OptiNets: An architecture to enable optimal routing for network mobility

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***Abstract*— More and more people want to access the Internet and Virtual Private Networks from anywhere at anytime. This has given rise to providing connectivity capabilities to commuters of public transportation systems. Internet access from moving vehicles has necessitated an architecture which relies upon a special entity, namely a Mobile Router to support the mobility of the entire network. This paper presents an optimal routing architecture for devices accessing the Internet through a Mobile Router deployed in such a mobile network. Our scheme takes into consideration all entities involved in a network mobility scenario and attempts to diffuse the mobility management load without burdening a single entity of the architecture. Our architecture has three main benefits. Firstly, it provides mechanisms for any type of mobile network node present in the network - mobility aware or mobility unaware - to communicate using optimal routes with their Correspondent Nodes. Secondly added functionality to the MIPv6 operation is neither required at the Correspondent nodes nor at the mobile network nodes. Thirdly, our architecture reduces and diffuses the processing burden at the Mobile Routers and their Home Agents.**

***Index Terms*— MIPv6, Home Agent, Mobile Router, NEMO Basic Support Protocol.**

I. Introduction

The notion of "Mobile Internet cafés" within public transportation systems will be a reality in the near future. It would be convenient for the passengers to use the terminals provided in trains and aircraft on long journeys rather than using their own mobile devices. These terminals can be used to access the web to play online games, listen to music etc. For the passengers who require access to VPNs, the idea of using an on-board terminal to slot in their "smart card" and use these terminals as their own mobile devices would be desirable. Providing such services to commuters has proved to be lucrative to companies. This has resulted in more and more researchers working towards mechanisms to enable Internet connectivity for moving networks.

The IETF has in recent years developed protocols such as Mobile IPv4 (MIP) [1] and Mobile IPv6 (MIPv6) [2] for supporting seamless connectivity to mobile hosts. These host mobility protocols however do not on their own meet challenges posed by the movement of entire networks. Realizing the need for the support of network mobility the IETF NEtwork MObility (NEMO) Working Group [3] has developed a protocol which specifically handles mobility of entire networks. Although the NEMO Basic Support protocol [4] handles the mobility of a set of nodes moving as a unit, the defined mechanism precludes optimal routing for the nodes within the network. There are a limited number of mechanisms defined to enable optimal routing for mobile networks; these schemes mainly focus only on a particular type of mobile network node that is either mobility aware or mobility unaware. Also the methods introduced in these mechanisms require added capabilities at Correspondent Nodes. This motivated us to define a complete network mobility architecture, which enables optimal routing for nodes within a mobile network irrespective of their capabilities. Our architecture only requires added functionality to the MIPv6 operation of Mobile Routers and their Home Agents. We also introduce a mechanism to distribute the Home Agent functionality to the Mobile Routers. This mechanism which we refer to as the Distributed Home Agent System enhances the OptiNets architecture in a number of ways.

The remainder of this paper is structured as follows. In the next section we introduce the terms used in our architecture. An overview of the MIPv6 protocol and NEMO Basic Support protocol is provided in Section 3. We compare our architecture to these two protocols to give a generalized view of the main objectives of the OptiNets architecture in Section 4. The Distributed Home Agent System is described in Section 5. We summarize the operations that are performed by the Mobile Routers and the Home Agents in Section 6. An evaluation of our architecture in Section 7 is followed by related work. Section 9 concludes this paper.

II. Terminology

In introducing the OptiNets architecture we use the following terms. A Mobile Router (MR) an entity which assists in achieving Internet connectivity for the nodes within a mobile network. MIPv6 enabled nodes which belong to the same home network link as the Mobile Router, is named as Local Mobile Nodes (LMN). MIPv6 enabled nodes which have a different home link to the Mobile Router's home link are referred to as Visiting Mobile Nodes (VMN). Nodes that belong to the same home link as the Mobile Router without MIPv6 capabilities are referred as Local Fixed Nodes (LFN).

III. MIPv6 and the NEMO Basic Support Protocol

The NEMO Basic Support protocol is an extension to the MIPv6 protocol to handle the mobility of an entire network which changes its point of attachment to the Internet and thus its reachability in the topology. In MIPv6 when a node moves in the Internet topology it sends an update of its current location in the form of a Binding Update to its Home Agent. The NEMO Basic Support protocol relies on the ability of the Mobile Router to convey the location updates to its Home Agent on behalf the entire network. The Mobile Router and its Home Agent uses bidirectional tunneling in order to preserve session continuity while the Mobile Router moves. The MIPv6 protocol has the desirable feature of optimal routing for the mobile network nodes, whereas with the NEMO Basic Support protocol there is no mechanism to enable route optimization. Fig. 1 depicts the operation of MIPv6 route optimization. Fig. 2 gives the operation of the NEMO Basic Support protocol.

