Design Issues for Mobility Management Schemes in Data Networks

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TR-OU-TNRL-06-104
April 2006

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***Abstract*— Mobility management of Internet nodes has been widely investigated over the last few years. Various schemes have been developed to support mobility in the Internet. While designing mobility management schemes, a few fundamental considerations have to be followed to achieve better performance. In this paper, we present a number of important issues that have to be considered while designing mobility management schemes. We also summarize a number of mobility management schemes proposed in the literature, and compare their features based on a common design framework.**

I. Introduction

Mobile users always intend to connect to Internet when they are on the way or visit a distant wireless place. The mobility support for mobile data communication should be accomplished by making sure that the Mobile Host (MH) is reachable even when it is moving. While the MH changes subnet, all the connections with the MH have to be transferred to the new subnet to keep the ongoing communications alive. This phenomena is referred to as handover. Data communication between hosts faces significant challenges when the MH hands over its connections between subnets while moving. The most important ones identified to date are abrupt connection loss or interruption during subnet change, high handover latency, high packet loss rate during handover, low throughput, and change in the Internet infrastructure to accommodate the features of mobility [1].

When an MH enters a new subnet, it needs to perform an IP address reconfiguration at the new point of attachment. Besides, it is necessary for an MH to update the location manager with its new address. These lead to a time delay during handover, referred to as handover latency. Increased handover latency consequently results in data loss and reduced throughput during handover. In order to decrease the handover latency, time taken during handover procedure should be reduced. Increased signaling costs during handover is also a prime concern in mobile environments. Signaling cost increases due to address reconfiguration and registration procedure needed while MH changes subnet.

Mobile IP (MIP) [2] is the standard proposed by IETF to support mobile data communication in IP networks. MIP suffers from a number of drawbacks in a mobile computing environment. Some of them are high handover latency, high packet loss rate during handover, and requirement for change in Internet infrastructure [1]. These drawbacks of MIP have been extensively studied in the literature, and several improvements ([1] [3]) of MIP based handover scheme have been proposed to solve the problems. In general, these schemes *focus* on improving three handover parameters, namely handover latency, packet loss, and signaling cost. Mobile IPv6 (MIPv6) also addresses some drawbacks of MIP. In spite of above improvements to MIP, still significant challenges exist in designing new handover schemes based on MIP.

MIP and MIPv6 are *network* layer based mobility management schemes. Besides them, a few *transport* layer based mobility management schemes also exist in the literature. To address the drawbacks of MIP, an IP diversity-based transport layer mobility management scheme, called SIGMA (Seamless IP diversity based Generalized Mobility Architecture) [4], has been developed through collaborative efforts of NASA and University of Oklahoma. Unlike MIP, SIGMA is based on end-to-end connection handover. SIGMA minimizes handover latency and packet loss with minimum signaling overhead during handover by exploiting multiple IP addresses to achieve soft handover.

A number of other transport layer based mobility managed schemes have also been proposed in the literature. Some of them are MSOCKS, Migrate, Reception Control Protocol (R^2CP), Mobile Multimedia Streaming Protocol (MMSP) and Mobile SCTP (mSCTP), Indirect TCP (I-TCP) and its derivatives, Mobile TCP (M-TCP) and Mobile UDP (M-UDP) [5].

The *objective* of this paper is to discuss the design issues related to mobility management schemes, and based on the design issues, compare the features of the mobility management schemes. This *allows* us to have a common platform of comparison and, most importantly, investigate the paradigms of possible improvements stemming from these solutions. It also gives the network engineers insights into the issues that have to be compared when designing new mobility management schemes. To have a generic understanding of the strength and weakness of these solutions, we compare different aspects of research and implementation issues of these mobility management schemes. Our *contribution* in the paper is to compare the features of existing mobility management schemes in the literature based on a common framework of

The research reported in this paper was funded by NASA Grant NAG3-2922.

important design issues for mobility management.

