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Network Mobility Route Optimization Problem Statement

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Abstract

With current Network Mobility (NEMO) Basic Support, all communications to and from Mobile Network Nodes must go through the bi-directional tunnel established between the Mobile Router and Home Agent when the mobile network is away. This sub-optimal routing results in various inefficiencies associated with packet delivery, such as increased delay and bottleneck links leading to traffic congestion, which can ultimately disrupt all communications to and from the Mobile Network Nodes. Additionally, with nesting of Mobile Networks, these inefficiencies get compounded, and stalemate conditions may occur in specific dispositions. This document investigates such problems and provides the motivation behind Route Optimization (RO) for NEMO.

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1. Introduction

With current Network Mobility (NEMO) Basic Support [1], all communications to and from nodes in a mobile network must go through the bi-directional tunnel established between the Mobile Router and its Home Agent (also known as the MRHA tunnel) when the mobile network is away. Although such an arrangement allows Mobile Network Nodes to reach and be reached by any node on the Internet, limitations associated to the base protocol degrade overall performance of the network and, ultimately, can prevent all communications to and from the Mobile Network Nodes.

Some of these concerns already exist with Mobile IPv6 [4] and were addressed by the mechanism known as Route Optimization, which is part of the base protocol. With Mobile IPv6, Route Optimization mostly improves the end-to-end path between the Mobile Node and Correspondent Node, with an additional benefit of reducing the load of the Home Network, thus its name.

NEMO Basic Support presents a number of additional issues, making the problem more complex, so it was decided to address Route Optimization separately. In that case, the expected benefits are more dramatic, and a Route Optimization mechanism could enable connectivity that would be broken otherwise. In that sense, Route Optimization is even more important to NEMO Basic Support than it is to Mobile IPv6.

This document explores limitations inherent in NEMO Basic Support, and their effects on communications between a Mobile Network Node and its corresponding peer. This is detailed in Section 2. It is expected that readers are familiar with general terminologies related to mobility in [4][2], NEMO-related terms defined in [3], and NEMO goals and requirements [5].

2. NEMO Route Optimization Problem Statement

Given the NEMO Basic Support protocol, all data packets to and from Mobile Network Nodes must go through the Home Agent, even though a shorter path may exist between the Mobile Network Node and its Correspondent Node. In addition, with the nesting of Mobile Routers, these data packets must go through multiple Home Agents and several levels of encapsulation, which may be avoided. This results in various inefficiencies and problems with packet delivery, which can ultimately disrupt all communications to and from the Mobile Network Nodes.

In the following sub-sections, we will describe the effects of a pinball route with NEMO Basic Support, how it may cause a bottleneck to be formed in the Home Network, and how these get amplified with

nesting of mobile networks. Closely related to nesting, we will also look into the sub-optimality even when Mobile IPv6 Route Optimization is used over NEMO Basic Support. This is followed by a description of security policy in the Home Network that may forbid transit traffic from Visiting Mobile Nodes in mobile networks. In addition, we will explore the impact of the MRHA tunnel on communications between two Mobile Network Nodes on different links of the same mobile network. We will also provide additional motivations for Route Optimization by considering the potential stalemate situation when a Home Agent is part of a mobile network.

2.1. Sub-Optimality with NEMO Basic Support

With NEMO Basic Support, all packets sent between a Mobile Network Node and its Correspondent Node are forwarded through the MRHA tunnel, resulting in a pinball route between the two nodes. This has the following sub-optimal effects:

- o Longer Route Leading to Increased Delay and Additional Infrastructure Load

Because a packet must transit from a mobile network to the Home Agent then to the Correspondent Node, the transit time of the packet is usually longer than if the packet were to go straight from the mobile network to the Correspondent Node. When the Correspondent Node (or the mobile network) resides near the Home Agent, the increase in packet delay can be very small. However, when the mobile network and the Correspondent Node are relatively near to one another but far away from the Home Agent on the Internet, the increase in delay is very large. Applications such as real-time multimedia streaming may not be able to tolerate such increase in packet delay. In general, the increase in delay may also impact the performance of transport protocols such as TCP, since the sending rate of TCP is partly determined by the round-trip time (RTT) perceived by the communication peers.

Moreover, by using a longer route, the total resource utilization for the traffic would be much higher than if the packets were to follow a direct path between the Mobile Network Node and Correspondent Node. This would result in additional load in the infrastructure.

- o Increased Packet Overhead

The encapsulation of packets in the MRHA tunnel results in increased packet size due to the addition of an outer header. This reduces the bandwidth efficiency, as an IPv6 header can be

quite substantial relative to the payload for applications such as voice samples. For instance, given a voice application using an 8 kbps algorithm (e.g., G.729) and taking a voice sample every 20 ms (as in RFC 1889 [6]), the packet transmission rate will be 50 packets per second. Each additional IPv6 header is an extra 320 bits per packet (i.e., 16 kbps), which is twice the actual payload!

- o Increased Processing Delay

The encapsulation of packets in the MRHA tunnel also results in increased processing delay at the points of encapsulation and decapsulation. Such increased processing may include encryption/decryption, topological correctness verifications, MTU computation, fragmentation, and reassembly.

- o Increased Chances of Packet Fragmentation

The augmentation in packet size due to packet encapsulation may increase the chances of the packet being fragmented along the MRHA tunnel. This can occur if there is no prior path MTU discovery conducted, or if the MTU discovery mechanism did not take into account the encapsulation of packets. Packet fragmentation will result in a further increase in packet delays and further reduction of bandwidth efficiency.

- o Increased Susceptibility to Link Failure

Under the assumption that each link has the same probability of link failure, a longer routing path would be more susceptible to link failure. Thus, packets routed through the MRHA tunnel may be subjected to a higher probability of being lost or delayed due to link failure, compared to packets that traverse directly between the Mobile Network Node and its Correspondent Node.

2.2. Bottleneck in the Home Network

Apart from the increase in packet delay and infrastructure load, forwarding packets through the Home Agent may also lead to either the Home Agent or the Home Link becoming a bottleneck for the aggregated traffic from/to all the Mobile Network Nodes. A congestion at home would lead to additional packet delay, or even packet loss. In addition, Home Agent operations such as security check, packet interception, and tunneling might not be as optimized in the Home Agent software as plain packet forwarding. This could further limit the Home Agent capacity for data traffic. Furthermore, with all traffic having to pass through the Home Link, the Home Link becomes a single point of failure for the mobile network.

