Supporting Reduced Location Management Overhead and Fault Tolerance in Mobile-IP Systems *

H. Omar, T. Saadawi and M. Lee
CUNY Graduate School, Department of Electrical Engineering
The City University of New York, City College
New York, NY 10031
{omar, eetns, mjlee}@ee-mail.engr.ccny.cuny.edu

Abstract*

The Base Mobile-IP, the Mobile-IP with the Route Optimization extension and Local Registration Mobile-IP are different approaches to support the mobility of IP hosts. Each one of those schemes has its own advantages and drawbacks. The route optimization solves the triangular route problem and the corresponding larger delay associated with the Base Mobile-IP with the expense of larger overhead for location management purposes. The local registration Mobile-IP scheme was introduced to enhance the performance by processing the MN's registration requests at a local agent. The local registration approach may effect other aspects of the Mobile-IP systems as the fault tolerance. The Base Mobile-IP and Mobile-IP with the Route Optimization schemes can be implemented on top of Hierarchical Local Registration Mobile-IP, thus it is important to tackle the issues affecting the performance in those environments. In this work we present a mechanism to enhance the performance of the Route Optimization Mobile-IP systems and a platform to support Foreign Agents fault tolerance in systems supporting local registration.

1. Introduction

One of the main features of the IETF Base Mobile IP Proposed Standard Protocol [1] is specifying minimum number of administrative messages, for location management purposes using a simple implementation. This simplicity associated with the Base Mobile IP Protocol comes with a potential degradation in performance. One of those drawbacks is the triangle routing feature that adds unnecessary delay for packets transmitted to the Mobile Nodes. The IETF Mobile-IP with the Route Optimization extension draft [2] tries to resolve this problem but it introduces additional overhead administrative messages and more processing issues (e.g., binding cache consistency) on the mobility support elements. To improve the efficiency under different conditions, the Mobile IP Protocol should have the ability to dynamically adapt its mode of operation and its parameters based on certain criteria. The local registration Mobile-IP scheme was presented in [7] and [12] providing an approach to allow the Mobile Nodes to send Registration Requests to regional Foreign Agents that does not forward the Mobile Node's request to the Home Agent. This approach aims to solve the problem of the relatively long time consumed in waiting for the Registration Reply from the far away Home Agent (HA). While solving this problem, the local registration approach imposes some requirements that affect some other aspects of the performance of Mobile-IP systems such as the fault tolerance. In this paper we propose an enhancement to the Route Optimization extension [2], using an adaptive system, with the objective of providing better performance and we present a platform that supports fault tolerance in the local registration Mobile-IP environment.

2. Background and related work

In the Base Mobile IP Protocol, when packets generated by a Correspondent Node (CN) are destined to a Mobile Node (MN), the transmitted packets from the source CN travel to the Home Agent that tunnels the packets and forwards them to the current Foreign Agent (FA) of the MN. When the Foreign Agent de-tunnels the packets, it forwards them to the MN. When the MN sends packets to a CN, it sends them directly through the FA. This sequence causes a triangle routing problem, in the CN-MN direction, causing performance degradation. In [3], the binding cache concept was introduced for the CN to resolve this problem before considering the same concept in the Routing Optimization IETF draft [2]. The binding cache concept is based on updating the CN by the new mobility binding to send the new packets directly to the care-of address not through the HA. The generation of

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the Binding Warning and the Binding Update messages can be triggered by each data packets received from the CN if either the FA or the HA infers from the received data packet that the source CN has a wrong, outdated, or no binding. The current Route Optimization specification requires both the HA and the FA to provide a mechanism to limit the rate of sending Binding Update and Binding Warning messages to the same node about any given mobility binding. The issue of reducing the number of location management messages can be considered at a different level than the rate limiting. For example, better efficiency for the mobility system can be achieved by avoiding sending the binding information to all nodes that support maintenance of a binding cache, and sending this information to a smaller number of nodes instead. We will call those Correspondent Nodes the valued CNs, and the selection criteria for this group will be discussed later.

