THE EFFECTS OF MOBILE IP MICRO-MOBILITY EXTENSIONS ON THE CHOSEN ASPECTS OF UDP/TCP PROTOCOLS' PERFORMANCE

Tomasz Dajda, Piotr Pacyna
Department of Telecommunications, University of Mining and Metallurgy
al. Mickiewicza 30, 30-059 Kraków, Poland

toomsby@poczta.onet.pl,
pacyna@kt.agh.edu.pl

ABSTRACT

Mobile IP protocol came into being mainly as an answer to the need for connecting laptop computers to Internet without the restraint of mobile terminal remaining within the area of his home WLAN. Nevertheless, its development nowadays is driven by the idea of 4G cellular network and IP as a general solution for global mobility. As a result several extensions have been devised that aim at improving Mobile IP performance, especially handover delays, during local, i.e. intra-domain handovers. However, the question lingers on what is their outcome on other aspects of data transmission, especially UDP and TCP protocols. The paper tries to point out the most important relations between the implementation of micro-mobility extension and the performance of UDP, and specifically TCP, based on a series of simulations done in ns-2, with the use of micro-mobility extension model implemented by the authors.

1. INTRODUCTION

Throughout the last decade the number of portable computers increased significantly and at the same time the trend towards providing Internet connectivity to every piece of equipment, in every place around the world became one of the driving forces for the telecommunication market. A need arouse to create a common All-IP network that the users would be able to access with their laptops not only at the workplaces but also at home and any other place providing wireless access service [Einsiedler].

Mobile IP is a protocol that aims at maintaining uninterrupted communication to a mobile node while it moves through a number of access networks without a limit to their location or IP address as long as the terminal has a link-layer connection. This so called 'macro-mobility' is the function supported by the base Mobile IP protocol and has been well developed. On the other hand, providing for changes in the location of the terminal within a single access network, i.e. 'micro-mobility', is still under evolution. Being perceived as a factor of paramount importance to the global mobility management, the evolution in 'micro-mobility' resulted in numerous extensions to Mobile IP protocol. They are discussed in the course of the paper.

2. MOBILE IPV4 AND MOBILE IPV6

Mobile IP [rfc3344] is a modification to IP protocol [rfc791] that allows nodes to continue to receive datagrams no matter where the nodes happen to be attached to the Internet.

Mobile IP is a layer-3 protocol which is suitable for mobility across heterogeneous as well as homogeneous media and places no constrains on the layer-2.

There are three entities introduced by the Mobile IP (see fig.2.1):

- ***Mobile node (MN)*** [rfc3344] is a host or router that changes its point of attachment. A mobile node may change its location maintaining IP address and continue to communicate with other Internet nodes. It is equipped with an IP address, so-called *home address* [rfc3344], which allows the MN to function in standard IP fashion when it is attached to its *home network* (subnet with matching subnet prefix). When the mobile node is visiting *foreign network* it can try to obtain a *care-of* address [rfc3344] – a topologically correct IP address.
- ***Home agent (HA)*** [rfc3344] is a node on a mobile node's home network that *tunnels* datagrams for delivery towards the mobile node when it is away from home network and

maintains current location information for the mobile node (location management).

- ***Foreign agent (FA)*** [rfc3344] is a node on a network visited by the mobile node that provides routing services to the mobile node while the latter is registered. The FA detunnels datagrams that were sent by HA and delivers them to the mobile node.

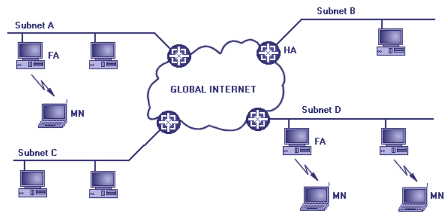

Figure 2.1. An example of placement of the Mobile IP entities [Perkins]

As the tunnel terminates at node's care-of address the latter is supposed to be reachable via standard IP routing. There are two ways of acquiring a care-of address:

- ***Foreign agent care-of address (FA mode)*** – a care-of address is an IP address of the FA. The foreign agent as the endpoint of the tunnel decapsulates datagrams and delivers them to the MN.
- ***Colocated care-of address (co-COA mode)*** – a care-of address is acquired by the MN as a local IP address through means external to Mobile IP. The address can be either temporary (obtained from DHCP server [rfc2131]), can be autoconfigured, or it may be owned by the MN as a long-term address for use only in the given network. The tunnel ends at mobile node which decapsulates datagrams by itself.

