CARE-OF-PREFIX ROUTING FOR MOVING NETWORKS IN MOBILE IP NETWORK

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Abstract: The future ubiquitous network will serve so many mobile terminals that it is extremely important to control them efficiently. One useful approach is to group terminals having similar movement characteristics and manage them in units of groups. Another important issue is the mobility management of moving networks, such as a network on a train or in a car, or a personal area network. Moving networks may be defined for a variety of situations and can lead to a lot of attractive applications. Moving network mobility support is indeed one of the most interesting research topics. In this paper, we clarify the difference between host mobility support and the conventional moving network mobility support, propose a mechanism for moving network mobility support and shows it is better than the conventional ones.

1 INTRODUCTION

Since the future ubiquitous network must serve several billion Mobile Nodes (MNs) (i.e., mobile terminals), it is extremely important to control them efficiently. Given this number of MNs, one key technique is to group MNs having similar movement characteristics, and manage them in units of groups. Another urgent topic is to enhance the mobility management of local networks, such as a network on a train, in a car, or a personal area network. This moving network mobility support and moving networks can be applied to a variety of situations and can lead to a lot of attractive applications. This mobility management is indeed one of the most interesting research topics today. Many groups including *IETF* are actively researching IP routing techniques to support moving network mobility. NTT DoCoMo Network Laboratories are also studying it as a key technology for IP^2 (IP based IMP Platform) (Yumiba, 2001), a platform we have proposed for the next-generation mobile network.

The representative requirements for moving network mobility support in IP are the same as those for host mobility support (mobility management for moving hosts rather than a moving network). They are:

(1) Route optimization
(2) Minimization of the packet header size
(3) Reduction in handoff signal overhead.

"Pinball" Routing (Thubert, 2004), in which packets are always transmitted via Home Agent (HA) (Johnson, 2004), cannot satisfy requirement (1) because it requires excessive network resources. Given requirement (2), we must minimize packet overhead by dispensing with encapsulation. Requirement (3) demands that handoff be achieved seamlessly with minimal packet loss and short handoff latency. Therefore, it is important to reduce the amount of handoff signals. The *NEMO WG* has proposed only partial solutions to these three requirements.

In this paper, we clarify the difference between host mobility support and the conventional moving network mobility support, and propose a solution that satisfies all the requirements. Its effectiveness was confirmed by using *network simulator 2* (called ns2).

Section 2 briefly describes the difference between host mobility support and the conventional moving network mobility support, and the requirements for moving network mobility support. Section 3 proposes the basic techniques of a new routing method applicable to moving networks. Section 4 introduces a new routing mechanism that uses these basic techniques for Mobile IP (MIP) (Johnson, 2004). Section 5 compares the proposed routing mechanisms with conventional ones.

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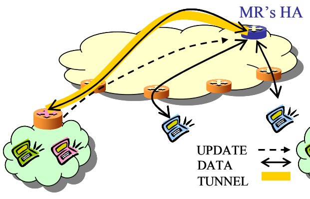


Figure 1: Basic

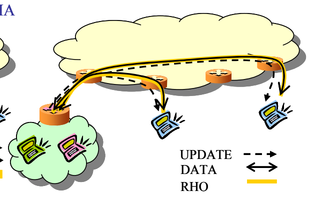


Figure 2: RRH

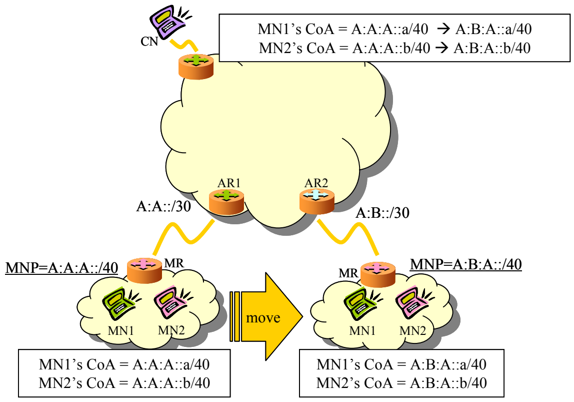


Figure 3: Care of Prefix

2 DIFFERENCE BETWEEN HOST MOBILITY SUPPORT AND THE CONVENTIONAL MOVING NETWORK MOBILITY SUPPORT

The characteristics and brief evaluations of NEMO Basic Support (hereafter referred to as Basic) (Devarapalli, 2004) and Reverse Routing Header (RRH) (Thubert, 2004), both of which are currently proposed in NEMO WG for moving network mobility support, are shown below.