Since the number of CNs communicating most frequently with a given MN is quite small, a third approach uses this fact to update the binding cache for this set of hosts only. Rajagopalan and Badrinath [5] use this approach to implement an adaptive scheme that enables a MN to dynamically determine its working set, and trade-off route and update costs in order to reduce the total cost. Other approaches to support effective location management were presented in [4] and [6]. A comprehensive reference for M-IP implementations and issues can be found in [12]. In this work, we propose an adaptive system that addresses the maintenance of binding cache at two levels, by providing a simple mechanism to dynamically select the valued CNs for which the binding information will be maintained. The other level is an adaptive scheme to implement the rate limiting for both the HA and the FA.

The local registration Mobile-IP was introduced to allow regional agents to process the Registration Requests sent from the MNs, without the need to forward those requests to the Home Agent. As described in [7], [12] and [17], the foreign agents are arranged hierarchically in the regional topology and the mobile node is allowed to move from one local area of the regional topology to another area of the same regional topology without the need to send a registration request to the HA. This arrangement can be accomplished by allowing the MN to register with a local foreign agent each time it moves to a new serving area. In order to forward the packets destined to the MN correctly, the FAs must cooperate to allow the HA and the CHs to have incomplete knowledge of the exact current location of the MN. This implies that the FA currently considered by the HA as the MN's care-of-address will have some kind of knowledge, or a pointer to another FA that have the knowledge, about the MN's exact current FA. In this hierarchical arrangement, the HA appears as a universal root and the current FA as a leaf node in the hierarchy. Registration Requests are sent to the nearest regional FA at the lowest level in the hierarchy, which is the nearest common ancestor to the care-of-addresses at the new and previous points of attachments, that remains the same across the handoff.

A feature that distinguishes the local registration Mobile-IP from other approaches is that the binding entry associated with a MN at each FA will point to a care-of-address at the next lower level of the hierarchy. Datagrams arriving at the top of the hierarchy from the HA will be decapsulated and encapsulated over a new tunnel ending at the next lower level of the hierarchy. This functionality assigned to the intermediate FAs will effect the robustness of the system such that the failure of an intermediate FA will prevent the packets routed using the hierarchical system from reaching this FA or any other FA on a lower level of the tree on a branch attached to this faulty FA.

It is clear from the above discussion that the Route Optimization Mobile-IP is characterized by relatively large location management overhead and is considerably less sensitive to FAs' failure. On the other hand, the local registration Mobile-IP provides less management overhead with the price of more sensitivity to the failure of FAs. Since applications running over Mobile-IP systems have different requirements and since both Base Mobile-IP and Route Optimization can run over local registration Mobile-IP, it is important to enhance the performance and strengthen the weakness of both schemes. In this work we present the adaptive scheme to enhance the performance of the Mobile-IP with the Route Optimization. Also we suggest a platform that tolerates the failure of FAs in local registration Mobile-IP systems.

3. The adaptive system approach

The Adaptive System limits when and which CN should receive the Binding Update messages and when to send the Binding Warning and Binding Update messages. The basic idea behind the Adaptive System is flexible enough to accommodate one or multiple criteria to consider when constructing the group of CNs that the Adaptive System identifies as valued hosts and justify the cost paid to maintain their caches up-to-date. In this system each MN keeps track of the current transmission rate associated with the CN currently involved with a session with this MN. For a CN exchanging traffic with a rate exceeding a threshold, the MN will identify this CN as a valued host. Figure 1 illustrates the elements and messages involved in the adaptive scheme. A detailed description of the adaptive system can be found in [9].

3.1 The Adaptive Rate Limiting

If the HA Binding Update Rate Limiting is implemented using a constant rate threshold, then the HA will prevent the generated Binding Update rate destined to a CN concerning a specific MN from exceeding this threshold. Using the same fixed threshold all the time for all communication sessions is not the best efficient way to deal with this issue, since different sessions are characterized with a different HA-CN delay, and also with different rates transmitted from different CNs. A more efficient approach is to consider each session as an individual one and adjust the Home Agent Binding Update Rate Limiting threshold according to the session characteristics. In our proposed scheme, the measured round trip delay between the HA and the CN is used to dynamically adjust this threshold, such that the time duration between any two successive Binding Updates to the same node about a specific mobility binding should not be less than the measured delay.