IV. OptiNets Compared to MIPv6 and the NEMO Basic Support Protocol

The main objective of our architecture for network mobility is to enable optimal routing for mobile nodes by exploiting the desirable features of the MIPv6 and the NEMO Basic Support protocol. In order to cater for the nodes that has no MIPv6 capabilities present in the network the NEMO Basic Support protocol assumes that all nodes present in the mobile network has no MIPv6 capabilities. It is evident that this assumption restricts the more capable nodes from achieving better performance. Therefore in our architecture we advocate on allowing the more capable nodes to participate in achieving optimal routing while putting only the least amount of burden on these nodes. We achieve this by requiring the Mobile Router to give the prefix of the foreign network to the nodes. This would enable the MIPv6-enabled nodes to configure an address specific to its current location and perform the route optimization procedure as standard MIPv6 nodes. By getting the Mobile Router to play the role of an Access Router and advertise the foreign network prefix to the nodes within the network the need for these nodes to perform a layer 2 handoff is alleviated. The nodes which are running on battery power need not communicate with an Access Router beyond the scope of the mobile network in order to obtain the foreign network prefix. As in NEMO Basic support protocol in the OptiNets architecture the mobile nodes within the network need not perform a link level handoff. The Local Mobile Nodes and the Visiting Mobile Nodes need only to use the new prefix advertised by the Mobile Router and auto configure a care of address and perform the MIPv6 route optimization procedure.

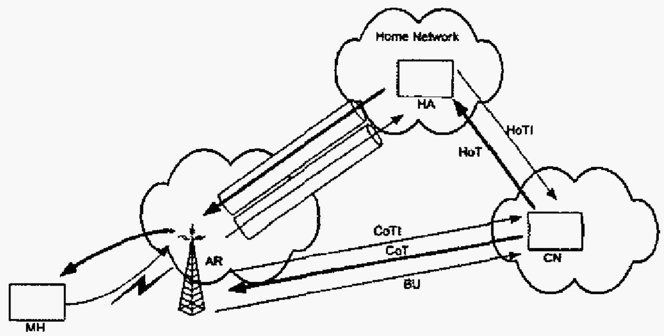

Fig. 1. MIPv6 Route Optimization Operation.

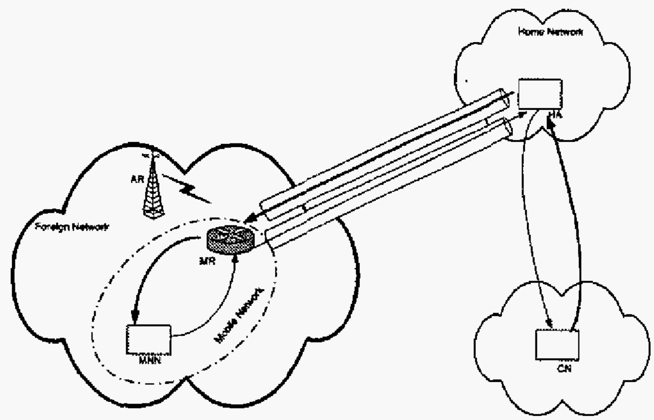

Fig. 2. NEMO Basic Support Protocol Bi-Directional Tunneling Operation.

We propose to enable optimal routing for the Local Fixed Nodes present in a mobile network by requiring the Mobile Router to send Binding Updates to the Correspondent Nodes which was first proposed by Ernst et al [5]. It is expected that on a typical on-board mobile network the number of Local Fixed Nodes would be much less than Local Mobile Nodes and Visiting Mobile Nodes. Typical Local Fixed Nodes can be considered as sensor devices deployed in the mobile network and the information obtained would need to be communicated with a central database. These reasons as well as in the OptiNets architecture we require the MR to keep tab of only the Correspondent Nodes of the Local Fixed Nodes enhances the scalability of our architecture. Since the Mobile Router needs to update only the Correspondent Nodes of the Local Fixed nodes a Binding Update explosion will not occur at the Mobile Router.

