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Evaluation of Nested Network Mobility Approaches

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Abstract: Due to the fast development of network technologies in the past few years, situations where not only a single node but an entire network roams and changes its point of attachment to the Internet has been revealed. However, an important requirement for any protocol supporting network mobility is to achieve continuous, optimal and secure communication to and from all nodes. Network Mobility (NEMO) developed by IETF is introduced for this purpose but it still suffers from some limitations. The main goal of this research is to study and evaluate the current approaches for mobility support in nested mobile networks. It introduces the main concepts of Mobile IPv6, which NEMO is extended from it and describes the basic functionality of Mobile Networks. More focus is given to nested Mobile Networks. In addition, this research aims to study and present the main approaches and researches done by Internet Engineering Task Force (IETF) regarding NEMO Basic Support. Lastly, discussion and evaluation will be performed on the current researches and protocols that are proposed to overcome the drawbacks of nested NEMO with highlighting their advantages and weaknesses.

Key words: Mobile IPv6, network mobility, nested NEMO, nested mobile networks, NEMO bs, mobile router

INTRODUCTION

Currently IPv6 communication is widely using wireless devices and mobile technologies. However, Mobile IP and Mobile IPv6 aim at maintaining Internet connectivity while a host is roaming, as users expect to be connected to the Internet from anywhere at anytime. Mobile IPv6, as Mobile IPv4, makes a mobile's movement (i.e., change of IPv6 address) transparent to the upper layer protocols and applications on the mobile as well as on correspondent nodes. Each MIPv6 mobile node has a home network and an IPv6 home address assigned to the MN within the network prefix of its home network. The MN's IPv6 home address does not have to change regardless of where the mobile is. A correspondent node can always address packets to a MN's IPv6 home address. Mobile IPv6 ensures that a MN can receive the packets addressed to its home address regardless of where the mobile is (Chen and Zhang, 2004).

The key benefit of Mobile IPv6 is that even though the MN changes locations and addresses, the existing connections through which the MN is communicating are maintained. To accomplish this, connections to MNs are made with a specific address that is always assigned to the MN and through which the MN is always reachable (Johnson and Perkins, 2004).

In Mobile IPv6, any mobile node is identified by its home address regardless of its point of attachment to the Internet. When the mobile node is located away from the home network, it is associated with a care-of-address. The Mobile IPv6 protocol requires registration of care-of-addresses with a home agent, thereby giving the home agent a mobile node's current attachment point to the Internet. The home agent then tunnels all the packets received for the mobile node to the node's present care-of-address. Figure 1 shows the tunneling operations in Mobile IP. The default encapsulation mechanism that must be supported by all mobility agents using Mobile IP is IP-within-IP. Using IP-within-IP, the home agent, the tunneling source, inserts a new IP header or tunnel header, in front of the IP header of any datagram addressed to the mobile node's home address. The new tunnel header uses the mobile node's care-of address as the destination IP address, or tunnel destination. The tunnel source IP Address is the home agent and the tunnel header uses 4 as the higher level protocol number, indicating that the next protocol header is again an IP header.

All correspondent nodes in Mobile lPv6 maintain a mapping of the mobile node's home address along with its current care-of-address. The mobile node is responsible for updating the mapping at the correspondent node

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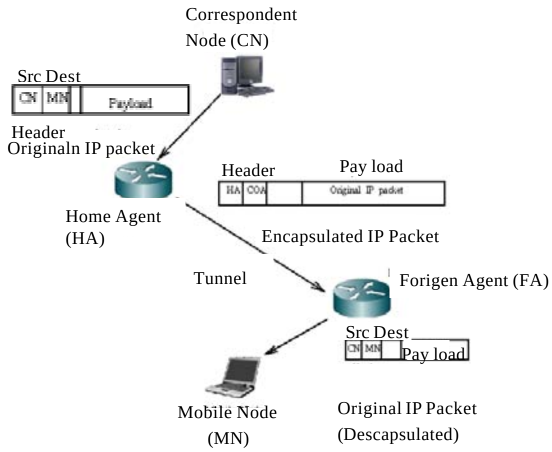

Fig. 1: IP tunneling

by sending binding update messages whenever it receives tunnelled packets from the home agent.