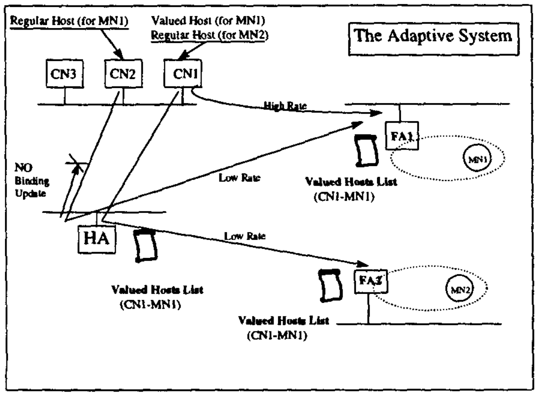

Figure 1. The Adaptive System

To implement the Adaptive Foreign Agent Binding Warning Rate Limiting, the aggregation of the delay values from FA to HA, from HA to CN and CN to FA should be considered when selecting a threshold. We have to notice that a reasonable accuracy in the delay measurement will suffice for this purpose. The overhead associated with implementing the Adaptive System can be categorized into processing overhead and control messages overhead. According to the Route Optimization specification [2], the Foreign Agent keeps information of associated with previous MN guests to be used when implementing both the Previous Foreign Agent Notification and the Foreign Agent Binding Warning Rate Limiting. Additional information of the same nature can be integrated easily to the already existing database or data structures to support the adaptive action such that the management overhead for the adaptive system can be justified and easily integrated into the Route Optimization approach.

3.2 Simulation environment for the Adaptive System

The simulation code was written using ModSim [13], a discrete event-driven object oriented simulation package. The mobility support system was constructed to follow the guidelines of the Base Mobile-IP [1] and the Route Optimization draft [2].

The mobility support elements used for the simulation are three CNs, one HA, fourteen FAs and six MNs. The network used for simulation consists of 18 cells, where each cell has a subnet housing only one stationary element either a HA, a FA or a CN. Any of the six Mobile Nodes can roam between cells serviced by the HA or by any FA. The MNs belong to the same Home network, thus serviced by the same Home Agent. Each subnet is connected to at least three of its neighboring subnets. The delay over a link between two neighbor subnets is set to one msec and that over the wireless link to 2.5 msec. Packet processing delay of 0.3 msec was considered for the mobility support elements. If (n) cells surround the current cell of the MN, the MN can move to any of the neighbor cells with a probability of (1/n). A bi-directional traffic is flowing between each CN-MN pair. Each of the Correspondent Nodes generating traffic with a variable rate destined to different Mobile Nodes. The packet generation rate of the CNs is selected to alternate in a value above and below a certain threshold. This threshold plays a role in the adaptive mechanism of the system. The value of the traffic generated by the CN is uniformly distributed between 20 and 100 packets per second for 80% of the simulation time, and no traffic is generated for the remaining 20% of the 60 minutes simulation time. The previous model was applied on the traffic associated with 50% of the MNs, while the other half is associated with traffic characterized by a uniformly distributed rate between 100 and 200 packets per second for 40% of the time. The rate of issuing Binding Update messages and Binding Warning messages is not allowed to exceed a specific threshold that was set to 150 message per second. It is assumed here that the New Foreign Agent will accept packets tunneled from the Previous Foreign Agent and intended to a Mobile Node before receiving the registration reply from the Home Agent.

3.3 Simulation results and analysis

The objective of the simulation was to verify the performance of the Adaptive System compared to the other two non-adaptive systems (The Base Mobile IP and The Mobile IP with the Route Optimization) over a range of different mobility rates. The comparison between different schemes will be based on the following aspects: the number of control messages, the number of dropped packets for traffic generated from CNs and received by MNs. The graphs below describe those performance aspects and compare between the different schemes.