In general, Mobile IP involves three relatively separate functions: agent discovery, registration and tunnelling and the basic operation of the Mobile IP includes the following steps [Perkins]:

- Mobility agents (HA, FA) broadcast agent-advertisement messages to advertise their presence on the subnet. A mobile node can alternatively request an agent-advertisement message from any locally present mobility agents by broadcasting an agent-solicitation message,
- After receiving an agent advertisement message the mobile node determines whether it is on its home network or visiting another (foreign) network,
- In case the MN is located on its home network it operates without mobility services. If it happens to return to the home network after a period of operation in foreign network it has to deregister with its HA using a sort of the normal registration process,
- If the MN discovers that it has changed its point of attachment it tries to obtain a care-of address on this network. The care-of address can either be a foreign agent care-of address or a colocated care-of address,
- After acquiring the new care-of address the MN registers it with its HA through the exchange of a registration request and registration reply messages.
- Corresponding node that wishes to communicate with MN sends datagrams to MN's home address. Those datagrams are intercepted by the HA and tunnelled to the mobile node's care-of address. Finally, they are delivered to the MN.
- Datagrams sent from the MH to corresponding node can either be tunnelled back to the HA by the use of *reverse tunnelling* [rfc3344] or routed in standard IP fashion directly to the corresponding node, which is referred to as *triangle routing* [rfc3344].

As the IPv6 [rfc2460] has been introduced a need for a modified mobility protocol has surfaced. The Mobile IPv6 protocol has obviously been developed based on the experiences with the Mobile IPv4, however the new features of the IPv6 enabled it to be fully integrated into IP [John02]. The main differences between the two mobility protocols include:

- a support for Route Optimization (see: chapter 3) is now built in as a fundamental part of the protocol rather than being added as an optional set of extensions that may not be supported by all nodes; direct routing from any correspondent node is allowed by default,
- a support for Mobile IPv6 nodes to coexist with routers performing 'ingress filtering' [rfc2267],
- Since the Mobile IPv6 protocol makes use of the IPv6 destination options its control traffic can be piggybacked on any existing IPv6 packets instead of being send by separate UDP packets as in MIPv4,
- The mentioned use of the care-of address as the source address in each packet's IP header also simplifies routing of multicast packets,
- There is no need for foreign agents as the support provided by them is replaced by IPv6 features, such as Neighbour Discovery [rfc2461] and Stateless Address Autoconfiguration [rfc2462],
- The movement detection mechanism in Mobile IPv6 provides bi-directional confirmation of a mobile node's ability to communicate with its default router,
- In MIPv6 only the packets relayed by the home agent need to be encapsulated. The majority of packets, which are sent directly to

the MN, make use of the IPv6 Routing header which results in less overhead,

- The home agent intercepts the datagrams destined to the mobile node using IPv6 Neighbour Discovery [rfc2461] rather than ARP [rfc826] as is used in Mobile IPv4. Neighbour Discovery has the advantage of not being dependent of the link layer,
- To discover the address of the home agent MIPv6 uses IPv6 anycast address [rfc2526], which returns only one packet to the MN, contrary to separate packet from every home agent returned by the directed broadcast mechanism used in MIPv4.

3. EXTENSIONS TO MOBILE IP

While the Mobile IP is widely regarded as an appropriate approach to macro-mobility management, some extensions to the basic protocol are necessary when its introduction as a micro-mobility management solution is considered. The main issue is the handover latency in case the mobile node roams in foreign network that is far away from its home network. When using basic Mobile IP protocol the mobile node has to register with its home agent each time it changes its point of attachment, even though the movement may happen between two local subnets of the same access network. Consequently, the idea common to all micro-mobility approaches is that of moving the functionality of the HA closer to the mobile node. Two classes of methods have been defined to fulfill this goal [CampbellA]. The first class employs the idea of 're-addressing' datagrams as in the base Mobile IP protocol and builds hierarchies of foreign agents. The other approach aims at modifying routing table entries so that the per-host routes are created and is obviously limited to intra-domain routing where adding such routes is feasible. Figures 3.1 and 3.2 compare the two classes of methods.

