Generic Models for Mobility Management in Next Generation Networks

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Abstract

In the network community different mobility management techniques have been proposed over the years. However, many of these techniques share a surprisingly high number of similarities. In this technical report we analyze and evaluate the most relevant mobility management techniques, pointing out differences and similarities. For macro-mobility we consider Mobile IP (MIP), the Session Initiation Protocol (SIP) and mobility management techniques typical of a GSM network; for micro-mobility we describe and analyze several protocols such as: Hierarchical MIP, TeleMIP, IDMP, Cellular IP and HAWAII.

Keywords: macro-mobility; micro-mobility; SIP; Mobile IP; Hierarchical Mobile IP; TeleMIP; IDMP; Cellular IP; Hawaii.

Contents

1. Introduction

The two most important phenomena impacting telecommunications over the past decade have been the explosive parallel growth of both the Internet and mobile telephone services. This has created an opportunity to offer integrated services through a wireless network, therefore mobility management has widely been recognized as one of the most important problems for a seamless access to wireless networks and services.

In this technical report we will examine several mobility management solutions, distinguishing between macro-mobility and micro-mobility. We will define a generic mobility management approach showing how two of the most important macro-mobility approaches, Mobile IP and SIP, can be related to the GSM mobility management architecture. A generic model for the micro-mobility management scheme will be considered to well describe all the different solutions found in the literature for this scope. Finally, we will analyze each micro-mobility solution separately to show similarities and differences among them, and we will evaluate them taking into account several important parameters, such as handoff time and packet loss.

2. Mobility Mangement in Multi-Access Networks: requirements and service scenarios.

Within new technological scenarios, mobility management has widely been recognized as one of the most important problems for a seamless access to wireless networks and services.

Conventionally, mobility management refers to terminal mobility. It is the essential technology that supports roaming users with mobile terminals to enjoy their services through wireless networks while moving into a new service area. The serving networks can be of any type, e.g., the Internet or an intranet, mobile ad hoc networks, personal communication systems, or a mix of these networks. The mobile node can freely change its point of attachment to the networks. The main function of mobility management is to efficiently support the seamless roaming of mobile users or devices within the whole serving networks.

Strictly speaking, terminal mobility is the only form of mobility currently supported by wireless systems including the dominant second generation (2G, e.g., GSM) and the initial phase of the third generation (3G, e.g., UMTS). Besides, in the next generation, with the development of communication and computing technologies and the increase in users' requirements, several new mobility types are emerging, including: personal mobility, session mobility, service mobility. Therefore, for a user roaming across heterogeneous networks, a complete mobility management scenario includes terminal mobility and the following types of mobility:

- Personal mobility: a user can be globally reachable by a unique personal ID and originate or receive a session by accessing any authorized terminal.
- Session mobility: a user can mantain an ongoing session while changing terminals, for example from mobile phone to PC desktop.
- Service mobility: a user can obtain subscribed and personalised services consistently even if the user is connected to a foreign network.

In general, mobility management schemes for wireless IP networks satisfy the following requirements:

1. Support of means for personal, session, service and terminal mobility, i.e., a mobility management scheme must allow users to access network services anywhere, as well as to continue their ongoing communication;
2. Support of both real-time and non-real-time multimedia services such as mobile telephony, mobile web access, and mobile data services in such a way that their prices and performances are comparable. In order to achieve this, mobility management schemes should interact effectively with the QoS management, and AAA schemes to verify the user's identity and rights, as well as to ensure that the QoS requirements and applications are satisfied and maintained as users roam between two networks.
3. Transparent support of TCP based applications. It should support TCP as is, without requiring any changes to TCP or TCP-based applications.
4. Efficient support of multicast and anycast as mobile stations move around.

From the viewpoint of functionality, mobility management for wireless IP networks consists principally of two activities:

- Location management enables the network to discover the mobile user's current point of attachment.
- Handoff management allows a user to continue its ongoing connection while changing its point of attachment to the network.

User mobility can be classified into two categories:

- Intradomain mobility or micro-mobility: it allows a mobile user to move from one cell within a subnet to an adjacent cell within another subnet, both subnets belonging to the same administrative domain.
- Interdomain mobility or macro-mobility: it allows a mobile station to move from one subnet within an administrative domain to another subnet in a different administrative domain.

3. Solutions to IP Mobility

3.1 Mobile IP and SIP

Two major IETF (Internet Engineering Task Force) protocols, the network-layer mobile IP, in its two versions Mobile IPv4 [1] and Mobile IPv6 [3], and the application-layer protocol SIP [2], are playing a dominating role in researching improved IP-based mobility management schemes.

Mobile IP was developed as a solution for inter-domain mobility across the Internet by the Mobile IP working group of the IETF. Its goal is to allow a mobile node to roam anywhere on the Internet and always be reachable by a single IP address, the home address, i.e., the address assigned to the mobile by its home network. When the mobile node roams in a foreign network, this entity assigns to the mobile node a temporary address (care-of address) which, in the basic Mobile IP, is known only by the home network.

Mobile IP is transparent to applications and transport protocols. It allows nodes using Mobile IP to interoperate with nodes using the standard IP protocol. There are two versions of Mobile IP: Mobile IPv4 and Mobile IPv6, each one addresses a particular version of IP. There are several differences between the two versions of the protocol and Mobile IPv6 solves some shortcomings of Mobile IPv4. Figure 3.1 shows the Mobile IPv4 registration process. This approach is the same used by Mobile IPv6 but without a Foreign Agent, as this protocol does not consider a Foreign Agent in its network architecture.

