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Contents

Chapter 1

Network Mobility

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Providing seamless Internet connectivity to mobile hosts has been studied in the IETF for some years now, and protocols such as Mobile IP and Mobile IPv6 have been developed. We are now witnessing the emergence of mobile networks, namely a set of hosts that move collectively as a unit, such as on ships aircrafts and trains. The protocols for mobility support therefore need to be extended from supporting an individual mobile device to supporting an entire mobile network. In this chapter the state-of-the-art in supporting the mobility of entire networks is examined. The problem is first motivated by considering typical network mobility scenarios and by identifying characteristics that require new solutions. The design requirements of the protocols that support network mobility are explored. Furthermore, current approaches for network mobility support and their strengths and weaknesses in addressing the design requirements is presented. The chapter is concluded by identifying some open research issues in the realization of mobile networks. [1]

1.1   Introduction

The prediction that most devices will be connected to a network is fast becoming reality with the almost ubiquitous availability of computing and wireless communication capabilities in most electrical and electronic devices. Two emerging forms of this ubiquitous connectedness are Personal Area Networks (PANs) that interconnect a user's devices together and vehicle networks especially in public transport systems which will enable groups of people to access network services, while on the move. In such situations employing one device namely a Mobile Router (MR) [1] for the mobility management of the entire network would be a lucrative solution in terms of performance and costs. This architecture is advocated, in particular by the IETF's NEtwork MObility (NEMO) Working Group [2] and its popularity is evidenced by an increasing number of commercial and research projects. The NEMO Working Group has standardized a protocol namely NEMO Basic Support Protocol [3], that ensures uninterrupted connectivity to nodes within a mobile network via a Mobile Router. This protocol extends the mechanisms utilized in the host mobility management protocol Mobile IPv6 [4]. In this chapter, the state-of-the-art for supporting network mobility is presented by extending the survey work carried out in [5]. Firstly the need for a new network mobility architecture is motivated and then characteristics and design goals of such an architecture is presented. This is followed by presenting network mobility schemes in an IPv4 and IPv6 setting. Open research issues pertaining to network mobility and some of the solutions that are proposed to address these challenges are then discussed.

1.2   Network Mobility: Why a new architecture?

Many researchers have been working toward developing mechanisms that provide permanent Internet connectivity to all Mobile Network Nodes (MNNs) via their permanent IP addresses as well as maintain ongoing sessions as the mobile network changes its point of attachment to the Internet. Host mobility protocols such as MIP and MIPv6 are not sufficient to handle network mobility due to two reasons. Firstly, not all devices in a mobile network such as the sensors on an aircraft may be sophisticated enough to run these complex protocols.

Secondly, once a device has attached to the MR on a mobile network, it may not see any link-level handoffs even as the network moves. Thus the host mobility protocols such as MIP and MIPv6 do not get triggers indicating link-level handoffs and as a result will not initiate handover and would necessitate support from a MR. NEMO Working group identifies 3 types of nodes that would be supported by a Mobile Router [6]. Local Fixed Nodes, i.e., nodes which belong to the mobile network and cannot move with respect to the Mobile Router, would typically not be able to achieve global connectivity without the support of the MR. There could also be nodes which can move with respect to the MR namely Local Mobile Nodes (home link belongs to Mobile network) and Visiting Mobile Nodes (home link does not belong to Mobile network). By employing a Mobile Router to act as a gateway, all of these types of nodes within the network should be able to achieve global connectivity irrespective of their capabilities. In the following subsections, we elaborate on some of the benefits of having a network mobility architecture that relies on a Mobile Router.

1.2.1 Reduced Transmission Power

The radio transmission distance from a Mobile Network Node (such as on ships and aircrafts) to an on-board MR is potentially much shorter than to another Access Router on the Internet. Thus by employing the MR as an Access Router, the nodes within the mobile network need only communicate with the MR using minimal power and these nodes need not be equipped with specialized high-power communication capabilities. For small devices running on battery power this reduction in power consumption could potentially be quite significant.

1.2.2 Reduced Hand-Off Signaling

Once the Mobile Network Nodes have established a link with the MR, the link does not need to be torn-down even as the mobile network moves. Since all communications beyond the scope of the mobile network is via the MR, only the MR needs to handle link layer hand-offs. This allows unsophisticated (i.e. hand-off unaware) devices to be deployed in the mobile network, potentially yielding low-cost mobile networks.

1.2.3   Reduced Complexity

Once a node joins a mobile network these nodes would not have to keep changing their address since this functionality would be performed by the MR. When the mobile network changes its point of attachment to the Internet only the MR needs to auto configure a location specific address. This reduces the need for the Mobile Network Nodes having to perform link layer handoffs as well as the need for auto configuring a new address. By having the MR perform these actions on behalf of the network nodes, the software and hardware complexity on the Mobile Network Nodes can be greatly reduced.

1.2.4   Increased Manageability and scalability

If protocol updates or additional features were to become necessary in the future, it is much easier to update software or policies on the MR than on each of the network nodes. Thus, a MR network mobility architecture offers an easy central point in managing the mobility features of the entire network and also increases the scalability of mobile networks.

1.2.5   Economic Incentive

From the point of view of transportation systems, it is often commercially lucrative to provide and charge for global connectivity to passengers' mobile devices through a MR installed in the vehicle, as is being currently done by air lines.

1.3   Network Mobility Characteristics and Design Requirements

Figure 1.1 depicts a typical mobile network operational scenario of a moving vehicle, for example an aircraft carrying passengers. The aircraft may be equipped with various devices, such as information panels in each cabin that provides information to the passengers, fuel sensors in the engine, and embedded sensors that gather information such as temperature,

pressure and wind velocity. These devices together constitute the Vehicular Area Network (VAN). Furthermore, the passengers may carry their personal wireless devices or even an entire Personal Area Network (PAN) of devices, which enter and exit the VAN as and when passengers embark and disembark the aircraft. A designated node in the PAN (such as the PDA denoted in Figure 1.1 as a PAN Mobile Router – as PMR) may act as the Mobile Router that helps connect the PAN to the VAN. The VAN is equipped with one or more Mobile Routers designated by MR1, MR2, and MR3 in Figure 1.1, (one MR in each cabin) that provide Internet connectivity to the nodes within the VAN. Using the above environment as an example, in the following sections we describe some of the characteristics of mobile networks and discuss how they influence the protocol design. Figure 1.2 illustrates an abstract view of a Vehicular Area Network.