Data packets that are delayed or discarded due to congestion at the Home Network would cause additional performance degradation to applications. Signaling packets, such as Binding Update messages, that are delayed or discarded due to congestion at the Home Network may affect the establishment or update of bi-directional tunnels, causing disruption of all traffic flow through these tunnels.

A NEMO Route Optimization mechanism that allows the Mobile Network Nodes to communicate with their Correspondent Nodes via a path that is different from the MRHA tunneling and thereby avoiding the Home Agent may alleviate or even prevent the congestion at the Home Agent or Home Link.

2.3. Amplified Sub-Optimality in Nested Mobile Networks

By allowing other mobile nodes to join a mobile network, and in particular mobile routers, it is possible to form arbitrary levels of nesting of mobile networks. With such nesting, the use of NEMO Basic Support further amplifies the sub-optimality of routing. We call this the amplification effect of nesting, where the undesirable effects of a pinball route with NEMO Basic Support are amplified with each level of nesting of mobile networks. This is best illustrated by an example shown in Figure 1.

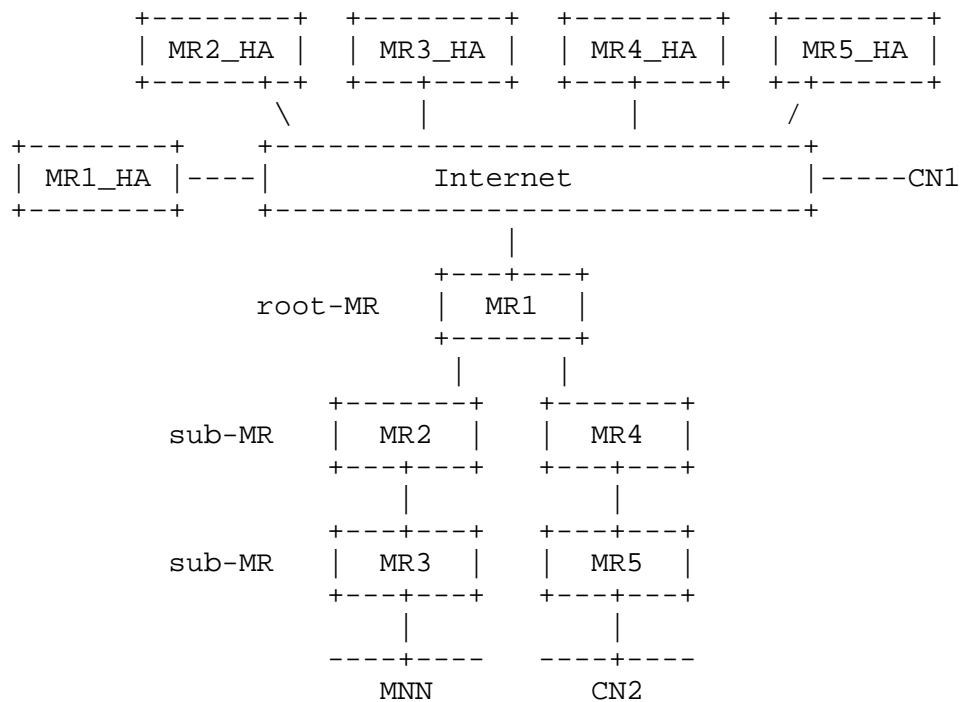


Figure 1: An Example of a Nested Mobile Network

Using NEMO Basic Support, the flow of packets between a Mobile Network Node, MNN, and a Correspondent Node, CN1, would need to go through three separate tunnels, illustrated in Figure 2 below.

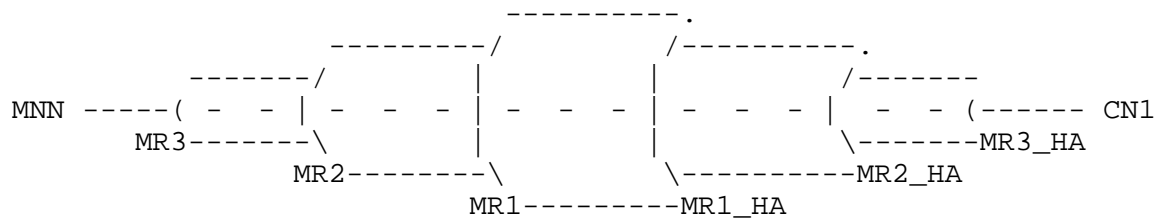


Figure 2: Nesting of Bi-Directional Tunnels

This leads to the following problems:

- o Pinball Route

Both inbound and outbound packets will flow via the Home Agents of all the Mobile Routers on their paths within the mobile network, with increased latency, less resilience, and more bandwidth usage. Appendix A illustrates in detail the packets' routes under different nesting configurations of the Mobile Network Nodes.

- o Increased Packet Size

An extra IPv6 header is added per level of nesting to all the packets. The header compression suggested in [7] cannot be applied because both the source and destination (the intermediate Mobile Router and its Home Agent) are different hop to hop.

Nesting also amplifies the probability of congestion at the Home Networks of the upstream Mobile Routers. In addition, the Home Link of each upstream Mobile Router will also be a single point of failure for the nested Mobile Router.

2.4. Sub-Optimality with Combined Mobile IPv6 Route Optimization

When a Mobile IPv6 host joins a mobile network, it becomes a Visiting Mobile Node of the mobile network. Packets sent to and from the Visiting Mobile Node will have to be routed not only via the Home Agent of the Visiting Mobile Node, but also via the Home Agent of the Mobile Router in the mobile network. This suffers the same amplification effect of nested mobile network mentioned in Section 2.3.

In addition, although Mobile IPv6 [4] allows a mobile host to perform Route Optimization with its Correspondent Node in order to avoid tunneling with its Home Agent, the "optimized" route is no longer optimized when the mobile host is attached to a mobile network. This is because the route between the mobile host and its Correspondent Node is subjected to the sub-optimality introduced by the MRHA tunnel. Interested readers may refer to Appendix A for examples of how the routes will appear with nesting of Mobile IPv6 hosts in mobile networks.

The readers should also note that the same sub-optimality would apply when the mobile host is outside the mobile network and its Correspondent Node is in the mobile network.

