Inter-domain Handover Scheme based on Forwarding Router Discovery for Mobile IP Networks

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***Abstract*— One of the main issues of Mobile IPv6 is handover latency that causes service disruption time. Although plenty of proposals significantly reduce the service disruption time, they suffer from redundant routing that causes packet misordering and excess bandwidth consumption. In this paper, we propose a new scheme that minimizes the redundant routing during the process of inter-domain handover by utilizing forwarding routers. Our proposed scheme consists of forwarding router discovery and proactive handover. Furthermore, we evaluate the proposed scheme in the view of packet misordering and bandwidth consumption, and clarify the effectiveness of the proposed scheme.**

***Keywords*—Mobile IP, Handover, Mobility, Packet Forwarding**

I. Introduction

In the forthcoming ubiquitous network era, Mobile IPv6 [1], [2] that provides mobility over IP network has particularly large expectations all over the world and is standardized as IETF RFC in this June. It specifies the operation of the IPv6 [3] Internet with mobile nodes (MNs). Each MN is always identified by its home address regardless of its current point of attachment to the Internet. While situated away from its home, an MN is also associated with a care-of address (CoA), which provides information about the MN's current location. IPv6 packets addressed to an MN's home address are transparently routed to its CoA [4].

However, Mobile IPv6 still suffers from serious service disruption problem, which is crucial to streaming services and especially to interactive communications. To cope with this problem, plenty of researches have been proposed [5–15]. Although those proposals significantly reduce the service disruption time, they suffer from redundant routing that causes packet misordering and excess bandwidth consumption during the process of inter-domain handover (handover between domains).

On the other hand, most of the proposals so far conduct packet forwarding at single router regardless of the number of connections. However, mobile users will have several connections and will consume more network bandwidth than ever in the forthcoming future, e.g. by receiving several audiovisual contents simultaneously from several correspond nodes (CNs). Under these circumstances, we are required to handle handover for each CN individually so that the handover performance can be optimized.

To cope with these problems, we propose a new scheme to minimize the redundant routing during the process of inter-domain handover so that packet misordering and bandwidth consumption will be minimized. Our proposed scheme consists of forwarding router (FwR) discovery and proactive handover. The former enables MN to utilize FwR located between previous access router (previous AR, PAR) and new AR (NAR) regardless of the PAR's unawareness of the network topology while the latter enhances the performance of handover with buffering and packet forwarding on FwR. Here, the FwRs are chosen for each CN individually so that the handover performance can be optimized in case MN has multiple connections. Moreover, the proposed scheme is compatible with Fast Handovers for Mobile IPv6 (FMIPv6) [14] with proper enhancement. In evaluation, we evaluate the proposed scheme in the view of packet misordering and bandwidth consumption, and clarify the effectiveness of the proposed scheme.

II. Related Works

In this section, several related works are described. Researches on mobility are categorized into 2 groups: micro (local) mobility and macro (global) mobility.

Micro mobility is intended to be utilized in a local level movement that is usually mobility inside a domain or an access network. Micro mobility provides seamless mobility support in limited geographical areas. Handover inside micro mobility area usually does not require IP address changes. HAWAII [5] and Cellular IP [6], [7] represent the researches on micro mobility. For instance, Cellular IP provides IP forwarding, minimal signaling, and soft-state location management by incorporating a number of important cellular system design principles such as paging in support of passive connectivity [11].

When MN performs handover between micro mobility areas, i.e. inter-domain handover, MN is required to configure new CoA (NCoA) and to update location information with Binding Update (BU) procedure. This type of mobility is called macro mobility. Hence, the handover latency for inter-domain handover consists of NCoA establishment delay and BU delay (the time needed to exchange BU messages with Home Agent (HA) and CNs).

To minimize the NCoA establishment delay, FMIPv6 [14] is proposed. When MN is belonging to the PAR, the MN configures NCoA and checks the validity of the address so that the MN can utilize the NCoA upon connecting to the NAR. This feature enables MN to send packets immediately upon connecting to the NAR. Therefore, this scheme significantly reduces the NCoA establishment delay. To minimize NCoA establishment delay, our proposed scheme must be compatible with FMIPv6 (See section III-C).

