Fast Handover Schemes for Future Wireless IP Networks: a Proposal and Analysis

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Abstract

In this paper, we describe three proposals to perform fast handover in IP-based hierarchical mobile networks for real time applications. Our protocols are designed to re-establish the communication session flow quickly and to minimize the service disruption delay that occurs during a Mobile IP handover. Analytical study is carried out to evaluate the performance of the protocols and Mobile IP (MIP). The simulation results display a comparative study of MIP and the proposed schemes in terms of the time taken to establish the new path toward the Mobile Host (MH) after it has crossed a cell boundary. Also shown are comparative simulation results of packets lost per handover and packet loss ratio during a voice session for both MIP and the first proposed handover.

Introduction

In recent literature [1-2], solutions have been proposed to support mobility in future IP based wireless networks. One of the challenges in keeping connection with the Internet, as a mobile user moves, is to provide real time services while achieving low latency handovers and minimum packet loss. The need to communicate efficiently on the move and to minimize service disruption caused by handovers is becoming increasingly important for delay sensitive applications such as Internet telephony and video-conferencing.

In this paper, we propose three IP based micro mobility schemes to perform fast handover.

The proposed protocols are first described. The network parameters are then introduced. An analytical evaluation of the proposed protocols performances is carried. The trade-off between the cost of sending agent advertisement messages over the wireless link and the packet loss ratio due to mobility is analysed. Finally results of simulation carried are displayed for comparison of the protocols.

I Handover protocols Overview

In the micro-mobility IP based schemes proposed, the gateway (Gtwy) will keep location information for the mobile nodes for an extended time in its routing cache. In all the proposed schemes, the uplink refresh messages are sent frequently enough to avoid routing entries for the mobile node current position to expire. In all the following, it is assumed that the Base stations (BS) detect the mobile Host (MH) movement by sending agent advertisements over the wireless link [5].

The control-message exchange and the functions executed during the proposed hard handovers are as follows.

I-1 Handover 1

In scheme 1, when the MH crosses a cell boundary and it receives the first agent advertisement from the new base station (BS):

- The mobile Host sends a path setup update message upstream destined for the old BS via the new BS.
- The path setup message is routed by IP on a hop-by-hop basis to the old BS via the crossover router. For each router the path setup update message adds an additional forwarding entry to the mobile user.
- When the path setup message is received at its destination, but some packets are still in the buffer of the old BS, they are retransmitted along the new route just established to the new BS.
- Then the old BS sends an acknowledgement of the path setup message destined for the new BS. This deletes the old entries along the old path. The crossover router forwarding entries will cause the incoming packets from the crossover router to be diverted to the new location of the MH.

Note that, in this scheme, if some incoming downlink packets arrive at the crossover router after the arrival of the path setup update messages and before the path setup acknowledgement, these packets will be held in a buffer. This will allow any packets previously sent to the old BS to be forwarded first along the new route to the new BS before newly downlink incoming packets from the Gateway (Gtwy). This technique is intended to allow delivery of the IP packets in the right sequential order at their destination.

I-2 Handover 2 (soft-state expiration)

When the mobile Host (MH) crosses a cell boundary:

- The MH sends a path setup update message addressed to the old BS via the new BS. The path setup update message makes each router add an additional forwarding entry for the mobile user.
- When the path setup message reaches the nearest crossover router, an acknowledgement is sent back to the MH along the new path just established by the path setup message. The destination address of the acknowledgement message was copied from the source address field of the path setup message.
- The path setup message is discarded when it reaches the nearest crossover router. The latter is identified as the first router on the path to the old BS that has at least one active routing entry for the mobile host IP address.
- Incoming packets are sent along the new path and (possibly) duplicated and sent along the old path if it is still valid.