The comparison of OptiNets to MIPv6 and NEMO Basic Support protocols is given in Table I.

In the NEMO Basic Support protocol the Mobile Router sends an aggregated Binding Update to the Home Agent of the mobile network on behalf of the nodes present in the network. In the OptiNets architecture we preserve this desirable feature by allowing the Mobile Router to capture the individual Binding Updates sent by the Local Mobile Nodes and send an

TABLE I
COMPARISON OF PROPOSED ARCHITECTURE TO MIPV6 AND NEMO BASIC SUPPORT

	Route Optimization (RO)	Layer 2 Handoff Avoided	Prefix Change Avoided
MIPv6	✓	✗	✗
NEMO Basic	✗	✓	✓
OptiNets	✓	✓	✗

aggregated Binding Update. This is made possible by distributing the functionalities of the Home agents to the Mobile Routers. We introduce in the next section the *Distributed Home Agent System*, which enhances our OptiNets architecture.

V. DISTRIBUTED HOME AGENT SYSTEM

In this system we introduce a secure mechanism which enables the Mobile Router to act as the Home Agent residing in the home network for the Local Mobile Nodes. This is enabled by running a lightweight protocol between the Home Agents and the Mobile Routers which we name as the *Distributed Home Agent Protocol (DHAP).*

The execution of this protocol would be initiated by a Mobile Router which has capabilities to perform the functionality of a Home Agent. The Mobile Router when attached to the home network would send an ARq message (Authorization Request message) to the Home Agent. The Home Agent runs an authentication protocol to verify the received message and if successful would send an AGr message (Authorization Grant) to the Mobile Router granting authority to act on behalf of itself. For security considerations we advocate on the initial authorization to be done only while the Mobile Router is present in the home network. The Home Agent would drop any packet with an ARq message originated from outside of the home network. In order not to introduce new control messages while away from the home network we suggest the use of a bit from the Binding Update Reserved fields as refresh messages for the authorization. The Home Agent would acknowledge the authorization refreshments by using a bit from the Reserved fields of the Binding Acknowledgement.

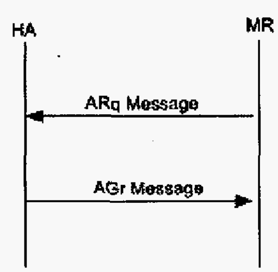

Fig. 3. DHAP Message Interactions.

VI. OPERATIONS PERFORMED BY MOBILE ROUTERS AND HOME AGENTS

In this section we list out the operations performed by the Mobile Routers and their Home Agents to support the OptiNets architecture. We exclude the operations performed when executing the DHAP protocol since it was given in the previous section.

A. *Mobile Router*

The following operations are performed by the Mobile Router.

1) Creating and maintaining a bidirectional tunnel with Home Agent

The Mobile Router would create and maintain a bidirectional tunnel with its Home Agent similar to the NEMO Basic Support protocol. The Mobile Router would use this bidirectional tunnel for any communication with the Home Agent.

2) Passing on Foreign Network Prefix Information

In order to give the current location information to the mobile network nodes the Mobile Router broadcasts the prefix it obtains from the Access Router of the foreign network. The Mobile Router sends periodic Router Advertisements on its Ingress interface. The nodes which are MIPv6 enabled can use this information to auto configure a location specific care-of address.

3) Home Agent functionality for the Local Mobile Nodes

The Local Mobile Nodes on obtaining the prefix information advertised by the Mobile Router would auto configure a Care-of Address for itself and would send a Binding Update to its Home Agent. The Mobile Router being authorized to take on the identity of the Home Agent would intercept these Binding Updates and would send a Binding Acknowledgement to the Local Mobile Node. This operation is executed transparently to the Local Mobile Nodes: i.e. the Local Mobile Nodes are not aware that its Binding Updates are intercepted by the Mobile Router and the Binding Acknowledgements are coming from the Mobile Router.

4) Sending aggregated Binding Updates to the Home Agent

The Mobile Router would send an aggregated Binding Update to the Home Agent in order to provide the current location of itself and the local nodes within the network.

5) Enabling optimal routing for Local Fixed Nodes

In order to enable optimal routing for the Local Fixed Nodes the Mobile Router would send Binding Updates to the Correspondent Nodes. Since the Local Fixed Nodes belong to the Mobile Network permanently the Mobile Router is authorized to take on the identity of these nodes when sending Binding Updates to the peer nodes.