In addition, this research aims to study and present the main approaches and researches done by Internet Engineering Task Force (IETF) regarding NEMO Basic Support.

AN OVERVIEW OF NEMO

Extending from MIPv6 (Johnson *et al*., 2004), Internet Engineering Task Force (IETF) proposed Network Mobility (NEMO) basic support protocol (Devarapalli *et al*., 2005) to support network mobility management and to ensure communication continuity for nodes in the mobile network. A mobile network (Fig. 2) includes one or more Mobile Routers (MRs) that provides access to the Internet. The MR transmits the packet to Mobile Network Nodes (MNNs) via its ingress interface and accesses the Internet through its egress interface. Moreover, the MR performs the Binding Update (BU) to the Home Agent (HA) without additional registration such that NEMO can reduce the signaling overhead. When an MR is in its home network, it is connected directly to its HA so that all traffic to and from the mobile network is delivered via the HA and the MR. The mobile network is connected to the Internet via an IP-IP tunnel between the MR and the HA when the MR is away from home.

When a MR moves to a new network, it obtains a Care-of-address (CoA) and sends a Binding Update (BU) to it's HA. The BU binds the new CoA of the MR with its permanent address (home address). The HA sends a Binding Acknowledgment (BA) to inform the MR of the status of the update. A tunnel is then established between the CoA of the MR and the address of the HA.

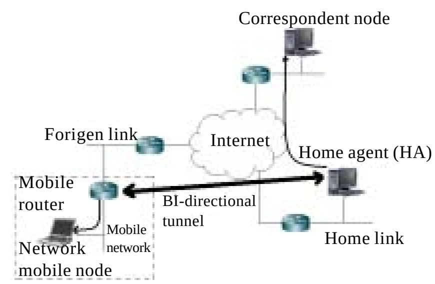

Fig. 2: Overview of NEMO BS protocol

The MR and its HA then deliver all traffic between the mobile network and the Internet via this tunnel. This overlay routing hides the mobility of the MR from the CNs and also from the MNNs. Thus, the MNNs do not need any mobility management capabilities to take advantage of the mobile Internet access (Petander *et al*., 2006).

The current point of attachment of the entire Mobile Network is hidden by MR; MRs announce their own prefix obtained on their home network and use a bidirectional tunnel with their home agent for all packets from and to MNNs. Therefore, all packets from MNNs will be tunneled to the home agent of the respective MR and there from routed to the relevant CN.

When an entire Mobile Network changes one of its point of attachment to the Internet, it can attach to a fixed link, or to another Mobile Network. In the second case, the aggregation of the two connected Mobile Network becomes a nested Mobile Network.

Although several advantages could be achieved by using NEMO Basic Support Protocol, such as reducing handoff overhead and power consuming, it still has several drawbacks. NEMO Basic Support suffers the pinball routing problem and non-optimal transmission paths (Thubert and Molteni, 2007) in the nested NEMO which further introducing significant delays and packet overheads.

Nested mobile network: In nested Mobile Network, the hierarchy of MRs increase the complexity of the route and/or router selection for MNNs. Each level of a Mobile Network implies the usage of a new tunnel between the MR and its home agent.