The rest of the paper is organized as follows: Section II gives a brief overview of mobility management schemes. In section III, we present design issues for mobility management schemes, and compare the performance of the mobility management schemes based on these design issues. Section IV includes the concluding remarks.

II. Architecture of Mobility Management Schemes

In this section, we give a brief description of the architecture of different mobility management schemes.

A. Mobile IP (MIP)

Fig. 1 shows a typical Mobile IP mobility management architecture. In order to reach the MH outside its home network area, MIP installs a Home Agent (HA) in the MH's home subnet to take care of all the packets sent to the MH. The Home Agent (HA) knows about the foreign location of the MH, and forwards all packets addressed for the MH to an agent in the foreign location (called as Foreign Agent (FA)) which finally delivers the packets to the MH, resulting in triangle routing of data packets (Fig. 1). Route optimization is used in several improvements of MIP to eliminated triangle routing.

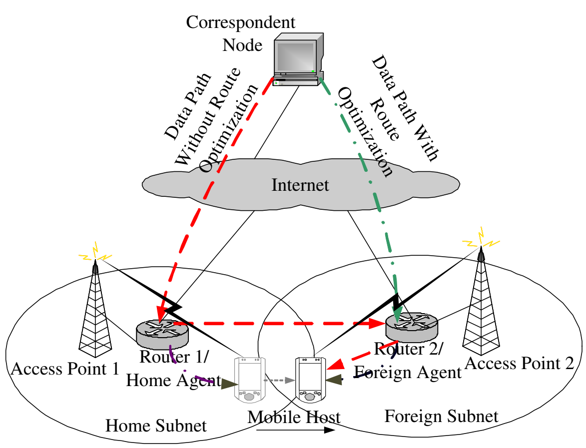

Fig. 1. Mobile IP architecture.

B. Mobile IPv6 (MIPv6)

Fig. 2 presents the architecture of the Mobile IPv6 scheme. MIPv6's working principle is almost similar to MIP with a few exceptions. Unlike MIP, MIPv6 does not use any foreign agent to acquire new care-of-address, and MH can configure its new address using statefull or stateless address auto-configuration. MIPv6 always uses route optimization to deliver data packets to the mobile host.

C. SIGMA

SIGMA is a transport layer based end-to-end mobility management scheme, and exploits IP diversity to achieve soft handover of mobile hosts between subnets. IP diversity refers to having multiple IP addresses in one mobile host. Unlike MIP and MIPv6, where the old connection has to be released before setting up the new connection during handover, SIGMA uses IP diversity to keep the old connection alive during the process of setting up the new connection, thus achieving seamless handover between access points. Fig. 3 shows the architecture of SIGMA for mobile environments. Instead of home or foreign agents, SIGMA requires a location manager to be incorporated in the Internet infrastructure to keep track of the address change in the MH.

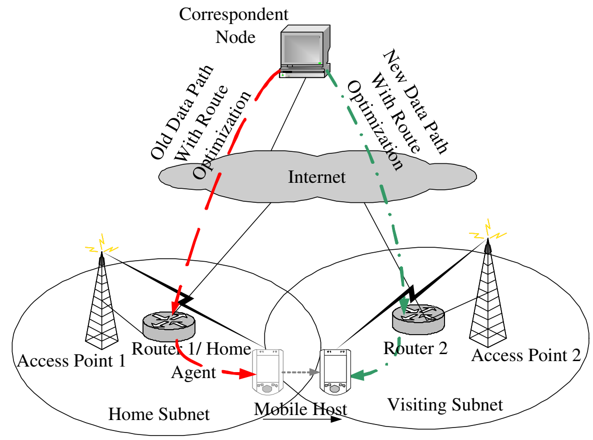

Fig. 2. Mobile IPv6 architecture.