To alleviate the impact of the BU delay, there are several schemes that performs packet forwarding from PAR to NCoA or to NAR in handover as is described in Smooth handover and FMIPv6 [12–14]. We term these forwarding scheme as ”conventional schemes” in this paper. Although these conventional schemes significantly reduce the service disruption time caused by BU delay, the packet forwarding from PAR causes redundant routing that causes packet misordering and excess bandwidth consumption. In micro mobility, MN does not suffer from these problems since all the routers in the network are under administration and they may implement protocol specific features. However, macro mobility schemes cannot usually utilize routers between handover networks except PAR and NAR since routers between PAR and NAR are unknown to them and are not under administration. It is obvious that handover can be optimized if we can utilize a router between PAR and NAR so that the router can assist handover with buffering and forwarding. To cope with this problem, this paper introduces FwR to support handover process while it does not require extra features to CN, and to MN other than FMIPv6.

III. Proposed Scheme

Our proposed scheme consists of FwR discovery and proactive handover. Since Mobile IP is more likely to be utilized in the MN-controlled handover circumstances such as Time Division Multiple Access (TDMA) network, we assume the handover is controlled by the MN. However, the proposed scheme can be adapted to the network-controlled handover case with proper modification. Here, we describe the FwR discovery scheme in section III-A, the proactive handover in section III-B, and then the compatibility with FMIPv6 in section III-C.

A. Forwarding Router Discovery

This section introduces the FwR discovery scheme. FwR is a router that buffers packets and redirects them to NAR, and FwR candidate is a router that can work as FwR. One of the most efficient places to buffer packets is in the router where the routing path from CN to PCoA and the one from CN to NCoA divert, called Cross over Router (CoR). However, since the location of CoR is always changing depending on the CN's location, it is undesirable to configure all the CoR addresses manually for each CN or to cache all the information for all CNs in large network. Therefore, the proposed scheme searches FwR for each handover.

In order to obtain the IP address of the ideal FwR, i.e. CoR, it is desirable to search a router that locates en route from CN to PAR as well as en route from CN to NAR. However, since it is infeasible to require CN any of our protocol specific features, and since it is PAR that we can control the best, in the proposed scheme, PAR searches FwR candidates en route from CN to PAR as well as the ones en route from PAR to NAR respectively as described in Fig. 1. Then the PAR compares the searching results and chooses the common and most upstream FwR candidate between the two searching results just before the MN moves out of the network with handover procedure. For instance, in Fig. 1, assuming that MN has connection with CN1, and that R2, R3, R5 and R8 are FwR candidates, PAR finds R2, R3, and R5 as FwR candidates en route from CN1 to PAR while it also finds R3 and R5 as FwR candidates en route from PAR to NAR. Since the most upstream common FwR candidate between the two searching results is R3, R3 is chosen as FwR. If PAR cannot find any common router between the two searching results, then the PAR itself is chosen as FwR.

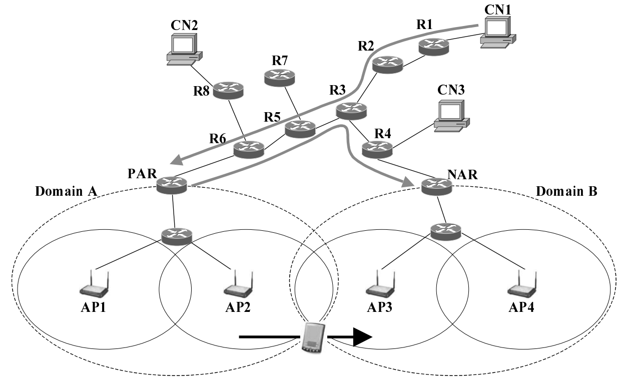

Fig. 1. Forwarding router discovery

In case that the CoR does not work as FwR candidate due to the lack of functionality or due to some failure, PAR searches FwR candidate that is closest to the CoR. In this example scenario, if R3 is not FwR candidate, R5 is chosen as FwR.