2.5. Security Policy Prohibiting Traffic from Visiting Nodes

NEMO Basic Support requires all traffic from visitors to be tunneled to the Mobile Router's Home Agent. This might represent a breach in the security of the Home Network (some specific attacks against the Mobile Router's binding by rogue visitors have been documented in [8][9]). Administrators might thus fear that malicious packets will be routed into the Home Network via the bi-directional tunnel. As a consequence, it can be expected that in many deployment scenarios, policies will be put in place to prevent unauthorized Visiting Mobile Nodes from attaching to the Mobile Router.

However, there are deployment scenarios where allowing unauthorized Visiting Mobile Nodes is actually desirable. For instance, when Mobile Routers attach to other Mobile Routers and form a nested NEMO, they depend on each other to reach the Internet. When Mobile Routers have no prior knowledge of one another (no security association, Authentication, Authorization, and Accounting (AAA), Public-Key Infrastructure (PKI), etc.), it could still be acceptable to forward packets, provided that the packets are not tunneled back to the Home Networks.

A Route Optimization mechanism that allows traffic from Mobile Network Nodes to bypass the bi-directional tunnel between a Mobile Router and its Home Agent would be a necessary first step towards a Tit for Tat model, where MRs would benefit from a reciprocal altruism, based on anonymity and innocuousness, to extend the Internet infrastructure dynamically.

2.6. Instability of Communications within a Nested Mobile Network

Within a nested mobile network, two Mobile Network Nodes may communicate with each other. Let us consider the previous example illustrated in Figure 1 where MNN and CN2 are sharing a communication session. With NEMO Basic Support, a packet sent from MNN to CN2 will need to be forwarded to the Home Agent of each Mobile Router before reaching CN2, whereas, a packet following the direct path between them need not even leave the mobile network. Readers are referred to Appendix A.3 for detailed illustration of the resulting routing paths.

Apart from the consequences of increased packet delay and packet size, which are discussed in previous sub-sections, there are two additional effects that are undesirable:

- o when the nested mobile network is disconnected from the Internet (e.g., MR1 loses its egress connectivity), MNN and CN2 can no

longer communicate with each other, even though the direct path from MNN to CN2 is unaffected;

- o the egress link(s) of the root Mobile Router (i.e., MR1) becomes a bottleneck for all the traffic that is coming in and out of the nested mobile network.

A Route Optimization mechanism could allow traffic between two Mobile Network Nodes nested within the same mobile network to follow a direct path between them, without being routed out of the mobile network. This may also off-load the processing burden of the upstream Mobile Routers when the direct path between the two Mobile Network Nodes does not traverse these Mobile Routers.

2.7. Stalemate with a Home Agent Nested in a Mobile Network

Several configurations for the Home Network are described in [10]. In particular, there is a mobile home scenario where a (parent) Mobile Router is also a Home Agent for its mobile network. In other words, the mobile network is itself an aggregation of Mobile Network Prefixes assigned to (children) Mobile Routers.

A stalemate situation exists in the case where the parent Mobile Router visits one of its children. The child Mobile Router cannot find its Home Agent in the Internet and thus cannot establish its MRHA tunnel and forward the visitor's traffic. The traffic from the parent is thus blocked from reaching the Internet, and it will never bind to its own (grandparent) Home Agent. Appendix B gives a detailed illustration of how such a situation can occur.

Then again, a Route Optimization mechanism that bypasses the nested tunnel might enable the parent traffic to reach the Internet and let it bind. At that point, the child Mobile Router would be able to reach its parent and bind in turn. Additional nested Route Optimization solutions might also enable the child to locate its Home Agent in the nested structure and bind regardless of whether or not the Internet is reachable.

3. Conclusion

With current NEMO Basic Support, all communications to and from Mobile Network Nodes must go through the MRHA tunnel when the mobile network is away. This results in various inefficiencies associated with packet delivery. This document investigates such inefficiencies and provides the motivation behind Route Optimization for NEMO.

We have described the sub-optimal effects of pinball routes with NEMO Basic Support, how they may cause a bottleneck to be formed in the Home Network, and how they get amplified with nesting of mobile networks. These effects will also be seen even when Mobile IPv6 Route Optimization is used over NEMO Basic Support. In addition, other issues concerning the nesting of mobile networks that might provide additional motivation for a NEMO Route Optimization mechanism were also explored, such as the prohibition of forwarding traffic from a Visiting Mobile Node through an MRHA tunnel due to security concerns, the impact of the MRHA tunnel on communications between two Mobile Network Nodes on different links of the same mobile network, and the possibility of a stalemate situation when Home Agents are nested within a mobile network.

4. Security Considerations

This document highlights some limitations of NEMO Basic Support. In particular, some security concerns could prevent interesting applications of the protocol, as detailed in Section 2.5.

Route Optimization for RFC 3963 [1] might introduce new threats, just as it might alleviate existing ones. This aspect will certainly be a key criterion in the evaluation of the proposed solutions.

5. Acknowledgments

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6. References

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Appendix A. Various Configurations Involving Nested Mobile Networks

In the following sections, we try to describe different communication models that involve a nested mobile network and to clarify the issues for each case. We illustrate the path followed by packets if we assume nodes only use Mobile IPv6 and NEMO Basic Support mechanisms. Different cases are considered where a Correspondent Node is located in the fixed infrastructure, in a distinct nested mobile network as the Mobile Network Node, or in the same nested mobile network as the Mobile Network Node. Additionally, cases where Correspondent Nodes and Mobile Network Nodes are either standard IPv6 nodes or Mobile IPv6 nodes are considered. As defined in [3], standard IPv6 nodes are nodes with no mobility functions whatsoever, i.e., they are not Mobile IPv6 or NEMO enabled. This means that they cannot move around keeping open connections and that they cannot process Binding Updates sent by peers.

A.1. CN Located in the Fixed Infrastructure

The most typical configuration is the case where a Mobile Network Node communicates with a Correspondent Node attached in the fixed infrastructure. Figure 3 below shows an example of such topology.