1.3.1   Set of Nodes Moving as a Unit

The defining characteristic of network mobility – the notion of a set of nodes moving as a unit – is evident in the above scenario. The aircraft can be viewed as a single node changing its point of attachment to the Internet. A network mobility protocol should be able to provide global access to all the nodes within the mobile network.

1.3.2   Local vs. Visiting Nodes

The mobile network in the above example includes visiting nodes, such as a passenger's wireless device, which is in a network different than its home network, as well as local nodes, such as the information panel which is within its home network. The network mobility protocol should cater to both these types of nodes.

1.3.3   Mobility Aware vs. Unaware Nodes

The mobile network may contain sophisticated nodes that are "mobility aware", namely, run protocols such as MIP or MIPv6 and are able to perform link layer handoffs. However,

it is quite conceivable that the mobile network may also contain nodes that are "mobility unaware", that is nodes that are not sophisticated enough to handle hand-offs. In the case of the aircraft considered above, the temperature, pressure and wind velocity information may need to be conveyed to a central database located outside the aircraft's network. Running sophisticated protocols on the low-cost sensors may be infeasible, and the network mobility support protocol should therefore be able to handle mobility on behalf of such nodes without requiring any special support from them. This goal, often termed "Network Mobility Support Transparency", is being strongly advocated by the IETF NEMO working group as very desirable when providing global connectivity to nodes within a mobile network [7].

1.3.4   Nested Mobility

In the scenario considered above, the VAN of the aircraft carries within it a PAN belonging to a passenger. Where a smaller mobile network could be contained in a larger one is known as nested mobility. The network mobility protocol needs to allow for at least two levels of recursive nesting. As we shall see in a subsequent section, nested networks have implications for routing and route optimization.

1.3.5   Multi-Homed Mobile Networks

The VAN in the aircraft shown above can be considered to be multi-homed if it has more than one active interface connected to the global Internet – these interfaces could be through one MR or via the different MRs in the different cabins. It is desirable that the Mobile Network Nodes be reachable even if one of the active interfaces fail. It would also be desirable to allow the Mobile Network Nodes to attach to the active interface which suits the application it is running. For example, a passenger downloading MP3 files and listening to music may best be supported over the least congested high bandwidth link.

It is likely that VANs, such as the aircraft VAN would use different access technologies: satellites while flying and WLAN/UMTS whilst on the ground. A MR offering connectivity to the nodes sitting behind it should be able to ensure reachability to those nodes irrespective

of the access technology being used.

Ernst et al [8] highlights the importance of multi-homing by illustrating the benefits and goals of multihoming considering real life scenarios.

1.3.6 Different Sizes of Mobile Networks

A passenger's Personal Area Network on its own with a single MR and few devices such as a PDA and a mobile phone is a very small scale network. The entire aircraft network on the other hand with a collection of subnets and a few hundred IP devices can be categorized as a large scale network. The network mobility solution should scale from small PANs to large VANs.

1.3.7 Disparate Handoff Rates

Wireless cells have a limited coverage area due to limited transmission range of base stations. Mobile networks may vary significantly in the speed they move at. For example the aircraft would be stationary or taxing at very low speeds whilst on ground and when airborne would be moving at high speeds. In addition the passengers themselves may be moving within the VAN. This would result in distinct handoff frequencies and network mobility solutions have to handle this wide range of handoffs.

1.3.8 Mobile Devices from Different Administrative Domains

A passenger's PAN could be from an entirely different domain from that of the mobile network. The passenger's mobile devices joining the aircraft network need to trust the MR in order to obtain Internet connectivity. This characteristic of mobile networks which requires interaction and trust among nodes from different domains has given rise to security issues unique to network mobility as opposed to host mobility in a MIPv6 network. For example Johnson et al [9] eliminated the need for a local routing proxy (Foreign Agent), which was a

feature of the MIP in designing the MIPv6 protocol. This enabled the end node to handle its own routing identifier, the Care-of Address. In the network mobility architecture this desirable feature of MIPv6 is again compromised by having the MR as an intermediary node in the end to end communication. This requires network mobility support solutions to address specific security issues as well as comply with the standard IETF securities policies and recommendations.

1.4   Network Mobility in IPv4 and IPv6

Advantages of the Mobile Router architecture have been recognized as early as in the 1990s. Hager et al [10] in their paper MINT- A Mobile Internet Router describe of a router with sufficient computational power to perform all necessary communication protocol operations and enable connectivity for nodes. The MINT router provides communication software transparency and the nodes connecting to the Internet via such a router need not be modified with basic mobility support software. The use of a Mobile Router for network mobility has been specified even in the very early Request For Comments [11] on IP mobility support. In the next subsections we present some of the research that has taken place on network mobility in an IPv4 and IPv6 setting.

1.4.1   IPv4 and Network Mobility

Here we present a summary of how mobile networks are handled with the use of IP mobility Support Protocol (MIP). This summary follows from the IP mobility support RFC 3220 [9].

The MR would act as the foreign agent and provide a foreign agent Care-of Address to the mobile nodes. Packets addressed to the mobile nodes within the mobile network go through the MR's Home Agent as well as the mobile node's Home Agent. If the nodes are fixed with respect to the mobile network then MIP specifies two mechanisms that enable global connectivity for these nodes. One method is to have a permanent registration with a Home Agent to reflect the Mobile Router's home address as the fixed host's Care-of Address.