Note that none of PAR, NAR, and MN is required to be aware of the topology of upstream network, and CN is not required any modification. Although this searching scheme contains potential deficiency as is later discussed at the end of section III-A.2, it still chooses a router that performs packet buffering and packet forwarding more efficiently than PAR without requiring CN any of our protocol specific features. The details of the discovery scheme is described in the following sections.

1) FwR Discovery en route from PAR to NAR:

Figure 2 illustrates the FwR discovery scheme en route from PAR to NAR. PAR sends FwR discovery message to all the NAR candidates (ARs that can be NAR next time). Although the PAR is simply an AR at this moment. we term this AR as PAR as a matter of convenience since the AR will become PAR later. When an FwR candidate receives FwR discovery message, it inserts its IP address inside the message and forwards the packet to the next router. Upon receiving FwR discovery message, the NAR candidates reply with FwR advertisement message that contains the FwR candidates' IP addresses.

This discovery scheme should be taken place periodically and should be cached inside PAR so that the discovery scheme is not required to be taken place so frequently. Since the topology between PAR and NARs rarely changes, and since the number of NARs are limited, it is often more beneficial to

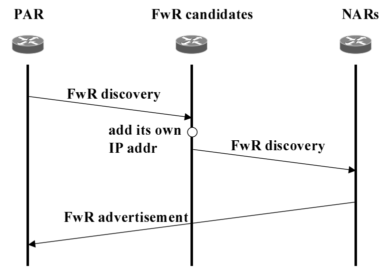

Fig. 2. FwR discovery en route from PAR to NAR

cache those result than to conduct discovery process for each MN.

2) FwR Discovery en route from CN to PAR:

The most efficient and easiest way to discover FwR candidates en route from CN to PAR is the one that CN sends FwR advertisement message to PAR. However, since we cannot expect CN any of our protocol specific features, we assign more features on PAR and FwR candidates instead and utilize BU messages and Binding Acknowledgement (BA) messages. FwR candidate discovery en route from CN to PAR is conducted when an MN moves into the network, and this information is utilized when the MN moves out of the network, i.e. the next handover. Since the PAR in Fig. 1 was NAR in previous handover, we describe the PAR as ŃAR in this section.

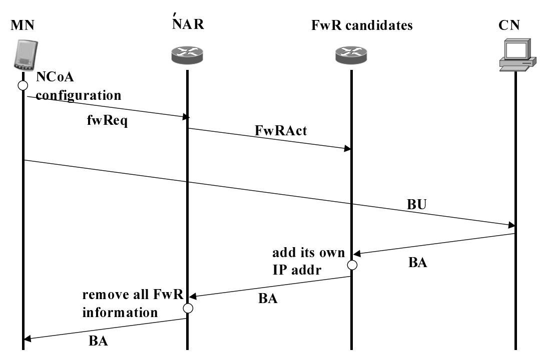

Fig. 3. FwR discovery en route from CN to PAR

Figure 3 illustrates the FwR discovery scheme en route from CN to PAR (ŃAR). The discovery starts when the ŃAR realizes new MN's connectivity. In the proposed scheme, ŃAR realizes it by receiving Forwarding Request (fwReq) message (See section III-B.2) while FMIPv6 utilizes Fast Neighbor Advertisement (FNA) message for that (See section III-C). Then, the ŃAR sends FwR Activation (FwRAct) message to the FwR candidates en route from the ŃAR to all the neighboring ARs that should be known by this time as described in section III-A.1. The FwRAct message contains the CN's IP address as well as the MN's NCoA. Upon receiving the FwRAct message, the activated FwR candidates start inspecting each arriving packet sent from the CN to the NCoA and check whether the packet is BA message or not. When an activated FwR candidate receives BA, it inserts its own IP address inside the packet and forwards the packet to the next router. Here, those activated FwR candidates are deactivated when they once insert its IP address inside BA packet or are deactivated after proper timeout period. Upon receiving the FwRAct message, the ŃAR stores those information concerning FwR candidates and deletes those information from the BA, which is then forwarded to the MN.

Provided the capacity of an FwR is almost full, and the burden to the FwR is excessive, the FwR candidate is not required to notify its presence to ŃAR. It is also not required to notify its presence if the FwR does not work due to some failure. Therefore, the FwR candidate may simply forward the BA message without any further action. This feature enables us to create some double, or triple FwR structure, which establishes the balanced burden router system.

