Integration of Ad hoc Network and IP Network Capabilities for Mobile Hosts

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Abstract. *Mobility of user devices connecting to the Internet is of major interest in today's research in networking. Users with portable devices, like laptops and personal digital assistants (PDA), connecting to foreign networks in the Internet want the same functionality as when connected to the home network, as well as accessibility through the home IP address. Ad hoc networking is also of major importance for connectivity between communicating mobile hosts without backbone infrastructure and for connectivity to access points. For the users as well as for the applications, network mobility should be transparent. The usage of the ad hoc network or the wired IP network should also be managed by the networking software and hidden from applications and users. In this paper we propose and describe an integrated connectivity solution and its software implementation between an ad hoc network running the Ad Hoc On-Demand Distance-Vector Protocol and a wired IP network where Mobile IP is used for mobility management. With the usage of ad hoc networking, a mobile host will be able to use multiple foreign networks to enhance the communication performance. A proposal to multihomed Mobile IP is presented to achieve this.*

1 Introduction

The rapid developments in wireless technology have made wireless communication appealing for connectivity to wired IP networks and the Internet, as well as for communicating peer-to-peer. The wireless local area network (WLAN) standard referred to as 802.11b [1] is widely deployed and theoretically supports the throughput of up to 11Mbps. Another standard, 802.11a [1] supports up to 54Mbps. The bandwidth will scale for many applications used in desktop computers and will gradually increase.

With the advent of high bandwidth wireless network access, new demands for network protocol support arise. To enable networking software to fully adopt the possibilities with wireless network access, new

functionalities need to be added to mobile hosts (MH) and to the wireless access network. MHs should benefit from the dynamic behaviour of wireless computer communication.

With wireless communication, device mobility is possible, and to manage mobility for an MH connecting to IP networks, where both the applications as well as the user are unaware of the network mobility, the Mobile IP (MIP) [2] is deployed.

Another type of network becoming popular because of the wireless capabilities in computer communications is ad hoc networking [3]. In ad hoc networks there is no such fixed infrastructure as a wired backbone with routers. Instead, all MHs, which are ad hoc hosts usually work as both end user hosts and routers within the ad hoc network. The address space in an ad hoc networks is created regardless of the hierarchy in wired IP network topology. Some ad hoc network proposals use clustering to create a hierarchical network scheme, while others use a flat address space. Ad hoc routing protocols can be classified into two major types: proactive and reactive routing protocols [4]. The proactive routing protocols always try to maintain a route to every host in the ad hoc network regardless of whether user data is being sent or not. The proactive approach is the one used in IP networks by routing protocols like RIP [5] and OSPF [6]. In ad hoc networks where mobility might be high, proactive routing protocols may not be optimal, since the path created to a destination may be obsolete when the destination is addressed. The reactive routing protocols on the other hand create a path to a destination when packets need to be sent there. If no user data is sent in the ad hoc network, no routes are created. In ad hoc networks, reactive routing protocols have proven efficient [7, 8]. Today ad hoc networks are usually seen as separate entities without connectivity to wired IP networks. This will likely change to make ad hoc networks part of the global connectivity within the Internet. Also, functionalities like multihomed ad hoc hosts as well as mobility between ad hoc networks should be considered.

The contribution of the work proposed and described in this paper includes:

- A gateway is proposed, connecting wired IP networks and ad hoc networks, where the ad hoc network uses a reactive ad hoc routing protocol. Communication can be ad hoc with a peer or by associating with an access point (AP) to use the wired network. Multi-hop ad hoc connections can be used for connectivity to an AP. MHs moving between ad hoc networks are managed by the MIP. By combining ad hoc networks and wired IP networks using MIP for mobility management, a dynamic and adaptable infrastructure is created, enhancing the network support to the mobile users.
- MIP is extended to enable MHs to register with multiple APs simultaneously. This enhances the network connectivity by enabling the MH, the home agent (HA) and the correspondent host (CH) to evaluate and select the best connection for their communication.
- A prototype has been created to verify and evaluate the gateway. The implementation uses MIPv4 and the Ad Hoc On-Demand Distance Vector Protocol (AODV) [9] for ad hoc networks. Multihomed MIP is currently being integrated.

The gateway described here hosts the functionality of the AP, the HA and the foreign agent (FA).

In section 2 we describe our design and implementation and section 3 describes related work. Section 4 concludes the paper and outlines future work.