In the re-addressing scenario datagrams are tunnelled to the mobile node through a hierarchy of foreign agents. The home agent tunnels packets to the parent foreign agent (i.e. FA higher in the hierarchy), which then decides to which of its direct descendants they should be tunnelled. Since the tunnelling is basically encapsulation accompanied by the change of the destination address, the FA actually *re-addresses* the packets hence the name of the scenario. When the mobile node changes its point of attachment the parent FA is informed, so that it could redirect packets appropriately, and no message is sent to the HA, so that the actual movement is hidden from the latter. Note that in this case the foreign agents can be many hops away from their parent FA.

In a routing-based scenario the datagrams are routed along the per-host routes once they have reached the domain gateway. Here, each node is directly connected to its parent.

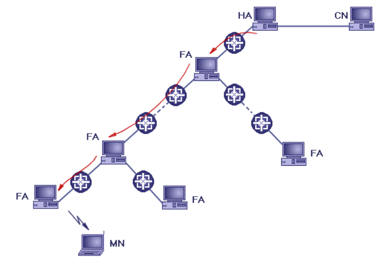

Figure 3.1 Re-addressing-based scenario

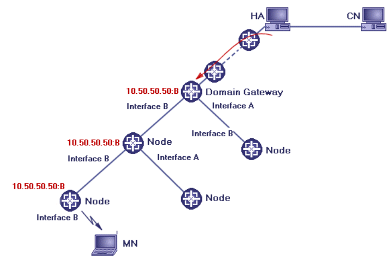

Figure 3.2 Routing-based scenario

There have been two micro-mobility proposals implementing routing-based scenario: Cellular IP (CIP) and Handoff-Aware Wireless Access Internet Infrastructure (HAWAII), however routing based solutions are considered infeasible due to their drawbacks, such as the lack of scalability that comes from the expansion of routing tables caused by storing per-host routes, or the sole fact that they require support from all nodes in a domain, whereas the re-addressing proposals rely only on those few nodes that serve as foreign agents. Generally, it is felt that the idea of the introduction of per-host routes to the routing tables denies the basic idea of IP routing which is to build hierarchies of addresses that allow concatenation of routes for entities (subnets, nodes) at the same level of hierarchy.

Re-addressing solution directly extends the concept of the Mobile IP base protocol. The time of re-capsulation of packets at each node is relatively short as actually only the outer IP header needs to be modified. Moreover, it can be easily introduced to almost every domain as the only modification is implementing a few foreign agents. Four proposals that employ a hierarchy of foreign agents have been devised for the Mobile IP protocol. These include: Localizing Registrations [Perkins], Dynamics HUT [Forsberg99], Regional Aware Foreign Agent [FooChua] and Regional Registrations [Gustafsson02]. All the solutions are similar in the way they provide delivery of packets. They all implement the idea of a switching agent, which may be a FA with enhanced functionality (Localizing Registrations, Dynamics), RAFA, or GFA/RFA in case of Regional Registrations.

The main difference is the transparency of the proposal to mobile nodes. Of course the simplest solution is to inform the mobile node of all the hierarchy of FAs and let it decide which agent will provide for switching of packets. The idea is used in Localizing Registrations proposal and its most significant drawback is that it requires special procedures to be added in the mobile node [Perkins]. On the positive side, Localizing Registrations does not require any changes to home agent.

The other proposal that is on no account transparent is Regional Registrations. First, mobile nodes have to support other extensions (such as FA-NAI extension) since in other case they would not be able to detect the change of the point of attachment. It results from the fact that if FA advertises only one care-of address it is the address of the GFA. Even though this proposal adds a few extremely helpful features such as the possibility of assigning the GFA address by network or forcing registration with the previous serving GFA, all those features imply the need for new functions being implemented not only in mobile nodes but also in home agents. Moreover, the operation of the proposal is based on numerous extensions to Mobile IP messages that may increase the overhead as well as the processing time of messages.

The two remaining proposals: Dynamics HUT and RAFA are fully transparent to mobile nodes and home agents. The only changes need to be applied to foreign agents and they are in no case severe.

The second main issue that differentiates the proposals is the choice and the use of the advertised addresses. In Localizing Registrations and RAFA proposals foreign agents advertise their own addresses as care-of addresses. Consequently, those addresses must be globally routable IP addresses. This prevents the implementation of those proposals in deep intranet structures. Under the HUT proposal foreign agents always advertise the address of the highest foreign agent and only this address must be globally routable [Forsberg99]. Similarly, in Regional Registrations domain, only the gateway foreign agent has to be assigned a non-private IP address.