As can be seen, the FwR candidates en route from CN to PAR (ŃAR) are discovered though the searching range is limited between the PAR and all the geographically neighboring ARs. The final selection of FwR will be conducted by comparing the FwR candidates en route from PAR to NAR and the ones en route from CN to PAR when the MN moves out of the network as described in section III-B. One deficiency of the proposed scheme is that PAR cannot choose CoR as FwR if the CoR is not en route from NAR to PAR. In this case, PAR simply chooses the FwR that is closest to the CoR and that is in the route from NAR to PAR.

B. Proactive Handover

When an MN is going to move out of a network, the MN performs proactive handover with the help of FwR. The proactive handover consists of proactive packet buffering and packet forwarding, which will be described in the following sections. The message flows utilized in proactive handover are described in Fig. 4, which will be also elaborated in the following sections.

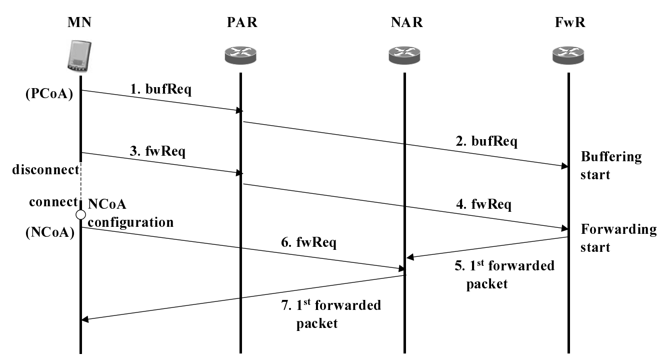

Fig. 4. Proactive handover message flows

1) Proactive Packet Buffering:

By forwarding packets from PAR to NCoA, handover goes very smoothly provided the two related networks are well-overlapped, and provided the MN can receive packets from both PCoA and NCoA simultaneously. However, otherwise, the packets sent to the MN before the establishment of tunnel will be lost. Therefore, our proposed scheme performs proactive packet buffering that compensates the lost packets before the establishment of tunnel as mentioned in [13]. Different from [13–15], the proposed scheme performs buffering at FwR, which replicates the packets sent from CN to MN. Then it forwards the original packets to the MN while it saves the replicated packets into its buffer. Those saved packets will be forwarded to NCoA upon receiving fwReq message.

The proactive handover begins with a buffering request (bufReq) message sent by an MN to PAR when the MN detects a candidate network for next handover point by L2 trigger, which should be defined depending on each network. The bufReq message includes the new AP identifier, with which the PAR knows the address of NAR by looking up its own database. The database should be created by periodic message exchanges with neighboring APs or by manual configuration or by other schemes though the scheme is outside the scope of this paper. Upon receiving the message, the PAR forwards the message to proper FwR that is decided by looking up the result of FwR discovery scheme with the NAR's address. Note that MN is not required to know the existence of FwR at all while PAR knows it.

Upon receiving the bufReq message, the FwR starts buffering and continues buffering until it receives fwReq message or until it gets timeout expired. FwR simply discards buffered packets after timeout expired. The MN may retransmit the bufReq message when necessary. During the handover decision process, it may receive another L2 trigger that suggests different network for handover. Then it sends bufReq message to the PAR, which forwards it to the proper FwR. If the FwR is the same one as before, it simply updates the timeout value. The FwR discovered by a failed L2 trigger will simply discard the buffered packets after timeout expired.

Here, the buffer size of FwR can be configured depending on the policy of administrator. The discussion concerning the buffer size is outside the scope of this paper.

2) Packet Forwarding:

When the MN is moving to new network, it sends fwReq message to PAR just before switching connection to new network. Upon receiving the fwReq message, the PAR forwards it to proper FwR, which in return starts forwarding packets sent from CN to PCoA to NAR preceded by the buffered packets inside the FwR. Upon receiving the packets, the NAR starts buffering those forwarded packets until it realizes the MN's existence under its network by receiving fwReq message.