2 Connecting IP Networks with Ad hoc Networks

The connectivity between wired IP networks and ad hoc networks integrates ad hoc networks into the global connectivity provided by the IP. Because of the capabilities of this connectivity, a more dynamic network infrastructure is created. This will enable the MIP to enhance its performance and reliability by using multiple network connections for MHs, in what we define as multihomed MIP.

2.1 Global Connectivity

Global connectivity is achieved by the layering in the TCP/IP [10] stack. In the physical layer, different physical equipment may be used, and in the datalink layer, different protocols can be used (e.g. Ethernet, Token Ring, Frame Relay). The network layer manages different datalink layer protocols and enables connectivity between them. The layers above the network layer (transport and application layer) are unaware of the differences in networking

technologies, thus enabling global connectivity. When connecting ad hoc networks with wired IP networks (see figure 1), the differences between the two types of networks should be considered in the network layer.

Routing and network management in wired IP networks are based on a relatively static topology, while routing and management in the ad hoc network need to manage a more dynamic and frequently changing topology.

In computer networking, routing protocols need to efficiently limit the routing information sent, in order to reserve network resources for user data. Ad hoc networks consisting of MHs with scarce resources should not have to manage routing information from the wired IP network, since this would severely impair performance in the ad hoc network. Also, inserting frequently changing ad hoc routing information into the wired IP network will increase the administrative overhead.

To manage the differences in the two types of networks and to achieve an efficient connectivity, ad hoc network is here a (sub-) network with its own network number. By identifying the ad hoc network with a network number, the only routing information sent in the wired IP network is this number and no internal ad hoc routing information. In ad hoc networks, the only information needed by MHs to access the wired IP network and the Internet is which gateway to use.

The ad hoc network can be seen as a Non-Broadcast Multiple Access (NBMA) [11] network and must be managed by the network protocol. The ad hoc network differs from networks like Ethernet since a packet broadcasted by one host cannot be seen by all other hosts in the same network in one hop. In ad hoc networks, all MHs need to re-broadcast the packet to enable all MHs to receive it.

To identify a host within a network (LAN) the Address Resolution Protocol (ARP) [12] is used in IPv4 and the Neighbour Discovery (ND) [13] in IPv6. However, to identify an MH within an ad hoc network they cannot be used since they are based on the premise that all hosts are reached in one hop. In this work, the reactive ad hoc routing protocol AODV is used. This conforms well to the soft state approaches used in the ARP and ND protocol.

MIP is used to manage MHs disconnecting from the home ad hoc network and connecting to foreign networks. MIP is extended to operate in ad hoc networks where MIP messages are managed multiple hops instead of one hop as in the current specification of MIP, which enables MHs multiple hops in the ad hoc network from an FA to register. The AODV protocol is modified to create routes based on MIP messages to enhance performance.

2.2 Multihomed Mobile IP

The most popular and widely deployed wireless connectivity solution today, 802.11, associates an MH with one AP at a time at the datalink layer. The MIP does not account for multiple simultaneous connections to different networks by MHs where connections are evaluated for performance.

With the integration of ad hoc networks and wired IP networks, an MH may sense multiple gateways (APs) in the ad hoc network, and simultaneous connectivity with multiple gateways will enhance performance and reliability (see figure 1). The present work describes a multihomed MIP enabling MHs to simultaneously connect to multiple networks for enhanced performance as well as reliability. The same home address can be used as the final destination through all care-of addresses used by an MH. With multiple registrations, packets sent from the MH and packets received from the HA and the CH may use different gateways.

First the MH will decide which networks to register with. The registrations are stored and used by the HA to select the care-of address for flows tunnelled from the HA to the MH. When route optimization is used, the CH will be informed by the HA in MIPv4 or the MH in MIPv6 about the available care-of addresses, and it will make the selection of which one to use.

The gateway(s) selection will be managed at the network layer. An MH is then able to decide which gateway(s) to use on other criteria than the signal-to-noise ratios. In the work described here, the delay is used to make the selection.

Fig. 1. An ad hoc subnet with a multihomed MH.

2.3 Design and Implementation

In the design and implementation described below, we make use of MIPv4, and the AODV routing protocol within the ad hoc network.

In this section we describe:

- How MIPv4 messages are managed in the ad hoc network.
- How an MH decides what FAs to register with, if it knows several.
- How a destination address from the ad hoc network is found in the ad hoc network or in the Internet.
- How multihoming in MIP is managed.