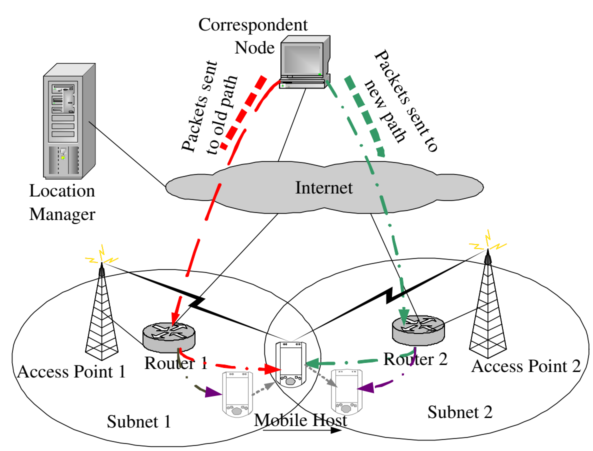

Fig. 3. SIGMA architecture.

D. Other Transport Layer Solutions

Migrate is based on Migrate-TCP [5] which releases the current IP address, retains a new IP address and reestablishes the ongoing connection with the new IP address. This process of transferring to a new connection is called connection migration.

Solutions like R^2CP, MMSP and mSCTP [5] can reconfigure the new IP address while still having the old one, so switching connection from the old one to the new one is seamless. This is possible because these solutions are based on IP diversity.

Fig. 4 presents the common architecture for the transport layer solutions like Migrate, R^{2}CP, MMSP and mSCTP.

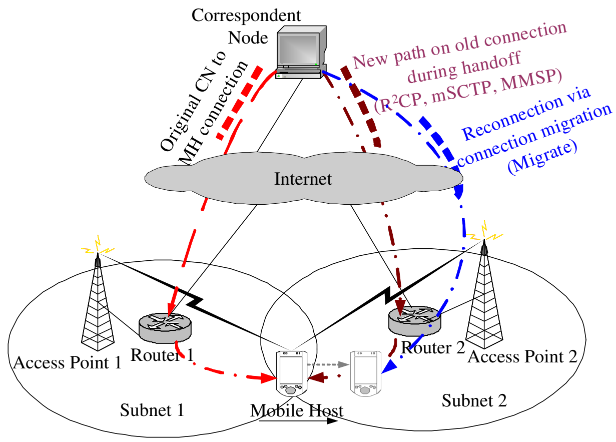

Fig. 4. Transport layer scheme architecture without gateway.

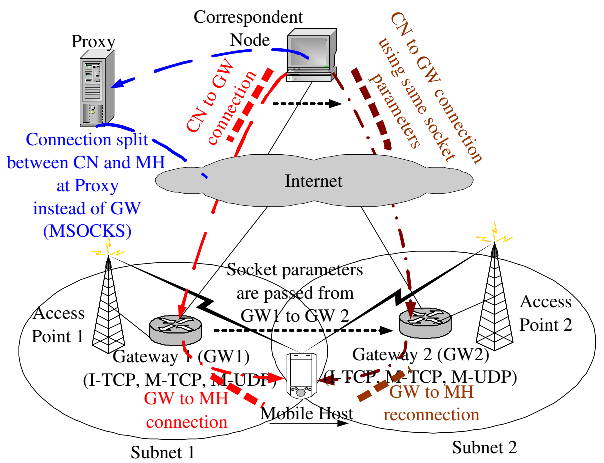

Fig. 5. Transport layer scheme architecture with gateway in the middle.

There is another group of solutions that use an intermediate entity between MH and CN to divide the connection. Fig. 5 shows this kind of mobility management architecture. MSOCKS belongs to this group and uses proxy as intermediate entity to divide the connection. It uses TCP-Splice [5] that splits the connection between MH and CN and keeps the proxy to CN part of the connection intact. Whenever MH has a new IP address, the connection between MH and proxy releases the old connection and reconnects using the new address. I-TCP and its derivatives M-TCP and M-UDP, also use gateways as intermediate entities to divide the connection.

III. Design Issues for Mobility Management Schemes

While designing mobility solutions, it is important to follow some fundamental design criteria. This section describes eight design criteria and compare the features of different mobility solutions based on these criteria. A summary of the comparison among the mobility management schemes based on eight design issues is given in table I and II.