When the MN moves into the new network, it sends fwReq message to NAR. Upon receiving the message, the NAR starts forwarding packets sent from FwR preceded by the buffered packets inside the NAR itself. If NAR does not receive any valid fwReq message for certain amount of time, the NAR discards those buffered packets.

As described in [14], the MN cannot send any packet to CN with NCoA until it finishes BU procedure. When it sends packets to CN before finishing BU procedure, the source field of the IP header should be PCoA as is described in FMIPv6. Upon receiving the packet, the NAR encapsulates the packet and forwards the packet to FwR by tunneling. Then the FwR decapsulates the packet and sends the original packet to CN. In this way, MN can also avoid the redundant routing not only in the packet receiving scenario but also in the packet sending scenario. Therefore, packet misordering, packet loss, and bandwidth consumption are suppressed as well.

C. Compatibility with FMIPv6

Our proposed scheme displays better performance by cooperating with FMIPv6. The required features for MN in the proposed scheme can be observed as an extension to the one in FMIPv6. In the proposed scheme, MN sends bufReq message while it sends RtSolPr message in FMIPv6. Also, it sends fwReq message in the proposed scheme before handover while it sends FBU in FMIPv6. Moreover, it sends fwReq message in the proposed scheme after handover while it sends FNA in FMIPv6.

By substituting bufReq message with RtSolPr message, fwReq message before handover with FBU message, and fwReq message after handover with FNA, the proposed scheme works with FMIPv6 without MN's noticing our protocol. In this case, the proposed scheme can gain better performance with the help of FMIPv6 though we need some enhancements for the behavior of the PAR and NAR to cooperate with FMIPv6, The detailed feature to cope with FMIPv6 is outside the scope of this paper.

IV. Evaluation

In this section, our proposed scheme is evaluated. We evaluate the proposed scheme in the view of packet misordering in section IV-A while we evaluate it in the view of bandwidth consumption in section IV-B.

A. Packet Misordering

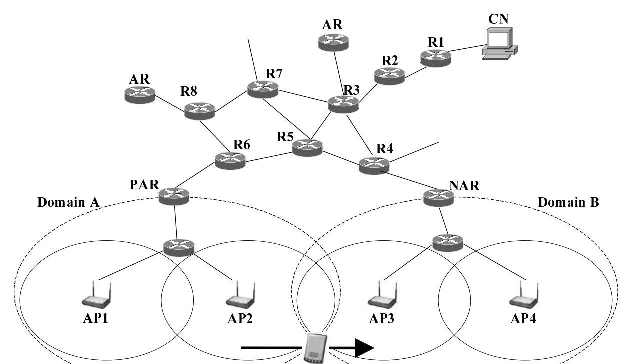

Fig. 5. Simulation topology

Firstly, we evaluate the proposed scheme in the view of packet misordering assuming an MN communicates with single CN. Ideally, the FwR is the CoR, which completely avoids packet misordering. However, as described in section III-A.2, FwR discovery sometimes cannot choose CoR by FwR discovery if the CoR is not en route from NAR to PAR, hence some packet misordering will occur. Although this misordering can be re-ordered in the MN provided the MN implements special function for that, otherwise those misordered packets are simply discarded or invoke packet retransmission depending on the higher layer protocols. Therefore, we evaluate the proposed scheme in the case CoR is not en route from NAR to PAR.

We utilized NS2 simulator [16] for this simulation and established simulation topology as described in Fig. 5. Here, the CN is sending CBR traffic to MN that is connected to AP2. After a while, the MN starts handover to the domain B. Here, domain A network and domain B network are overlapping though the MN cannot receive packets from both networks simultaneously. Upon receiving fwReq message, the FwR starts forwarding packets to the NCoA. Likewise upon receiving BU message, the CN starts sending packets to NCoA directly. R5 is chosen as an FwR while R3 is CoR. Here, we analyzed the packet misordering caused by the difference between the route from CN to NCoA and the one from FwR to NCoA. In this simulation, the delay for each link was set to 10 msec and the bitrate was set to 128 kbps. We measured the number of misordered packets when we changed the value of packet interval. The packet size was changed so that the bitrate is always fixed on 128 kbps.