B. *Home Agent*

The Home Agent would provide the functionality of a standard MIPv6 Home Agent and would provide the following added functionality in order to support network mobility.

1) Creating and maintaining a bidirectional tunnel with the Mobile Router

This tunnel would be used to communicate with the Mobile Router when the mobile network is away from the home network. Packets destined for the mobile network would be forwarded to the Mobile Router using this tunnel (with the exception of packets destined for Local Mobile Nodes away from the mobile network).

2) Execution of a Longest Prefix Matching algorithm

In order to cater for Local Mobile Nodes away from the home network but not in the vicinity of the Mobile Router the Home Agent needs to look up its Binding cache with a longest prefix matching algorithm.

VII. EVALUATION

The NEMO Basic Support Protocol handles mobility for each and every node present in the mobile network in a similar manner. The operation of the protocol assumes that all nodes within the network are mobility unaware. We argue that this approach poses many hindrances when attempting to achieve optimal routing for the nodes within the network. Our OptiNets architecture takes advantage of the capabilities of the nodes within the network. Our architecture exploits the added capabilities of nodes present within the mobile network in achieving optimal routing but we do not preclude the less capable nodes. The main advantages of adopting the OptiNets architecture over MIPv6 are summarized below in order to highlight the benefits of this scheme.

A. Advantages of Distributed Home Agent System

A Home Agent would have to potentially manage more than one mobile network and if the Local Mobile Nodes individually send Binding Updates to the Home Agent this would create a Binding update explosion at the Home Agents. In order to avoid this in the OptiNets architecture we introduced a lightweight protocol between the Mobile Routers and their Home Agents. In the following subsection we show that the overhead created by running this protocol is a minimal compared to the potential gains in the overall architecture.

1) Load Sharing

In the OptiNets architecture by distributing the load of the Home Agent to the Mobile Routers enables the Home Agent to share its load. If there are α number of Mobile Networks with β number of Local Mobile Nodes then without the distributed architecture the Home Agent would have to process a significantly higher amount of Binding Updates. The processing burden at the Home Agent with MIPv6 is given by *PBm* and the processing burden with DHAP is given by *PBo*.

$$PBm = 2(\alpha\beta + \alpha) = 2\alpha(\beta + 1) \quad (1)$$

$$PBo = 2\alpha$$

Fig. 4 depicts that in the OptiNets architecture the processing burden does not depend on the number of Local Mobile Nodes and that the increase in the processing burden is linear.

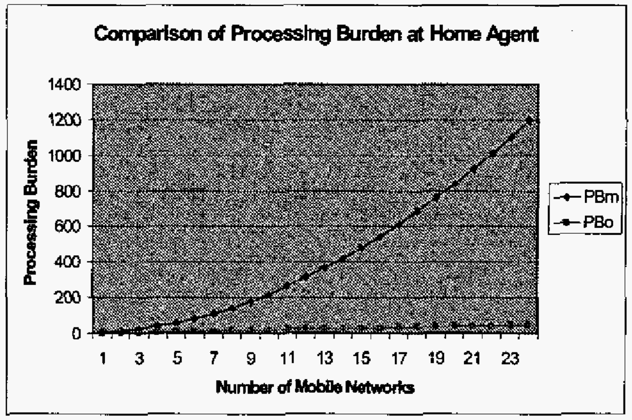

Fig. 4. Comparison of MIPv6 and OptiNets processing burdens at the Home Agent.

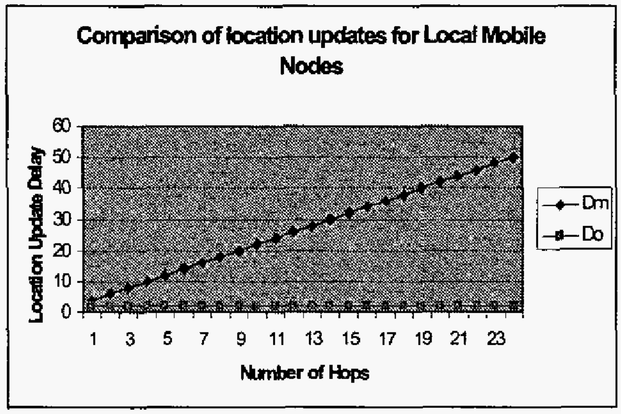

Fig. 5. Comparison of Location Update Delays for Local Mobile Nodes.