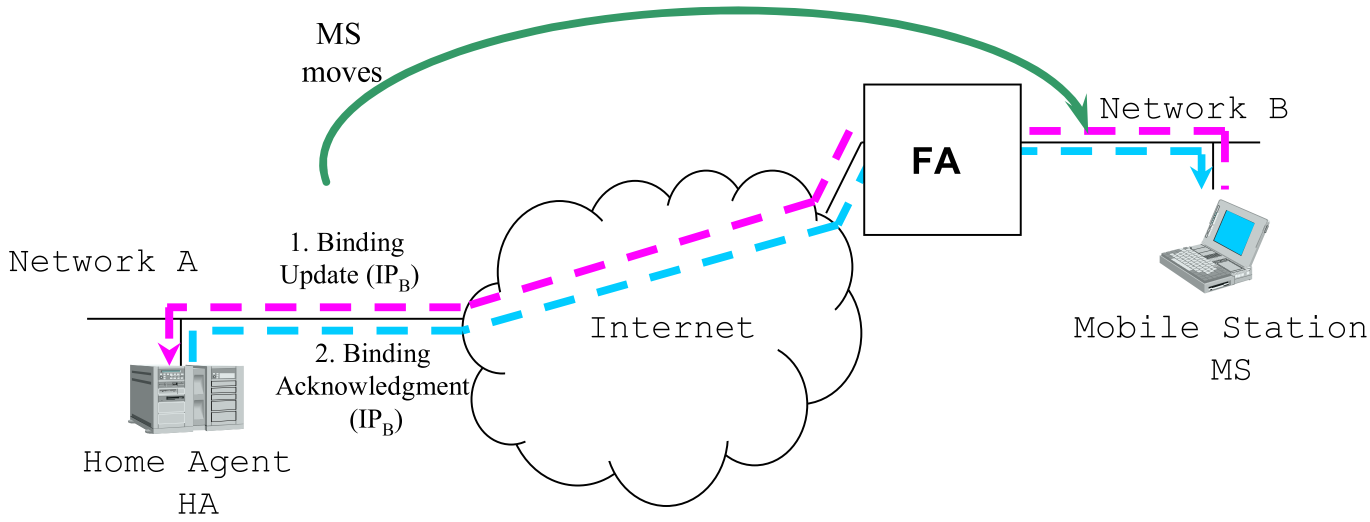

Figure 3.1 Mobile IPv4 registration process: MS registers at its Home Agent

Although Mobile IP is a complete solution for mobility, it is by no means the only one. A possible alternative to Mobile IP is the Session Initiation Protocol (SIP).

SIP was initially designed as an application-layer multimedia signalling protocol for creating, modifying, and terminating end-to-end sessions with multiple participants, but can also provide personal, session and service mobility. Although SIP can be extended for terminal mobility [4], a pure SIP approach for all kinds of mobility is in question [36], [37], as with an application layer protocol the mobility is not transparent to the transport layer allowing interruptions of TCP connections.

The following picture, Figure 3.2, shows the SIP registration process. As we can see, this approach is very similar to Mobile IP, expecially to the Mobile IPv6 scheme, where no Foreign Agent (FA) is required.

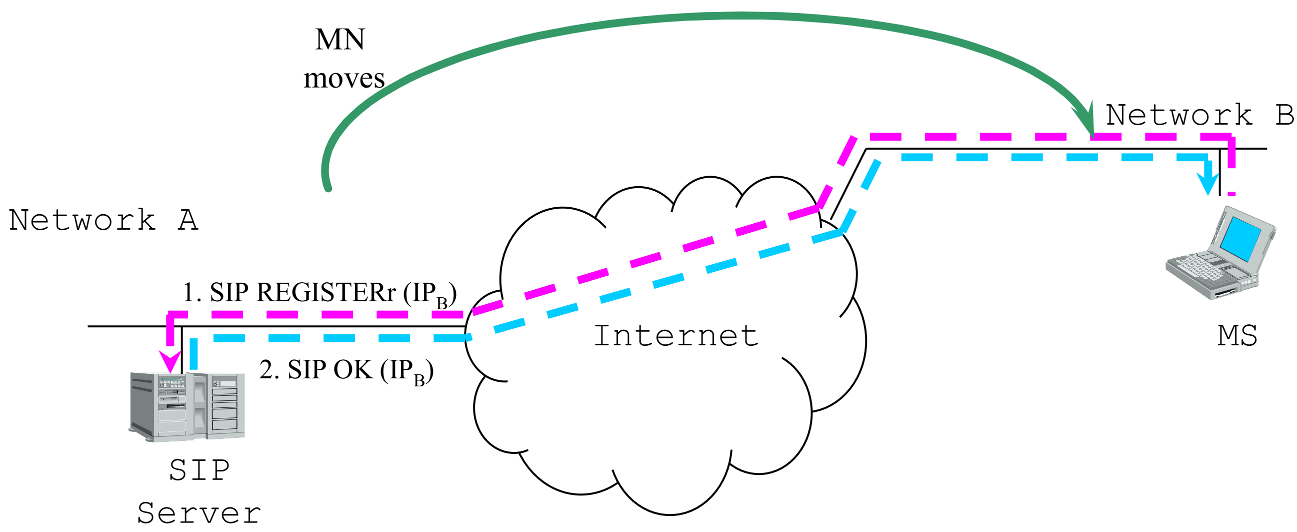

Figure 3.2 SIP registration process: MS registers at its home SIP server

To better understand similarities between Mobile IP and SIP, we can look at Table 1.

	Bssic Mobile IPv4	**Mobile IPv6**	**SIP**
ISO/OSI Level	Network Layer	Network Layer	Application Layer
Architecture	Home Agent in the home network Foreign Agent in the visited network	Home Agent in the home network	SIP Home Proxy Server in the home network
IP address update	1. MS sends a BINDING UPDATE to HA.	1. MS sends a BINDING UPDATE to HA. 2. MS sends a BINDING UPDATE to CN. 3. The ongoing connection between MS and CN is updated	1. MS sends a RE-INVITE to CN. 2. The ongoing connection between MS and CN is updated 3. MS sends a REGISTER to the Home Proxy.
Upload data path	MS -> CN	MS -> CN	MS -> CN
Download data path	CN -> HA -> MS	CN -> MS	CN -> MS

Table 1. Correspondences between Mobile IP and SIP.