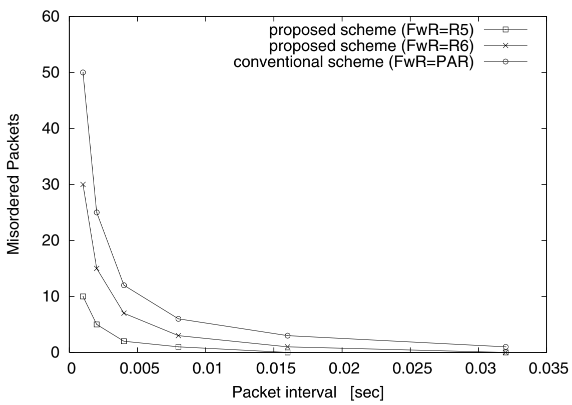

Fig. 6. Packet misordering (single connection scenario)

Figure 6 shows the result of this simulation. It illustrates the packet misordering for both conventional scheme (FwR=PAR) and the proposed scheme (FwR=R5). It also shows the case that R6 is working as the FwR instead of R5. The X-axis represents the packet interval in the unit of second while the Y-axis represents the number of misordered packets. As can be seen, when the packet interval is smaller, the misordering happens more. Although the proposed scheme also suffers from the packet misordering, the amount of misordered packets is significantly reduced compared to the conventional scheme that forwards packets from PAR.

Secondly, we evaluate our proposed scheme in the view of packet misordering assuming an MN has multiple connections during its handover process. In the proposed scheme, the MN can utilize one FwR for each connection so that the redundant routing for each connection will be minimized.

In Fig. 1, assuming that an MN has connections with CN1, CN2, and CN3 respectively during the process of handover from domain A to domain B, the PAR chooses one FwR for each CN. Hence R3 is chosen as the FwR for the connection with CN1, R6 is chosen as the FwR for the connection with CN2, and R4 is chosen as the FwR for the connection with CN3. Here, we assume that R3, R4, and R6 are FwR candidates. In this way, the MN can choose the most suitable FwR for each CN. Depending on the policy of the network, the multiple FwR support can be enabled or disabled. Provided the multiple FwR support is disabled, the PAR must choose the common FwR for all connections. In Fig. 1, R6 and PAR are the possible candidates for common FwR. Since R6 is more upstream router than PAR, R6 is chosen as the FwR.

TABLE I
PACKET MISORDERING (MULTIPLE CONNECTION SCENARIO)

	packet misordering
CN1	40 packets
CN2	0 packet
CN3	60 packets
Total	100 packets

To evaluate the effectiveness of the proposed scheme, the number of misordered packets was measured by utilizing the NS2 simulator assuming the topology described in Fig. 1. Here, CN1, CN2, and CN3 are individually sending 128kbps CBR traffic (packet interval=0.001sec) to the MN. Table I shows the number of misordered packets in case we forbid multiple FwR support. Since CN1 and CN3 cannot utilize CoRs as FwRs, and they utilize R6 as FwR, undesired packet misordering occurs for the connection with CN1 and for the one with CN3. When we utilize multiple FwR support, we utilize R3 as the FwR for CN1, R6 as the FwR for CN2, and R4 as the FwR for CN3, hence no packet misordering occurs for each connection. As can be seen, choosing one FwR for each connection significantly reduces the amount of packet misordering.

B. Bandwidth Consumption

We evaluate our proposed scheme in the view of bandwidth consumption assuming Fig. 1 is our simulation topology. By utilizing FwR discovery, the AR (PAR) in domain A knows that R3, R5 and R6 are FwR candidates for the handover from domain A to domain B while the AR in domain B knows that R3 and R4 are FwR candidates for the handover from domain B to domain A. All MNs are receiving 2 Mbps traffic from CN1 all the time, and they are moving between domain A and domain B. We assume the duration that causes temporal redundant routing is 1 second in this simulation model. The number of MNs moving from one network to another is described as uniform pseudorandom number and is calculated by Box-Muller transformation (average=10, standard deviation=2) in this evaluation.

