA
1	MN1	3GPP	HNP1	IP1(MAG1)
2	MN1	WiFi	HNP1,2	IP2(MAG2)

(b) After the LMA receiving HUA

Figure 5: Binding Cache Entry

The key difference between proactive and reactive approach is that in the case of the re-active approach, the HNPs assigned to the MN is not shared across attachments in advance. Each attachment will be assigned with a unique HNP as described in the PMIPv6 standard [1]. The HNP1 is shared on the MAG2 only when the flow1, which is associated with the HNP1, is moved to the MAG2.

With the re-active approach, the implementations need only to extend the MAG and LMA to enable them to exchange HUR and HUA when the flow mobility occurs.

B. Flow-based routing

To support flow-based routing the LMA should be able to bind a particular flow to a Proxy-CoA without affecting other flows associating with the same HNP. To do that, we need to perform the extensions as follows:

1) Multiple Care-of Address registration:

The LMA is extended to allow a mobile node to register multiple proxy care of address (Proxy-CoA), which is the same situation as described in the RFC 5648. The LMA maintains multiple binding cache entries for a MN. The number of binding cache entries of a MN is equal to the number of the MN's interfaces attaching to the MAG. Figure 4.a shows two binding cache entries of the MN1. Each entry is representing for a MN's interface and associates with a Proxy-CoA.

2) Shared-prefix model support:

With the extensions described in the previous section, the LMA can bind a HNP to multiple Proxy-CoAs (MAGs). Figure 4.b shows that, on receiving HUA from MAG2, the LMA updates the corresponding entry record to bind the HNP1 to the Proxy-CoA IP2 of the MAG2. The HNP1 is now shared between MAG1 and MAG2.

3) Flow binding support:

Each LMA maintains a flow binding table [fig.5]. Similar to flow binding described in [8], each flow binding entry points to a specific binding cache entry identifier (BID). When the LMA decides to move a flow, it simply updates the pointer of the flow binding entry with the BID of the interface to which the flow will be moved. The traffic selector (TS) in flow binding table is defined as in [8]. TS is used to classify the packets of flows basing on specific parameters such as service type, source and destination address … The packets matching with the same TS will be applied with the same forwarding policy. As shown in the figure 5, all TCP packets are moved from MAG1 to MAG2.

FID	TS	BID	Action	Mode
1	TCP (Flow1)	1	Forward	Active
2	UDP	2	Forward	Inactive

(a) Before the flow mobility occurs

FID	TS	BID	Action	Mode
1	TCP (Flow1)	2	Forward	Active
2	UDP	2	Forward	Inactive

(b) After the LMA decides to move TCP flow 1 to the MAG2

Figure 4: Flow binding table

C. Protocol operations

1) Local Mobility Anchor Operation (LMA)

The LMA operation is extended for exchanging the HUR/and HUA messages with the MAG. The LMA will send HUR message to the MAG whenever it discovers out that the MAG need to be updated with new HNPs. The following sub-section discusses more detail about the extended operations at the LMA.

- *Sending HUR:* When a HNP is needed to be shared on a MAG, the LMA will send an HUR message including the HNP to that MAG to request it to setup a tunnel and update the routing path for the HNP. Depending on the way of implementation, proactive or reactive signaling approach, the trigger for sending an HUR message is different. With proactive signaling approach, the HUR will be initiated whenever a new HNP is assigned to the MN. In contrast, with the reactive signaling approach, the HUR will be initiated only when the LMA decides to move a flow and the HNP used by that flow is not valid on the destination MAG.
- *Receiving HUA:* After sending HUR, the LMA waits for the HUA from MAG. On receiving the HUA, the LMA updates binding cache to bind the HNP to an extra Proxy-CoA. Figure 4 shows the Binding Cache Entries of the MN1 before and after the LMA receiving HUA message from the MAG2. In the figure 4.a the HNP1 is bounded only to the IP1 of MAG1. After the LMA sends HUR to request the MAG2 to update with the HNP1, the HNP1 is now bounded to the IP2 of the MAG2 as showed in the figure 4.b.
- *Moving a flow:* When the LMA decides to move a flow, it first checks whether the HNP used by that flow is valid on the destination MAG or not by checking the existing binding cache entries of the MN. If it is valid, the LMA just updates the flow binding cache entry list with new BID. If it is not valid the LMA sends HUR message to request the destination MAG to update with the HNP used by the flow. After that, if the MAG sends an HUA message to the LMA, the LMA will update the binding cache entry to bind the HNP to new Proxy-CoA [Figure 4.b] and then update the flow binding entry list with the destination BID. Figure 5 shows the flow binding list entry before and after it is updated. In the figure 5.a, the flow 1 is associated with the binding cache entry 1. It means that the flow 1 is forwarded via the Proxy-CoA of the MAG1. After that the LMA updates the flow binding list entry with the new binding cache entry 2. The flow 1