Basic constructs a bidirectional tunnel between a Mobile Router (MR) and the HA of that MR. Packets from/to MNs in a moving network are always carried via this tunnel (Fig. 1). When the moving network moves, handoff is achieved by reconstructing a tunnel. Specifically, a bidirectional tunnel is reconstructed between the Care of Address (CoA) (Johnson, 2004), which an MR is allocated by the new AR (Access Router), and the HA address of the MR. CoAs of MNs in the moving network remain unchanged even if handoff occurs. This hides the move of the moving network from the MNs in the moving network. Furthermore, even if there are many MNs in the moving network, handoff can be achieved easily because only this bidirectional tunnel needs to be reconstructed. Therefore, there is a high possibility that requirement (3) can be met. However, the undesirable effect of Pinball Routing is significant if the HA of the MR is far from the moving network. Additionally, packet overhead is greatly increased because packets are doubly encapsulated, once for the bidirectional tunnel and another for the CoA of the MN. Therefore, Basic cannot meet requirements (1) and (2).

RRH satisfies requirement (1) (Fig. 2). Specifically, routing is optimized as follows. All CNs are informed of the CoA of the MR, and the packets destined to MNs in the moving network are transmitted with Routing Header Option (RHO) in IPv6 (Deering, 2004). That is, the CoA of the MR and the CoA of the MN are attached. With regard to Requirement (2), RRH yields packet header sizes that lie between those of Basic and host mobility support. When the moving network moves, it is necessary to inform all CNs of the change in the CoA of the MR. The more CNs there are, the more handoff signals are sent. Therefore, RRH cannot meet requirement (3).

As mentioned above, neither of the two conventional mechanisms can satisfy all requirements. This is due to the assumption made by NEMO WG for the moving network. NEMO WG assumes that the prefix inside a moving network, i.e. Moving Network Prefix (MNP), is fixed (Devarapalli, 2004) (Thubert, 2004). Given this assumption, MNP is not changed even if a moving network moves. Therefore, to connect to an MN in the moving network, it is necessary to use the CoA of the MR in addition to the CoA of the MN in the moving network. This increases the packet header size. The MR-CoA is needed to construct a bidirectional tunnel in Basic, or to set it in the RHO in RRH.

The technologies proposed in Section 3 dispense with this assumption. That is, MNP is changed to adapt to the hierarchical address for the AR to which the moving network is connected. This enables packets to be routed to an MN in the moving network using only MN-CoA in the moving network, as in the case of host mobility support.

3 PROPOSED BASIC TECHNIQUES

3.1 Care of Prefix

As described in Section 2, the conventional mechanisms require the use of both of MR-CoA and

MN-CoA to route packets to an MN in the moving network, which increases packet overhead. Therefore, it is necessary to find a solution that minimizes packet overhead. The solution should be to use only one CoA, as in the case of host mobility support. The Care of Prefix (CoP) (Suzuki, 2003) technique is used to implement this. Specifically, an MR is allocated a CoP by the AR to which the moving network is connected. This CoP is an MNP in the hierarchical topology that embraces the moving network. After that, the MR uses this CoP to

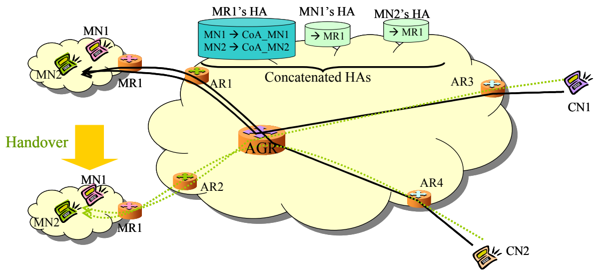


Figure 4: Concatenated HAs and Aggregate Router

assign a CoA to the MNs in the moving network. In this way, packets for an MN in the moving network can reach the MN using only MN-CoA (Fig. 3).

The method of allocating the CoP is shown in Figure 3, using the IPv6 method as an example. Suppose that the net mask of the AR, which is an edge router of the core network, is 30 bits long. The moving network is allocated a CoP with a 40-bit mask to form a hierarchical structure that embraces the moving network.