Figure 3 is a simple illustration of nested mobile network after two MRs move from home link to foreign link. In NEMO Basic, when a CN sends a packet to MN2 under the situation depicted in Fig. 3, the packet will pass through the tunnel between each MNN and its HA with the tunnel within a tunnel approach described by (Devarapalli *et al*., 2005). The packet from the CN

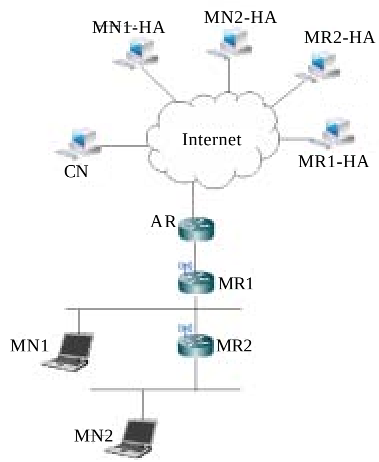

Fig. 3: Nested mobile network

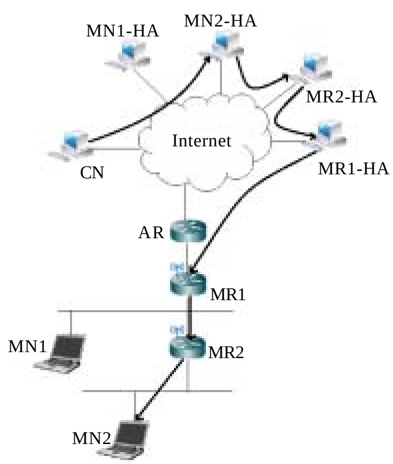

Fig. 4: NEMO basic operation with nested mobile networks

traverses through following sequence for routers as shown in Fig. 4.

Correspondent node (CN)→Mobile Node 2's Home Agent (MN2-HA)→Mobile Router 2's Home Agent (MR2-HA)→Mobile Router 1's home Agent (MR1-HA) →Mobile Router 1 (MR1)→Mobile Router 2 (MR2)→Mobile Node 2 (MN2).

As a result, NEMO Basic has some fundamental problems such as header overhead due to tunneling and high delay due to packet forwarding by HA. Moreover, with nested mobile networks, the problem increases with each nested level. In fact, exchanged packets must go through the HAs of all MRs of higher levels before reaching their destination. This is known as the pinball routing problem. Furthermore, IP-in-IP encapsulations lead also to high handoff latency that may imply packet losses and disconnections.

Internet engineering task force(IETF) contributions: Beside the standard document of NEMO Basic Support protocol (Devarapalli *et al*., 2005), the Network Working Group of IETF has contributed several RFCs (Informational documents) to highlight and analyze features and problems of NEMO Basic Support, in addition to many related Internet drafts issued by others. Next, a brief description about these RFCs and some Internet drafts will be presented:

- RFC4885 Network Mobility Support Terminology (Ernst and Lach, 2007) defines a terminology for discussing Network Mobility (NEMO) issues and solution requirements
- RFC4886 Network Mobility Support Goals and Requirements (Ernst, 2007) outlines the goals expected from network mobility support and defines the requirements that must be met by the NEMO Basic Support solution
- RFC4887 Network Mobility Home Network Models (Thubert *et al*., 2007) documents some of the usage patterns and the associated issues when deploying a Home Network for Network Mobility (NEMO)-enabled Mobile Routers, conforming to the NEMO Basic Support. The aim here is specifically to provide some examples of organization of the Home Network
- RFC4888 Network Mobility Route Optimization Problem Statement (Ng *et al*., 2007a) investigates sub-optimal routing problems especially with nesting of Mobile Networks and provides the motivation behind Route Optimization (RO) for NEMO
- RFC4889 Network Mobility Route Optimization Solution Space Analysis (Ng *et al*., 2007b) documents various types of Route Optimization in NEMO used to overcome the limitations of using (MRHA) tunnel and explores the benefits and tradeoffs in different aspects of NEMO Route Optimization
- RFC5177 Network Mobility (NEMO) Extensions for Mobile IPv4 (Leung *et al*., 2008) describes a protocol for supporting Mobile Networks between a Mobile Router and a Home Agent by extending the Mobile IPv4 protocol
- RFC5488 Network Mobility (NEMO) Management Information Base (Gundavelli *et al*., 2009) defines a portion of the Management Information Base(MIB), the Network Mobility (NEMO) support MIB, for use with network management protocols in the Internet community. In particular, the NEMO MIB