is now associated with the Proxy-CoA 2 of the MAG2 as shown in the figure 5.b. Thus the flow 1 is successfully moved from MAG1 to MAG2

2) *Mobile Access Getway Operation*

The MAG operation is extended for exchanging the HUR/and HUA messages with the LMA. Two operations are added as follows:

- *Receiving HUR:* On receiving the HUR message, the MAG sets up its endpoint of the bi-directional tunnel to the LMA with the HNP which is piggybacked in the HUR; and also sets up the routing path for the traffic using HNP included in the HUR.
- *Sending HUA:* After successfully setting up the tunnel and routing path for new HNP, the MAG sends HUA including the HNP to inform the LMA that the flows using HNP can be forwarded via the MAG.

3) *Mobile Node Operation*

For simplicity, we assume that the MN uses a single logical interface to hide all of its available physical interfaces. The followings are necessary requirements of the logical interface to support flow mobility.

- The logical interface can simultaneously attach to multiple MAGs by using multiple interfaces.
- The logical interface can accept all the packets receiving from any physical interfaces that are abstracted by the logical interface, if the packets have a valid HNP.
- The logical interface must transmit uplink packets on the same physical interface on which the downlink packet was received for the particular prefix/flow.
- The forth requirement is important for supporting flow mobility since it can guarantee that packets belonging to the same session are routed along the same path. In other words a flow mobility decision made at the LMA will be understood at the MN as an implicit decision when the packets belonging to the same flow will arrive at a new interface. The detailed discussion about logical interface is provided in [2].

D. Messages Format

1) *HUR*

The HUR can be a new message. However we can utilize the current PBA message for using it as a HUR with the following extension fields:

- Acknowledge (A): The A bit is set by the LMA to request an HNP update acknowledgement to be returned upon receipt of the HUR.
- Message type (T): The T bit is set by LMA to indicate that it is a HUR message.
- The mobility options: The mobility option field is a variable-length field. It contains all new HNPs that are assigned to the new attachment of the MN.

2) *HUA*

The same as HUR, we can utilize the existing PBU message for using as a HUA with the following extension fields:

- Message type (T): The T bit is set by MAG to indicate that it is a HUA.
- The mobility options: The mobility option field is a variable length field. It contains the HNP that is needed to be shared.

3) *PBU*

A new flag (F) is included in the Binding Update Massage to indicate to the LMA that the MN can support flow mobility. This field is necessary only when the LMA cannot acquire information about flow mobility capacity of the MN from the MN's policy profile. In this case, the MN will signal the MAG about its flow mobility capacity by using layer 2.5 signaling message. The MAG then set the value of F flag to inform the LMA about the flow mobility capacity of the MN. The F flag MUST be set to 1 if the MN can support flow mobility and MUST be set to 0 if the MN cannot support flow mobility.

IV. PERFORMANCE EVALUATION

We have performed simple NS-3 simulation for validating the basic operation of PMIPv6 flow handover procedure with pro-active signaling procedure. NS-3 network simulator version 3.9 is used with IEEE 802.11 (WLAN) and IEEE 802.16 (WiMax) network environment. For the details of basic PMIPv6 design and implementation in NS-3, refer to our previous work [12]. In order to support the proposed PMIPv6 flow mobility, the virtual interface and the flow binding manager in the MN and the paired control interface in the LMA are additionally implemented to our basic PMIPv6 implementation in NS-3. The control interface in the LMA includes the module of flow handover decision and the handler of HUR/HUA messages. We also update MAG so that it includes the handler of HUR/HUA messages.