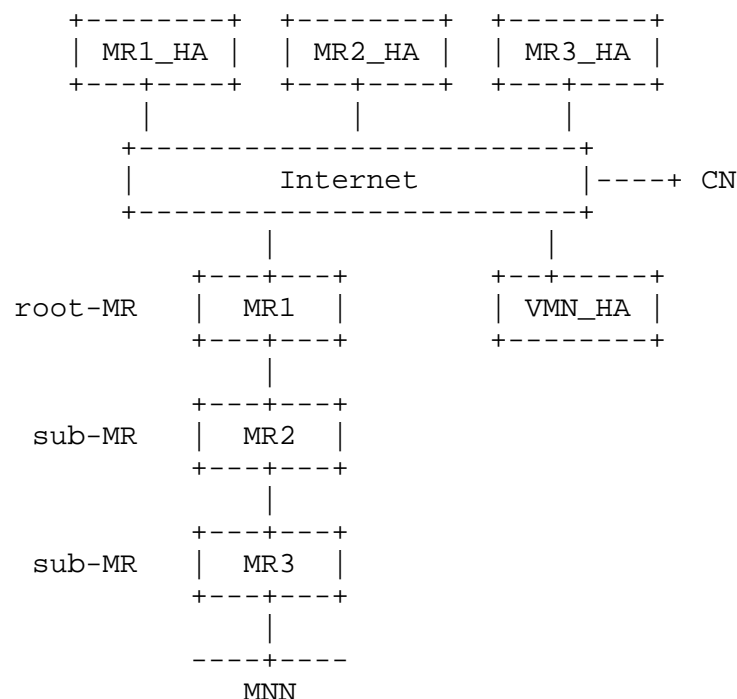


Figure 3: CN Located at the Infrastructure

A.1.1. Case A: LFN and Standard IPv6 CN

The simplest case is where both MNN and CN are fixed nodes with no mobility functions. That is, MNN is a Local Fixed Node, and CN is a standard IPv6 node. Packets are encapsulated between each Mobile Router and its respective Home Agent (HA). As shown in Figure 4, in such a case, the path between the two nodes would go through:

```

      1       2       3       4       3       2       1
MNN --- MR3 --- MR2 --- MR1 --- MR1_HA --- MR2_HA --- MR3_HA --- CN
LFN                                     IPv6 Node

```

The digits represent the number of IPv6 headers.

Figure 4: MNN and CN Are Standard IPv6 Nodes

A.1.2. Case B: VMN and MIPv6 CN

In this second case, both end nodes are Mobile IPv6-enabled mobile nodes, that is, MNN is a Visiting Mobile Node. Mobile IPv6 Route Optimization may thus be initiated between the two and packets would not go through the Home Agent of the Visiting Mobile Node or the Home Agent of the Correspondent Node (not shown in the figure). However, packets will still be tunneled between each Mobile Router and its respective Home Agent, in both directions. As shown in Figure 5, the path between MNN and CN would go through:

```

      1       2       3       4       3       2       1
MNN --- MR3 --- MR2 --- MR1 --- MR1_HA --- MR2_HA --- MR3_HA --- CN
VMN                                     MIPv6

```

Figure 5: MNN and CN Are MIPv6 Mobile Nodes

A.1.3. Case C: VMN and Standard IPv6 CN

When the communication involves a Mobile IPv6 node either as a Visiting Mobile Node or as a Correspondent Node, Mobile IPv6 Route Optimization cannot be performed because the standard IPv6 Correspondent Node cannot process Mobile IPv6 signaling. Therefore, MNN would establish a bi-directional tunnel with its HA, which causes the flow to go out the nested NEMO. Packets between MNN and CN would thus go through MNN's own Home Agent (VMN_HA). The path would therefore be as shown in Figure 6:

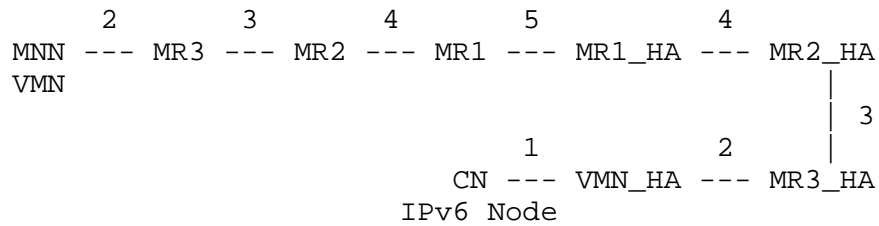


Figure 6: MNN is an MIPv6 Mobile Node and CN is a Standard IPv6 Node

Providing Route Optimization involving a Mobile IPv6 node may require optimization among the Mobile Routers and the Mobile IPv6 node.

A.2. CN Located in Distinct Nested NEMOs

The Correspondent Node may be located in another nested mobile network, different from the one MNN is attached to, as shown in Figure 7. We define such configuration as "distinct nested mobile networks".

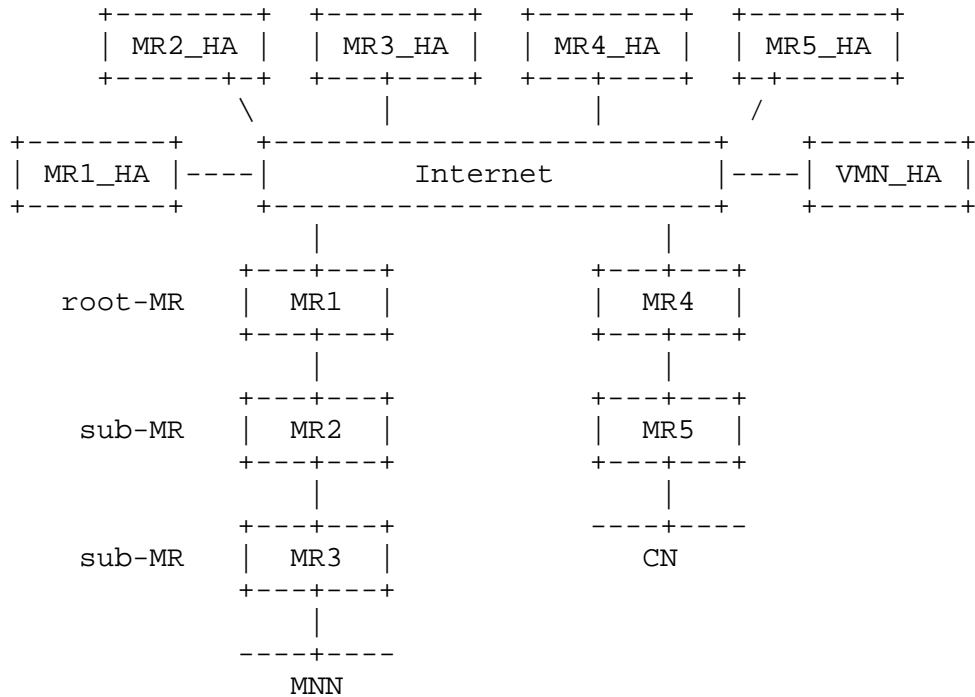


Figure 7: MNN and CN Located in Distinct Nested NEMOs

A.2.1. Case D: LFN and Standard IPv6 CN

Similar to Case A, we start off with the case where both end nodes do not have any mobility functions. Packets are encapsulated at every Mobile Router on the way out of the nested mobile network, decapsulated by the Home Agents, and then encapsulated again on their way down the nested mobile network.