An MH will run the AODV protocol to communicate with peers and to access the wired IP network through the gateway (also running AODV). To manage the mobility of MHs between ad hoc networks, MHs as well as the gateways run the MIP, where the software for the FA and HA runs in the gateway.

For the MIP messages specified to be sent link-local in a LAN, with a TTL value of 1, we have changed the value to indicate the size of the ad hoc network or the length in hops to an MH.

We have made the AODV protocol MIP-aware to recognize MIP messages so that ad hoc hosts (MH and gateway) can install routes based on the messages. Hosts forwarding agent advertisements will install a route to the FA. When an MH then registers with an FA by sending a registration request to the agent, a route will be available, without the need to do an explicit RREQ for the FA. The registration request creates a route for the registration reply, and the agent solicitation message creates a route for the unicasted agent advertisement.

An MH discovers a path to a destination by sending an route request (RREQ) for the destination. If the destination is known to be outside the ad hoc network, the gateway replies with a proxy RREP (ProxyRREP) to the source. The packets will then be sent to the gateway that forwards them on the wired network. For a destination within the ad hoc network, the gateway will function as an ad hoc host forwarding the RREQ.

For a gateway to know which hosts are in the ad hoc network, the AODV protocol requires information of the visitor list in the FA, and all hosts homed in the ad hoc network have to have the same network number as the gateway connecting to the ad hoc network. These requirements are the same as for a LAN in IP networks managing mobility. When a route is requested for a destination with a network number different from the ad hoc network, the visitor list is searched by the AODV process to see if the destination is available in the ad hoc network. If the destination is not within the network, the gateway sends a ProxyRREP to the source. If the destination is a foreign MH visiting the ad hoc network, normal AODV operations are used to discover the destination within the network. Figure 2 illustrates this.

Fig. 2. The process in the gateway to manage AODV RREQ messages.

A ProxyRREP is also sent if a destination homed in the ad hoc network is connected to a foreign network. The HA functionality used is as specified in MIPv4. Packets coming to the gateway will be processed as shown in figure 3.

To manage several FAs covering an ad hoc network there is a need to synchronize the visitor information between the FAs. Without synchronization, a gateway may conclude that a destination is within the wired IP network and send a ProxyRREP to the source, while the destination is in fact within the ad hoc network but registered with another FA.

Fig. 3. The flow in the gateway to process an incoming packet.

The FAs synchronize their visitor lists using the wired IP network to relieve the ad hoc network, and the information is synchronized when an entry is added or deleted from the visitor list in a gateway. All gateways will thus be able to see if a visiting host is within the ad hoc network even if it is not registered with the gateway receiving the RREQ. The HA binding cache does not have to be synchronized between the gateways since the gateway responding with a ProxyRREP will be the gateway acting as an HA for the MH connected to a foreign network. Other gateways will ‘believe’ that the MH is in the ad hoc network.

When several FAs serve an ad hoc network, an MH must be able to choose the best FA(s) to register with. Also, an

MH may discover multiple ad hoc networks. This is managed by multihomed MIP.

Multihoming is managed by the MIP and hidden from the IP routing and ad hoc routing, making IP routing protocols like RIP and OSPF as well as AODV unaware of this. For a sender, multihomed MIP can be considered an any-cast approach [14] where a sender relies on the network protocol to find the best available destination for the packets. The best available destination for packets will be one of possibly multiple care-of addresses used by an MH. In IPv6, an any-cast address is used to reach the best available destination (server) among multiple destinations supporting the service required. The approach in this paper for a sender to any-cast address an MH, is that the MH’s home address is used to locate the best care-of address (gateway). The difference from the any-cast approach in IPv6 is that it is address-based instead of server-based and the destination will be the same host.

Since no routing information is redistributed between the wired IP network and the ad hoc network the, total distance to an MH can not be managed in any of the routing protocols. The selection of which care-of address to use for an MH as described in this article is made based on the delay, where the delay will include both the wired network and the ad hoc network. IP routing is used between the HA or the CH (in the wired network) and the care-of address selected, but the selection of which care-of address to use is managed by multihomed MIP and based on the delay including both networks. Between the gateway and the MH, ad hoc routing is used.

Fig. 4. Processing of registration requests in the HA.

The MH must decide which foreign network(s) to register with. An MH receiving advertisements from foreign networks will monitor the available networks and measure the round trip time (RTT) to the gateway, see figure 4. This time is recorded for each advertisement and the gateway(s) with the smallest metrics calculated from the RTTs are registered at the HA. An MH is configured with the maximum number of networks to register.