In scheme 2, the old entries are not now deleted by the path setup acknowledgement message but remain valid for duration of time until they are deleted by expiration of the routing entries lifetime. This scheme is intended to recover from packet loss quickly when the MH goes back to the previous BS soon after handover to the new BS. One of the disadvantages of scheme 2 is that it allows stale location information about the mobile host to be valid for the length of time (less than the Lifetime of the routing entry at the crossover router) after the mobile had actually left the old base station. So although scheme 2 is cheaper in terms of the number of control messages needed to complete the handover, it is more expensive in terms of the number of IP traffic packets sent incorrectly towards the old position of the mobile. The latency needed to complete the handover is smaller as it is only the round trip time between the new base station and the crossover router. This is possible in a connectionless protocol where it is not necessary to tear down the old path before establishment of the new route. This scheme is based on the expiration of the old (soft state) entries along the old path and renewal only of new entries along the new route.

I-3 Handover 3 (multicast based)

This handover (scheme 3) is based on multicasting the downlink traffic to the base stations at the edge of the sub-domain. The proposed multicast mechanism to direct the traffic to the mobile user is processed as described in [3].

II Performance evaluation

The notations and values, used in the analysis which follows and simulation platform are introduced in Table 1

Symbol	Definition	Value
B_W	Bandwidth of the wired backbone.	100 Mbs
B_{wl}	Bandwidth of the wireless link.	2Mbs
L_W	Latency of the wired link (includes propagation delay and link layer delay).	0.5 ms [5]
L_{wl}	Latency of the wireless link (prop delay + Link layer delay).	2ms[5]
P_x	[1]Router or Agent route lookup delay + packet Processing delay (at the IP layer).	10^{-6} s [6]
N_{new}	Number of hops between the MH new location and the crossover router.	>=2
N_{old}	Number of hops between the crossover router and the old point of attachment of the MH.	>=2
S_{ctrl}	Average Size of a control message (agent advertisement, Registration request/reply, path setup/acknowledgment).	400 bits
D_Int	Average overall delay a packet encounters while travelling across the wide area Internet.	>=25ms

Table 1:Network parameters

In this section, expressions of the handovers cost for both Mobile IPv4 without route optimisation and the proposed IP based wireless protocols are derived. The handover disruption time is the sum of three terms:

Discovery period (θ): The time for a mobile node to discover that it has moved to a new BS or foreign agent coverage area. This period of time includes the time to receive a new agent advertisement after crossing a cell boundary. In mobile IPv4, this period includes the time for the MH to realize that it has changed subnet based on the subnet ID matching.

Establishment time (T_c): The time to complete a MIP registration or to establish the new route to the mobile node.

Completion time: The time to receive the first forwarded IP packet after the new path has been established.

In all the cases, it is assumed that the MH is roaming outside its home network and is receiving downlink traffic only.

II-1 Establishment time calculation

[1] Note that the route lookup and the processing of control messages are done at all nodes in the routing table of the IP module.

Mobile IP without route optimisation

It is assumed that on each handover, the MH is changing subnet. Therefore on each handover, the MIP has to perform a registration with the Home Agent (HA). As a result, in Mobile IP, T_c is the time to complete the registration signalling exchange as specified in [4]. Its average is

$t_c=2.(S_{ctrl}/B_{wl})+2.N_{new}(S_{ctrl}/B_W)+2.L_{wl} + 2.N_{new}.L_W +2(N_{new}+1).P_x+2.D\_Int$

When the HA is located outside the network visited, D_Int, will be the predominant term.

Considering Table 1 values and $N_{new}=2$, $t_c=6.422ms +2.D\_Int$

Handover scheme 1

$t_c=2.(S_{ctrl}/B_{wl})+2.L_{wl}+2.(N_{new}+N_{old}).(S_{ctrl}/B_W)+2.(N_{new}+N_{old}).L_W + (2.(N_{new} + N_{old})+1).P_x$

On the above assumptions with $N_{new}=N_{old}=2$, $t_c=11.609ms$

Handover scheme 2

$t_c=2.(S_{ctrl}/B_{wl})+2.L_{wl}+2.N_{new}(S_{ctrl}/B_W)+2.N_{new}.L_W+2(N_{new}+1).P_x$

$N_{new}=N_{old}=2$, $t_c=6.422ms$

Handover scheme 3

$t_c=2.(S_{ctrl}/B_{wl})+ 2. L_{wl} + P_x$

$N_{new}=N_{old}=2$, $t_c=4.406ms$

Scheme 3 is comparatively the fastest one. Table 2 further presents the mobility model and evaluation parameters.