Usually the MR's Home Agent would be used for this purpose. The second method requires the MR to advertise connectivity for the entire mobile network using normal IP routing protocols through a bidirectional tunnel to its own Home Agent.

1.4.2 IPv6 and Network Mobility

Although it has been claimed that MIP could support mobile networks as single mobile nodes, experimentations conducted in Motorola Planete Inria labs [12] have shown that this is not the case with the MIPv6 protocol. These experiments have shown that the Home Agent fails to redirect packets destined for the Local Fixed Nodes sitting behind a Mobile Router. If a packet is addressed to a Local Fixed Node the Border Router in the Home network would attempt to forward it the MR since the MR is the next hop towards the Local Fixed Node. The Home Agent acting on behalf of the MR (assuming the MR has registered its new Care-of Address with the HA by means of Binding Updates) would intercept the packet. Although the HA has a Binding Update for the MR it has no Binding Update for the destination address on the packet (Local Fixed Node's home address). The Home Agent being unable to handle this packet would reroute it to the Border Router. The Border Router would once again attempt to route this packet causing a repetition of the above process paving the way to a routing loop. MIPv6 protocol's inability to handle mobile networks and the network mobility characteristics and design goals have paved the way to the NEMO Basic Support Protocol.

NEMO Basic Support Protocol

The NEMO Basic Support protocol is a natural extension to the host mobility protocol, MIPv6. It specifies a mechanism which enables all nodes within a mobile network to be reachable via permanent IP addresses, as well as maintain ongoing sessions as the MR changes its point of attachment within the topology. This protocol which runs on the MR and its Home Agent (HA) ensures uninterrupted connectivity to the mobile network nodes, without considering issues such as route optimization.

When a MR attaches to an Access Router in a foreign network it acquires a Care-of Address from the visited link. Upon obtaining the new address it informs its Home Agent of its current location by way of a registration message, namely a Binding Update. If the MR is acting as a router as opposed to a mobile host then this is indicated to the MR's HA by way of enabling a the Mobile Router flag (R) in the Binding Update message. Further, the MR informs the HA of the mobile network prefixes. (Note that in some scenarios the Home Agent would already know which prefixes belong to a MR by an alternate mechanism such as static configuration. In these cases, the MR does not include any prefix information in the Binding Update.) A positive Binding Acknowledgement from the HA with the MR flag set received by the MR indicates the completion of the binding process and the establishment of a bi-directional tunnel between the MR's Care-of Address and the Home Agent's address. Any packet addressed for a Mobile Network Node would then be intercepted by the HA and would be forwarded to the MR at its Care-of Address. The MR, then decapsulates the packets and forwards them to the mobile nodes. Packets in the reverse direction are also tunneled via the HA in order to overcome Ingress filtering restrictions [13]. In this case the HA decapsulates the packets and forwards them to the Correspondent Nodes.

Nested Mobility Management with the NEMO protocol   So far we have considered only Local Fixed Nodes, which are not capable of managing their own mobility. However, a mobile node managing its own mobility such as a passenger with a MIPv6 capable mobile device may enter the mobile network treating it as a foreign network. Such a Visiting Mobile Node node will send a BU to its own HA informing it to deliver all traffic to its new Care of Address using IPv6 tunneling. This results in two, nested levels of mobility management, since the MR manages the mobility of the mobile network. The mobility of the Mobile Router is hidden from MNNs, even if they are capable of handling their own mobility. Thus all packets would traverse via the Mobile Router's Home Agent as well as the Visiting Mobile Node's Home Agent with the NEMO protocol. This indirect routing path hinders the performance of the Mobile Network significantly and this issue will be discussed in a subsequent section.

In the case of nested mobile networks there would be an overhead of nested bi-directional

tunnels. To illustrate the communication path and the nested bi-directional tunnel overhead in the case of nested mobile networks, consider a Correspondent Node (CN) that sends a packet to a mobile device in the passenger's PAN traveling within the train's VAN. This operation of the nested mobility scenario is depicted in Figure 1.3. Again, it is assumed that the PAN's MR (PMR) has registered the Care-of Address it obtained from MR2, with it's HA (HA-PMR). Furthermore as before MR2 has registered the VAN prefixes and the Care-of Address with it's HA (HA-MR2). A packet from a CN is initially addressed to the home address of the mobile device and gets routed to its home network (1). In the home network it is intercepted by the HA-PMR. A route lookup there indicates that the mobile node's prefix is at the VAN's care-of address. The HA-PMR then encapsulates and tunnels the packet to the VAN's care-of-address (2). At the VAN's home network this gets intercepted by VAN Mobile Router's Home Agent HA-MR2. Its route lookup of the VAN's care-of-address determines that the packet needs to be encapsulated and tunneled yet again to the care-of-address in the network to which the VAN is currently attached (3). When this doubly encapsulated packet reaches MR2, which recognizes the outer care-of address as its own strips it off to reveal the care-of-address of the PMR. It sends the packet to the PMR (4), which again recognizes the (only remaining) care-of address as its own, strips it off, and sends the original packet to the mobile device in the PAN (5). Packets from the mobile device back to the CN traverse the same path in the reverse direction.

1.5 Network Mobility Open Research Challenges

As described in the previous section the NEMO Basic Support protocol defines a mechanism which enables session continuity to all Mobile Network Nodes by means of bi-directional tunneling between the MR and its HA. In defining this solution, in order to cater for mobility unaware nodes within the mobile network, the Working Group has assumed that all nodes within the network are mobility unaware. Although this assumption guarantees complete mobility transparency to the Mobile Network Nodes it hinders the overall performance of the system significantly. This indirect routing issue and some other challenges that need to be addressed for network mobility to be a truly ubiquitous experience will be examined below.

1.5.1   Indirect Routing

According to the NEMO Basic Support protocol all packets to and from Mobile Network Nodes traverse through the bi-directional tunnel between the MR and its HA. This indirect routing mechanism leads to issues that degrades the overall performance of the network. There are many undesirable side effects of indirect routing pertaining to the NEMO protocol that have been identified by Ng et al [14]. Some of these side effects are given below.