Figure 2 shows the ratio of the number of control messages to the total number of transmitted packets over different mobility rates. Although it is obvious that the Base Mobile IP provides the least number of location management messages, we notice that the Adaptive System provided a noticeable reduction of the number of location management messages compared to the case of the Mobile IP with the Route Optimization. This reduction is accomplished by limiting the transmission of the Binding Update and the Binding Warning Messages. This reduction is not associated with a costly penalty since those filtered control messages are intended to provide some of the correspondent nodes with the most updated location information. Those CNs that are not receiving the update information, are currently generating traffic rates that are not high enough to justify the high cost of providing them with the premium location information.

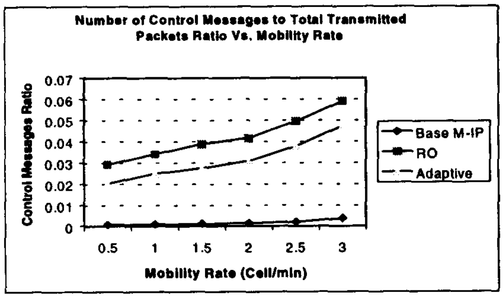

Figure 2. Effect on number of control messages

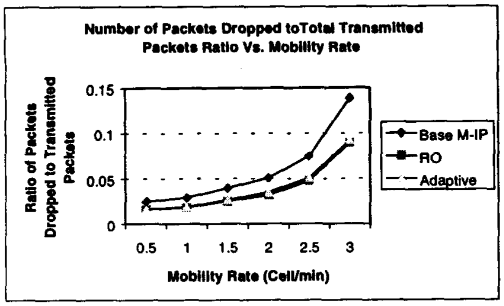

Figure 3. Effect on number of dropped packets

Figure 3. shows the ratio of the dropped packets to the total number of transmitted packets. Since that the Adaptive System follows the Route Optimization guidelines in using the Previous Foreign Agent Notification technique to reduce the number of dropped packets, the Adaptive System provides a very comparable performance to that of the Route Optimization. This is expected since the penalty of limiting the number of binding update messages in the Adaptive System may cause a slight increase in the average packet delay, but it will not increase the number of packets dropped.

4. Tolerating FA failures in Local Registration Mobile-IP systems

In the following subsections we will describe the issues related the operation of the local registration Mobile-IP and the effect on FA fault tolerance. We will describe two approaches to implement FA fault tolerance in this environmnet.

4.1 Hierarchical Local Registration Mobile-IP: Architecture and Operation

In a Hierarchical Local Registration Mobile-IP system (HLRM-IP for short), the FAs are arranged hierarchically in a regional topology. A MN is allowed to move from one serving area of the regional topology to another area of the same regional topology without the need to send a registration request to the HA. Instead, the MN is allowed to send registration requests to a regional FA that tracks its regional movements but does not forward the mobile node's request to its HA.

In HLRM-IP, the MN is trying to minimize the amount of tracking required to maintain its connectivity by identifying the smallest region for which the mobile node has not traversed any regional boundary. To accomplish this functionality, each ancestral FA considers the MN to be registered at the FA just below in its hierarchy. While regional registration requests propagate from level to level in the leaf to root direction, the regional registration replies propagate in the opposite direction. In addition, the FA advertisements contain the complete regional hierarchy of FAs suppporting the local registration. When moving to a new service area, the MN will examine the hierarchical list of FAs in the new FA's advertisement looking for the nearest common ancestor to the care-of-addresses at the new and previous service areas. The local registration request generated by the MN is then relayed from the FA currently serving the MN to the next higher level of the hierarchy and towards the common ancestor FA. In this way, each FA in the hierarchy between the MN and the root FA will be able to maintain a binding for the MN. The registration replies follow the same path but from the root to the leaf FA allowing the intermediate FA to examine the status of the registration request and update the binding accordingly. A point to consider here is that the binding entry associated with the MN at each FA will point to the care-of-address at the next lower level of the hierarchy. Another point to consider is that a datagram arriving at the top of the hierarchy from the HA will be decapsulated and reencapsulated over a new tunnel ending at the next lower level of the hierarchy.