A. Throughput

Throughput refers to the total amount of data that are successfully received at the destination side.

1) MIP: MIP achieves lower overall throughput for the following two reasons: (1) triangle routing, and (2) association/session interruption.

- **Triangle Routing:** Triangle routing means the packets between CN and MH must be routed along a triangular path longer than the optimal one, which introduces higher latency and high network load in MIP. Both in MIP (in extensions) and MIPv6, the route optimization protocol is proposed to solve the triangle routing problem, which allows packets to be routed along an optimal path from CN to MH [6]. However, the route optimization protocol may cause high signaling and processing costs.
- **Association/Session Interruption:** In MIP, MH uses the new CoA (Care-of-Address) to continue data communication, which might interrupt the previous session due to the delay in CoA registration to HA. The session broken during this time might cause data packet retransmission, and congestion window can shrink severely.

2) MIPv6: In MIPv6, an MH may use more than one CoA at a time. To assist smooth handovers, an MH should retain its pervious CoA as a (non-primary) CoA, and should still accept packets at this address, even after registering its new primary CoA with its HA [6]. This reduces the chances of session or association interruption.

3) SIGMA: Compared to MIP, SIGMA can achieve much higher overall throughput as it does not have triangle routing, and there is less association/session interruption. SIGMA can minimize the possibility of session break by employing the IP-diversity feature of underlying transport protocol. Specifically, SIGMA can always manage to switch to the new path (associated with the new IP address) before the old path failure.

4) Other Transport Layer Solutions: Solutions like Migrate, MSOCKS, Indirect TCP and its derivatives migrate connections at the end hosts during handover. It involves disconnecting from one existing connection and reconnecting with a new one; the new connection should be able to identify the old connection and continue. All the packets destined for the host via the old IP address will not be able to reach the destination, resulting in a drop of throughput. If the transport layer protocol is not aware of mobility, the congestion control mechanism would trigger a slow start, resulting in a further drop of throughput. On the other hand, solutions like MMSP, R^{2}CP and mSCTP are based on IP diversity (multi-homing) based soft handover, very similar to SIGMA. This enables them to perform seamless transition from one connection to the next one without noticeable drop in throughput.

B. Handover Latency

Handover latency is one of the most important benchmarks for evaluating handover schemes.

1) MIP: The handover latency of MIP is due to: (1) address reconfiguration at the new point of attachment, (2) registering the new address with HA, and (3) tunnel setup between HA and FA. It is important to note that, whenever address

TABLE I
COMPARISON BASED ON THROUGHPUT, HANDOVER LATENCY, PACKET LOSS AND SIGNALING COST ISSUES

Scheme	**Throughput**	**Handover Latency**	**Packet Loss**	**Signaling Overhead**
MIP	Throughput decreases due to - • Triangle routing • TCP session interruption • Congestion window shrinks severely due to timeout or packet loss	Handover latency increases due to - • Address reconfiguration at the new point of attachment • Registering the new address to the HA • Tunnel setup between HA and FA	• Packet loss is high during handover due to the failure of the old link	• Registration to HA • Tunneling setup
MIPv6	• No triangle routing if route optimization is used, increasing throughput • Session interruption may occur if multiple CoAs are not used	• Same issues as in MIP, although several improvements have been proposed	• Less than MIP if multiple CoAs can be used • Fast handover scheme has been proposed to reduce packet loss	• New CoA registration to HA • Binding updates to CN
SIGMA	Better throughput due to - • No triangle routing • Seldom association interruption due to multihoming	• Handover latency is less than MIP because it is defined as service disruption time	• Less than MIP due to multihoming	• New address Configuration • CN update (Add IP, Set Primary, Delete IP) • Location manager update
Other Transport Layer Solutions	• MMSP, mSCTP and R^2CP: Better throughput as no new association due to IP diversity • MSOCKS, Migrate, I-TCP and Derivatives: drop in throughput for connection reestablishment • Mobility awareness avoids slow start due to loss/delay during handover	• MMSP, mSCTP and R^2CP: reduces delay during handover using IP diversity • MSOCKS, Migrate, I-TCP and Derivatives: sequential handover process causes more delay	• MMSP, mSCTP and R^2CP: reduced packet loss by receiving packets destined to old address • MSOCKS, Migrate, I-TCP and Derivatives: loose on the fly packets	• MMSP, mSCTP and R^2CP: New address registration and CN update • MSOCKS: update proxy • Migrate: Request and connection reestablishment • I-TCP and Derivatives: updating the new gateway + new IP address at CN