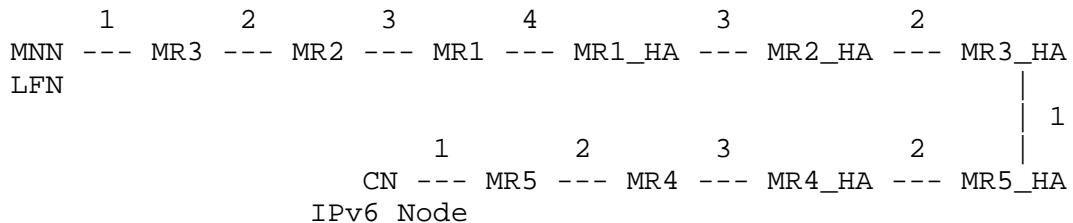


Figure 8: MNN and CN Are Standard IPv6 Nodes

A.2.2. Case E: VMN and MIPv6 CN

Similar to Case B, when both end nodes are Mobile IPv6 nodes, the two nodes may initiate Mobile IPv6 Route Optimization. Again, packets will not go through the Home Agent of the MNN or the Home Agent of the Mobile IPv6 Correspondent Node (not shown in the figure). However, packets will still be tunneled for each Mobile Router to its Home Agent and vice versa. Therefore, the path between MNN and CN would go through:

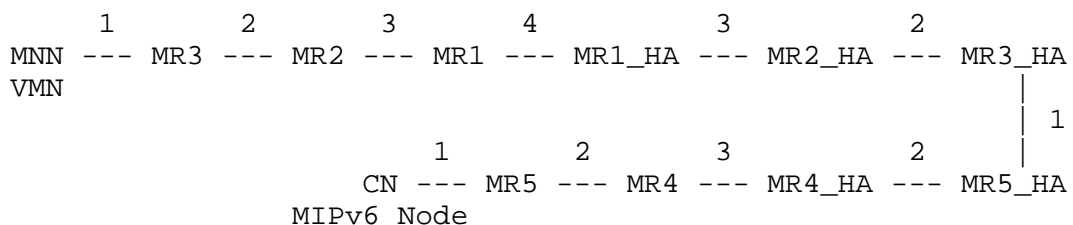


Figure 9: MNN and CN Are MIPv6 Mobile Nodes

A.2.3. Case F: VMN and Standard IPv6 CN

Similar to Case C, when the communication involves a Mobile IPv6 node either as a Visiting Mobile Node or as a Correspondent Node, MIPv6 Route Optimization cannot be performed because the standard IPv6 Correspondent Node cannot process Mobile IPv6 signaling. MNN would

therefore establish a bi-directional tunnel with its Home Agent. Packets between MNN and CN would thus go through MNN's own Home Agent as shown in Figure 10:

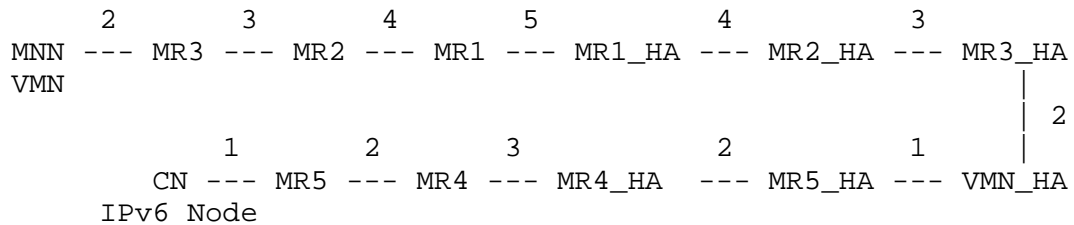


Figure 10: MNN is an MIPv6 Mobile Node and CN is a Standard IPv6 Node

A.3. MNN and CN Located in the Same Nested NEMO

Figure 11 below shows the case where the two communicating nodes are connected behind different Mobile Routers that are connected in the same nested mobile network, and thus behind the same root Mobile Router. Route Optimization can avoid packets being tunneled outside the nested mobile network.