To summarize, all the re-addressing proposals are quite similar, however some features that were mentioned above stress the advantages of the HUT extension as the one that is transparent to mobile nodes and home agents and at the same time supports multiple levels of hierarchy (which is not the case with RAFA that is also transparent). Additionally, Dynamics HUT proposal allows the use of private FA addresses. The Regional Registrations extension has the same benefit and also supports additional functionality, which makes it extremely useful as long as the changes to home agent and mobile nodes can be afforded (or rather forced by the standard to be used).

The Hierarchical MIPv6 extension [Soliman01] devised for specifically for Mobile IPv6 derives from Regional Registrations proposal. Fortunately, several features of the latter have been improved, as e.g. mobile nodes conforming to the base MIPv6 protocol may function properly in HMIP domains without any modifications, and additional modes of operation have been introduced that allow the HMIP mobile node operation while its home agent features only basic MIPv6 functions. Additionally, the use of mobile nodes that cannot acquire a topologically correct address is allowed.

Additionally, a number of extensions not directly connected with micro-mobility have been defined for the use with Mobile IP base protocol. The most important of them is Route Optimization. The Mobile IP base protocol allows transparent interoperation between mobile nodes and their correspondent nodes, but forces all datagrams destined to a mobile node to be routed through its home agent (*triangle routing*). In extreme cases, when the mobile node and its correspondent node are located on the same network, it causes a significant delay and a non-negligible network load that could be otherwise avoided. Route optimization [Perkins][Perkins01] aims at elimination of the triangle routing and introduces several extensions that provide the means for correspondent nodes to cache the bindings for the mobile node and to tunnel their datagrams directly to the care-of address indicated by that binding, without the assistance of the home agent. Additionally, functions are provided for the datagrams in flight or sent to out-of-date care-of address to be forwarded directly to the mobile node's new care-of address.

4. SIMULATION GUIDELINES

To assess the operation of micro-mobility extension to base Mobile IP protocol, the Network Simulator version 2.1b7 for Unix has been used. It was also due to ns-2 popularity and abundance of available extensions that the authors of this work decided to commit the experiment to that tool. As the base version of ns-2 supports only the Mobile IPv4 base protocol, NOAH routing agent designed by Jörg Widmer from Berkeley University has been used [Widmerpage]. No ns-2 extensions providing micro-mobility management for Mobile IP were available and for that reason the author decided on implementing one of the re-addressing proposals on his own. Since two levels of FA hierarchy are sufficient to study the operation of the micro-mobility extension, a simplified RAFA proposal was implemented. The apparent reasoning behind the choice considers the fact that it is one of the simplest and at the same time most effective solutions. Moreover, as it is transparent to mobile nodes and home agents no changes needed to be made to the code of those entities.

Topology used in simulations (fig. 4.1) comprised of the entities that are essential for showing all three kinds of handover including: home-network-to-visited-network, visited-network-to-visited-network, and visited-network-to-home-network, which are marked as HA-FA, FA-FA and FA-HA, respectively. Therefore, it consists of two foreign agents, a home agent, a correspondent node that is the source of the packets destined to the mobile node, and the central router that serves as a Regional Aware Foreign Agent when the micro-mobility extension is employed.

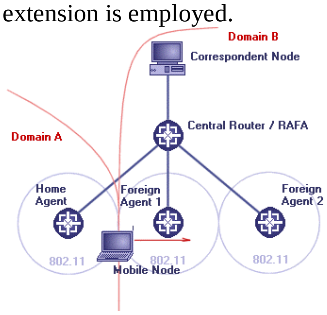

Figure 4.1 Topology of the simulated network

All wired links are 10Mbit/s connections with a delay of 10ms with the exception of the link between the central router and the home agent (CR-HA link), which has a delay that will vary in the simulation. The delay between correspondent node and the central router is the same as for the foreign agents since it is assumed that the correspondent node resides in the same domain as FAs and CR. The home agent is located in another domain. 802.11 Wireless LAN [IEEE802.11] is simulated in the wireless medium.