3.2 Generic Model

As seen before, Mobile IP and SIP have a similar architecture and mobility management scheme, especially if we compare Mobile IPv6 and SIP. The biggest difference is the layer at which the two approaches work: network and application layer. We can consider a generic model that describes the session update. This model is depicted in Figure 3.3, where the MS anchor point can be the Home Agent, in case of Mobile IP, and the Home SIP Server, in case of SIP.

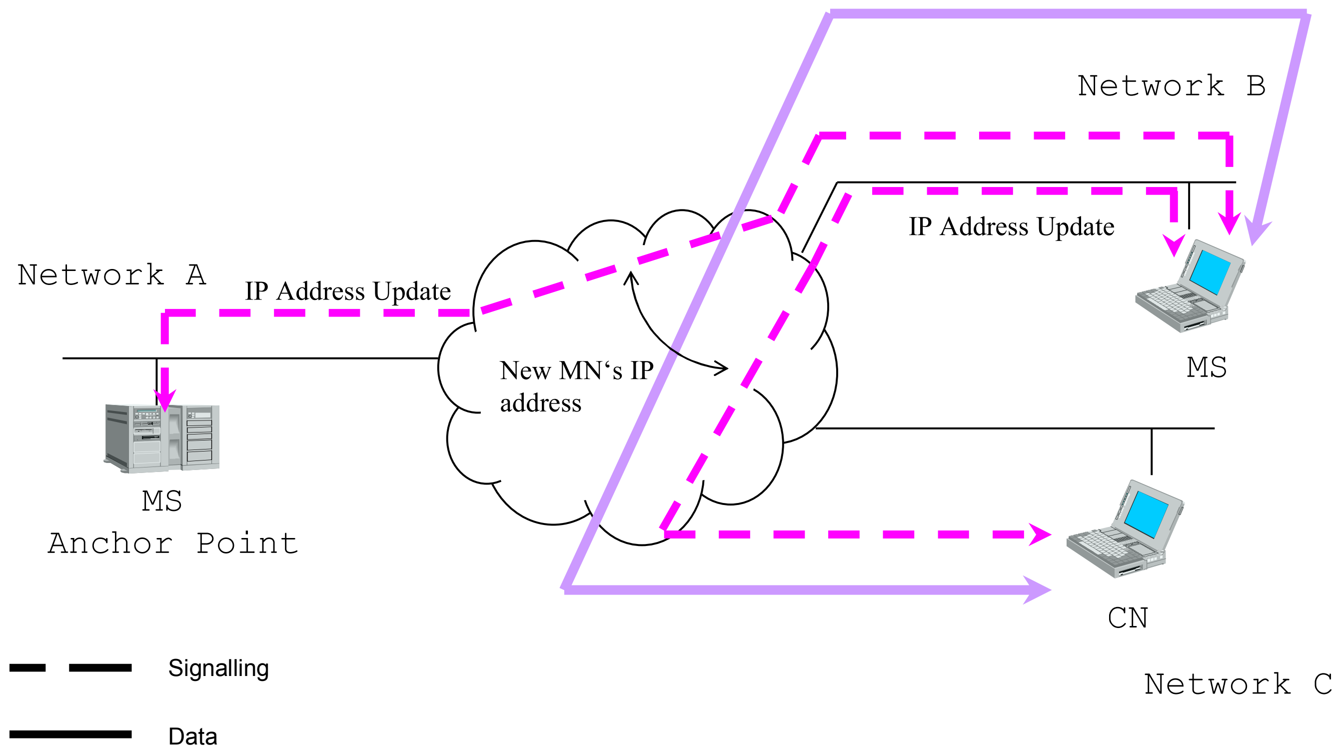

Figure 3.3 MS moves during a call

When a mobile station (MS) moves from a network to another, it must inform its Anchor Point of its new IP address. If the mobile device changes its address during an ongoing connection, it must give its new IP address to the correspondent node to allow the CN to continue to communicate with the MS. Furthermore, both mobile IP and SIP resemble the GSM network architecture. The GSM architecture consists of three important network elements:

- The Mobile Switching Center (MSC), responsible for routing calls, tracking of the mobile users and security functions.
- The Visitor Location Register (VLR), a database that stores information about users currently served by the MSC, is often located close to an MSC.
- The Home Location Register (HLR) holds further user information, such as the actual location and subscription data.

When a mobile station is switched on in a new location, or it moves to a new location, it must register with the network to indicate its current location. So, a location update message is sent to the new MSC/VLR, which records the location area information, and then sends the location information to the subscriber's HLR. The HLR sends a subset of the subscriber information, needed for call control, to the new MSC/VLR, and sends a message to the old MSC/VLR to cancel the old registration. Figure 3.4 shows this registration process.