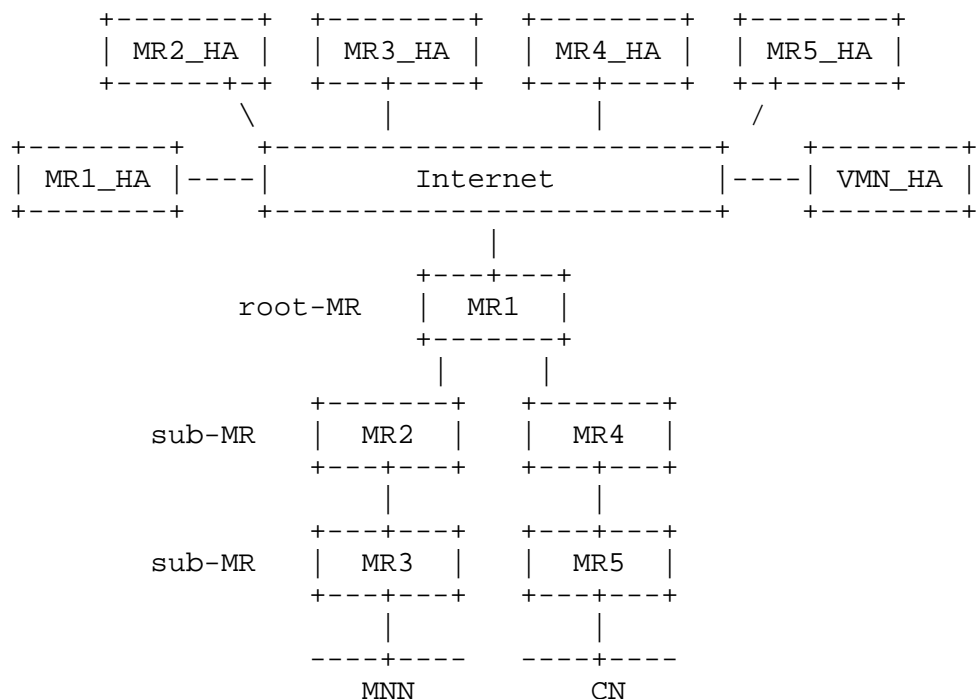


Figure 11: MNN and CN Located in the Same Nested NEMO

A.3.1. Case G: LFN and Standard IPv6 CN

Again, we start off with the case where both end nodes do not have any mobility functions. Packets are encapsulated at every Mobile Router on the way out of the nested mobile network via the root Mobile Router, decapsulated and encapsulated by the Home Agents, and then make their way back to the nested mobile network through the same root Mobile Router. Therefore, the path between MNN and CN would go through:

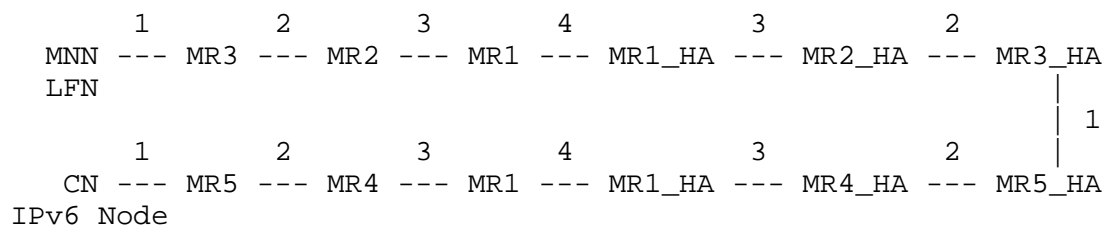


Figure 12: MNN and CN Are Standard IPv6 nodes

A.3.2. Case H: VMN and MIPv6 CN

Similar to Case B and Case E, when both end nodes are Mobile IPv6 nodes, the two nodes may initiate Mobile IPv6 Route Optimization, which will avoid the packets going through the Home Agent of MNN or the Home Agent of the Mobile IPv6 CN (not shown in the figure). However, packets will still be tunneled between each Mobile Router and its respective Home Agent in both directions. Therefore, the path would be the same as with Case G and go through:

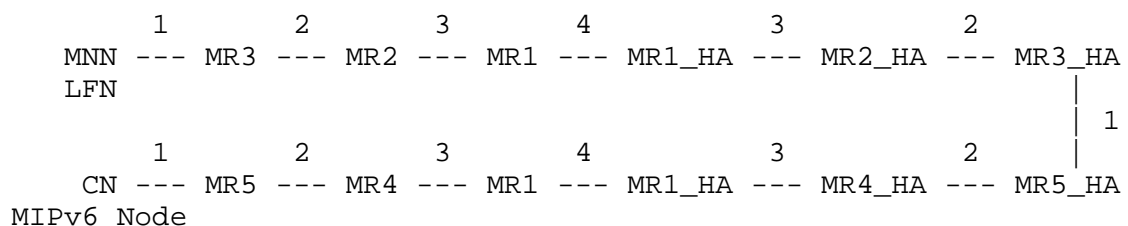


Figure 13: MNN and CN Are MIPv6 Mobile Nodes

A.3.3. Case I: VMN and Standard IPv6 CN

As for Case C and Case F, when the communication involves a Mobile IPv6 node either as a Visiting Mobile Node or as a Correspondent Node, Mobile IPv6 Route Optimization cannot be performed. Therefore, MNN will establish a bi-directional tunnel with its Home Agent. Packets between MNN and CN would thus go through MNN's own Home Agent. The path would therefore be as shown in Figure 14:

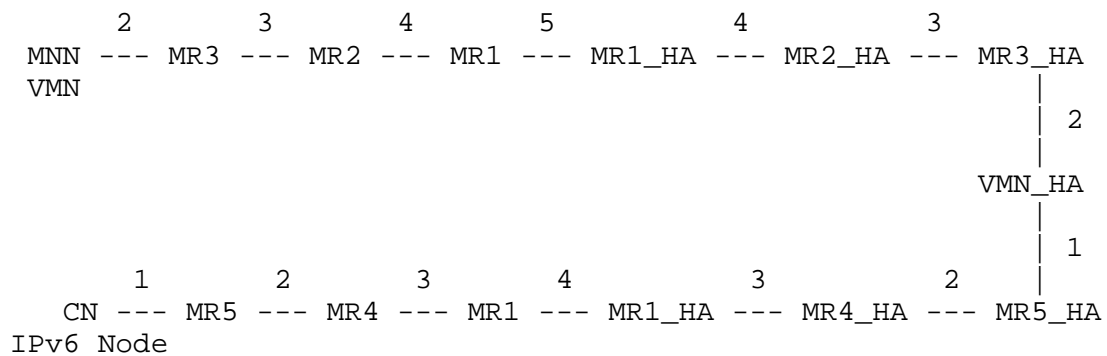


Figure 14: MNN is an MIPv6 Mobile Node and CN is a Standard IPv6 Node

A.4. CN Located Behind the Same Nested MR

Figure 15 below shows the case where the two communicating nodes are connected behind the same nested Mobile Router. The optimization is required when the communication involves MIPv6-enabled nodes.