2) Low Home Agent location update latency for Local Mobile Nodes

The location update delay is at a minimal with the OptiNets for the Local Mobile Nodes. Reduction in location update delays reduces the loss of packets as well. The number of hops to the Mobile Router playing the role of the home Agent in our architecture is typically one. Let the number of hops to the Home Agent on the home network be H and the delay incurred for a Local Mobile Node when operating on MIPv6 without the support of the OptiNets architecture be Dm and with the support of OptiNets be Do. The Do and Dm are taken as the transmission delay for a Binding Update and the Binding Acknowledgment to reach the destinations. It is evident that the delay incurred in our architecture is a constant of 2 whereas by solely relying on MIPv6 the delay is dependent on H, and would be 2H. Fig. 5 depicts the comparison of the above delays. Latency due to loss of packets on flight is excluded in this comparison which is a significant issue when the Home Agent is many hops away.

3) Reduction in traffic beyond the scope of the mobile network

As in the NEMO Basic protocol the Mobile Router would send an aggregated Binding Update to the Home Agent located in the home network on behalf of the Local Mobile Nodes. This reduces the traffic generated beyond the mobile network significantly in the OptiNets architecture in comparison to MIPv6. This reduction in the traffic (without considering retransmission delays) is directly proportional to the reduction in the processing burden at the Home Agent. In the MIPv6 protocol given the high number of messages to the Home Agent incidence of retransmissions is also much higher, further increasing the amount of traffic beyond the mobile network.

B. Advantages of MR advertising foreign network prefix on its Ingress interface

The proximity to a Mobile Router would be less than to an Access Router outside of the network. Therefore Mobile Nodes within the network are able to reduce the signaling cost which is directly proportional to the distance when obtaining the foreign network prefix in the OptiNets architecture. Moreover the mobile nodes need not have sophisticated technology in order to communicate with an Access Router outside of the mobile network which could potentially be via satellite links.

VIII. RELATED WORK

In order to overcome the Binding Update explosion Ernst et al [6] has proposed a scheme in which the Mobile Router sends a single PSBU to a multicast address. The Correspondent Nodes can subscribe to this address. It is necessary for each mobile network to have an individual multicast address and this address needs to be registered with the Domain Name Server (DNS). The scheme requires changes to the MIPv6 operation of Correspondent Nodes as well as to the DNS system which is largely deployed.

Optimized Route Cache Management protocol (ORC) [7] relies on scattering a route of a mobile network to portions of the Internet by means of Binding Routes (an association between the mobile network prefix and the care-of address) and ORC routers. The ORC routers are used in order to maintain a Binding Route to the mobile network persistently. Since it is not possible to make every router on the Internet an ORC router it has been suggested that these routers be deployed in networks where there are Correspondent Nodes for the mobile network. This scheme would only provide optimal routing if ORC routers are available on the Correspondent Nodes networks.

The above three schemes when achieving optimal routing for mobile network nodes does not take into consideration the capabilities of the nodes within the network. Jeong et al [8] and Perera et al [9] has suggested a way to achieve route optimization for mobile network nodes by taking into consideration that there would be nodes within the network which are MIPv6-enabled. These schemes suggest the delivery of the foreign network prefix by the Mobile Router to the nodes within the network in order to enable optimal routing. Therefore these nodes within the network need not communicate with an Access Router outside of the mobile network when obtaining the prefix of the foreign network. The MIPv6-enabled nodes can auto configure a care-of address and achieve optimal routing using the MIPv6 route optimization techniques. Perera et al [9] further propose the Mobile Router to play the role of a Home Agent for nodes which has an added capability to reconfigure the Mobile Router to be their Home Agent dynamically. The nodes which are able to do so need not periodically send Binding Updates to a Home Agent outside of the mobile network. This optimization is achieved only if the local MIPv6-enabled nodes within the network have further capabilities to recognize the Mobile Router as a sub Home Agent.

The schemes [6], [7] cater for the mobility unaware nodes in achieving optimal routing. The schemes [8] and [9] suggest techniques to achieve optimal routing for MIPv6-enabled nodes. The OptiNets architecture introduced in this paper encompasses mechanisms to achieve optimal routing for any type of node present in the mobile network while requiring changes to only the Mobile Routers and their Home Agents.

IX. CONCLUSIONS

In this paper we presented an architecture to enable optimal routing for any type for mobile network node. We showed that in our architecture we can reap the desirable properties of having a Mobile Router to support the mobility of a set of nodes while not hindering the correct operation of the route optimization procedure of MIPv6.

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