reconfiguration starts, ongoing communication is interrupted; resulting in increased handover latency.

2) MIPv6: As in MIP, three significant delays are involved during the handover: (a) Move Detection latency, (b) Registration latency (c) Binding update latency [6]. To reduce the handover latency in MIPv6, Yegin et al. [7] has proposed two handover schemes: (1) Anticipated Fast Handover Protocol, where the MH or access router has predictive information about the handover which can be helpful to reduce handover latency, (2) Tunnel Based Fast Handover protocol which is similar to the previous one except that there is minimum involvement of layer 3. Multiple CoAs can also be used for smooth and seamless handover in MIPv6 [6].

3) SIGMA: SIGMA also employs procedures like address reconfiguration and location update to location manager. Moreover, MH also notifies CN about all IP address update by dynamic address update procedure. The definition of handover latency in SIGMA is, however, different because it employs IP-diversity features of transport protocols during handover. Here, the handover latency is defined as the service disruption time at the application layer. Service disruption time is the difference between the time instant the first data packet is received by the MH through the new data path after the handover and the time instant the last data packet was receive through the old data path. SIGMA, thus, only measures the interruption time experienced by the application layer. This service disruption time is very small as SIGMA can receive data using the old path while preparing the new path.

4) Other Transport Layer Solutions: In Migration based solutions, MH detaches from one connection and re-attaches to another one. This consists of releasing obsolete address, acquiring new address, reconnecting using the new address and sending packets via the new address. This whole process adds up to the handover delay. IP diversity based solutions acquire the new address and establishes the new path and start communicating via the new path while still receiving data from the old one. Thus, these solutions reduce handover latency.

TABLE II
COMPARISON BASED ON DEPLOYMENT, SCALABILITY, SECURITY AND QOS ISSUES

Scheme	Deployment Issues	Scalability Issues	Security Issues	QoS Issues
MIP	• Introduction of HA • Introduction of FA	• Relies on HA : single point of failure • Tunnelling	• Interferes with firewall • Interferes with ingress filtering	• Interruption during handover increases handover latency • Requires QoS support in routing • Requires QoS support in tunnelling
MIPv6	• No FA is needed, although HA is still required • For route optimization, special supports are needed in the IPv6 nodes	• No need for HA • HA still acts as broker • Supports multiple home agents	• Not fully firewall cooperative • Still problem exists with ingress filtering	• Handover latency still exists
SIGMA	• Employs IP-diversity based transport protocol • Introduction of location manager	• Relies on location manager	• Cooperates with firewall • Cooperates with ingress filtering	• Lower handover latency and packet loss
Other Transport Layer Solutions	• MSOCKS: requires proxy • I-TCP and Derivatives: require gateways for subnets and inter-gateway communication • MMSP, mSCTP, R^2CP and Migrate: require respective transport layer protocols • Migrate: introduces location manager	• MSOCKS: relies on proxy - single point of failure • I-TCP and Derivatives: rely on gateways • Migrate: relies on location manager	• Cooperate with firewall • Cooperate with ingress filtering	• Low handover latency and packet loss

C. Packet Loss

Packet loss during handover is an important issue in designing mobility management schemes.

1) MIP: In MIP, packet loss is caused mainly because of the failure of the old path before the completion of the registration. In MIP, the communication resumes only after the registration is finished. During the period of registration, data packets will be queued at HA. These packets will be dropped if the queue at HA is full or the packets are timed out.