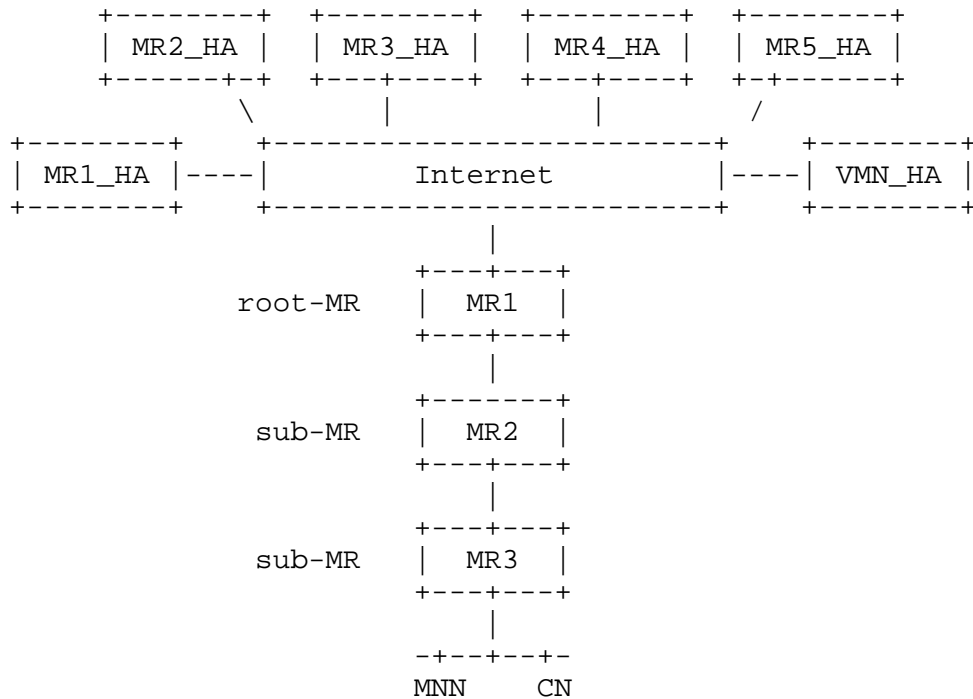


Figure 15: MNN and CN Located Behind the Same Nested MR

A.4.1. Case J: LFN and Standard IPv6 CN

If both end nodes are Local Fixed Nodes, no special function is necessary for optimization of their communications. The path between the two nodes would go through:

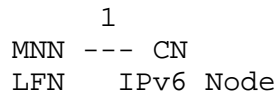


Figure 16: MNN and CN Are Standard IPv6 Nodes

A.4.2. Case K: VMN and MIPv6 CN

Similar to Case H, when both end nodes are Mobile IPv6 nodes, the two nodes may initiate Mobile IPv6 Route Optimization. Although few packets would go out the nested mobile network for the Return Routability initialization, however, unlike Case B and Case E, packets will not get tunneled outside the nested mobile network. Therefore, packets between MNN and CN would eventually go through:

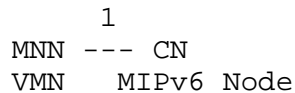


Figure 17: MNN and CN are MIPv6 Mobile Nodes

If the root Mobile Router is disconnected while the nodes exchange keys for the Return Routability procedure, they may not communicate even though they are connected on the same link.

A.4.3. Case L: VMN and Standard IPv6 CN

When the communication involves a Mobile IPv6 node either as a Visiting Mobile Network Node or as a Correspondent Node, Mobile IPv6 Route Optimization cannot be performed. Therefore, even though the two nodes are on the same link, MNN will establish a bi-directional tunnel with its Home Agent, which causes the flow to go out the nested mobile network. The path between MNN and CN would require another Home Agent (VMN_HA) to go through for this Mobile IPv6 node:

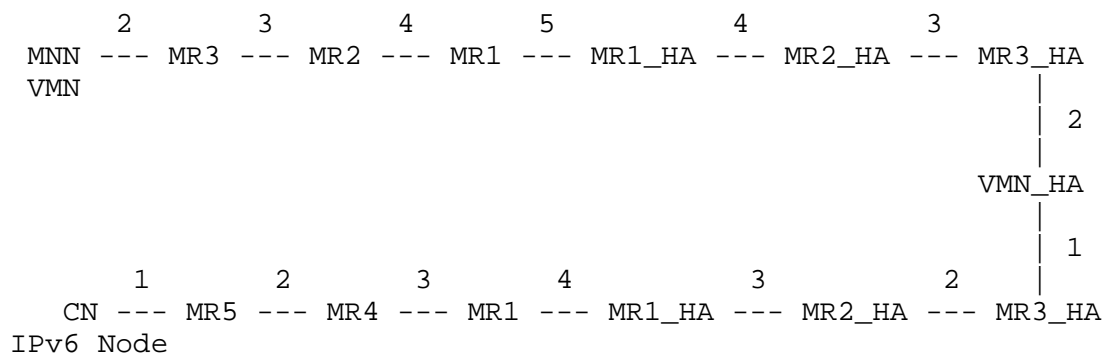


Figure 18: MNN is an MIPv6 Mobile Node and CN is a Standard IPv6 Node

However, MNN may also decide to use its Care-of Address (CoA) as the source address of the packets, thus avoiding the tunneling with the MNN's Home Agent. This is particularly useful for a short-term communications that may easily be retried if it fails. Default Address Selection [11] provides some mechanisms for controlling the choice of the source address.

Appendix B. Example of How a Stalemate Situation Can Occur

Section 2.7 describes the occurrence of a stalemate situation where a Home Agent of a Mobile Router is nested behind the Mobile Router. Here, we illustrate a simple example where such a situation can occur.

Consider a mobility configuration depicted in Figure 19 below. MR1 is served by HA1/BR and MR2 is served by HA2. The 'BR' designation indicates that HA1 is a border router. Both MR1 and MR2 are at home in the initial step. HA2 is placed inside the first mobile network, thus representing a "mobile" Home Agent.

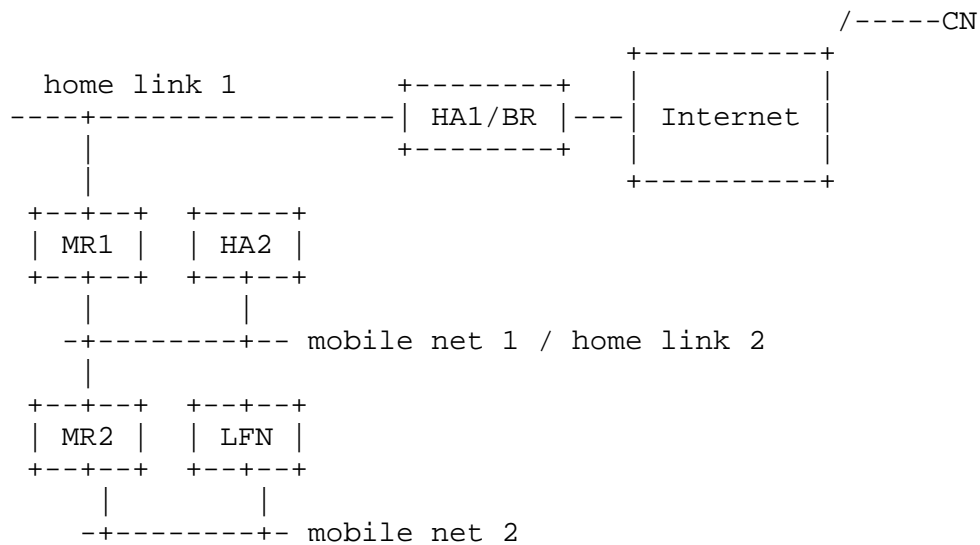


Figure 19: Initial Deployment

In Figure 19 above, communications between CN and LFN follow a direct path as long as both MR1 and MR2 are positioned at home. No encapsulation intervenes.