5. Simulation Results

5.1 UDP Scenario

In the first part of the simulation the relation between the distance of the MN from the home agent and the delay, throughput, and packet loss has been examined. A simulated teleconference stream was employed, with the UDP CBR rate of 400kbit/s instead of standard 384kbit/s (for the sake of presentation of results). The interpacket spacing of the source was set to be equal to the delay of the links i.e. 10ms. This also ensured high resolution of the measurement. As can be easily computed the size of the packets was 500B. The simulation lasted 250s and the source started emitting packets after 25s. The mobile node was initially located at its home agent, and after first 50s of the simulation moved to the Foreign Agent1 at the speed of 20 m/s. Subsequently, in the intervals of approximately 50s it moved from FA1 to FA2, from FA2 to FA1 and back from FA1 to its HA. Consequently, four handovers occurred in the simulation. Data was collected every 10ms, which ensured maximum possible resolution. The parameter that was changed throughout the experiment was the HA-CR link delay.

Handover performance of base Mobile IPv4 and RAFA proposal was compared with respect to: handover latency, packet loss during handover, end-to-end delay and average rate of the received stream.

As can be seen in figures 5.1 and 5.2 RAFA definitely improves the latency of FA-FA handover. That latency is equal to 20ms and independent of the HA-CR link delay. This derives from the fact that the registration request messages during FA-FA handover are forwarded to RAFA (located at CR) which is only 10ms away. The other 10ms of the latency is the time that takes data packets to travel from RAFA to FA. As expected RAFA does not reduce the latency of HA-FA handover.

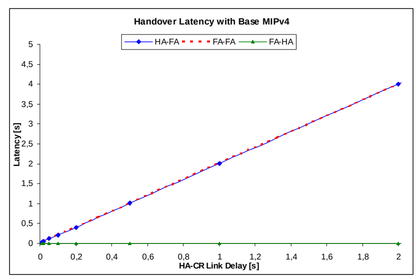

Figure 5.1 Handover latency with base MIPv4

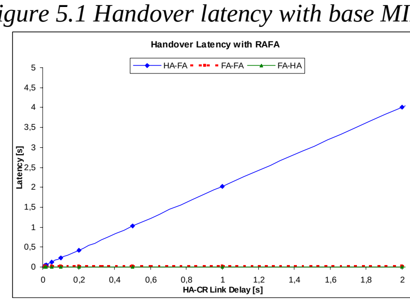

Figure 5.2 Handover latency with RAFA

Packet loss during HA-FA and FA-HA handovers remains unchanged while RAFA is used. However, the loss during FA-FA was reduced as a result of minimized handover latency. One important point should be noted. Even though the micro-mobility extension does improve the performance of handover within a domain, the change of the point of attachment between two domains is unaffected. It is true for all kinds of handover, including FA-FA handover and it was not shown by the experiment only because the two FAs were located in one domain.

While RAFA improves the handover latency, end-to-end delay remains unaffected by the extension. The reason for this is that even though the RAFA has a binding for the mobile node it does not intercept the packets destined to the mobile node: it just forwards them based on the routing table entry. The use of Route Optimization would reduce the end-to-end delay of packets send to the mobile node while it is located at one of FAs. The end-to-end delay for MN staying at its HA would remain the same.

The improvement in the intra-domain handover latency has a huge influence on overall performance even in case of the scenario when only a half of handovers take place within one domain. In practice, the movement between subnets located in one domain is much frequent than between subnets of different domains, and the frequency of intra-domain handover rises with the number of subnets in one domain.

5.2 TCP Scenario

In this scenario the effect of RAFA operation on the performance of TCP protocol has been evaluated. Correspondent node generates FTP traffic that relies on TCP Reno [Fall95] protocol for delivery. FTP source in ns-2 is saturated so the rate of the stream depends solely on the congestion control of the TCP mechanism. The packets generated by the source have the size of 1kB, and the acknowledgements of 40B are sent back to the correspondent node by means of triangle routing; no reverse tunnelling is employed. The movement pattern for the mobile node was retained for the sake of simplicity. Cells had a coverage area of 20 meters. The performance of base Mobile IPv4 and RAFA proposal was compared with respect to: the size of congestion window, round-trip time (RTT) as evaluated by the TCP source, and bandwidth gained by the FTP flow. Data was collected every 200ms, that proved to ascertain necessary resolution and at the same time an appropriate integration interval for smoothing the round-trip time estimates. The parameter that was changed in the experiment was again HA-CR link delay.

In the figures 5.3 and 5.4 congestion window for base Mobile IP and MIP with RAFA micro-mobility extension is presented. One can note, that when RAFA is used the window is not reduced during FA-FA handovers as it is with base MIP. This results from the fact, that due to the use of RAFA the latency of those handovers has constant value of approximately 20ms and during those 20ms mobile node can receive packets from the old FA due to the overlapping of wireless cells. Consequently, no packets are lost during FA-FA handover. However, in case the cells do not overlap, and the mobile node cannot receive packets from two base stations simultaneously (the latter is common in TDMA networks) the congestion window was reduced to 1 and TCP entered slow start [rfc2001], even though only a few packets were lost (fig. 5.5).