2) MIPv6: MIPv6 can use multiple CoAs to reduce packet loss during handover. While acquiring a new CoA, MIPv6 can still use old CoA to receive on-the-fly packets; thus reducing packet losses [6]. Fast handover schemes [7] can also be used in MIPv6 to reduce packet loss during handover.

3) SIGMA: In SIGMA, whenever there is a path available during the handover, SIGMA manages to send data packets through the available path. In the ideal case, dynamic address update should be sent timely so that the CN switches to the new IP address before the old IP address becomes unavailable. Therefore, packet loss is minimized by using the IP-diversity feature of the underlying transport protocol during the handover.

4) Other Transport Layer Solutions: IP diversity enabled mobile devices can simultaneously utilize multiple IP addresses. Therefore, solutions like MMSP, R^2CP and mSCTP reduce packet loss during handover by letting on-the-fly packets to be delivered using the soon-to-be-obsolete IP address while receiving the new packets via the new IP address. Migrate, MSOCKS and Indirect TCP have to release the old IP address before getting the new one. Thus packets already destined to the old IP address will be lost. This handover packet loss is inevitable for hard handover-based transport layer solutions.

D. Handover Signaling Costs

Signaling costs refer to the costs of sending control packets to perform the handover.

1) MIP: In MIP the signaling costs includes: (a) New CoA configuration with the FA, (b) Registration to HA, and (b) Tunnelling setup.

2) MIPv6: When MH detects a handover, it generates a new Care-of-Address (CoA) by IPv6 address autoconfiguration. MH registers its new primary CoA with its HA [6]. The MH then updates associated mobility bindings in CN so that CN can perform route optimization [6]. Thus in MIPv6, the signaling costs are similar as in SIGMA due to binding updates in CN.

3) SIGMA: Signaling in SIGMA includes: (a) New address configuration, (b) CN update (Add IP, Set Primary, and Delete IP), and (c) Location manager update. SIGMA may have higher signaling cost than MIP due to CN update during handover. However, by introducing hierarchical location manager, SIGMA can greatly reduce the signaling costs for location update.

4) Other Transport Layer Solutions: For intermediate entity based solutions, the mobility information is updated at the MH and at the intermediate entity. For MSOCKS, the signaling cost is the cost of updating the proxy. In I-TCP and its derivatives, it is for updating the new gateway and updating new IP address at CN. Migrate has signaling cost for updating the CN with the new address (request + connection establishment). For MMSP, mSCTP and R^2CP, this cost is going to be the sum of first two costs of SIGMA. So in terms of signaling cost, SIGMA is more expensive than most of the transport layer solutions.

E. Deployment

Deployment refers to the required changes in the applications, infrastructure, and end hosts at the network. Changes in the applications refer to the modifications in communicating applications, whereas changes in the end hosts refer to the changes in the protocol stack at MH or CN. Infrastructure modification means the incorporation of extra hardware into existing Internet architecture to implement a particular scheme.

1) MIP: In MIP, the presence of firewall and Network Address Translation (NAT) in existing IP network challenge the introduction of home address and care-of-address, requiring significant changes in the applications. MIP introduces HA and the widely distributed FA to support host mobility; requiring changes in the existing Internet infrastructure. In MIP, MH has to be aware of the mobility, but requires no change at the CN.

2) MIPv6: As in MIP, changes in the applications are needed in MIPv6, although several improvements are proposed. In MIPv6, there is no need to deploy FAs as in MIP. MIPv6 nodes can operate in any location without any special support required from the local router. To support route optimization, in MIPv6, all IPv6 nodes (MH, CN and HA) must support home address destination option, the mobility header, and also maintain binding update lists [6].