In this way, MNP (i.e. CoP) reflects the hierarchical topology of the core network so that MN-CoA can be resolved from anywhere within the core network. In addition, a CoA can be generated from a CoP without any risk of duplication. Since the CoP is uniquely allocated to each moving network, duplicate CoAs are not generated for MNs that are connected to the same AR.

CoP makes it possible to meet requirements (1) and (2) at the same time because a CN can directly send packets to an MN in a moving network using only MN-CoA in the same manner as in host mobility support. However, when handoff occurs, the CoAs of all MNs in a moving network must be changed. This dramatically increases the number of handoff signals sent to the HAs of all MNs, and similarly the number of those sent to all CNs if route optimization is implemented. Therefore, it is difficult to meet requirement (3).

3.2 Concatenated HAs

As mentioned in Section 3.1, the use of CoP cannot meet requirement (3). One problem is that handoff signals must be sent to the HAs of all MNs in a moving network. To solve this problem, we propose Concatenated HAs (Suzuki, 2003) (Fig. 4).

In this technique, each HA of each MN does not hold its CoA. Instead, it holds the information that the MN is in a certain moving network. Specifically, the information of MN-MR concatenation is registered with the HA of each MN, while the CoAs of all MNs are registered with the HA of that MR. This makes it possible to limit the number of entities updated at handoff. At handoff, only the HA of the MR requires updating rather than the HAs of all MNs.

3.3 Aggregate Router

As mentioned in Section 3.1, there is another problem that prevents requirement (3) from being satisfied. It is that handoff signals must be sent to all CNs. To solve this problem, we propose the AGgregate Router (AGR) (Fig. 4). The purposes of the AGR are twofold: localize handoff signals and aggregate the handoff signals that are sent to all CNs. Specifically, the AGR manages the mobility of the moving network as well as the HA of MR, i.e., the AGR maintains the CoAs of all MNs in the moving network, and each CN holds the binding information that indicates that MN-CoA is the AGR address. If the CoAs of all MNs in the moving network are changed due to handoff, the MNs do not need to send handoff signals to each CN. They only send handoff signals to the AGR. This localizes the handoff signals. Furthermore, we aggregate them if MR sends a handoff signal to AGR instead of all MNs. Moreover, the binding information that MN-CoA is AGR address can also be registered at each HA of each MN in the moving network..

All packets destined to MNs in a moving network are carried via the AGR. Therefore, the AGR should be placed at the optimal location considering the movement characteristics of the moving network, the location of each CN and so forth. If necessary, the AGR must be relocated. The AGR location should be chosen so that no roundabout communication paths are created between MNs to CNs as a result of network movement (factor (1)). Also, the frequency of AGR relocations should be minimized (factor (2)). If the AGR is located near the moving network, i.e. in the lower part of the core network, each communication path can be optimized and the handoff procedure can be localized (factor (3)). However, this increases the frequency of AGR relocations due to handoff. On the other hand, if the AGR is located in the higher part of the core network, the communication paths may not be optimal and the handoff procedure may not be localized. Fortunately, AGR relocation, which is an expensive procedure, rarely occurs. As described above, there is a trade-off between factors (1)-(3). The determination of the optimal AGR location requires attention to all these factors.