The network topology is shown in Figure 6. There are three CBR over UDP traffics with 3.2 Mbps from the CN to the MN. WLAN has higher priority by default policy, and WiMax does for the UDP2 traffic. Figure 7 shows the throughput for the UDP traffics. After WLAN is activated at the beginning of the simulation, UDP1 and UDP2 start to send via WLAN at 1.5 seconds. When WiMax is activated at 5.0 seconds, UDP2 performs flow handover from the WLAN to the WiMax because WiMax has higher priority for the UDP2. The reason of increased throughput more than the serving rate just after flow handover is that queued packets in the WLAN interface queue due to congestion are delivered while ordinary packets are serving through WiMax. After flow handover of UDP2, it serves with its full rate. At 11.0 seconds, the LMA decides to move UDP1 to the WiMax due to decrease of throughput after UDP3 is started to send at 10.0 seconds. After rapid increasing of throughput due to receiving both interfaces at the same time, UDP1 serves with its full rate as well.

It should be noted that there are unfair throughput period before 5.0 seconds. Two over-rated traffics with the same interface cause full of interface queue and packet drop. When the interface queue is not full yet, the fair distribution between UDP1 and UDP2 packets is satisfied. However, when the

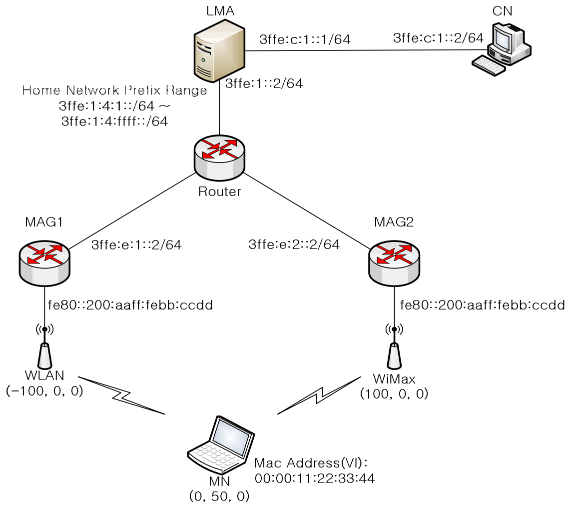

Figure 6: Simulation topology

interface queue is full, due to the characteristic of the drop-tail queue, a series of queuing operation, which are one packet is sending, an arrived packet is queued, and another arrived packet is dropped, is performed. Since the serving rates of UDP1 and UDP2 are the same, their order is alternative. As a result, UDP2 is dropped more than UDP1 if the interface queue of WLAN is full. Figure 8 depicts the received packet sequence for UDP1 and UDP2 in the MN. For each UDP traffic different symbol is assigned based on the transit MAG for the received packets. Since there are two flow handovers, which are at 5.0 seconds and at 11.0 seconds approximately, two breaking points of graph are shown in the figure.

Top-left subfigure shows the packet sequence in case of flow handover of UDP2. Since 5.55 seconds, UDP2 packets through MAG2 are arrived at the MN. However, there are arriving packets through MAG1 as well. Hence, it can be explained the rapid increasing of throughput after flow handover. With the same manner, the packets for the UDP1in the bottom-right subfigure are arrived at the MN from both interfaces. It is noticed that the group of packets which are through MAG2 using WiMax interface has the same arrival time because the transmitting unit of WiMax is Burst, which can contain several packets together.

V. CONCLUSIONS

The network-based flow mobility is a promising technology that can help the operators to comprise various heterogeneous access networks to extend their network capacity at low cost. The IETF NETEXT working group introduced several solutions to get this goal. This paper provides a promising solution to support the network based flow mobility in PMIPv6 basing on a comprehensive overview on the literature of the IETF NETEXT working group. Our next plan is to implement and evaluate the performance of the re-active signaling procedure. We will compare the performance of two signaling approaches and perform more detail analysis of the advantages and disadvantages of each procedure.