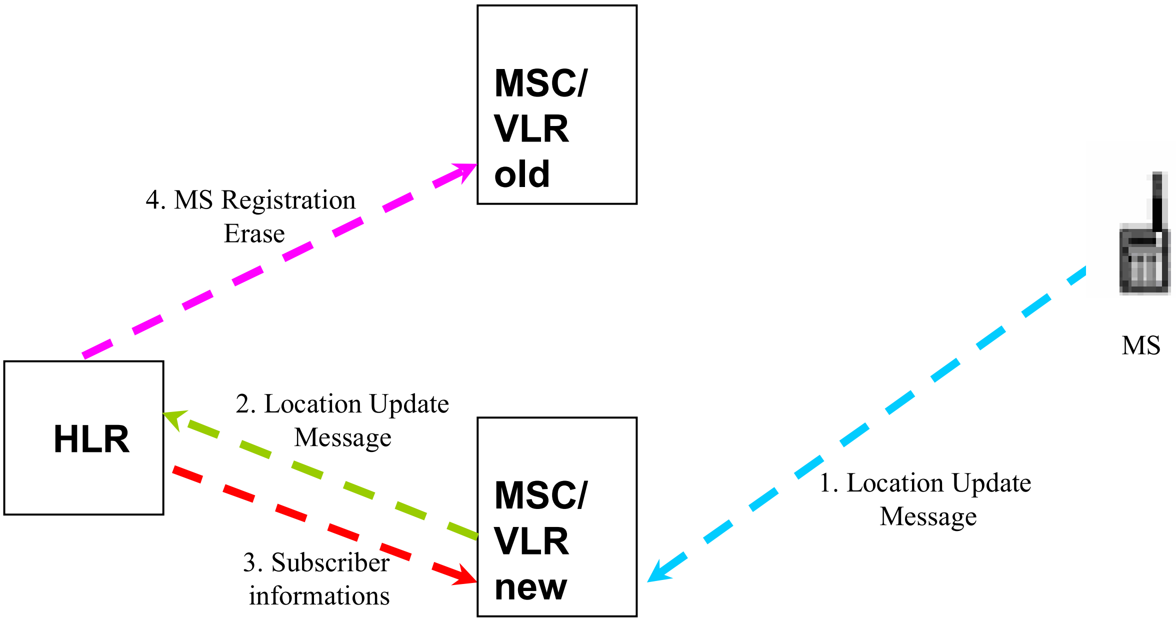

Figure 3.4 GSM registration process : MS registers at its HLR

To better align the GSM architecture with our general model, we have to consider GSM call routing (Figure 3.5).

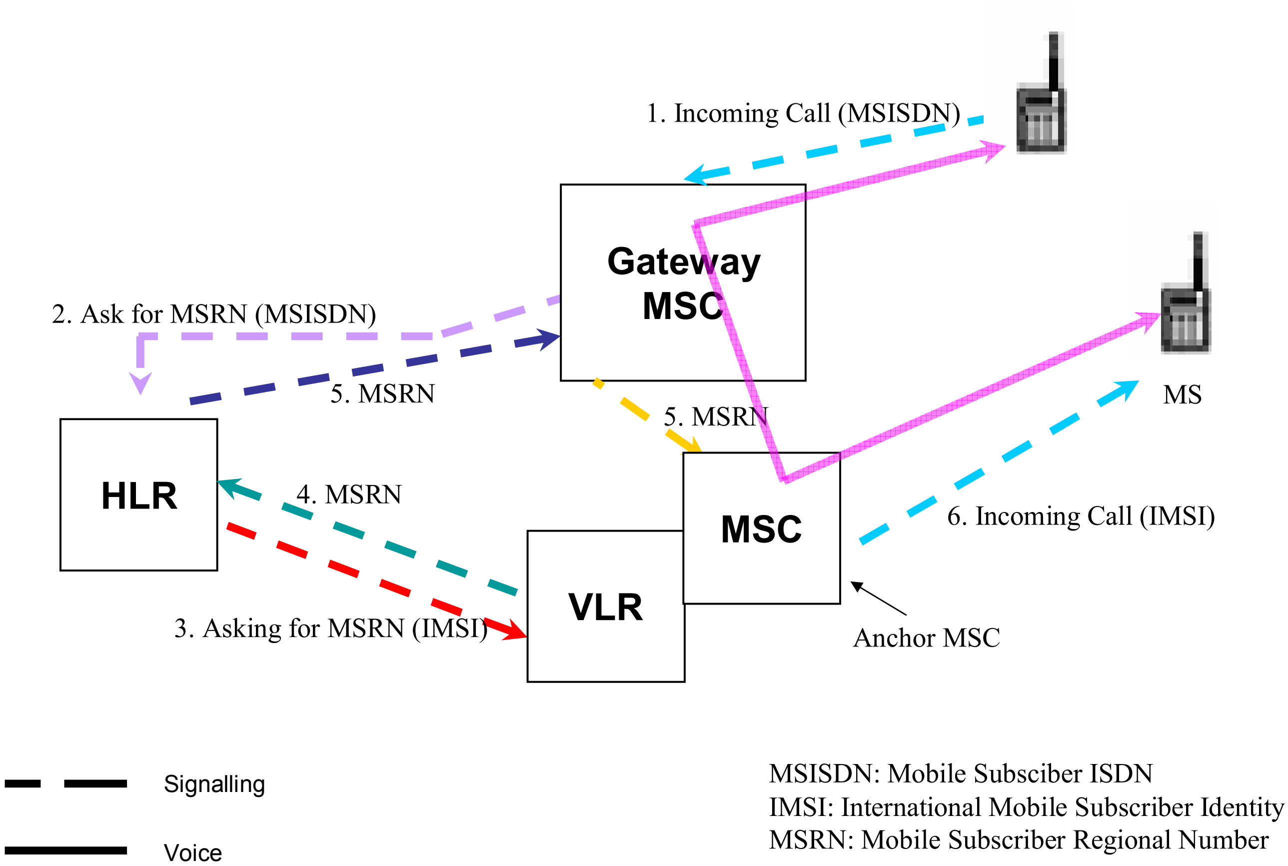

Figure 3.5 GSM Call Routing

The HLR is the first network element to be queried when there is an incoming call for the mobile device, as it is the only element in the home network aware of the current position of the mobile node. The Home Location Register can be compared to the Home Anchor Point in our general model previously described. When the mobile moves during an incoming call, changing the MSC and the VLR to which it is connected, it must inform the HLR using the registration process showed in Figure 3.4. In this approach the mobile node does not inform the correspondent node about its new MSC, so the correspondent node conitinues to be served by the first MSC, which we can call anchor MSC. If during the call, the MS changes among several MSC, the new one informs the anchor MSC to route the call towards itself and the anchor MSC remains active in the routing path until when the call ends.

As the anchor MSC re-routes the traffic towards the MS, we can define it as Home Anchor Point for the data. For its functionalities, this element can be identified with the Mobile IP Home Agent, and with a SIP Data Proxy, a new element that actually is not present in the SIP architecture.