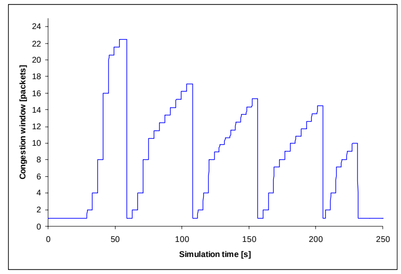

Figure 5.3 TCP Congestion window with base MIP, for HA-CR link delay of 2000ms

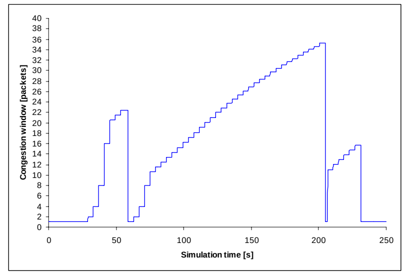

Figure 5.4 TCP Congestion window with RAFA, for HA-CR link delay of 2000ms

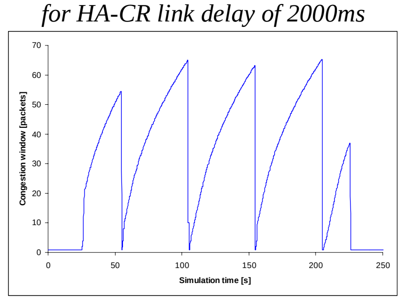

Figure 5.5 TCP Congestion window with RAFA, non-overlapping cells, HA-CR link delay of 200ms

Round-trip time does not change due to the RAFA operation and remains the same as in case of the base Mobile IP protocol as illustrated in figure 5.6. Obviously, even when the mobile node was located at one of the foreign agents, and 20ms of link delay away from correspondent node, packets destined to it still had to travel via Home Agent. The difference between round-trip time value for mobile node located at the HA and at the FA is a result of additional 10ms delay of the CR-FA link (crossed twice that sums up to 20ms) that packets and acknowledgements have to travel through.

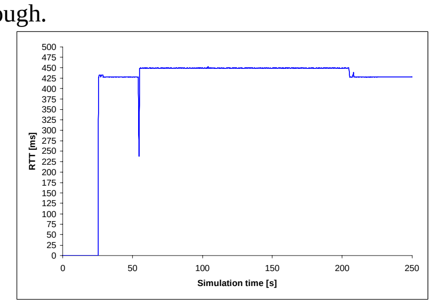

Figure 5.6 Round-trip time with base Mobile IP, for HA-CR link delay of 200ms

According to the figure 5.7 bandwidth acquired by the FTP flow under base Mobile IP drops suddenly with the increase in HA-CR delay. This is caused by the fact that RTT increases and the TCP sender has to await for acknowledgements for previous packets to arrive before it can send another packet and increase the size of congestion window. For the sake of illustration, if the window had the constant size of one, the interval with which the packets would be sent by the TCP sender would be equal to RTT. Window size greater than one enables more packets to be sent without previous acknowledgements, however the number of them is always equal to the window size. Even though TCP tends to maximize the congestion window size for a given link, the movements of the mobile node in the simulation prevent it from reaching the optimum. For smaller RTTs the average size of the congestion window is closer to optimum than for huge values of RTT, where the window is increased at longer intervals owing to the time that takes acknowledgements to arrive back to the sender. Consequently, when RTT increases, not only is the optimal size of the congestion window larger, but also the convergence to that value slower.

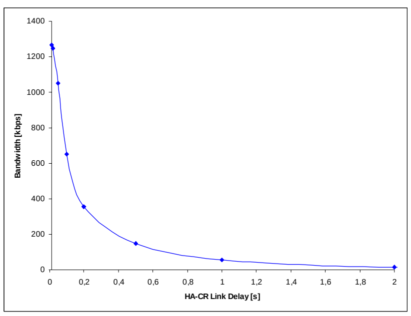

Figure 5.7 Bandwidth acquired by FTP flow, with base Mobile IP

In the figure 5.8 bandwidth acquired by the FTP flow in case of base Mobile IP as well as Mobile IP with RAFA extensions is shown. One can notice, that even though RAFA improves the performance of Mobile IP, this is only a minor improvement and still the RTT is the major factor contributing to the drop of bandwidth. That stresses the necessity of its reduction by e.g. the use of route optimization present in MIPv6. The second interesting observation is that there is no difference between RAFA and base Mobile IP when the handover latency is less than one second, as the mobile node moves through the overlap area and no packets are lost by either RAFA or base MIP.