Figure 4. represents a Hierarchical Local Registration Mobile-IP system. The operation of the system may best be summarized by an example. The system has one HA and two root FAs, FA1 and FA2. The nodes named FAx

are FAs supporting the HLRM-IP, while nodes named Rx are regular routers supporting no FA functionality. Each FA announces the higher part of the hierarchy that this FA is located on it. For example FA4 will anounce the chain FA4/FA3/FA1 while FA11 will anounce FA11/FA7/FA5/FA3/FA1.

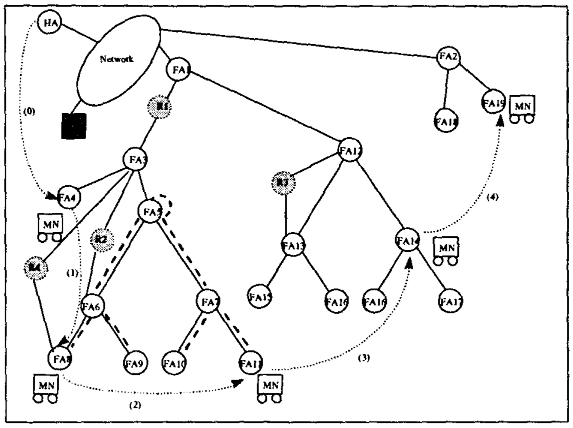

Figure 4. Hierarchical Local Registration M-IP

When the MN start moving from home to FA19, visiting the intermediate agents FA4, FA8, FA11 and FA14, it is clear that it is only when MN moves to FA19 (step 4), then the MN needs to send the Registration Request to the HA. As long as the MN is moving within the area served by the same root FA (FA1 is the root FA for the FAs visited in steps 0 through 3), the HA need not to be involved in the MN registration. When the MN moves to a FA beyond the scope, or hierarchy, of the current root FA, the MN will need to send the registration to its HA to inform him about the new root FA (after step 4, the MN will inform its HA about FA2 as the new root FA).

4.2 FA fault tolerance in HLRM-IP

A charteristic that distinguishes HLRM-IP from other Mobile-IP approaches is that the failure of any of the FAs along the path between the root FA and the leaf FA will cause the MN located at the leaf FA to loose its connectivity. Considering figure 4. with no faulty FA and FA8 as the current serving area where the MN is located, the data packets generated from CN and destined to the MN will be forwarded to the HA, then the HA will tunnel the packets to the root FA (FA1) and FA1 will tunnel the packet to FA3, FA3 will tunel to FA5 and FA5 will tunnel to FA6 to finally tunnel the packets to F8. The failure of any of those FAs will break the path between the root and the leaf FA (FA8). We should notice that this situation occurs even if a route bypassing the faulty FA (FA5 in figure 4.) exists, for example the path FA3-R2-FA6, because FA5 is needed to point to the next lower FA in the hierarchy and not just as a routing node. Considering the case of Non Hierarchical Local Registration systems and assuming the failure of the same FA5, we will notice in this case that FA5 is not needed for its tunneling function and that other routing node as R2 will be able to route the packet and deliver it to the FA serving the MN. In this paper we will introduce two possible schemes to handle the loss of service problem resulting from a FA failure in HLRM-IP environment. The first possible solution will consider the MNs affected by the failure of the FA and revert them to Non HLRM-IP mode. The other approach considers healing the broken segment in the encapsulation-decapsulation chain caused by the failure of the FA, by removing this faulty FA from the hierarchy. The details of both mechanisms and the needed control functions for the implementation will be described next. In the following discussion we will consider the presence of an element called the Hierarchy Registry located with the root FA that keeps information regarding the FAs on the different levels of the hierarchy.