Summarizing, Figure 3.6 depicts a general model which can describe the Mobile IP, SIP and GSM mobility management approaches.

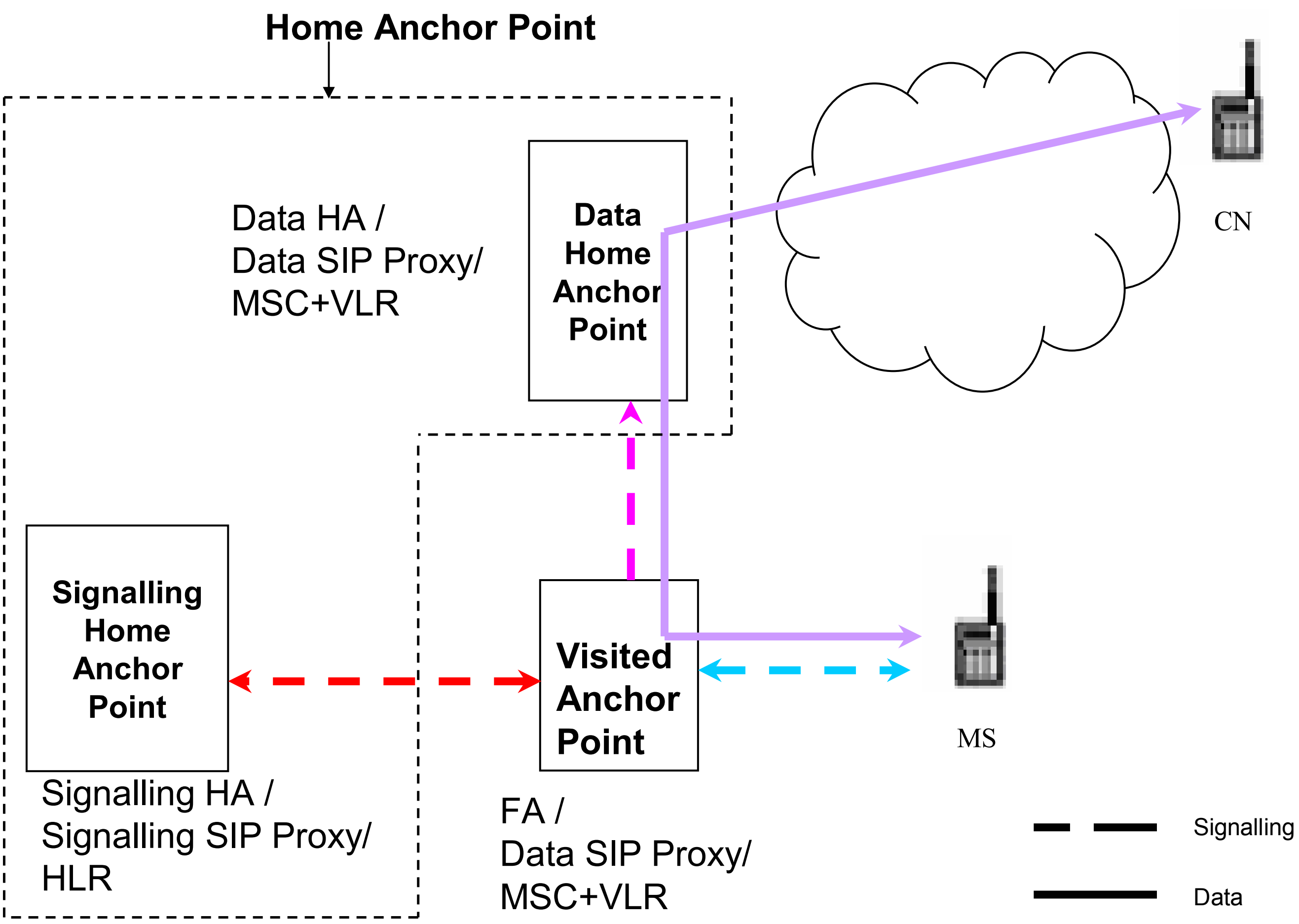

Figure 3.6 General Mobility Management Model

3.3 M-SCTP

Mobile IP and SIP are not the only possible solutions to IP mobility. Another approach is to manage terminal mobility at the transport layer.

The "Stream Control Transmission Protocol" (SCTP) [7] is an IETF proposed standard for the transport layer. It is designed to replace TCP. Like TCP, SCTP is reliable but offers new features such as multi-streaming and multi-homing. In particular, the multi-homing feature enables a single SCTP endpoint to support multiple IP addresses within a single association. This feature allows SCTP to be a solution at the mobility management problem without adding any special router agents in the network.

In SCTP, each endpoint is aware about all the IP addresses of the peer before the association is completely established, and these IP addresses must not be changed during the session. In order to perform a dynamic address reconfiguration SCTP uses an extension (called Dynamic Address Reconfiguration, ADDIP [8]), which enables SCTP to add, delete and change the IP addresses during an active connection. SCTP with the ADDIP extension is called M-SCTP (Mobile-SCTP) [5], [6].

The procedure works as depicted in Figure 3.7.