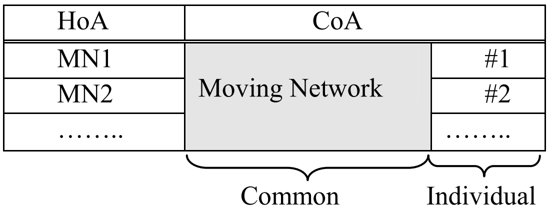


Figure 5: Hierarchical Address Management

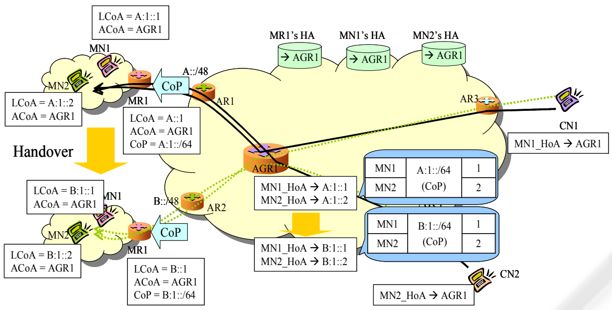


Figure 6: Care of Prefix Routing on MIP

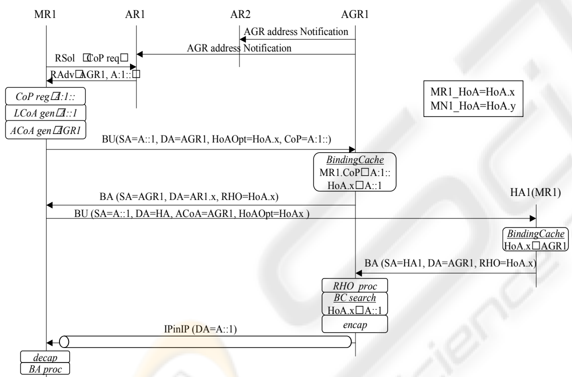


Figure 7: MR joins

3.4 Hierarchical Address Management

Even if the techniques described in Sections 3.1 to 3.3 are used, it is still necessary to inform the AGR and the MR's HA of the updated CoAs, as all CoAs are changed when a moving network moves. The volume of handoff signals depends on the number of MNs in a moving network. Therefore, the data volume of handoff signals can become very large. To achieve seamless handoff, it is important to reduce the number of handoff signals. Hierarchical Address Management provides a solution to this problem (Fig. 5).

In Hierarchical Address Management, the CoA of each MN in a moving network is divided into the common information and the individual information. The common information indicates the location of the moving network, and this is changed when handoff occurs. On the other hand, the individual information indicates the location of each MN in a moving network, and this need not be changed even if handoff occurs. CoP, as mentioned in Section 3.1, makes this address management possible because an AR allocates an individual prefix using the same subnet mask as given to the moving network to avoid generating duplicate CoAs. The MR connected to the core network, the AGR, and the MR's HA manages the binding information using this management technique. Thus, handoff can be achieved by updating only the common information. As mentioned above, Hierarchical Address Management solves the problem by reducing handoff signal volume, not quantity.

In short, Hierarchical Address Management along with Concatenated HAs and AGR make it possible to meet requirement (3) for seamless handoff.

4 CARE-OF-PREFIX ROUTING IN A MOBILE IP NETWORK

Combining the basic techniques described in Sections 3.1 to 3.4 can yield a new routing mechanism for moving network mobility support that has the same performance as host mobility support. We call it Care-of-Prefix Routing (CoPR). Figure 6 provides an overview of CoPR. Here, the HA of each MN in the moving network holds the binding information indicating that the CoA of each MN is the AGR address. Thus, Concatenated HAs is omitted. The following details the specification of CoPR.

Figure 7 shows the sequence for connecting MR1 to AR1. AGR1 sends its address to AR1 and AR2, which are connected as the subordinate of AGR1. When MR1 connects to AR1, MR1 sends a Router Solicitation (RSol) (Johnson, 2004) containing a request for a CoP. Next, AR1 sends a Router Advertisement (RAdv) (Johnson, 2004) containing the CoP (A:1::) to MR1 and AGR1. After that, MR1 creates its on-Link CoA (LCoA) (Johnson, 2004) (A::1), sets the AGR1 address as its Alternate CoA (ACoA) (Johnson, 2004), and registers its CoP. MR1 then sends a Binding Update (BU) (Johnson, 2004) containing its LCoA and CoP to AGR1, which registers the binding information. Also, MR1 sends a

BU to the HA of MR1 to register the AGR1 address as its ACoA.

