A Multihoming approach to Mobile IP

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Abstract. Mobile IP is the standard for mobility management in IP networks. With today's emerging possibilities within wireless broadband communication, mobility within networks will increase. New applications and protocols will be created and Mobile IP is important to this development, since Mobile IP support can be used to allow mobile hosts to move between networks with maintained connectivity. This article describes multihomed Mobile IP enabling mobile hosts to register multiple care-of addresses at the home agent, to enhance the performance of wireless network connectivity. Flows can be load-balanced between care-of addresses to achieve a more reliable connectivity. A prototype is also described.

1 Introduction

With the use of wireless local area networks (WLAN), new challenges arise and mobile hosts (MH) will face multiple access points (AP) with possibly different capabilities and utilization.

The work described in this article is based on 802.11b [1] technology. In 802.11b, there are two different Basic Service Sets (BSS) for connectivity: infrastructure BSS and independent BSS. In infrastructure mode the association with an AP is based on link-layer mechanisms using the signal quality. The selection is invisible to upper layer protocols and one association at a time is possible. In independent BSS a network interface can communicate with all others within communication range without association and this is the mode used in ad hoc networks [2].

The selection of which AP to associate with should also be available for higher level protocols, the applications and the users. It might be that the signal quality is somewhat better to one AP but the overall performance is better at another. Then it is reasonable to use the AP with the best overall performance. Wireless connections are prone to errors and by using multiple simultaneous connections to APs, a more reliable connectivity is achieved.

In the largest study so far [10], a university campus equipped with WLANs is evaluated. 476 APs are spread over 161 buildings divided into 81 subnets. 5,500 students and 1,215 professors are equipped with laptops. The study shows that 17% of the sessions involves roaming and that 40% of it is between different subnets, causing the IP traffic to fail. MHs sometimes perform frequent handovers between APs while being in the same place.

The study [10] shows the Mobile IP (MIP) [3,4] requirements and the potential to associate with multiple APs simultaneously to avoid breaking and disrupting sessions.

The work in this article describes an approach to enhanced network connectivity to MHs connecting to WLANs. The MIP is extended to support multihomed connectivity where multihoming is managed by MIP. A prototype is also described. This will enable the AP selection on other criteria than just the signal-to-noise ratio and hereby avoid rapid re-associations. Traffic to and from an MH can be sent using multiple APs.

Section 2 describes multihomed MIP. In section 3 related work is presented and section 4 concludes the paper and discusses future work.

2 Multihomed Mobile IP

Multihomed MIP enhances the performance and reliability for MHs connecting to WLANs. Wireless connections are prone to errors and changing conditions which must be considered to enable applications for desktop computers to be usable on MHs connecting wireless.

The multihoming is managed by the MIP and hidden from the IP routing, keeping IP routing protocols like the Routing Information Protocol (RIP) and Open Shortest Path First (OSPF) unaware. For a sender, multihomed MIP can be considered an any-cast approach [5] where a sender relies on the network protocol to use the best available destination for the packets. The available destination 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. 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.

The MH keeps a list of all networks with valid advertisements and registers the care-of address at the HA (and the CH if MIPv6 route optimization is used) for the networks supporting the best connectivity. To evaluate the connectivity, the MH monitors the deviation in arrival times between advertisements and calculates the metric based on this information (see formula 1). This metric is used to describe the MH's connectivity to foreign networks. A small metric indicates that agent advertisements sent at discrete time intervals arrive without collisions and without being delayed by the FA. This indicates available bandwidth as well as the FA's capability to relay traffic to and from the MH. Among the care-of addresses registered at the HA, the FA with the smallest metrics will be installed as the default gateway in the MH.

$$\text{SampleDelta} = \text{CurrentArrivalTime} - \text{LastArrivalTime}. \quad (1)$$

$$\text{MeanDelta} = \text{SampleDelta} \times \delta - \text{MeanDelta} \times (1 - \delta).$$

$$\text{Metric} = (\text{SampleDelta} - \text{MeanDelta})^2 \times \mu + \text{Metric} \times (1 - \mu).$$

The selection of which care-of address to use for an MH is based on the delay between a CH or the HA and the MH, where the delay includes wireless links. In IP routing with protocols like RIP and OSPF a wireless last hop link is not considered in the route calculation. A hop count of 1 is used in the RIP protocol, and a static link cost in OSPF based on the link (usually Ethernet) connecting the APs. In multihomed MIP, IP routing is used to the care-of address selected but the selection of what care-of address to use is managed by MIP. The HA makes its own selection and the CH does the same if route optimization is used.