- Increased packet overhead - Tunneling requires the packets to be encapsulated thus increasing the per packet overhead. This overhead reduces the portion of bandwidth available for application data. For example real time traffic with a packet size of 100 bytes would experience a 40% overhead. On a high cost satellite link such a magnitude of overhead would not be economically viable.

- Increased processing delay - The encapsulation and decapsulation processes would potentially involve tasks such as encryption/decryption which would incur an increased processing delay.

- Increased chances of packet fragmentation - The size of a packet increases due to encapsulation and this could lead to potential packet fragmentation. Packet fragmentation would result in further delays and inefficiencies in bandwidth usage.

- Increased susceptibility to link failure - The indirect routing creates a longer path for each packet traversing to and from a Mobile Network Node to Correspondent Nodes. The chances of link failure is thus higher due to the longer path.

- Potential bottleneck in the Home Network - Since all the packets to and from each and every Mobile Network Node is via the Mobile Router's Home Agent, this increased traffic load would lead to congestions at the home network.

In Figure 1.3, tracing the path from a Correspondent Node to a device in the PAN, nested within the VAN illustrated how the route departs more and more from the optimal as the number of nested levels increase. This multi-angular routing issue which is referred to as pinball routing, is highly undesirable because it amplifies the adverse effects of sub optimal

routing with each level of nested mobility. Each added level of nested mobility requires an additional tunnel encapsulation, and these extra IPv6 headers increase the packet size and the associated overheads. Solutions that optimize the routes also reduce the levels of indirection, thereby overcoming the side effects of non optimal routing such as increase in packet size. This multi-angular routing issue referred to as pinball routing could hinder the deployment of mobile networks since it gives rise to a negative impact not only on the mobile network but on the Internet as a whole.

Providing optimal routing in a network mobility setting is not an easy task. This is due to the introduction of an intermediary node in the communication between a node inside a mobile network and a Correspondent Node. This has raised an issue in using MIPv6 route optimization mechanisms for network mobility, namely that the nodes within the mobile network are unable to perform the MIPv6 Return Routability test (RR), which is needed to verify to the Correspondent Nodes that the home address and the Care-of Address are collocated. Even if the Mobile Network Nodes are MIPv6 capable these nodes do not have their own Care-of Addresses, to perform route optimization. If the MR performs the MIPv6 route optimization procedure on behalf of the nodes sitting behind it, then this would require extensions to the MIPv6 operation of Correspondent Nodes and would also severely impact the scalability of MRs. Scalability is affected because the MR would be required to keep account of Correspondent Nodes and would need to send Binding Updates to them on behalf of the nodes within the network. In a typical mobility scenario such as on public transportation systems the number of Correspondent Nodes communicating with Mobile Network Nodes could reach up to several hundreds. Recognizing the impracticability of requiring the MR to send Binding Updates to Correspondent Nodes several route optimization solutions have been proposed and these will be presented in a subsequent section.

1.5.2 Mobile Router Handoff Performance

A NEMO handoff which is similar to a MIPv6 handoff is preceded by a link layer handoff and an IP layer network attachment procedure. In the case of Mobile Router handoffs Mobile Router handoffs significant breakages in connectivity would potentially have an impact on

a large number of nodes. Perera et al [15] has implemented and analyzed the handoff performance of Mobile Routers with the NEMO protocol and has shown that the NEMO approach results in significant breakages in connectivity due to handoffs. Their results of handoff latency [16] show that due to the NEMO handoff process all nodes within the mobile network depending on the MR for their mobility management incurs severe end-to-end TCP performance degradations and packet losses.

1.5.3   Mobile Network Prefix Delegation

One or more mobile network prefixes need to be assigned to a mobile network either dynamically or statically in order for the MR to use on the links within the mobile network. The NEMO Basic Support protocol does not provide the means for provisioning the Mobile Routers with essential parameters such as Home Network Prefixes. With the current NEMO protocol there is no mechanism which enables the MR to obtain a Mobile Network Prefix dynamically, only static configuration at the initial set up allows the MR to obtain Mobile Network Prefixes. Static configuration could lead to binding inconsistencies because after the initial set up of associations between the MRs and their Mobile Network Prefixes there is no mechanism to maintain the matching states. This could lead to routing loops and unreachable prefixes. Further, if the Mobile Network Prefixes need to be modified there is no mechanism to do so.

1.5.4   Multihoming issues

A multihomed mobile network would have more than one point of attachment between the Internet and the MR. With the NEMO protocol multihoming translates to simultaneous multiple bi-directional tunnels. Although the NEMO Basic Support protocol neither prevents nor explicitly specifies mechanisms to handle multihomed mobile networks there could be issues pertaining to deploying such networks. Some of the issues pertaining to deployment of multihomed mobile networks, as analyzed by [17] is listed below.

- Unbroken connectivity - If one or more of the active connections fail then there needs to be a mechanism by which the Mobile Network Nodes that were served by the failed connection to be served by an alternate one.

- Path Selection - In a multihomed mobile network since there would be more than one bi-directional tunneling path available, there needs to be a dynamic mechanism to select the most suitable path. The Home Agents, Mobile Routers, Mobile Network Nodes and applications or a combination of these entities should be able to select the path. In the case of a hybrid mechanism these entities need to cooperate in making the decision.

- Failure Detection - Failures could happen at the Mobile Routers, Home Agents, Access Routers etc. and mechanisms to detect such failures in time in order to make use of alternate options available in a multihomed network would allow a more robust system.

- Multihoming in nested mobility - There could be be many real life scenarios where a multihomed mobile network would be nested within another mobile network. For example in Figure 1.1 in the aircraft scenario the passenger's PAN could potentially be a multihomed network attached to the Vehicular Area Network. Such cases of network mobility could lead to complex configurations and could possibly create infinite routing loops.