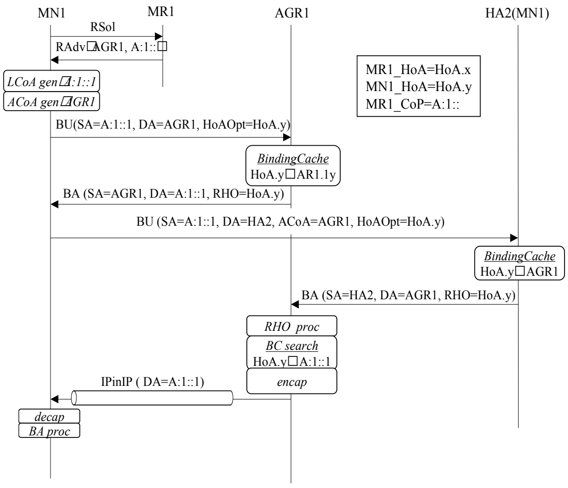


Figure 8: MN joins

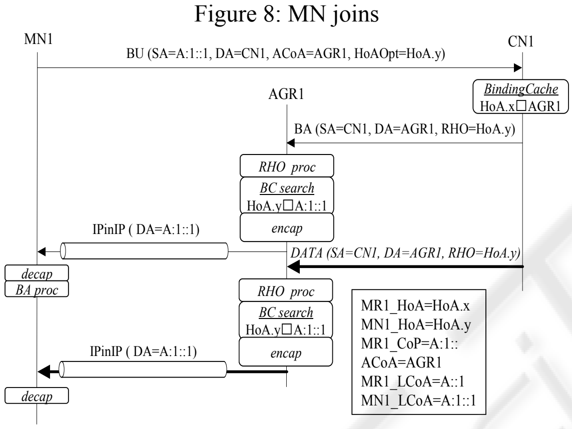


Figure 9: Optimization of the route to CN

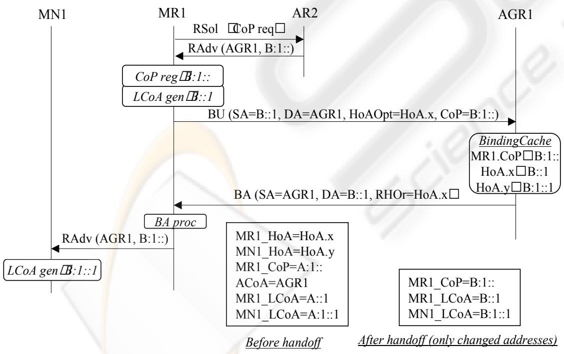
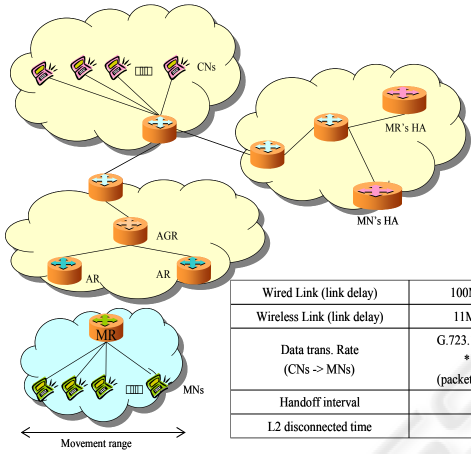


Figure 10: Handoff

Figure 8 shows the sequence for connecting MN1 to MR1 in the case where MR1 is already connected to AR1. MN1 creates its LCoA (A:1::1) and its ACoA (AGR1 address) from the RAdv received from MR1. Next, MN1 sends a BU with its LCoA to AGR1, and a BU containing the ACoA to its HA. At that time, AGR1 caches the relation that MN-CoA1 is from the CoP of MR1.



Wired Link (link delay)	100Mbps (1ms)
Wireless Link (link delay)	11Mbps (1ms)
Data trans. Rate (CNs -> MNs)	G.723.1(6.3Kbps) * Num. of MNs (packet size: 24byte)
Handoff interval	2s
L2 disconnected time	20ms

Figure 11: Simulation Conditions

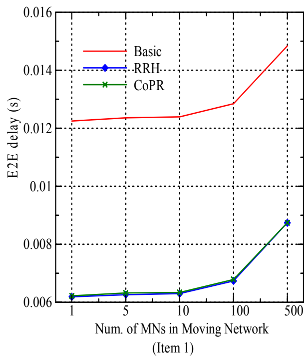
Figure 9 shows the sequence of route optimization from CN1 to MN1. MN1 sends a BU to register the binding information that MN-CoA1 is ACoA (AGR1 address). In this situation, CN1 can send packets destined to MN1 via AGR1 using RHO. AGR1 encapsulates this packet with the LCoA (A:1::1) of MN1 after locating the LCoA (A:1::1) of MN1 in its binding cache and transmits this packet to MN1.