Before informing the HA and CHs about the current location of the MH, the MH must decide which foreign networks to register with. An MH receiving advertisements from foreign networks will monitor the available networks and calculate the deviation in arrival times. This is recorded for each sender and the networks with the smallest metric calculated from the deviation are registered at the HA. An MH is configured with the maximum number of care-of-addresses to register.

Since the MH may register multiple associations with foreign networks, the HA can have multiple bindings for an MH's home address. Based on the round trip time (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.

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 based on the MIP version used it will either tunnel the packets (MIPv4) or use the routing header (MIPv6). Route optimization is managed by the HA (MIPv4) or the MH (MIPv6), sending the CH information of which care-of address to use. In multihomed MIP multiple care-of addresses may be sent. The selection by the CH for which care-of address to use can be based on:

- longest prefix match
- the first address received
- delay

Considering the proposal made to MIPv4 for route optimization without explicitly measuring the RTT (e.g sending ICMP echo requests) between the CH and the MH, longest prefix match and the arrival order are the options available. With the proposal for route optimization made to MIPv6 the care-of address selection made by the CH is managed the same way as by the HA. However, instead of the MH sending the RTT time delayed by one registration request, the CH itself measures the RTT by monitoring the time between sent binding refresh update messages and binding update response.

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 APs 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 1).

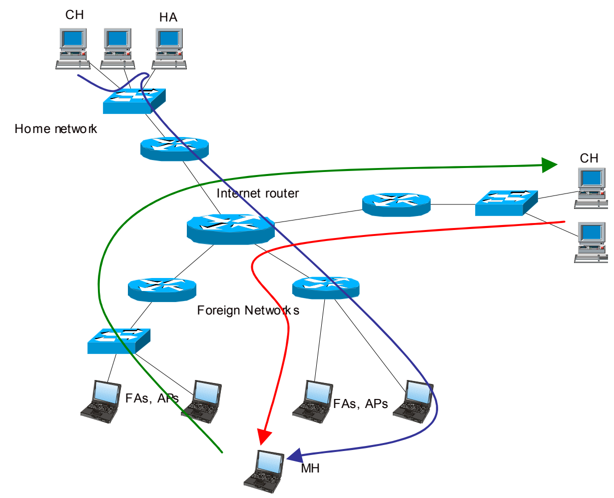

Fig. 1. A multihomed connectivity scenario where the HA, CH and MH make their own selections of which care-of address to use.

The metrics for the selection of care-of address made by the HA and CH (if route optimization is managed by the MH) is based on the Jacobson/Karels algorithm [6] (se formula 2). A small value is preferred.

To avoid rapid changes resulting in flapping of the care-of addresses and the default gateway because of metrics close in value, a new care-of address or gateway is only chosen if its value is less than the value used minus a threshold.

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

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

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

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

2.1 The prototype

This section describes the prototype and the changes made to MIP. MIPv4 is used as the framework and the use of an FA is assumed. Route optimization is handled by MIPv4 and MIPv6 in different ways; In MIPv4 route optimization messages are sent by the HA to CHs. In MIPv6 the MH informs CHs about its address. To add this behavior to MIPv4 as well, both types of route optimization are considered.

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.

An HA receiving the registration request with an N-flag will keep the existing bindings for the MH. One of the registered care-of addresses will be used to forward packets to the MH. For the HA to be able to make the selection, the RTT to the MH through the 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.