I. Revert to Non HLRM-IP Mode:

In the case of a FA failure, all MNs serviced directly by this FA or by a FA located in a lower level in the hierarchy and on a path on which the faulty FA (FA_F) is an intermediate point will suffer from loss of service. In this approach, all HAs which any of their MNs are affected with the FA failure will be notified. Considering Figure 4, the failure of FA5 and the current location of MN is FA8, this task can be accomplished as follows:

a) The FA (FA_H) in the hierarchical level just above the faulty FA (FA3 will detect the failure of FA5).
b) FA3 will construct a list (MN_list) of those MNs affected by this failure. In our simple example this will be our only MN. In a practical example this list will contain all MNs currently served by any of the FAs from FA5 to FA11. FA3 is able to construct this list since it has binding entry pointing to FA5 as the FA serving MNs currently located in any FAs from FA5 to FA11.
c) FA3 will contact the Hierarchy Registry to get a list (FA_list) of the FAs in the lower level directly connected to the faulty FA (FA6 and FA7).
d) For each FA in the FA_list, the FA_H will send the MN_list.
e) Upon receiving the MN_list, each FA will perform one of two possible actions. If none of the entries in the MN_list exists in the visitor list of the FA, no further processing is needed and the MN_list is disregarded. If one or more of the MNs included in the MN_list is found in the visitor list of the FA, the list will be forwarded to the next lower FAs in the hierarchy (as indicated in the visitor list). While multiple copies of the MN_list will be forwarded to the lower level if the MNs are distributed among

multiple branches, only one copy will be forwarded if multiple MNs are located in different FAs but on the same branch.

f) On receiving the MN_list, each of the affected MNs will send a non regional Registration Request to its HA. When this Registration Request is received by the HA, the HA will update its table to register the serving FA as the current FA in place of the root FA.

g) The MN will need to send a Registration Request with the Previous Foreign Agent Notification option. This notification option in its turn will be forwarded to the root FA. This will have the effect of removing the binding information for the affected MN on the root FA. When route optimization is implemented, the root FA may receive packets from a CN destined to a MN affected by the faulty FA. The CN will have a binding pointing to the root FA as the current FA serving the MN. On receiving such packet, the root FA will generate a Binding Warning to the HA.

h) It is expected that the faulty FA will come back in service after the time needed to repair and for failure recovery. The FA_H may regularly examine the status of the FA_F. When FA_F recovery is detected, the FA_H may send a message of the type "Local Registration Solicitation" directed towards the affected MNs announcing that those MNs can start using local registration. The issuance of this message can be delayed using a timer if it is required to keep the MNs for extra time in the Non HLRM-IP mode.

II. Two (or n) step pointer self-healing mode

This approach may be used when reverting back to Non HLRM-IP is not preferred, which may be the case if the delay associated with non-local registration can not be tolerated. The basic idea of this solution is to heal the breakage in path caused by the faulty FA. This can be accomplished by bypassing this faulty FA such that the FA in the hierarchical level just above the faulty FA will remove the faulty FA from his copy of the hierarchy, and consider the FA in the level just below the faulty FA as its tunnel end. This will have the effect of re-attaching the subtree that has been isolated from the hierarchy after the FA failure.

In an environment as a battle field, it is expected that other surrounding FA in the hierarchy will be subjected to similar attacks and will have higher probability of failure. In such cases, the FA in a higher level may point to a FA in a two steps lower or much lower level that has less probability of failure.The steps needed to implement this scheme are:

a) The FA detects the failure of the FA at the lower level (FA3,or FA_H, detects the failure of FA5)

b) FA_H will construct a list (MN_list) of those MNs affected by this failure. (MN_list=MN)

c) FA_H will contact the Hierarchy Registry to get a list (FA_list) of the FAs directly connected to the faulty FA (FA_list=FA6 and FA7)

d) FA_H will send the message FA_Change_HIR to members of the FA_list. This message carries the list of MNs that FA_H has binding for. On receiving this message, each member of the FA_list will change its hierarchy information such that FA_H will become the FA in place of the faulty FA. In addition, a FA_Change_Hir_Confirm message will be sent from each member of the FA_list containing information about which MNs it has binding for such that the FA_H can update its binding and forward packets to the correct FA. The FA_Change_HIR will be propagated downwards. FAs will need to know the new hierarchy to be used when announcing their local registration support. The same information is to be sent to the Hierarchy Registry.