3) SIGMA: In SIGMA, the applications must employ an IP-diversity and multistreaming enabled transport protocol. SIGMA has no problem with firewall and NAT because the communication between the MH and CN are always direct and transparent. SIGMA only introduces the location manager for better location management. Existing DNS server in the Internet can be used as location managers in SIGMA [8]. SIGMA requires both MH and CN to use IP-diversity based transport protocol.

4) Other Transport Layer Solutions: Transport layer solutions are end-to-end, thus compatible with NAT and firewall. All the transport layer solutions are required to have mobility aware transport layer at the MH. MSOCKS require mobility aware transport layer in the intermediate proxy but not at the CN. For I-TCP and its derivatives, the transport layer at gateways is mobility aware, but not at CN. For Migrate, both MH and CN have mobility aware transport layers.

Many transport layer solutions do not need any additional infrastructure. But MSOCKS uses connection redirection based on proxy, and I-TCP and its derivatives are based on gateways, requiring mobility aware proxies or gateways to be installed in the network.

F. Scalability, Availability and Fault Tolerance

Scalability refers to the ability of handling large number of simultaneous node handovers.

1) MIP: In MIP, the HA is often seen as the “heart” of the mobility system. Therefore, HA usually hosts a large number of subscribers that makes it vulnerable to the problem of single point of failure. If the HA fails, MH does not learn about the failure until re-registration. After HA failure, no packet will be forwarded to MH and to make situation worse, the entire MIP mechanism fails to work.

2) MIPv6: In MIPv6, though there is no need for FA, HA still acts as a broker to handle packets destined to MH, giving rise to the same problem. If HA is down, packets sent from new CN will get dropped in home network. MIPv6 supports multiple home agents so that when a HA is down or unavailable for the reconfiguration of the home network, MH can use “dynamic home agent address discovery” to discover a new HA [6].

3) SIGMA: SIGMA’s scalability bottleneck lies in the location manager. Location manager in SIGMA is quite similar to HA in the MIP except that the chance of CN disconnection from the MH is greatly reduced by the IP-diversity features of the underlying transport protocol.

4) Other Transport Layer Solutions: Transport layer schemes like MMSP, mSCTP or R^2CP handle handover at the end hosts, thus scalable to any network topology. I-TCP and its derivatives are dependant on the coverage of gateways as the mobility is handled via the connection handover across gateways. MSOCKS uses proxy server to split a connection and mobility is handled under the coverage of the proxy. Thus these schemes are bounded by the presence of gateways and proxy servers in the middle, making those intermediate nodes network bottlenecks. Location management system in Migrate is very similar to SIGMA, thus if MH acts as a server, the failure at the location manager makes the new connection requests from CN to fail.

G. Security

Security, an important design criteria for mobility schemes, deals with two issues: (a) Firewall (b) Ingress Filtering.

- **Firewall:** Firewalls block all classes of incoming packets to a subnet that do not meet specified criteria. Furthermore, enterprise firewalls are typically configured to block packets from entering via the Internet that appear to be originated from internal computers.
- **Ingress filtering:** Ingress filtering means that the border routers discard packets coming from within the enterprise if the packets do not contain a source IP address configured for one of the enterprise’s internal networks.

1) MIP: Firewalls, in particular, cause difficulty for MIP because packets originating from the MH carry the MH's home address, and would thus be blocked by the firewall. Although this permits management of internal Internet nodes without great attention to security, it presents difficulties for MH wishing to communicate with other nodes within their home enterprise networks.

In MIP, complications are also presented by ingress filtering operations because MH would use their home address as the source IP address of the packets they transmit.

2) MIPv6: Though some of the firewall now can handle IPv6 packets, most of the firewalls do not know about the MIPv6 control message. So it is hard to complete the full registration and binding process since the firewall cannot interpret the information carried in the MIPv6 packet header. Even more, in MIPv6, the communication between MH and CN requires authentication and encapsulation by IPSec protocol. Most firewalls either block the IPSec protocol or do not support it.

MIPv6 mobile node uses care-of-address as source address in foreign network. Correspondent node uses IPv6 routing header rather than IP encapsulation, so there is no ingress filtering problem in MIPv6 [9].