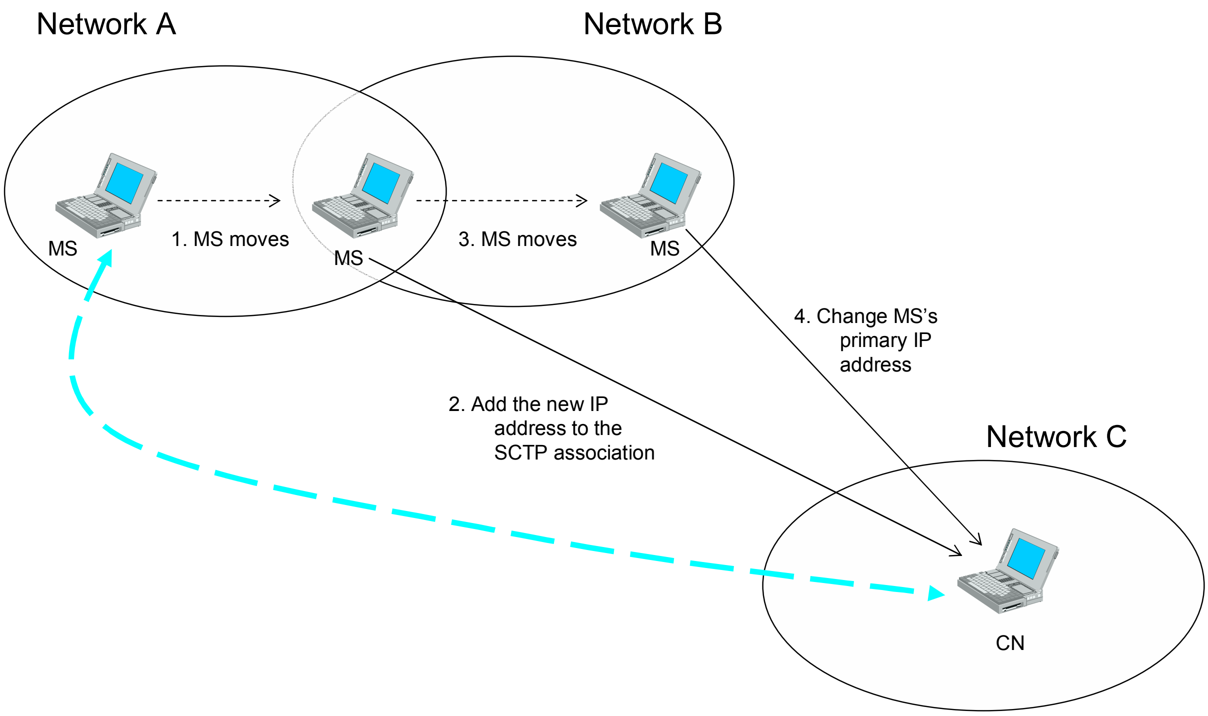

Figure 3.7 M-SCTP: Mobile Stream Control Transmission Protocol

During association startup between the two end points, a list of transport addresses (i.e. IP address-port -pairs) is provided between the communicating entities. These addresses are used as the endpoints of different streams. SCTP regards each IP address of its peer as one "transmission path" towards this endpoint. One of the addresses is selected as initial primary path, which may be changed later if needed. The ADDIP extension used in M-SCTP aids in this dynamic address reconfiguration.

In the Figure 3.7, the mobile station MS initiates an SCTP association with the corresponding node CN. The resulting association consists of the exchange of their IP address between MS and CN (the primary path). After a while, the MS decides to move from network A to network B. When the MS, moving towards network B, obtains its new IP address, it sends this information to CN, which updates its list. When the MS is totally in the network B, the old IP address becomes inactive, so the mobile sends this information to CN, which deletes the old IP address from its address list.

From the description above, we note that the protocol is mainly targeted for client-server services in which the client initiates the session with a fixed server. In fact, in a peer-to-peer service, if the CN is initiating the association towards the MS, a location management scheme is required: Mobile IP or SIP can be used for the CN to find the MS current location and to establish an SCTP association. After the association is successfully set up, the M-SCTP can be used for providing seamless handover, as discussed earlier. However, the seamless handover procedure is another problem, since it is not yet specified how the mobile can acquire the new IP address and how it can be reacheable simultaneously by using two IP addresses.

Another problem, very important nowadays, is related to security issues. The protocol offers some security measures, such as the use of a four-way handshake, which is a heavy mechanism, and IPsec to achieve data integrity and data confidentiality. It does not prevent man-in-the-middle attacks.

Lastly, another problem is that SCTP is not deployed and maybe will never be deployed as TCP is so long used that to think to replace it is not a realistic idea.

4. Micro-Mobility management

The major shortcoming of Mobile IP and SIP is that location updates are always generated whenever the MS changes subnet. If the MS and Home Agent for Mobile IP, or SIP Home Proxy for SIP, are separated by many hops in a wide area network, location updates need to travel over the entire path from the MS to the Home Agent/Home Proxy before the change in the mobile location is effectively communicated to the HA and, in the case of Mobile IPv4, ongoing connections are restored. This causes a large handoff delay and a frequent generation of location update messages, since in a wireless environment, and especially in a cellular one, subnet changes occur fairly rapidly. This has led to the development of protocols that support intra-domain mobility, also known as IP micro-mobility.

IP micro-mobility protocols are designed for environments where mobile hosts change their point of attachment to the network frequently (e.g., cellular networks, Wi.Fi. networks), avoiding overhead in terms of delay, packet loss and signalling that macro-mobility protocols introduce. Despite the apparent differences between IP micro-mobility protocols, the operational principles that govern them are largely similar. This assertion allows us to define a generic model to describe micro-mobility schemes.

4.1 General micro-mobility approach

Several solutions have been proposed for micro-mobility, but all of them can be described considering one architectural model, and two different ways of operation.

We will define as Domain Router (DR) the gateway router of the domain network visited by the mobile station, and as Subnet Router (SR) a generic router inside the network.

Figure 4.1 shows an example of this generic network architecture. The dotted line between the DR and the SR means that there are other SRs in between.