Figure 10 shows the sequence triggered by moving network handoff. MR1 updates its CoP and informs AGR1 of the update, after getting the new CoP (B:1::). The subnet mask of this new CoP should be the same as that of the previous CoP (A:1::). When AGR1 updates the CoP of MR1, AGR1 also updates all the LCoAs of all MNs since they are also subordinates of MR1. More precisely, only the common information is updated, since MN1 creates its new LCoA after receiving RAdv, which contains the new CoP (B:1::) sent by MR1. In CoPR, MN-CoA1 (B:1::1), which AGR1 manages, has already been updated so that it is not necessary for MN1 to send a BU to AGR1. In this way, BUs can be omitted from each MN in the moving network to the AGR. If the AGR address is changed, it is necessary to update ACoAs of MN1 and MR1.

5 PERFORMANCE EVALUATION

We have evaluated CoPR, Basic and RRH, using network simulator 2. Figure 11 shows the parameters and the topology used in the simulation.

This simulation assumed that the AGR location was optimal, as shown in Figure 11. The simulation time was 10 seconds, and the first 2 seconds were discarded to eliminate the influence of jitter. We evaluated each mechanism assuming 1, 5, 10, 100,



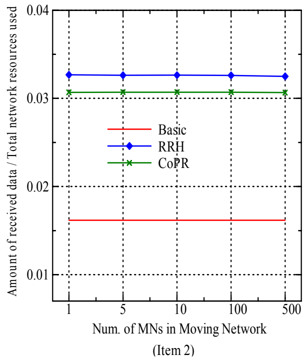
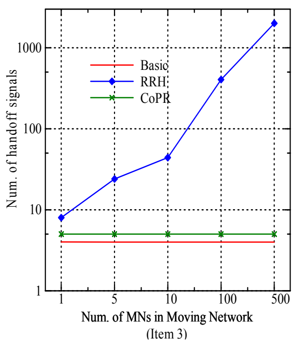


Figure 12: Comparison over Num. of MNs (Item 1).

Figure 13: Comparison over Num. of MNs (Item 2)



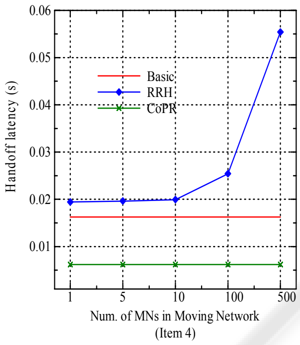


Figure 14: Comparison over Num. of MNs (Item 3)

Figure 15: Comparison over Num. of MNs (Item 4)

and 500 MNs in the moving network. The following items were evaluated:

(1) E2E delay

(2) Amount of received data / total network resources used

(3) Handoff signal overhead

(4) Handoff latency

(5) Amount of packet loss

Item 1 is the mean delay of packet transmission from a CN to an MN in the moving network, and indicates the degree of route optimization. Item 2 indicates the throughput on each hop. This should increase if the route is optimized, packet header size is minimized, and discarded packets are minimized. The inverse of this measure indicates the network resource that should be provided for given traffic. Item 3 is the number of handoff signals, i.e. RSol, RAdv, BU, and Binding Ack (BA) (Johnson, 2004), per handoff. Item 4 is the mean time from handoff initiation to completion. Item 5 is the total discarded packets caused by the handoff. Items 3 to 5 also indicate handoff performance.

Comparisons for items 1 and 2 for various numbers of MNs are shown in Figures 12 and 13.

With respect to items 1 and 2, the results of CoPR are good as shown in each figure. This is because CoPR implements both route optimization and minimization of packet header size.

With regard to item 1, CoPR is superior to Basic in terms of performance regardless of the number of MNs. The degree of superiority would increase if the HA is separated from the MR, because the packets must pass through the bidirectional tunnel from the MR to its HA. On the other hand, CoPR and RRH offer similar levels of performance since both of them optimize routing.

With regard to item 2, the ratio of CoPR performance to those of the conventional methods is almost independent of the number of MNs. The ratio is 1.90 when compared to Basic. This shows that CoPR transmits data more efficiently than Basic. This difference is due to the difference in encapsulation distance of Basic and CoPR. Basic uses a longer encapsulation distance, from the MR to its HA, whereas CoPR encapsulates only the route from the MN to the AGR. On the other hand, the performance ratio is 0.94 for RRH. The reason is as follows. In RRH, packets are transmitted with an RHO that sets two CoAs, MR-CoA and MN-CoA, from the CN to the MN. In comparison, in CoPR, the packets are transmitted with an RHO that sets one AGR address from the CN to the AGR, and also by encapsulation from the AGR to the MN. Therefore, CoPR is better and this ratio is larger if the CN is farther from the moving network than considered in this simulation environment. The reciprocal of item 2 represents the network resources needed to support the traffic of a new service. In other words, increasing item 2 makes it cheaper to put a service into operation.