1.5.5   Security and Reliability Issues

In NEMO the MR needs to allow subscribers from different domains to get Internet connectivity through it. In such settings where static trust relationships are lacking a variety of security threats arise. In the NEMO Basic Support protocol the use of IPsec to protect signaling messages is advocated. The protocol itself does not specify any mechanisms to handle security related or reliability related issues. Petrescu et al [18] have described the security threats related to the NEMO protocol. They have identified signaling between the MR and the HA and nested mobility configurations as two main sensitive points of the protocol. Jung et al [19] in their threat analysis draft on NEMO especially highlights issues related to IPsec and other tunneling mechanisms between the MR and the HA. Perera et al [20] has identified failures of Mobile Routers in different mobility scenarios and has shown

how a new mobility architecture namely the Ambient Networking architecture [21] with its in-built enhanced failover management functionality has a potential for creating resilient networks. Until a new mobility architecture such as the Ambient Networking architecture becomes a reality it is evident that security mechanisms for network mobility would be an extremely difficult challenge.

1.5.6   AAA Issues (Authentication, Authorization and Accounting Issues)

Providing Internet access to passengers of public transportation systems would necessitate much consideration for Authentication, Authorization and Accounting issues. Access control is vital in such wireless public access networks in order for any NEMO solution to be viable.

Currently within the IETF MIPv6 Working Group there is much interest shown in adapting IPv6 AAA mechanisms for host mobility. Mechanisms to adapt the designated AAA protocol Diameter, for a MIPv6 network is currently being studied [22]. But network mobility introduces new AAA issues due to Mobile Network Nodes relying on a previously unknown entity to take care of their mobility management tasks. Recognizing such issues Barz et al [23] have outlined a network access control model for vehicular mobile networks. Since the introduction of network access control via AAA entities causes handover delays, Barz et al [23] advocate on distributing these entities to minimize such delays.

Billing mechanisms for passengers of public transportation systems for Internet services is a very important issue that needs to be tackled from the business point of view.

1.6   Route Optimization

In large Mobile networks, requiring the MR to send each Correspondent Node an individual Binding Update causes a Binding Update implosion. In order to overcome this scalability issue Ernst et al [24] have proposed a method in which the MR sends a Prefix Scope Binding Update to a multicast address to which Correspondent Nodes would have subscribed. A

mobile network needs to have a multicast address which it registers with the Domain Name Server (DNS). The MR sends a periodic Binding Update containing the mobile network prefix and the MR's Care-of Address to this multicast address. Correspondent Nodes can join the multicast group using IPv6 multicast mechanisms. Although this solution is beneficial for large mobile networks with many Local Fixed Nodes it requires major changes to MIPv6 and also to the already widely deployed DNS system.

Optimized Route Cache Management protocol (ORC) [25] 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. Some Interior Gateway Protocol (IGP) routers named as ORC routers are used in order to maintain a Binding Route (BR) to the mobile network persistently. Whenever the MR moves ORC routers receives a BR notification which will be cached in their routing tables. The ORC routers will advertise a proxy route to the mobile network by using IGP protocols and will capture packets destined to the mobile network. The packets will be forwarded to the Care-of Address on the Binding Route, thus avoiding routing via the MR's home network. 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 Node's networks.

Jeong et al [26] proposed an optimization mechanism for MIPv6 enabled nodes by requiring the Mobile Router to be a Neighbor Discovery proxy. This technique requires the MR to act as bridge to the Visiting Mobile Nodes in order for these nodes to be virtually connected to the foreign link while requiring the MR to act as a router for the Local Fixed Nodes. Perera et al [27] have proposed and implemented [16] a route optimization technique, OptiNets RO, which requires the MR to act as an Access Router to the Visiting Mobile Nodes and deliver the foreign network prefix on its Ingress interface. This enables the MIPv6 capable nodes within the mobile network to auto configure a location specific Care-of Address. This OptiNets RO technique exploits the desirable characteristics of both NEMO and MIPv6 protocols. By employing this route optimization technique it is evident that the mobile nodes need not perform a link level handoff as in the NEMO Basic Support

protocol and these nodes are able to achieve optimal routing as in MIPv6.

Several route optimization techniques were also proposed in the context of nested mobile networks, Kang et al [28] suggested the use of a bi-directional tunnel between the Home Agent and the Top Level MR (TLMR) to improve the routing latency. In their scheme, a tunnel is setup between TLMR of the nested mobile network and Home Agent of each MR. The TLMR advertises it's existence by using an extended Router Advertisement message. Each MR relays the extended Router Advertisement message of TLMR transmitted from its parent MR to it's child MR. After receiving the extended Router Advertisement message, the MR registers with the TLMR and notifies the address of the TLMR to it's own Home Agent. When the TLMR receives a registration message from the MR, it detects a relationship between the MR and it's Access Router and uses this information to create a tunnel to each MR. Ohnishi et al [29] proposed a HMIP-based approach for route optimization. They suggested employing the TLMR as the MAP (as in the context of HMIPv6 [30]). In their approach, a Mobile Network Node registers it's location within the nested mobile network once to TLMR, and also registers the location of the nested mobile network (the TLMR's subnet address) to it's Home Agent. This hierarchical series of registrations allows the Home Agent of MRs to directly send packets to the TLMR. Thubert et al [31] have proposed the use of a new routing header called the Reverse Routing Header (RRH) in order to build a nested mobile network which avoids the nested tunnels overhead. The Reverse Routing Header which is similar to the MIP Loose Source Routing, records the route out of the nested mobile network. This can be converted to a routing header for packets destined to the mobile network. In order to further illustrate the RRH solution, consider the nested mobile network bi-directional tunneling depicted in Figure 1.3. The packets originating from a node in the PAN has to go through two home agents before reaching the Correspondent Node leading to very inefficient pinball routing. If a RRH is used the PMR would in addition to tunneling the packet to its Home Agent add a routing header with a predetermined number of slots. In the first slot the PMR puts its home address. This packet then has the PMR's care-of address as source address and PMR's Home Agent (HA_PMR) as the destination address. The next router (in this case last router) on the path which is MR2 notices that the packet already contains a RRH, so it overwrites the source address of the packet with its own address (MR2 care-of address) and puts the PMR's care-of address in the second slot. The

outer packet now has MR2_COA as source address and HA_PMR as destination address. When the packet reaches HA_PMR, this Home Agent uses the information on the RRH in entering a binding update for the PMR's home address. Now when a packet arrives for PMR to its home network HA_PMR can trivially construct a routing header with MR2_COA and PMR_COA. This allows bypassing the home agent of MR2. It is evident even if there are n levels of nested mobility the packet would go through only a single Home Agent, bypassing (n-1) Home Agents.