With a care-of address advertised by an FA, the MH is not allowed to use the Address Resolution Protocol (ARP). This will confuse other hosts connected to the network and may cause problems when the MH disconnects and moves to another network. To avoid this in MIP, the MH monitors the MAC address in the frame containing the agent advertisement, and installs the binding between the FA's MAC address and the IP address in the ARP table, for the FA registered with. When a packet is sent using the default gateway, an entry in the ARP table will already be available and no ARP request is needed. In multihomed MIP, the MH will maintain multiple registrations with different FAs as well as keep control of available FAs not registered with. All IP addresses for the FAs are installed in the forwarding table, and the bindings between the IP and the MAC addresses are installed in the ARP table.

We considering both the proposal for MIPv4 as well as how MIPv6 manages route optimization. For MIP multihoming, multiple packets must be sent to inform the CH of multiple care-of addresses. The binding update is extended with an N-flag to signal multihomed binding updates. The first binding update clears the N-flag to erase the binding cache in the CH from possibly stale entries. The rest of the binding updates have the N-flag set. The CH will install a tunnel to the MH in its forwarding table based on the information in the binding updates. The decision of which care-of address to install as the tunnel end-point in the forwarding table is based on the selections described earlier. When an MH performs a handover between networks and changes from one care-of address to another, the binding update needs to express both the new and old care-of address, so that the HA and the CH knows which binding to update. In the case of a single-home binding, only the new care-of address is included.

When a binding is about to expire, CH sends a binding request message to the HA. The binding request must include the care-of address for the binding so that the HA knows which binding to respond with. Without the care-of address included, binding updates are requested for all care-of addresses. An HA will respond with care-of addresses for all available bindings for an MH.

If a binding request is sent for one care-of address and multiple bindings are maintained, the binding update will have the N-flag set. This will inform the CH whether other bindings are maintained as well. If the care-of address requested in the binding request message has no binding in the HA, the HA will respond with a binding update with a lifetime set to 0.

To manage route optimization where an MN sends binding updates (instead of the HA) to the CHs as in MIPv6, the same messages is used as described above. The advantage of this method for route optimization is that RTT can be measured by the CH by monitoring the departure time of binding requests and the arrival of binding updates. The selection of the care-of address to install as the tunnel end-point is based on formula 2.

The algorithm for processing of MIP message in the MH is shown in algorithm 1. The processing in the HA is shown in algorithm 2

var $N_{foreign}$: set of available fa and announced care-of address;
N_{reg} : set of registered care-of addresses;
M_{adv} : array of calculated metrics;
T_{regReq} : array of clock times for RTT measurements;

Processing a <**agent advertisement**, fa, care-of-address> message: **begin**
receive <**agent advertisement**, fa, care-of-address>;
if $fa \notin N_{foreign}$ **then begin**
$N_{foreign} := N_{foreign} \cup \{fa, \text{care-of-address}\}$;
$M_{adv}[fa]$:= initilize;
if $|N_{reg}|$ < max care-of addresses to register **then begin**
$N_{reg} := N_{reg} \cup \{fa, \text{care-of-address}\}$;
if $|N_{reg}| > 1$ **then**
set(n-flag)
else
clear(n-flag);
send <**registration request,** home-address, ha, care-of-address, n-flag, 0> to ha via fa;
$T_{regReq}[fa]$:= clock
end
end
else
$M_{adv}[fa]$:= calculated metric according to formula 1;
end

Processing a <**registration reply**, home-address, ha> message: **begin**
receive <**registration reply**, home-address, ha> from fa;
$T_{regReq}[fa]$:= clock - $T_{regReq}[fa]$
end

Time expires for a binding to a fa: **begin**
if $|N_{reg}| > 1$ **then**
set(n-flag)
else
clear(n-flag);
send <**registration request,** home-address, ha, care-of-address, n-flag, $T_{regReq}[fa]$ > to ha via fa;
$T_{regReq}[fa]$:= clock
end