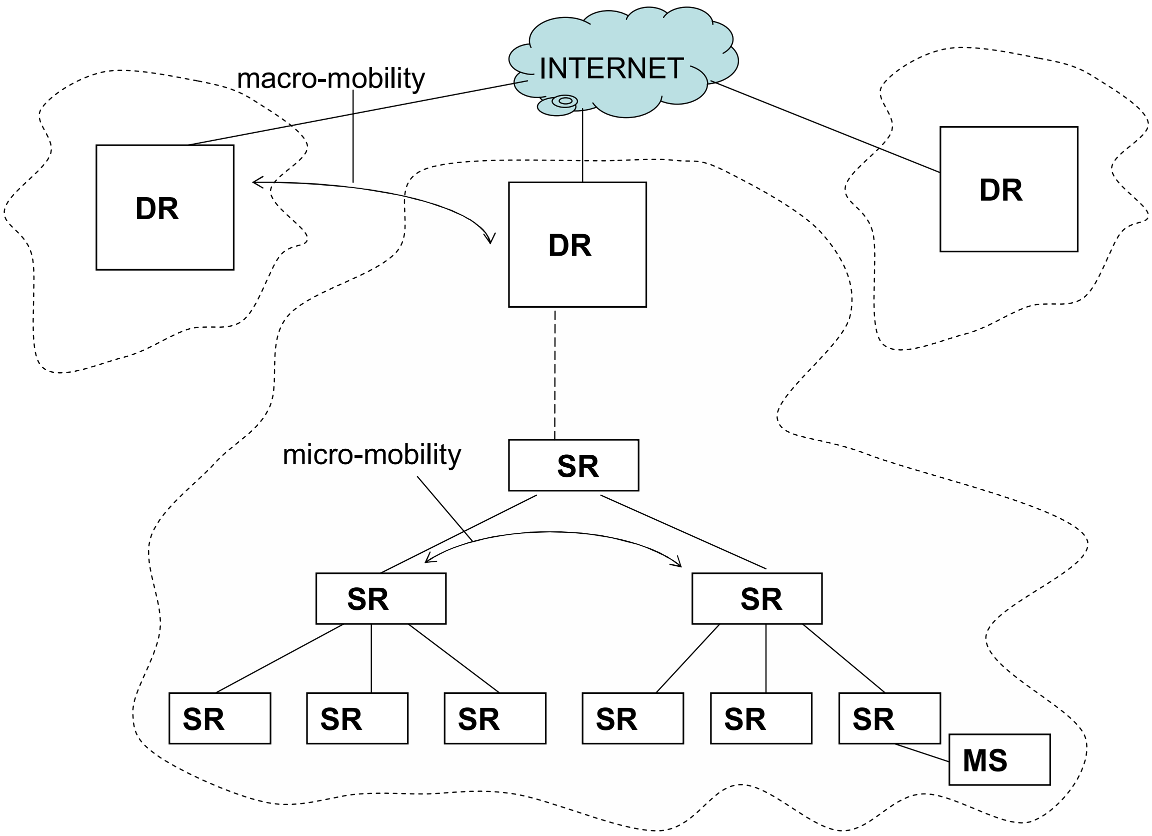

Figure 4.1 Network model for micro-mobility management protocol

The DR acts as border router and filters between registrations intended for the home anchor point (HAP) and those resulting from intra-domain movement, that do not need to reach the HAP.

A micro-mobility protocol behaves as follow: The MS obtains a domain Care of Adderess (DCoA) when it connects to a foreign domain and registers this address with his home anchor point, which can be a Home Agent, if the macro-mobility is managed by Mobile IP, or a SIP home proxy, if SIP is used. This DCoA remains valid until the mobile station stays in that domain, so the movement inside the domain is transparent to the home anchor point. The only element able to find the MS inside the domain is the DR. In fact, when the MS moves inside the domain changing its IP address the mobile station performs a registration process only with the DR, to allow it to update its information. The DR manges a list of mobile stations whose data path traverses it and the update procedure of this list allows us to divide the well-known micro-mobility protocols into two classes: Mobile IP based (Hierarchical Mobile IP [9] [10], IDMP [11] [12] [13], TeleMIP [14]), because the idea is similar to the Mobile IP approach, and hop-by-hop routing based (Cellular IP [15] [16], HAWAII [17]), because the idea is to update the data path from the DR to the MS updating all the SRs on the path. In this way every node, the DR and all SRs involved, know only the next hop to which send the data and not the entire path toward the MS.

When the MS enters in a foreign domain it registers with the SR to which the device attaches itself. This SR forwards the registration message to the DR of the domain which assigns a DCoA to the MS. The MS informs the home anchor point about its new IP address, and, the CN if there is an active session between the two nodes, of its new location, sending to HAP, and to CN eventually, its new address. When the HAP forwards a packet coming from the CN to the mobile node (if the CN knows the MS DCoA the packet is sent directly from the CN to the MS), this packet is intercepted by the DR, which is the only entity aware of the exact position of the MS inside the domain and delivered to the MS.

About the Mobile IP based protocols, when the MS moves within the domain, it performs only local registrations: the MS informs about its new positions only the DR and not the HAP. A local registration is a registration process in which the mobile sends a registration message to the DR each time it changes the SR to which it is attached, and it contains the new address that the DR has to use to reach the MS. We will call this address Throughway Care of Address (TCoA).

The hop-by-hop routing based protocols do not assign two temporary addresses to the MS. The MS acquires only the DCoA, inside the domain is used the home IP address to recognize the mobile. When MS changes SR each node between DR and the MS is updated with the information about the next hop that the packet has to traverse in order to reach the mobile. This update is done by a data packet sent by the mobile toward the DR, as in the case of Cellular IP, or by signalling messages, as for HAWAII.

Handoff management allows the network to forward the traffic to the mobile station since it ensures that the network always knows the current location of the mobile station. Unfortunately, even if a mobile node is not transmitting any data, the network still needs to know its location. If a MS that is not transmitting changes its SR, it will be impossible to forward a packet destined to it if the network does not know where the mobile is located. This means that each change of position must be signaled and this causes the mobile to consume large amounts of power. To avoid frequent position updates, networks add paging architecture, which divides the network into distinct geographical areas, called paging areas, comprising several subnets. When the MS has no data to transmit, it only issues a beacon when changing its paging area. This implies that the DR only knows an approximate location of the mobile, the MS current paging area. An incoming packet destined to the mobile station forces the DR to perform a paging procedure to find its precise location that is the SR where the MS is located inside its paging area. On the other hand, to send data packets after having been in idle mode, the MS must first inform the DR of its current location.