1.7 Seamless Handoffs

A NEMO handoff can occur in two ways, 1) MR first loses connectivity with its current Access Router and becomes unreachable at its current Care-of Address, and then establishes connectivity with a new Access Router and acquires a new Care-of Address. This is known as a Break-Before-Make handoff. 2) MR establishes connectivity with a new AR while still being connected to the old AR and performs a so-called Make-Before-Break handoff after the connectivity is established. In the first case the connectivity between MNNs and CNs is broken for the duration of the handoff therefore the handoff latency translates directly to packet loss. In the second case the communications are not affected by the handoff latency.

Localized mobility management schemes, such as Hierarchical Mobile IPv6 [30] and Cellular IP [32] aim to reduce the effects of network latency between Mobile Node and its Home Agent. Another large factor in Mobile IPv6 handoff latency is the network attachment latency. Use of optimized procedures such as Optimistic DAD [33] and Fast Router Advertisements [34] for the network attachment can reduce the latency to half to two roundtrip times between Mobile Node and its Access Router. Link layer handoffs from old base station or Access Point to a new one and authentication procedures are another factor affecting the handoff latency which can be improved using access technology specific optimizations [35].

As long as a Mobile Router connects to only one network at a time and is limited to performing Break-Before-Make handoffs, handoffs are likely to cause some degree of disruption to traffic. Fast Mobile IPv6 [36] provides an access technology independent way of emulat-

ing Make-Before-Break handoffs by buffering and using a localized forwarding scheme which could be used in a network mobility setting. However, the potential performance benefits from the emulated Make-Before-break handoffs are offset by the increased complexity required in the access network. Petander et al [37] has addressed this issue and has proposed and implemented an access technology independent Make-Before-Break handoff scheme for Mobile Routers. They have shown that by using a dual interface MR where one interface is utilized for data communications and the other interface for scanning it is possible to achieve virtually loss free handoffs. Since the scanning and the handoff is performed on a different interface to that of the active interface this approach enables Make-Before-Break handoffs and minimizes the packet losses incurred due to handoff latencies without any network infrastructure support. A further benefit of this approach is that it alleviates the periodic interruption to the active data communication that would occur if scanning is performed on the same interface.

1.8   Prefix Delegation Mechanisms for NEMO

Droms et al [38] has extended the DHCPv6 protocol to handle the assignment of dynamic prefix delegation for NEMO. In order to do so they extend the Home Agent capabilities to perform the duties of a DHCPv6 Delegating Router and the Mobile Router to perform the capabilities of a Requesting Router. The DHCPv6 protocol messages would flow through the NEMO bidirectional tunnel between the Home Agent and the Mobile Router. Kniveton et al [39] argues that this DHCPv6 based solution is not desirable due to reasons such as the need for the Home Agent to have a colocated Delegating Router functionality, operational overheads etc. Thus they advocate on extending the NEMO Basic Support protocol in order for the MR to synchronize its Mobile Network Prefixes and obtain new ones dynamically instead of using another protocol such as DHCPv6 Prefix delegation protocol. They propose extensions to the current NEMO protocol in order to handle dynamic prefix delegation, resynchronization at binding creation after loss of states, Mobile Network Prefix renumbering and configuration checking for loop avoidance.

1.9 Multihoming Solutions

A mobile network being multi-homed due to the MR being multi-homed is one of the least complicated configurations. This case can be handled by the solutions proposed for host mobility since the MR is seen as a single node in the global topology. On the other hand much research work needs to be done in order to handle multi-homed mobile networks due to multiple MRs.

The Inter Home Agents protocol (HAHA) proposed by Wakikawa et al [40] allows a Mobile Router/Mobile Node to utilize multiple Home Agents simultaneously. The adopted mechanism is to place multiple Home Agents serving the same home prefix on different links which coordinate with each other to provide Home Agent redundancy and load balancing. Chung et al [41] addresses the issue of, how to "best" distribute the user traffic among the set of available access networks in a multihomed on-board mobile network. Two traffic distribution schemes are proposed which optimizes the profit and performance of the mobile network operator. In order for policy driven mechanisms supported by multi-homed mobile networks to be realized it is necessary to consider accounting issues that arise inadvertently. Providing QoS for mobile network nodes by exploiting the redundancy provided in multi-homed mobile networks is a research area that needs further study.

1.10 Network Mobility Projects

Along with the IETF NEMO working group network mobility research projects influences the evolvement of network mobility protocols. We consider some of these projects in the following subsections.

1.10.1   eMotion (Network in Motion) child project of OCEAN (On-board Communication, Entertainment And iNformation)

OCEAN [42] which is a University of New South Wales and Australian Research Council sponsored project with collaborators being National ICT Australia (NICTA) [43] and Boeing Airline Company was founded in 2003. This project recognizes the need for extension of Internet services for public transportation systems and encompasses two research areas namely networking and data management. The child project eMotion [44] handles networking issues pertaining to providing global Internet access to passengers via Mobile Routers and wide area wireless access systems. This project has implemented a network mobility test bed [45] and has studied the NEMO protocol extensively and has proposed many optimizations for network mobility [16].