4.3 Comparing the two schemes

In this section we will show simulation results that describe the behavior of the two proposed techniques to support the FA fault tolerance in hierarchical environment. The environment simulation is composed of 20 MNs moving between the FAs at the leaf of a local registration hierarchical tree of eight levels. Any MN can move to one of the adjacent cells. The delay over a link between two FA on the hierarchy is set to one msec. The delay between any FA and a routing element is set to 2 msec, and the delay over wireless link is set to 2.5 msec. The delay between the HA and the root FA is set to 4 msec. A unidirectional uniform traffic is generated from two correspondent nodes to the different MNs. The emulated failure pattern corresponds to multiple FA failures in sequence on adjacent level of the hierarchy. The failure rate is Gaussian distributed with averages as shown in figure 5. For the Revert to non-HLRM-IP mechanism, the system is allowed to stay in this mode for 0.5 minutes after the last failure before returning to the HLRM-IP mode. Simulation time of 1500 minutes was considered, with randomly distributed mobility rate between 1 and 5 moves/minute. The case of the Base Mobile-IP is considered in this simulation.

The criteria we are using to compare between the two schemes is the ratio of the number of packets dropped to the total transmitted packets destined to the MNs, due to the failure of the FAs and during the recovery process. The ratio is evaluated over different values of failure rates. As mentioned previously, the revert to non HLRM-IP approach is generally characterized by larger value for the time needed to recover from failure due to the time consumed in the HA registration process. Although this is true for the case of failures on the same hierarchy level, the Revert approach may outperform the Self-Healing mode when considering the case of failure on adjacent levels since one corrective action will allow the system to survive multiple failures without the need to consider more actions. This is illustrated in figure 5, where for failure rates averaged less than two, the Revert mechanism provides more packet loss since for each failure event, it is expected that all affected MNs will need to send Home registration. When the failure rate increases, and considering that the MNs stay in the non HLRM-IP for a specified time before returning to the HLRM-IP mode, we will notice that the Revert mode will outperform the Self-Healing mode due to the fact that a MN in the Revert mode may issue one Home registration during multiple FA failures.

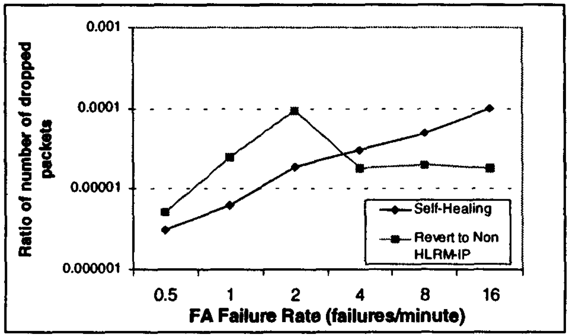

Figure 5. Ratio of number of packets dropped to the total number of transmitted packets

5. SUMMARY AND CONCLUSION

In this paper, we presented two schemes to provide efficient and robust Mobile-IP system. First, we introduced an adaptive approach to be implemented in the IPv4 mobility support systems to improve the performance of the Mobile-IP with the Route Optimization extension. The proposed adaptive system shows scalability features since the performance is not affected by neither the mobility rates nor by the number of the Mobile Nodes implemented in this approach. The Adaptive System is also expandable such that it may include more adaptive algorithms to accommodate different criteria and modes of operation for the mobility support elements. The second scheme aims to provide a robust platform that tolerate FA failure in Hierarchical Local Registration Mobile-IP system by suggesting two possible approaches to overcome the service interruption caused by the failed FA. The adaptive scheme and the fault tolerant mechanism integrate together to provide an efficient Route Optimization Mobile-IP system that uses Local Registration that is characterized by less overhead and tolerance for FA failure.

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