The HA will have multiple bindings for an MH's home address registering multiple care-of addresses. Based on the RTT between the HA and the MH, one of the care-of addresses will be installed as the tunnel end-point to the MH. The measuring of RTTs is based on the registration messages sent between the MH and the HA (see figure 5).

Fig. 5. Processing of registration requests in the HA.

A CH sending packets to an MH without route optimization will send them to the MH's home network, where the HA will make the selection of which care-of address to use to forward the packets. With route optimization, the CH will send the packets to the MH without using the HA and will itself tunnel the packets to the selected care-of address. The care-of address information is sent by the HA to the CH. In multihomed MIP, multiple care-of addresses may be sent. The selection at the CH for which care-of address to use can be based on:

- longest prefix match
- first address received
- delay

The choice of care-of address is based on individual selections by the HA, the CH and the MH for packets sent by them. In a scenario where an MH has registered three care-of addresses and there are two CHs, one using the HA to communicate with the MH and the other using route optimization, three different gateways may be used: one by the HA, another by the CH using route optimization and the third by the MH to send packets (see figure 6).

The MH keeps a list of all foreign networks with valid advertisements and some of the entries will be in a second list identifying the networks it is registered with.

Fig. 6. A multihomed connectivity where the HA, CH and MH make their own selections of which care-of address to use.

2.4 Implementation

The gateway as well as the MHs run the MIP software and the AODV software (see figure 7). The MIP software used is the HUT distribution [22] and the AODV software is a distribution from Uppsala University[23]. The operating system used is Linux [24].

Fig. 7. The processes in a mobile host and their relationship, using the forwarding table in the kernel.

The software in the gateway looks as in figure 7 with the extension of the shared memory between the MIP and the AODV processes, so that the AODV process will be informed of visiting MHs. If the gateway hosts an HA as well, the shared memory will also contain the hosts homed in the ad hoc network and connected to a foreign network.

The MIP and AODV software operates by modifying the forwarding table within the Linux kernel. In the kernel the forwarding process manages packets by using this information.

The MH keeps a list of all FAs sending agent advertisements, and registers the care-of address at the HA for the FAs supporting the smallest metrics. To select the FA(s) to register with, the MH sends an Internet Control Message Protocol (ICMP) echo request to the FAs it knows about. To calculate the metrics used for comparison the Jacobson/Karels algorithm [15] is used (see formula 1). The algorithm accounts for both the RTT and the deviation in the measurements.

$$\text{Difference} = \text{SampleRTT} - \text{EstimatedRTT}. \quad (1)$$

$$\text{EstimatedRTT} = \text{EstimatedRTT} + (\delta \times \text{Difference}).$$

$$\text{Deviation} = \text{Deviation} + \delta(|\text{Difference}| - \text{Deviation}).$$

$$\text{Metric} = \mu \times \text{EstimatedRTT} + \phi \times \text{Deviation}.$$

To avoid rapid changes resulting in flapping of the care-of addresses registered at the HA, a new FA is only chosen if the value differs beyond a certain threshold.

In MIP, an MH receiving an agent advertisement assumes the previous link layer sender to be the FA, and uses this address for its registration request. This must be modified to function in ad hoc networks, otherwise the MH will believe an intermediate host in the ad hoc network forwarding the agent advertisement to be the FA. We reserve the first care-of address field in the agent advertisement for the FA address within the ad hoc network (see figure 8). The MH can then discover the address of an FA multiple hops away.

0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
type										length										sequence number											
registration lifetime										R B M F M G V reserved																					
foreign agent address on the ad hoc network																															
zero or more care-of addresses																															

Fig. 8. The modified agent advertisement extension for the ad hoc network..

The agent solicitation message is also modified to function in the ad hoc network for the same reason as the agent advertisement. The solicitation message used in the standard MIP is the same as the router solicitation message. Figure 9 shows the agent solicitation extension added to the router solicitation.

0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
type										reserved																					
source address																															

Fig. 9. The agent solicitation extension added to the router solicitation.