3) SIGMA: SIGMA does not use the home address to identify the MH; requiring no capsulation of packets. Therefore, it will work harmonically with the firewall because there is always end-to-end communication in SIGMA after the handover.

In SIGMA, whenever there is communication between the MH and CN, the packets will use source IP address configured for one of the enterprise's internal networks. Therefore, SIGMA will have no problem working with the ingress filtering.

4) Other Transport Layer Solutions: In all the transport layer solutions, MH carries the IP address of the domain it is currently visiting, requiring no tunneling/encapsulation. Thus firewall should not be an issue with these solutions, and also ingress filters would not discard packets generated from the MH.

H. QoS

Quality of service (QoS) in network environment conventionally refers to four pivot attributes: reliability, delay, jitter, and bandwidth [10]. Reliability refers to the rate and probability of packet loss and bit error during transit, while delay is the amount of time required to forward a packet from one point to another. Some applications such as web surfing and voice over IP, which have higher real-time requirement, are delay sensitive. Packets which arrive at the destination in irregular time intervals cause jitter effect, and bandwidth is the rate at which packets are transited in a network.

1) MIP: QoS in MIP has been incorporated with several techniques, including buffering, admission control, packet scheduling, reservation protocol (RSVP), and DiffServ. In MIP, the tunnelling technique is heavily used to send encapsulated packets from MH to CN. Both two end-points, FA and HA, have to agree on the QoS parameters and utilize them before the end-to-end connection is built.

2) MIPv6: In MIPv6, several enhancements have been proposed to reduce handover latency. Hierarchical MIPv6 (HMIPv6) [11] proposes a hierarchical mobile agent architecture to reduce the registration latency from MH to HA. Fast handovers for MIPv6 (FMIPv6) [12] introduces a mechanism to configure a new IP address before entering a new subnet, which reduces the handover latency.

3) SIGMA: In SIGMA, the handover latency and packet loss rate is alleviated utilizing multihoming. On the other hand, since SIGMA utilizes transport protocol with multiple interfaces, the power management schemes have to be developed if used in handheld devices such as PDA.

4) Other Transport Layer Solutions: In I-TCP, the gateways will establish the TCP connection to host on fixed network for mobile host, which solves the unreliability problem in wireless communication. Balakrishnan et al.[13] proposed the snoop protocol which also uses gateways for handling packets and retransmission. Samaraweera et al. [14] utilize the round trip delay to differentiate between packet loss due to congestion and link error, which helps to reduce the TCP error recovery time.

I. Implementation in Space Networks

NASA is using Mobile IP based schemes (MIP and MIPv6) to build future space communication networks [15]. CISCO, in collaboration with NASA, has developed a Mobile Router named CLEO which includes all the MIP and MIPv6 functionalities. NASA along with CISCO and SSTL, have experimented the functionalities of MIP in space networks with UK-DMC disaster monitoring satellite which has CLEO router onboard. The limitations of MIP based schemes discussed before in this paper are still applicable for space networks.

SIGMA can be used in space networks to provide smooth handover between spacecrafts [4]. Fu et Al. [4] have illustrated the effectiveness of SIGMA to achieve seamless handover of satellites between adjacent ground stations. Various features of SIGMA can be directly mapped to the architectural elements of the space handover scenario [4]. SIGMA, with its many advantages over Mobile IP, is very suitable for managing handovers in space networks. No results are available in the literature regarding the suitability of other transport layer solutions in the space environment.

IV. Conclusion

This paper presents eight design issues for mobility management schemes, and compares the features of ten schemes based on the design issues. We conclude that SIGMA takes into account all of the design issues, due to which it exhibits higher performance than other mobility management schemes. Our second conclusion is that most of the transport layer solutions, including SIGMA, can easily be incorporated with existing network security infrastructures, and are more suitable than network layer based mobility management schemes for mobile environments. The design issues considered in this paper can be used by the network engineers when considering new mobility management schemes.

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