In the next step, consider that the MR2's mobile network leaves home and visits a foreign network, under Access Router (AR) like in Figure 20 below.

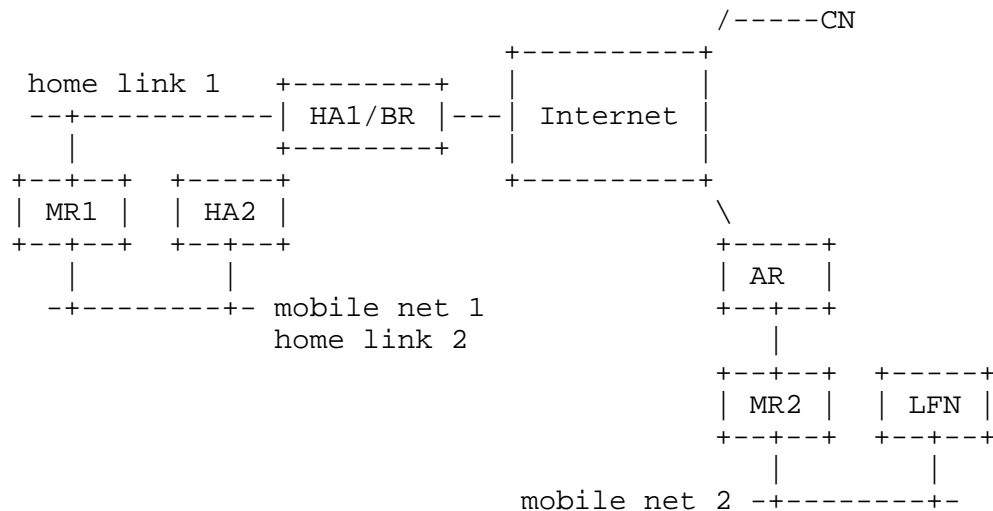


Figure 20: Mobile Network 2 Leaves Home

Once MR2 acquires a Care-of Address under AR, the tunnel setup procedure occurs between MR2 and HA2. MR2 sends a Binding Update to HA2 and HA2 replies with a Binding Acknowledgement to MR2. The bi-directional tunnel has MR2 and HA2 as tunnel endpoints. After the tunnel MR2HA2 has been set up, the path taken by a packet from CN towards LFN can be summarized as:

CN->BR->MR1->HA2=>MR1=>BR=>AR=>MR2->LFN.

Non-encapsulated packets are marked "->" while encapsulated packets are marked "=>".

Consider next the attachment of the first mobile network under the second mobile network, like in Figure 21 below.

After this movement, MR1 acquires a Care-of Address valid in the second mobile network. Subsequently, it sends a Binding Update (BU) message addressed to HA1. This Binding Update is encapsulated by MR2 and sent towards HA2, which is expected to be placed in mobile net 1 and expected to be at home. Once HA1/BR receives this encapsulated BU, it tries to deliver to MR1. Since MR1 is not at home, and a tunnel has not yet been set up between MR1 and HA1, HA1 is not able to route this packet and drops it. Thus, the tunnel establishment procedure between MR1 and HA1 is not possible, because the tunnel between MR2 and HA2 had been previously torn down (when the mobile net 1 moved from home). The communications between CN and LFN stops, even though both mobile networks are connected to the Internet.

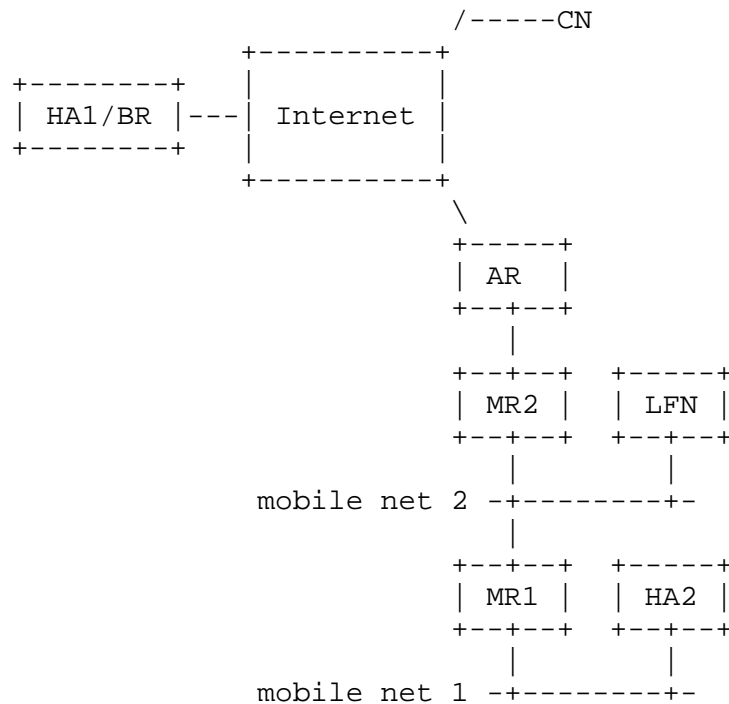


Figure 21: Stalemate Situation Occurs

If both tunnels between MR1 and HA1, and between MR2 and HA2, were up simultaneously, they would have "crossed over" each other. If the tunnels MR1-HA1 and MR2-HA2 were drawn in Figure 21, it could be noticed that the path of the tunnel MR1-HA1 includes only one endpoint of the tunnel MR2-HA2 (the MR2 endpoint). Two MR-HA tunnels are crossing over each other if the IP path between two endpoints of one tunnel includes one and only one endpoint of the other tunnel (assuming that both tunnels are up). When both endpoints of one tunnel are included in the path of the other tunnel, then tunnels are simply encapsulating each other.

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