To register a care-of address at the HA, a registration request is sent, and to enable the HA to distinguish between a non-multihomed and a multihomed registration, an N-flag is added to the registration request (see figure 10). An HA receiving the registration request with an N-

flag will keep the existing bindings for the MH. For the HA to be able to select a care-of address when forwarding packets to the MH, the RTT to the MH through different care-of addresses is measured. The MH monitors the time between registration requests and registration replies and calculates the RTT. The RTT is added as an extension in the next registration request. The HA will maintain all registrations for an MH and based on the metrics it will install a tunnel into the forwarding table with the care-of address with the smallest metrics.

0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
type										S B D M G V P N										lifetime											
home address																															
home agent																															
care-of address																															
identification																															
extensions																															

Fig. 10. The modified registration request message.

The MH will maintain multiple registrations with different FAs as well as keep control of available FAs not registered with.

For route optimization, the binding update sent from the HA to a CH is shown in figure 11. The binding update is extended to carry multiple care-of addresses. The CH will install a tunnel to one of the MH's care-of addresses in its forwarding table. The decision of which care-of address to install as the tunnel end-point in the forwarding table is based on the longest prefix match. If two care-of addresses have the same match, the first listed will be used.

When the binding is about to expire, the CH sends a binding request to the HA, and the HA will reply with the current bindings of an MH to the CH.

0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1
type										A I M G reserved										lifetime											
mobile host home address																															
identification																															
One or more care-of addresses																															

Fig. 11. The modified binding update message.

3 Related work

In [16] a work is described to modify RIP for ad hoc networks and with MIP. This approach uses a proactive ad hoc routing protocol less efficient in ad hoc networks. In [17-20] proposals for connections between MIP and AODV are made. In [19] MIPv4 and AODV are connected so that MIP messages will be managed in the ad hoc network. The question of how to choose between multiple

FAs is not addressed, and an MH in the ad hoc network has to discover by itself if a destination is within the ad hoc network or not. If the gateway 'thinks' it can receive the destination, it replies with an FA RREP (like the proxyRREP). But before an MH can use the gateway, it first needs to conclude that the destination is not within the ad hoc network and this will delay the connection setup time. MIPv6 management with AODV is proposed in [18] using the ND protocol. The same approach for destinations in the IP network is taken as in [19] and it is proposed that router advertisements should not be sent without router solicitation. However, in [17] measurements show that it is more efficient to use the normal MIP behaviour where advertisements are sent without solicitations. In [17] and [20] an approach to choosing between multiple FAs is described, and the selection is made based on the hop count between the FA and the MH. Hop count may however not be the best way to measure which FA to register with since network load is not considered. In [21] MIP and the ad hoc routing protocol DSR are addressed.

In MIPv4, an option for simultaneous bindings is proposed for sending packets to multiple care-of addresses for an MH. Packets will be duplicated at the HA and one copy sent to each registered care-of address, so that packets can be received through multiple APs. This option was proposed to decrease the number of dropouts of packets during handover, and for an MH with bad connections to APs to receive the same packet through several APs, with an increased probability of a good connection. The solution does not however enable network layer decisions of the best connection to use, and it will waste resources in the ad hoc network.

In the current specification of MIPv6, all traffic uses the same care-of address. This prevents the MIP from fully utilizing the dynamics within global connectivity including ad hoc networking, and should therefore be altered.

4 Conclusion and further work

In this article we propose and describe an integrated connectivity solution and its implementation connecting IP networks and ad hoc networks running the reactive AODV routing protocol, where MIP is used to manage mobility. The software supports the creation of areas covered by gateways connecting wireless MHs to the Internet. MHs will be able to communicate peer-to-peer or with hosts in the IP network. Our approach proposes a new way to locate a destination inside the ad hoc network or in the IP network, and the selection of FA(s) based on the RTT between the MH and the FA.

MIP is extended to manage multiple simultaneous connections with foreign networks. Based on the registered care-of addresses, multiple paths can be used for packets to and from an MH. Enhanced throughput and a more reliable

connection are achieved. The current prototype is based on MIPv4 but will in the next phase be deployed on MIPv6 as well.

To avoid sending explicit ICMP echo requests in the ad hoc network to measure the RTT, a study will be done on whether only the jitter in arrival time between received agent advertisements can be used to decide the performance of a connection to a gateway. A study will also be performed on the impact of the delay between the measurement of the RTT and the time the HA receives the information, since the RTT is sent one registration request later than when it was measured.

We are currently running performance tests and collecting statistics. We will compare our proposal to those in [17] and [20]. The performance and the time to discover a destination in the ad hoc network or in the IP network will be evaluated and compared to the proposals in [17-20].

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