1.10.2   Ambient Networks Project

AMBIENT networking project [21] is geared towards increasing competition and cooperation in an environment populated by a multitude of user devices, wireless technologies, network operators and business entities. This architecture aims to extend all IP networks with three fundamental requirements of today's networking world. These requirements include dynamic network composition, mobility and heterogeneity. By encompassing these notions the Ambient Networks (AN) project strives to achieve horizontally structured mobile systems that offer common control functions to a wide range of different applications and air interface technologies. The ambient networking approach includes the flexibility of every end system to be not just a node but also an entire network. Therefore network mobility is inadvertently a central focus of this architecture.

1.10.3 OverDRiVE (Over Dynamic multi-Radio networks in Vehicular Environments)

OverDRiVE [46] is an Information Society Technologies (IST) project and is ongoing work of the DRiVE [47] project. The main objective of this project is to enable high-quality wireless communication to vehicular networks in multi-radio access environments. This project too uses the Mobile Router architecture for network mobility in an IPv6 setting.

1.10.4 Nautilus6 (WIDE Project)

The WIDE (Widely Integrated Distributed Environment) project which was launched in 1988 established the Nautilus6 working group [49] to deploy mobile Internet. In order to do so the Nautilus6 Working Group uses the IETF standards whenever appropriate. Nautilus6 NEMO working group was established in November 2003 and is specifically looking at issues concerned with mobile networks. This group has a demonstration test bed as well as a indoor NEMO test bed.

1.10.5 InternetCAR (Internet Connected Automobile Researches)

The demand for Intelligent Transportation Systems (ITS) has influenced the need for projects such as the InternetCAR [50]. This project which is also a WIDE project was launched in 1996. Their main aim is to view a car as a node on the Internet and to provide Internet connectivity permanently and in a transparent manner regardless of the underlying access medium.

The InternetCAR project implemented the Prefix Scoped Binding Update approach for network mobility proposed by Ernst et al [51]. The details of this implementation and the requirements for connecting vehicles to the Internet are described in [52].

1.10.6   FleetNet - Internet On the Road

FleetNet [53] project too aims to connect vehicles to the Internet. But the MR-HA bidi-
rectional tunneling architecture for network mobility is not the approach adapted when
providing Internet connectivity to the devices in a vehicle in FleetNet. This project has in-
troduced a novel network mobility architecture named as MOCCA (MObile CommuniCation
Architecture).

The MOCCA architecture relies on a new entity namely an Internet Gateway installed
on roadsides which plays the role of a gateway router for the devices requiring Internet
connectivity. These gateways can be regarded as FleetNet radio nodes since they run the
same communication system employed on the vehicles. The Internet Gateways have another
interface which connects them to the Internet. The devices in the vehicles are able to obtain
connectivity through the Internet Gateways transparently. This MOCCA architecture has
been developed by Bechler et al [54].

1.11   Conclusion

This chapter presented the basic network mobility architecture using mobility scenarios in
order to highlight the benefits of such an architecture. As shown, providing basic network
mobility support is relatively simple and requires only minimal extensions to the MIPv6
operations of the MR and its Home Agent. On the other hand, providing route optimization
for the nodes within the mobile network is quite challenging, given the MR-HA Bi-directional
tunneling architecture. The IETF NEMO working group is chartered only to standardize
solutions for basic network mobility; nevertheless numerous members within the community
are currently working on optimal routing solutions for a network mobility setting. The future
of network mobility at IP level 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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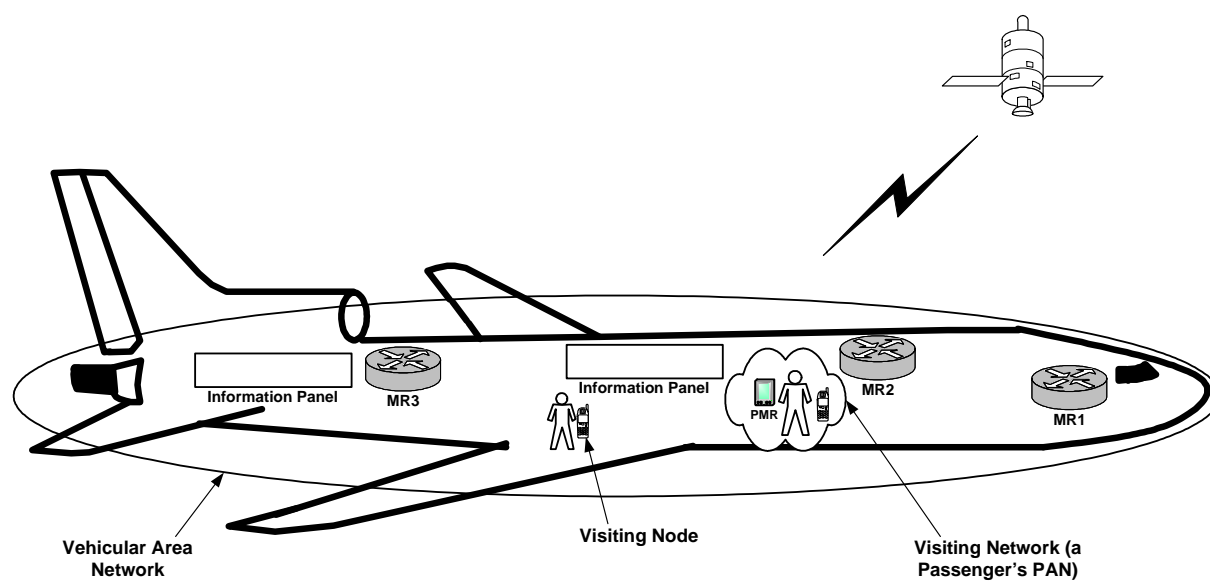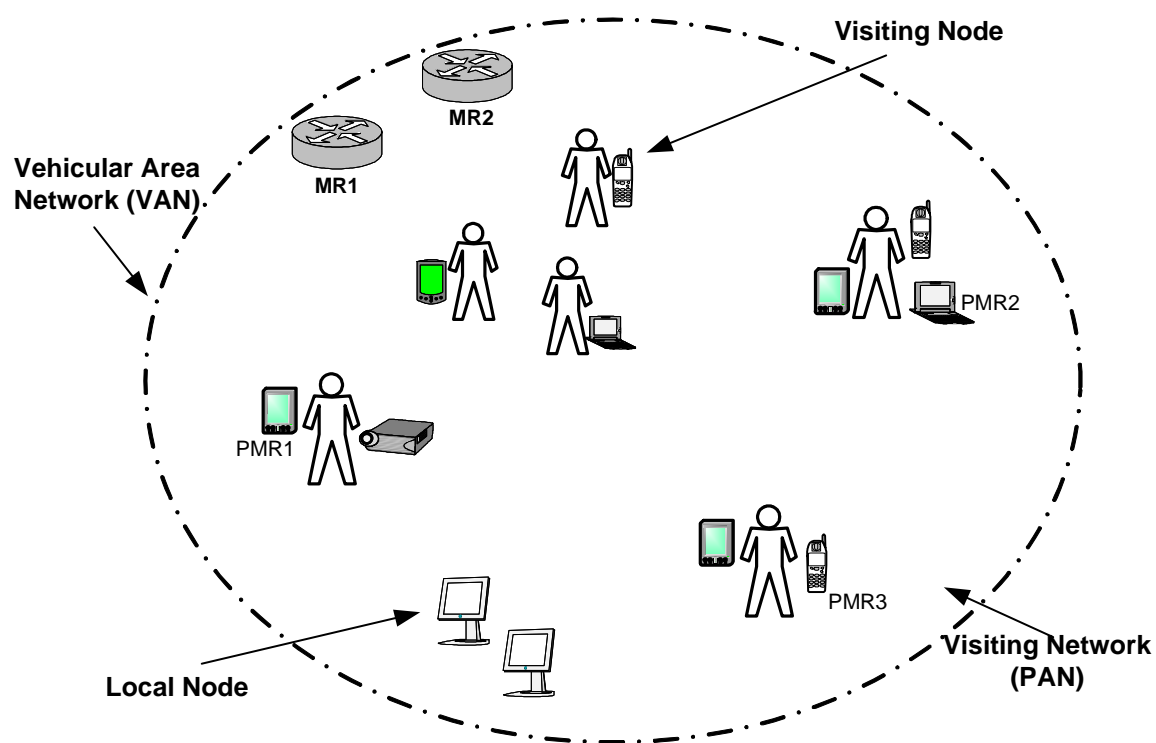
Figure 1.1: Mobile Network Scenario