II-2 Mobility parameters

Symbol	Description
(N_{pkt_lost})	Average number of packets lost during a handover.
$(N_{pkt\_lost})_{session}$	Average number of packets lost during a session due to mobility.
$(N_{pkt\_Tx})_{session}$	Total number of packets transmitted by the correspondent host (CH) during a session.
Nb_hdv	Number of handovers during a session.
t_{cell}	Mean value of the cell residence time.
D_{rate}	Average downlink rate at which IP packets are sent by the CH.
θ_0	Mean discovery time.
t_c	Average of establishment time.
P_{sz}	Average packet size of an IP packet.
S_{agt_adv}	Size of an agent advertisement packet.
L_s	Average length of a session.
$(Pkt\_loss)_R$	Average ratio of packet loss per session.
T_{agt_adv}	Period at which BS sends agent advertisements over the wireless link.

Table 2: Mobility parameters

Under the assumption that the MH is moving in a uniform direction across the wireless cells:

$Nb\_hdv = L_s/t_{cell}$

Assuming that there is no buffering at the routers or gateway, the average number of packets lost during a handover while the mobile is receiving downlink real time IP packets is:

$N_{pkt\_lost}= D_{rate}.(\theta_0 + t_c)/P_{sz}$

In this calculation the completion time was neglected.

$(N_{pkt\_lost})_{session} = Nb\_hdv.\ D_{rate}.(\theta_0 + t_c)/P_{sz}$

$(N_{pkt\_Tx})_{session}= (D_{rate}.\ L_s)/ P_{sz}$

$(Pkt\_loss)_R =(N_{pkt\_lost})_{session} /(N_{pkt\_Tx})_{session}$

The result is:

$(Pkt\_loss)_R = (\theta_0 + t_c)/ t_{cell}$

Assuming that $\theta_0 =1/2.\ T_{agt\_adv}$

$(Pkt\_loss)_R = (1/2.\ T_{agt\_adv} + t_c)/ t_{cell}$ (1)

From (1), the mean percentage of packets lost per session does not depend on the downlink bit rate or the length of the session. It only depends on the mean cell residence time and the time taken to discover and complete either a mobile IP registration or a micro mobility handover.

The bigger the T_{agt_adv}, the longer the discovery period will be. It has been shown that the packet loss increases along with the discovery time [7]. Conversely, a short agent advertisement period will incur higher bandwidth utilization in the wireless link. Therefore there is a trade-off between the frequency of sending agent advertisements over the wireless link and the packet loss ratio. In the following, we derive an expression for the optimum value of the agent advertisement period.

II-3 Trade off between T_{agt_adv} and packet loss ratio

The rate at which agent advertisement packets are sent over the wireless link is:

$1/T_{agt\_adv}$ (2)

The percentage of wireless bandwidth used by the agent advertisement message mechanism is therefore:

$100.(S_{agt\_adv}/(T_{agt\_adv}.B_{wl}))$ (3)

The largest T_{agt_adv} values will minimize (3). On the other hand, the smallest T_{agt_adv} will minimize the percentage of packets lost given in (1). Therefore, the optimum value of T_{agt_adv} that will minimize both (1) and (3) is the solution of the equation 100.(1)=(3). Its expression is (4):

$$T_{(agt\_advt)_0} = -t_c + \sqrt{t_c^2 + \frac{2.S_{agt\_adv}.\tau_{cell}}{B_{wl}}} \qquad (4)$$

Where t_c has been expressed in II-1 for both the micro mobility schemes and for mobile IP.