Firstly, we assumed all FwRs have unlimited capacity and one best-located FwR, i.e. R3, will assist all the MNs' handover. Figure 7 shows the comparison between conventional scheme and the proposed scheme in the view of bandwidth consumption of the link between R5 and PAR. The X-axis shows the time after this simulation starts while the Y-axis shows the bandwidth consumption between PAR and R5 in the unit of bitrate. As can be seen, the proposed scheme saves bandwidth consumption compared to the conventional scheme all the time. Here, the average bandwidth consumption with the proposed scheme was 216 Mbps while the one in the conventional scheme was 256 Mbps. Hence, though the bandwidth consumption saving gain varies depending on the topology, the proposed scheme saved bandwidth consumption by 15.6% compared to the conventional scheme in this simulation.

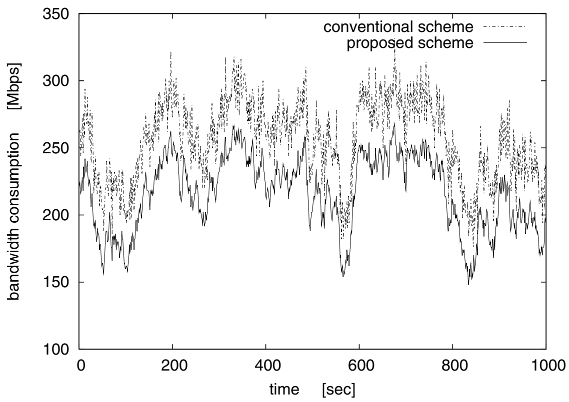

Fig. 7. Bandwidth consumption

Secondly, we assumed FwR has limited capacity and each FwR supports up to certain amount of handover procedure. Since forwarding and buffering inside FwR are extra burden for routers, it is natural that the number of handover process that one FwR can handle at the same time is limited. Here, we name "capacity" as the number of handover processes that one FwR can handle at the same time. Figure 8 shows the relationship between capacity of FwR and bandwidth consumption for the link between R6 and R5, and for the link between PAR and R6. X-axis shows the capacity of each FwR while Y-axis shows the bandwidth consumption in the unit of Mbps. Note that R3 is the FwR that helps handover from domain A to domain B as well as the one from domain B to domain A. As can be seen, the more capacity each FwR has, the more we can save bandwidth consumption until the bandwidth consumption reaches minimum value. And the more closer the link is to PAR, the less bandwidth consumption it suffers.

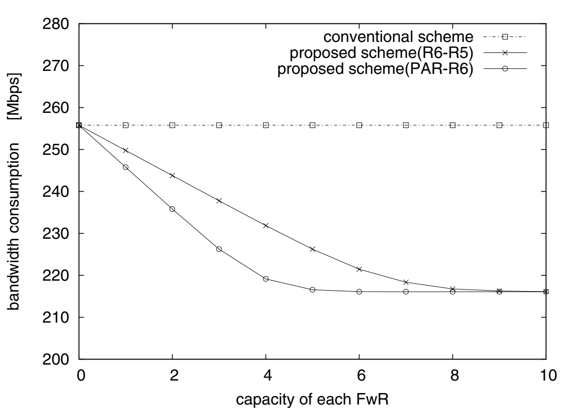

Fig. 8. Impact of FwR's capacity

V. Conclusion

To enable smooth inter-domain handover, we proposed a new scheme consisting of forwarding router discovery and proactive handover. The former enables MN to utilize FwR located between PAR and NAR regardless of the AR's unawareness of the network topology while the latter enhances the handover performance with packet buffering and packet forwarding at FwR. In evaluation, we examined our proposed scheme in the view of packet misordering and bandwidth consumption. The feature of choosing FwR for each connection is efficient for the MN with several connections during the process of handover. The proposed scheme alleviated the redundant routing caused by handover process and minimized packet misordering and bandwidth consumption. Although the proposed scheme is intended for macro mobility, we cannot expect most of the routers to work as FwR. However, by strategically locating a couple of FwR candidates in the network, plenty of MNs can benefit from the proposed scheme. The proposed scheme is compatible with FMIPv6 with proper enhancement and is expected to reduce handover latency even more by cooperating with the protocol.

As a future work, we will implement the proposed scheme and evaluate the performance under real environments.

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