Figure 1.2: Abstract View of a Vehicular Area Network

Home Network
MR2
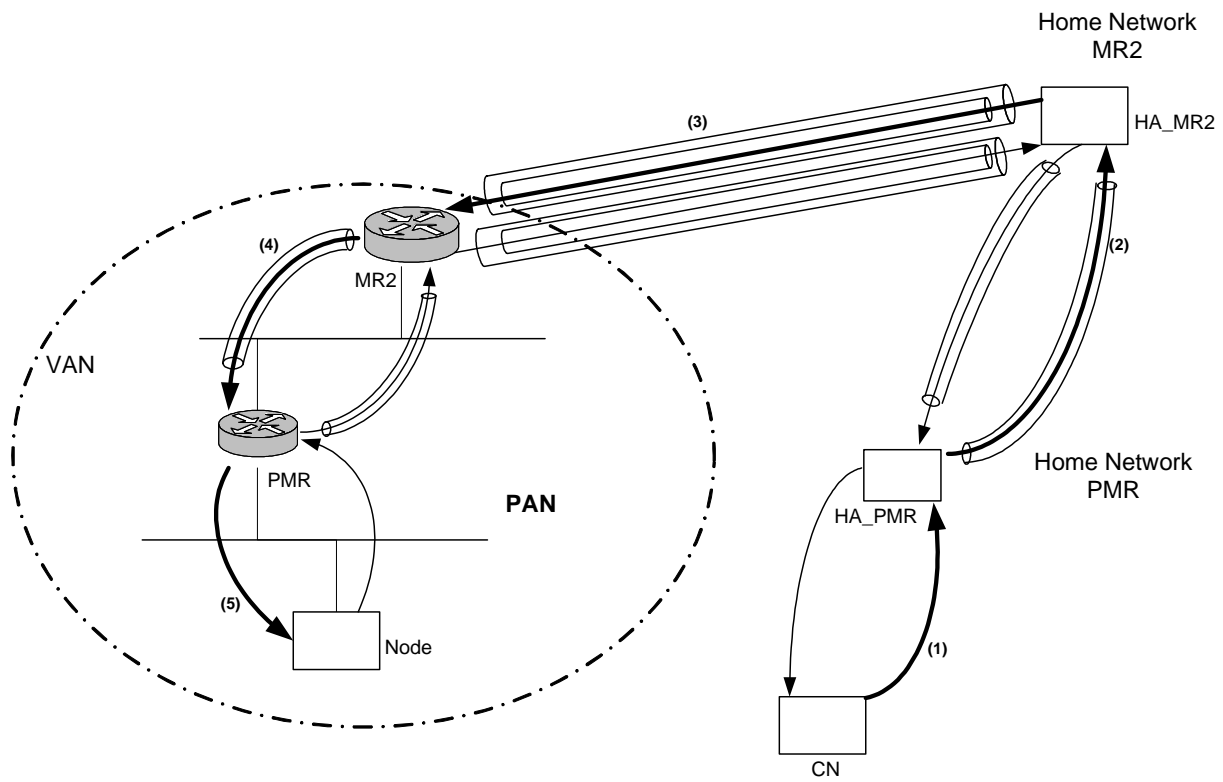
(3)

HA_MR2

(4)

MR2

VAN

(2)

PMR

PAN

Home Network
PMR

HA_PMR

(5)

Node

(1)

CN

Figure 1.3: Nested Bi-directional Tunneling