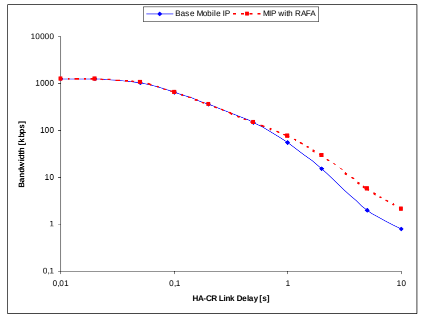

Figure 5.8 Comparison of bandwidth acquired by FTP flow, logarithmic scale

6. Summary and Conclusions

The Mobile IP protocol was devised as an answer to the need for macro-mobility solution in all-IP networks. It effectively provides for the change of IP address when mobile nodes roam in a wide set of networks. However, the movement of mobile nodes from one subnet to another within a single administrative domain that results in the change of IP address is always accompanied by a temporary interruption of communication while the given node follows the registration procedures of base Mobile IP. Not only is that interruption undesired, but also in case of delay sensitive applications and real-time services, such as Voice over IP (VoIP) or teleconferencing, it may prove intolerable and extremely damaging.

To avoid service disruption several extensions to the Mobile IP protocol were devised. These extensions aim at providing ways and means for local, intra-domain registrations and decorrelate handover latency from the distance to the HA. Several benefits resulting from the introduction of a hierarchical micro-mobility extension to the base Mobile IP protocol have been proved. First of all it indeed decreases the handover latency comparing to the base Mobile IP protocol as long as the home agent is outside the domain in which the mobile agent is currently located. additionally, this latency no longer depends on the delay of the link to home agent, but only on the intra-domain delays, which are usually far smaller. Consequently, the loss of packets that occurs during handover is minimised to the extent that it is not influencing TCP congestion prevention algorithm as long as the adjacent cells that the mobile node moves through have a common coverage area. Last but not least, the performance of TCP is improved when a micro-mobility extension is used while compared to the base Mobile IP, especially in case of a distant home agent.

Nevertheless, micro-mobility extensions are not without disadvantages and shortcomings. Not only do all require some degree of modifications, such as implementation of foreign agents, made to existing network, but also most of them cannot

provide full functionality unless changes are made to mobile nodes and home agents. Whereas those extensions solve a few problems that arise when the mobile node moves away from the home agent, they leave out several major issues. First of all, as it was shown in the experiment, whilst they decrease handover latency, they do not reduce packet end-to-end delay. This proves to have dire consequences when TCP traffic is being sent do the mobile node, namely, data rate drops severely when the distance to the home agent increases, even if there are no packets lost during handovers. Additionally, we can imagine that while the micro-mobility extensions address the mobility management in a single domain that is possibly distant from the home agent, the mobile node would have to move through countless other domains to reach that specific one. During this migration the borders of domains would often be crossed and resulting handovers would cause severe problems with communication as the inter-domain handovers are not a subject of micro-mobility extension but of base Mobile IP protocol.
Lastly, micro-mobility extension alone cannot provide for smooth handovers in case of TDMA networks, when the mobile node cannot receive packets from two base stations simultaneously. Even in 802.11 WLAN the smooth handover is only possible under the assumption of overlapping cells.

As a consequence several other extensions must be used with those concerning micro-mobility to provide for uninterrupted service. The most important of those is Route Optimization that significantly reduces the end-to-end delay by creating mobility bindings in correspondent nodes. We can imagine that this fact will greatly improve performance of TCP, making the RTT independent of the distance to home agent. However, it has yet to be examined if the packets that are sent by an unaware correspondent node via the home agent would not destabilise congestion prevention algorithm. Where mobile nodes cannot receive packets from two base stations simultaneously, the Low Latency Handovers may be used together with a micro-mobility extension to reduce or totally eliminate the loss of packets during handovers hence providing for smooth handover.