will be used to monitor and control a Mobile IPv6 node with NEMO functionality

RELATED WORKS

Many studies and researches have been conducted to solve the problems encountered by Mobile Networks. Kim, (2006) proposed a cost-effective mobility modelling in nested Network Mobility which is based on binding update multi-cast by various mobility patterns of mobile nodes in nested Network Mobility. This proposed scheme is combined Hierarchical Mobile IPv6 with Network Mobility because a mobile networks and mobile nodes move in tandem and create a hierarchy in the wireless network to management of micro-mobility and seamless handoff in a nested NEMO environment. This scheme can minimize binding update costs for MNNs and MRs by multicasting the binding update toward CNs. Thus, it performs much better than NEMO protocol, especially when the number of MNNs or MRs or CNs increases.

Chang *et al*. (2007) focussed on resolving pinball routing and RO storm problems for the nested NEMO by proposing a novel hierarchical Care-of Prefix (CoP) with the Binding Update Tree (BUT) scheme, which is called HCoP-B in this research. HCoP-B achieves shorter playback disruption time and buffering time for ongoing real-time applications executed by MNNs in the nested NEMO and thereby smaller buffer spaces for storing packets that need to be redirected to MNNs at its new location after handoff.

Reverse Routing Header (RRH) (Thubert and Molteni, 2007) which is similar to the MIP Loose Source Routing, is proposed in order to build a nested mobile network which avoids the nested tunnels overhead. It uses a type 4 routing header from the MN to record the Home Address (HoA) of each intermediate MR in the nested NEMO. As the packet arrives at the HA of the MN's serving MR, i.e., the closest MR, these routing information is stored in its binding cache for determining the optimal route of packets back to the MN in a type 2 routing header. In this way, RRH only needs to build a bidirectional tunnel between the MN's serving MR and the MR-HA, which resolves the pinball routing problem. However, RRH introduces extra packet length and processing overhead for the routing header of each packet, which increases with the number of levels of the nested mobile network. The CN and MR-HA need spaces to record routing information for each MN.

Based on NEMO BS, ROTIO, Cho *et al*. (2006) proposes a routing optimization scheme with the Extended Tree Information Option (xTIO) (Thubert *et al*., 2009). Each MR in the nested NEMO sends a normal BU, which contains the home address of the top-level mobile router (TLMR), to its home agent and a local BU, which contains routing information between the issuing MR and the TLMR, to the TLMR. ROTIO guarantees location privacy and mobility transparency. This scheme also achieves intra-NEMO route optimization and seamless handoff support by modifying router advertisement and binding update messages. ROTIO suffers only two levels of nested tunnels, i.e., one between the closest MR of the MN and the MR's HA and the other between the TLMR and the TLMR's HA, to send a packet from a CN to an MN in the nested NEMO. However, ROTIO suffers the non-optimal transmission path, increased packet overhead and TLMR/MR binding cache sizes.

The Care-of Prefix (CoP), Suzuki *et al*. (2005) proposed a routing mechanism using hierarchical mobile network prefix assignment and hierarchical re-routing to optimize the routing and to reduce handoff signal overheads. The CoP flow consists of three stages: (1) the prefix delegation; (2) the binding update and (3) packet re-transmission. CoP resolves the pinball routing problem without suffering significant packet overheads of RRH. As the NEMO is allocated a new CoP only one BU is sent by the TLMR to the Aggregate Router (AGR) to modify its binding cache instead of multiple BUs sent by all MNs in the NEMO which reduces handoff signal overheads. However, CoP introduces problems. First, CoP spends more time to delegate CoPs for MRs of each level which in turn raises total handoff latency. Second, the AGR cannot be placed at an optimal location for all CNs which increases transmission delay and consumed bandwidth.