Items 3 and 4 for RRH change rapidly with the number of MNs. Figures 14 and 15 show the comparisons for various numbers of MNs.

With regard to item 3, both Basic and CoPR offer low and constant values. On the other hand, in RRH, increasing the number of MNs increases the number of handoff signals. Specifically, if the number of MNs is 500, CoPR has about the same level of performance as Basic, while it requires 2,000 fewer handoff signals than RRH. The reason is that RRH demands that all MNs in the moving network send a BU to each CN and HA.

For item 4, the performance ratio of CoPR to Basic is 0.38, regardless of the number of MNs. This difference depends on the BU destination. If the HA of the MR is located farther from the moving network than considered in this simulation environment, the degree of superiority of CoPR would increase. On the other hand, the ratio of CoPR to RRH depends on the number of MNs, e.g. 0.32 with one MN, 0.11 with 500 MNs. This shows that CoPR has lower handoff latency than RRH. The superiority of CoPR over RRH is due to the fact that the BU destination is only the AGR in CoPR, compared to all CNs and all HAs in RRH. Therefore, if the number of CNs and MNs in the moving network is increased or the distance between an MN and its HA, or between an MN and a CN is increased, the handoff latency of RRH increases dramatically. In short, CoPR is much better than RRH.

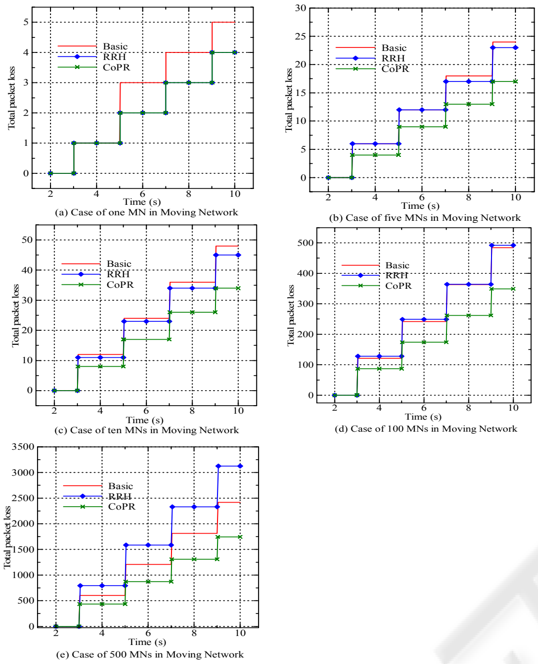


Figure 16: Comparison on each case (Item 5)

Figure 16 shows the comparisons for different numbers of MNs regarding item 5, i.e., the total packet loss. As these figures show, the amount of discarded packets on CoPR is the smallest of the three methods, regardless of the number of MNs. Additionally, the three methods have different time ranges of discarded packets. For Basic, it is from the L2 disconnect time until the binding information that the MR's HA manages is updated. For RRH, it is from the L2 disconnect time until the binding information that each CN manages is updated. For CoPR, it is from the L2 disconnect time until the binding information the AGR manages is updated. This value of RRH becomes worse than those of the other methods as the number of MNs increases. This is because the number of handoff signals increases as the number of MNs grows.

6 CONCLUSION

This paper clarified the difference between host mobility support and conventional moving network mobility support, and proposed new routing mechanisms for moving network mobility support that meet all requirements. Specifically, this paper proposed four basic techniques: Care of Prefix, which minimizes the packet header size, Concatenated HAs and Hierarchical Address Management, which reduce the number and volume of handoff signals, Aggregate Router, which aggregates and localizes handoff signals, and CoPR, which is a mechanism for applying these basic techniques to MIP.

We verified the effectiveness of our proposed mechanisms using network simulator 2. Quantitative analyses showed that CoPR is the best in terms of five measures: E2E delay, amount of effective received data / total used network resources, amount of handoff signals, handoff latency, and amount of discarded packets. As mentioned above, CoPR is superior to the conventional solutions proposed in NEMO. We will construct an experimental system and verify the feasibility of the proposal mechanisms.

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