Time expires, compare N_{reg} and $N_{foreign}$: **begin**
if $\min\{M_{adv}[w] : w \in N_{foreign} \wedge w \notin N_{reg}\} < \max\{M_{adv}[w] : w \in N_{reg}\}$ - threshold **then begin**
$fa := \{w : \min\{M_{adv}[w]\} \wedge w \in N_{foreign} \wedge w \notin N_{reg}\}$;
$\{fa_{min}, \text{care-of-address}_{min}\} := \{\{x, y\} : \{x,y\} \in N_{foreign} \wedge x = fa\}$;
$fa := \{w : \max\{M_{adv}[w]\} \wedge w \in N_{reg}\}$;
$\{fa_{max}, \text{care-of-address}_{max}\} := \{\{x,y\} : \{x,y\} \in N_{reg} \wedge x = fa\}$;
$N_{reg} := N_{reg} \setminus \{fa_{max}, \text{care-of-address}_{max}\}$; $N_{reg} := N_{reg} \cup \{fa_{min}, \text{care-of-address}_{min}\}$;
if $|N_{reg}| > 1$ **then**
set(n-flag)
else
clear(n-flag);
send <**registration request,** home-address, ha, care-of-address$_{min}$, n-flag, 0 > to ha via fa_{min};
$T_{regReq}[fa_{min}]$:= clock
end
end

Algorithm 1. The processing of MIP messages in the MH

```
var B_mh  : set of bindings;
    T_mh  : array of tunnels;
    M_rtt : array of calculated metrics;

Processing a <registration request, home-address, ha, care-of-address,
                                             n-flag, rtt > message: begin
  receive <registration request, home-address, ha, care-of-address, n-flag,
                                                 rtt > from mh via fa;
  if {home-address, care-of-address} ∉ B_mh then begin
    B_mh := B_mh ∪ {home-address, care-of-address};
    M_rtt[home-address, care-of-address] := initialize
  end;
  if ¬n-flag then
    forall binding ∈ {{x, y} : {x, y} ∈ B_mh ∧ x=home-address ∧
                                                y ≠ care-of-address} do
      B_mh:= B_mh \ binding;
  M_rtt[home-address, care-of-address] := calculated metric according to
                                                      formula 2 (rtt);
  tunnel := T_mh [home-address];
  if M_rtt[home-address, tunnel] - threshold > min{M_rtt[home-address, x] :
                                                        x ≠ tunnel} then
    T_mh [home-address] := {x : min{M_rtt[home-address, x]} ∧ x ≠ tunnel};
  send <registration reply, home-address, ha> to mh via fa
end
```

Algorithm 2. The processing of registration requests in the HA.

3 Related work

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 success. The solution does not enable the network layer to decide which connection to use and it will waste resources in the WLAN.

In the current specification of MIPv6, all traffic uses the same care-of address. This prevents the dynamics of the MIP from fully utilizing the dynamics in WLANs and should be altered.

In [7], an approach to multihoming for survivability is proposed, managed at the datalink layer and based on radio signalling. This approach restricts the selection of APs to the datalink layer and is not available to higher levels.

In [8], a transport layer protocol is proposed striping data between multiple links to achieve bandwidth aggregation. The work presented in this paper instead aims to evaluate multiple connections and how to use the best available connection(s) to forward packets.

Another transport layer solution is presented in [9] for multihomed hosts. Here the sender selects one of the host's IP addresses as the destination address for the packets. If the IP address becomes unavailable due to network failure, the protocol will switch to another IP address for the same destination host with maintained connectivity at the transport layer. An extension for mobility to [9] is described in [11]. With our approach any transport layer protocol can be used.

In [12] a policy based approach to multihoming with Mobile IP is described. Our approach instead uses metrics based on measurements to decide how to manage multihoming.

4 Conclusion and future work

The work here described extends the MIP 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. The approach will also prevent MHs from flapping between foreign networks due to the fact that an MH has similar quality of connectivity to multiple APs.

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.

A study will be performed on the impact of the delay between the measure 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.

An MH can connect to multiple APs simultaneously and to manage this, the network interfaces are configured in independent BSS mode. Another option is to use two or more interface cards in infrastructure BSS mode, but still the association is made in the datalink layer. The association should be made available to higher protocol layers and provided through an Application Programmer's Interface (API). Future work will look into possible solutions to achieve this.

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