An Advanced Handoff Scheme (AHS) which overcomes some limitations of nested Mobile Network is proposed in (Rho *et al*., 2008). They Combine the Hierarchical Prefix Delegation protocol (HPD) and the Hierarchical Mobile IPv6 (HMIPv6) functionality to enable the improvement to the micro-mobility problem and the location address of MNNs created in Hierarchical Mobile Network Prefix (HMNP) assignment. Furthermore, a Mobility Management Router (MMR) is allowed to update the binding information of all MNNs in a mobile network without getting Binding Update messages (Bus) from the MNNs as the MMR receives a BU from the MR in the mobile network, when the MR moves locally within the MMR domain. This handoff scheme also enables packets to be optimally routed to MNNs in the mobile network via MMR. The simulation was done by NS-2. The result of this scheme shows improvements in term of handoff latency, signaling overhead and transmission delay, although the packet overhead in AHS is higher than in HPD.

Table 1: Comparison of NEMO based protocols

Protocol	Main characteristics	Advantage	Limitations
NEMO BS	•Bi-directional tunneling	•Location privacy	•Route optimization •Packet overhead •The pinball routing problem in nested NEMO
RRH	•Similar to the MIP Loose Source Routing	•Resolves the pinbal l routing problem •Avoids the nested tunnels overhead	•Handoff disruption •Packet overhead •Binding •Update storm
ROTIO	•Routing optimization scheme with the extended tree information option	•Location privacy •Mobility transparency •Seamless handoff support •Solve the pinball routing problem	•The non-optimal transmission path •Increased packet overhead •Increased TLMR/MR binding cache sizes •Binding Update storm
CoP	•Hierarchical mobile network prefix assignment+ hierarchical re-routing	•Reduce handoff signal overheads •Resolves the pinball routing problem	•High total handoff latency •Increased transmission delay and consumed bandwidth •Binding Update storm
AHS	•Combine HPD+ HMIPv6	•Educe handoff latency, signalingoverhead and transmission delay	•High packet overhead •Handoff disruption
RBU+	•MIPv6 route optimization	•Reduced packet header size •Reduces the pinball routing cost	•Location privacy •Binding Update storm
ARO	•MIPv6 route optimization •It's simple and needs minimum changes in •Increased packet overhead the existing NEMO BS	•Reduced packet overhead	•Long convergence time •Location Privacy

Access router option (ARO) (Ng and Hirano, 2004) is based on the route optimization mechanism of MIPv6. In this scheme, the HAs of the MRs collect binding information from upper-level MRs. Since the route is optimized step by step, the process needs a long convergence time, which is proportional to the levels of nesting. In ARO, the whole binding cache in the HA has to be searched recursively to find the optimal path to the MNN and the number of recursive steps for each packet is proportional to its levels of nesting.

The Recursive Binding Update Plus (RBU^+) (Hosik *et al*., 2004) scheme is basically operated under the MIPv6 route optimization unlike the Nemo BS. It is a modification of ARO, in which the optimal route is found when the binding update messages are received by the HAs. This recursive binding update allows the HAs to maintain the binding information for the CoA of the TLMR. To handle a packet that arrives at the TLMR, RBU^+ adopts ad hoc network routing inside the mobile network. MRs can maintain a routing table (proactive) or construct a routing path on demand (reactive). However, the extensive handoff disruption caused by a long convergence time and weak location privacy, are still problems in RBU^+.

To summarize and highlight the advantages and limitations of the protocols Table 1 lists a comparison of these protocols.

CONCLUSION

As more and more portable devices are being Internet enabled, the need for entire networks to be mobile is necessary. Network Mobility (NEMO) is an extension to current Mobile IPv6 that enables a router to act as a mobility agent on behalf of an entire network of IP devices. In addition to NEMO BS protocol, many researches and studies have been proposed to solve the limitations faced NEMO. This research presented some of these works and protocols based on NEMO and highlighted their main advantages and weaknesses. The future of NEMO at a large scale relies on the ability to provide advanced mobility support that can coexist with the currently deployed protocols.

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