In Figure 1, an analytical solution of the optimum agent advertisement period (agt_adv_period) sent by the BS over the wireless interface is presented. For different mean cell residence time values with $t_c=6.422ms$ and $N_{new}=N_{old}=2$, the optimum agent advertisement periods for each mobility rate are given by the intersections between the two types of curves. Moreover (4) can be used to set the agent advertisement period of a system in an environment where the mobility behaviour of the users described by cell sizes and speed (mean cell residence time) is approximately known. It can also contribute to setting the cell sizes when the optimum agent advertisement is already given. For instance in mobile IP as specified in [4], a mobility agent is recommended to send broadcast agent advertisements at a maximum rate of one per second ($(T_{agt\_adv})_{min}$=1s). Therefore from (4) by neglecting t_c, (1=4. $t_{cell}/10^4$), the mobility behaviour of users that mobile IP could support optimally is such that $t_{cell} \geq 2500$sec.

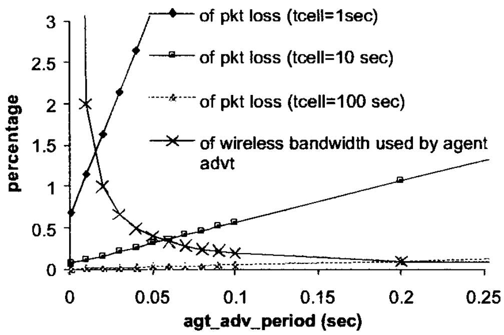

Figure 1: Analytical optimum Agt_adv period

III: Simulation performance

III-1 Parameters

Internet Delay module:
The Internet module introduces a delay, which is the sum of a constant term and a random variable with an erlang distribution. The constant term is denoted as c_D_Int and the erlang parameters, namely scale and shape, are such that the mean value is 0.01 [8]. The Internet delay module was introduced between the following pairs of network entities: CH-Gtwy, Home agent (HA)-Gtwy, CH-HA.

Discovery period:
Handovers in the simulation platform are triggered by expiration of the discovery period θ, which is a random variable. If x is a random outcome of the Poisson process with mean value $T_{agt\_adv}/2$, θ is defined as:

$$\theta = \begin{cases} x, \\ \frac{T_{agt\_adv}}{2}, x > T_{agt\_adv} \end{cases}$$

Mobility model:
The mean cell residence time of MH (t_{cell}) is modelled by a Gamma distribution.

Voice traffic:
A stream of 200 bytes UDP over IP packets is used to simulate voice traffic. The packet inter-arrival time is constant and taken equal to 20ms.

III-2 Results

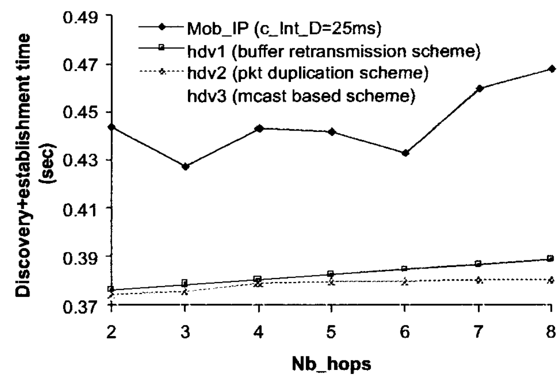

Figure 2: Handover performance, Impact of the Topology

For this simulation T_{agt_adv} was taken as 1 second and θ as just defined.

Handover 1 and 2 causes the time to establish the path to the new base station to increase with the number of hops between the gateway and the new base station. Handover 3 (multicast based) is the fastest one in terms of route establishment since the path setup message does not have to propagate all the way up to the crossover router. For the base mobile IP, the time taken for the registration to be completed is insensitive to the topology of the access network. In fact the sum of discovery and registration times, is independent of the number of hops in the access network. This is due to the higher Internet delay and Internet variation delay required by the registration packet to travel to the HA and come back to the gateway at the entrance of the foreign network. The constant part of the Internet delay (25ms) is far bigger than the time taken for the registration packet to reach the new BS from the gateway. For each scheme, the simulation results were obtained by taking an average over 200 handovers and more.

In, Figure 3, it appears that the micro mobility scheme is relatively insensitive to the delay due to the Internet whereas, for Mobile IP without route optimisation, the number of packets lost will increase due to the longer time needed to register with the HA located outside the visiting network.