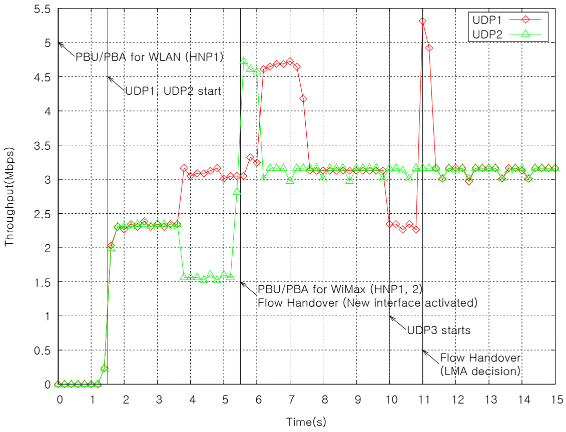

Figure 7: Throughput of UDP1 and UDP2 traffics in the MN

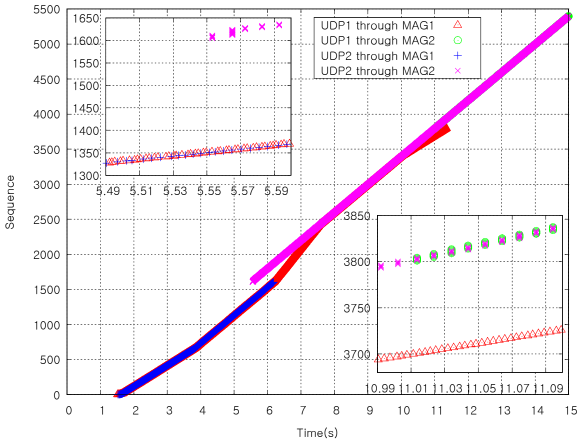

Figure 8: Packet sequence for UDP1 and UDP2 in the MN

REFERENCES

[1] S.Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, B. Patil, “Proxy Mobile IPv6,” IETF RFC5213, August 2008.

[2] T. Melia, S.Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, B. Patil, “Logical Interface Support for multi-mode IP Hosts,” IETF NETEXT WG , August 2010.

[3] T.M.Trung, Y.Hong, Y.Han, “Flow mobility support in PMIPv6”, IETF NETEXT WG, September 2010.

[4] Bernardos, CJ., Jeyatharan, M., R. Koodli, R., Melia, T., and F. Xia, "Proxy Mobile IPv6 Extensions to Support Flow Mobility ", IETF NETEXT WG, July 2010.

[5] Koodli, Rajeev. and Kuntal. Chowdhury , "Flow Handover for Proxy Mobile IPv6", IETF NETEXT WG, October 2009.

[6] Xia, F., "Flow Binding in Proxy Mobile IPv6", IETF NETEXT WG, June 2010.

[7] Johnson, D., Perkins, C., and J. Arkko, "Mobility Support in IPv6", RFC 3775, June 2004.

[8] Tsirtsis, G., Soliman , H., Montavont , N., Giaretta , G., and K. Kuladinithi , "Flow Bindings in Mobile IPv6 and NEMO Basic Support", IETF MEXT WG, August 2010.

[9] Wakikawa, R., Devarapalli, V., Tsirtsis, G., Ernst, T., and K. Nagami, "Multiple Care-of Addresses Registration", RFC 5648,

[10] Qualcomm, “3G/WiFi Seamless Offload”, Technical report, March 2010

[11] K.-S. Kong, Y.-H. Han, M.-K. Shin, H.-R. You, and W. Lee, "Mobility Management for All-IP Mobile Networks: Mobile IPv6 vs. Proxy Mobile IPv6," IEEE Wireless Communication, Vol. 15, No. 2, pp. 36-45, April 2008

[12] H.-Y. Choi, S.-G. Min, Y.-H. Han, J. Park, and H. Kim, “Implementation and Evaluation of Proxy Mobile IPv6 in NS-3 Network Simulator,” In Proceeding of Ubiquitous Information Technologies and Applications (CUTE), December 2010.