Be that as it may, there is still a lot of research that has to be done in the field of IP micro- and mobility in general. One can imagine, that the possibly perfect solution for all-IP network would be extending the hierarchy of foreign agents, or rather Mobility Access Point as in the future IP network IPv6 is to be used, from a single domain to the whole Internet. Thus, the hierarchy of MAPs would span through all domains, providing for ideal solution where local registrations are separated from home registrations that MAPs are responsible for. In this way whether the mobile node changed the access point within or between domains there would be always a regional access point that could be informed of that change. However, this vision for the future is bound to face major problems, for example the possible localisation of MAPs in the backbone would prove to be an interference to the operation of the core, fast switching nodes. Even this issue cannot be answered right now, and there are surely many others that are likely to surface in the oncoming years. At the end of the day, the engineers responsible for the evolution of mobility protocols have to monitor the changes in the development of QoS-aware network architectures and develop their solutions appropriately to the opportunities that are appearing.

7. References

[Einsiedler] H. Einsiedler, J. Jähnert, K. Jonas, M. Liebsch, R. Schmitz ‘Mobility Support for a Future Communication Architecture’,

[rfc3344] RFC 3344 ‘IP Mobility Support for IPv4,’ Charles E. Perkins et al., August 2002,

[rfc791] RFC 791 ‘Internet Protocol,’ J. Postel, STD 5, 1981,

[rfc2131] RFC 2131 ‘Dynamic Host Configuration Protocol,’ R. Droms, March 1997,

[rfc2460] RFC 2460 ‘Internet Protocol, Version 6 (IPv6) Specification,‘ S. Deering, R. Hinden, December 1998,

[rfc2267] RFC 2267 ‘Network Ingress Filtering: Defeating Denial of Service Attacks which employ IP Source Address Spoofing,’ P. Ferguson, D. Senie, January 1998,

[rfc2461] RFC 2461 ‘Neighbour Discovery for IP Version 6 (IPv6),’ T. Narten, E. Nordmark, W. Simpson, December 1998,

[rfc2462] RFC 2462 ‘IPv6 Stateless Address Autoconfiguration,’ S. Thomson, T. Narten, December 1998,

[rfc2526] RFC 2526 ‘Reserved IPv6 Subnet Anycast Addresses ,’ D. Johnson, S. Deering, March 1999,

[rfc826] RFC 826 ‘Ethernet Address Resolution Protocol: Or converting network protocol addresses to 48.bit Ethernet address for transmission on Ethernet hardware,’ D. C. Plummer, November 1982,

[Perkins] Charles E. Perkins ‘Mobile IP – Design Principles and Practices’,

[Forsberg99] Dan Forsberg, Jari T. Malinen, Jouni K. Malinen, Tom Weckström ‘Dynamics - HUT Mobile IP Technical Document,’ August 1999,

[FooChua] Internet Draft ‘Regional Aware Foreign Agent (RAFA) for Fast Local Handovers,’ S. F. Foo, K. C. Chua, <draft-chuafoo-mobileip-rafa-00.txt>, November 1998, [Gustafsson02] Internet Draft 'Mobile IPv4 Regional Registration,' Eva Gustafsson, Annika Jonsson, Charles E. Perkins, <draft-ietf-mobileip-reg-tunnel-06.txt>, March 2002,

[Soliman01] Internet Draft 'Hierarchical MIPv6 mobility management (HMIPv6),' Hesham Soliman, Claude Castelluccia, Karim El-Malki, Ludovic Bellier, <draft-ietf-mobileip-hmipv6-05.txt>, July 2001,

[Perkins01] Internet Draft 'Route Optimization in Mobile IP,' Charles E. Perkins, <draft-ietf-mobileip-optim-11.txt>, September 2001,

[Widmerpage] http://www.icsi.berkeley.edu/~widmer/index.html

[IEEE802.11] IEEE Standard 802.11, 'Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications,' June 1999,

[Fall95] K. Fall, S. Floyd, 'Comparisons of Tahoe, Reno, and Sack TCP,' December 1995,

[rfc2001] RFC 2001 'TCP slow Start, Congestion Avoidance, Fast Retransmit and Fast Recovery Algorithms', W. Richard Stevens, January 1997,

[CampbellA] Andrew T.Campbell, Javier Gomez, Sanghyo Kim, Chieh-Yih Wan, 'Comparison Of IP Micromobility Protocols,' Columbia University,

[Johns02] David. B. Johnson, Charles Perkins, Jari Akko, "Mobility Support in IPv6", internet-draft, May 2002.