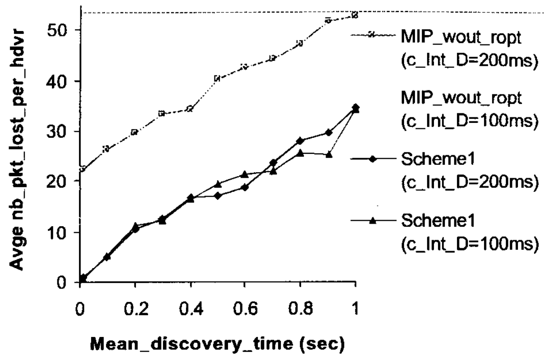

Figure 3: Simulation Voice traffic (t_{cell}=10 sec)

In figure 4, MIP triangular routing is also affecting the packet loss when the MH is moving fast.

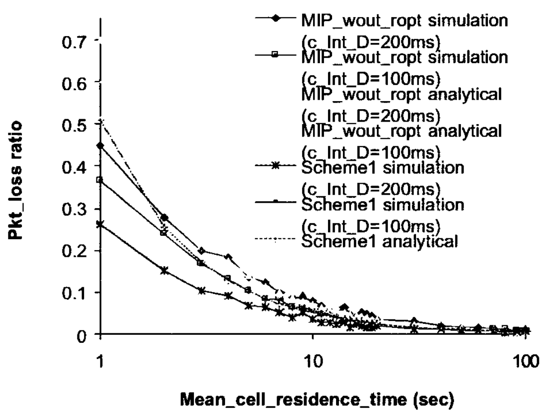

Figure 4: Packet loss ratio voice traffic only

For the results in, Figure 3, 4, $N_{new}=N_{old}=2$ and simulation time as 2000 sec. For smaller values of t_{cell}, the larger analytical packet loss ratios from (1) when the MH is moving very fast are due to the function θ, which yields a smaller average value of the discovery time ($\theta_0 < 1/2(T_{agt\_adv})$).

Conclusion

In this paper, we propose three IP based protocols to perform fast handover in a hierarchical wireless IP network. All the proposed schemes are designed so that the MH sends a path setup via the new BS after the MH has crossed a cell boundary. The first scheme takes a longer time to complete and more signalling exchange is required to set up the new path and delete the routing cache entries along the old path. On the other hand schemes 2 and 3 are faster but consume more network resources due to incoming IP packets duplicated or multicast and sent along old active paths. The comparative evaluations both analytical and by simulation, display improvement of local wireless IP schemes against MIP when the HA is located outside the access network where the MH is currently roaming.

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References

[1] R. Ramjee, T. La Porta, S. Thuel, K. Varadhan, L. Salgarelli, "IP micro-mobility support using HAWAII", IETF draft, January 2001.

[2] H. Soliman, C. Castellucia, K. El-Malki, L. Bellier, "Hierarchical MIPv6 mobility management", IETF draft, September 2000.

[3] A. Stephane, A. Mihailovic, A. H Aghvami, "Mechanisms and hierarchical topology for fast handover in wireless IP networks", IEEE communications Magazine, pp 112-115, November 2000.

[4] C. Perkins, "IP Mobility Support ", IETF RFC 2002, October 1996.

[5] S. Seshan, "Low-Latency Handoff for Cellular Data Networks" Ph.D dissertation 1995.

[6] H. C. B. Chan, H. M. Alnuweiri, V. C. M. Leung. "A framework for optimizing the cost and Performance of Next-Generation IP routers", IEEE Journal on Selected areas of communications, vol 17, No.6, June 1999.

[7] R. Caceres, N Padmanabhan, "Fast and scalable wireless handoffs in support of Mobile Internet Audio". ACM Mobile Networks and Applications (MONET) Journal, Vol. 3, No. 4 December 1998.

[8] P. Manzoni, D. Ghosal, G. Serazzi, "Impact of mobility on TCP/IP: An Integrated Performance Study", IEEE JSAC, Vol 13, pp 858-867 June 1995.