Only few proposals among the micro-mobility protocols that we consider use a paging architecture. For these proposals we will discuss the algorithm used to perform the paging when comparing them.

Problems

The model relies on a tree-like network architecture, which allows restricting the number of nodes involved in handoff management to a small set composed of the nodes closest to the MS. Unfortunately, hierarchical architectures present major drawbacks with respect to robustness and scalability. In fact such structures are extremely vulnerable to a failure of one of the stations at the higher levels of the hierarchy which are the most heavily loaded too. To solve this problem some proposals (TeleMIP, IDMP) use more than one DR in each domain network and load balancing algorithms among DRs.

Another important issue is the security problem. None of the proposals suggest how to authenticate a local registration update sent by the MS to the DR, to prevent attacks.

4.2 Evaluation criteria

In this section we will consider five IP micro-mobility protocols: hierarchical Mobile IP, TeleMIP, IDMP, Cellular IP, HAWAII, and we will evaluate them according to four criteria: handoff latency, packet loss, involved stations and robustness. In particular:

- Handoff latency is the amount of time needed by the mobile station to complete the handoff process; in particular, it is the amount of time that elapses between the moment in which the MS becomes aware that it has to change its current attachment point to the moment in which the mobile node registers to a new attachment point.
- Packet loss indicates the amount of data lost during the handoff.
- Involved stations are the number of nodes that must update their routing tables because of the MS performing an handoff process.
- Robustness is the ability of the architecture to support a high volume of traffic.

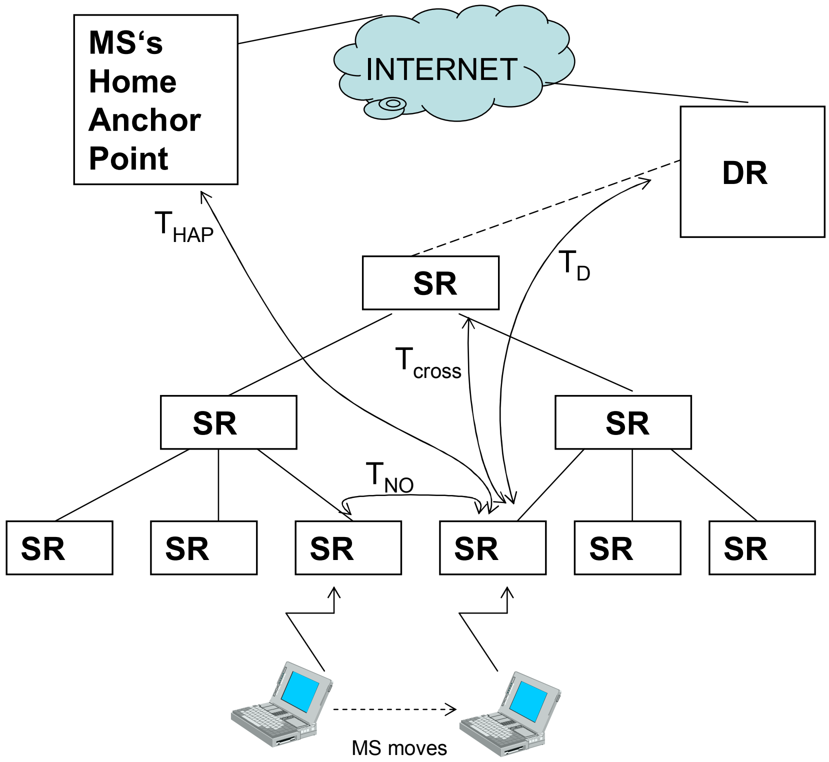

Figure 4.2 Intra-domain movement in a multi-level network hierarchy

To evaluate the performance of the protocols, we consider the network model shown in Figure 4.2 and define the following parameters:

- When the mobile node changes SR inside the domain it has to inform the DR of its new location. The average handoff delay for this operation is T_D and N_D is the average number of SR nodes between the MS and the DR.
- When the mobile node moves from an SR to another, the average handoff delay is T_{NO}, and N_{NO} is the average number of hosts between the MS new and old point of attachments.
- We call crossover node the intersection node between the path that connects the old and new point of attachments of the mobile node and

the path that connects the new point of attachment of the mobile node and the DR. N_{cross} is the average number of nodes between the mobile node and the crossover node for a given handoff which must update their routing tables, and T_{cross} is the average time that the mobile node needs to inform the crossover node about its new point of attachment.

- When the mobile node changes DR performing an inter-domain handoff, it has to inform its HAP of its new location. T_{HAP} is the average time that the mobile station needs to perform this registration update process.
- Another important source of delay for the handoff, expecially for real-time applications, for which is important that the movements of the MS are detected as fast as possible to decrease packet loss, is the detection of the occurrence of a handoff. We will call this delay T_{det}.

4.3 Similarities, differences and evaluations

In this section we will present the five selected IP micro-mobility protocols showing the differences within our general architecture and evaluating them using our criteria.

Hierarchical Mobile IP

In Hierarchical Mobile IP [9] (Figure 4.3) the elements DR and SR are called, respectively, a Gateway Foreign Agent (GFA) and a Regional Foreign Agent (RFA), which are classic Mobile IP Foreign Agents with various enhanced capabilities. It is a multiple level hierarchy architecture, having multiple SRs between the DR and the mobile. In this multiple level architecture, when the

MS changes the SR to which it is currently attached, the local registration is only sent to the crossover SR (Figure 4.3 describes a two level architecture, so, in this case, the crossover SR is the GFA). In this way the higher levels of the hierarchy are not aware of the details of the mobile's movements and the handoff management is limited to a small number of nodes.

Hierarchical Mobile IP is a centralized system architecture: a centralized DR manages all the traffic within a regional network, which means that the DR is the critical node.

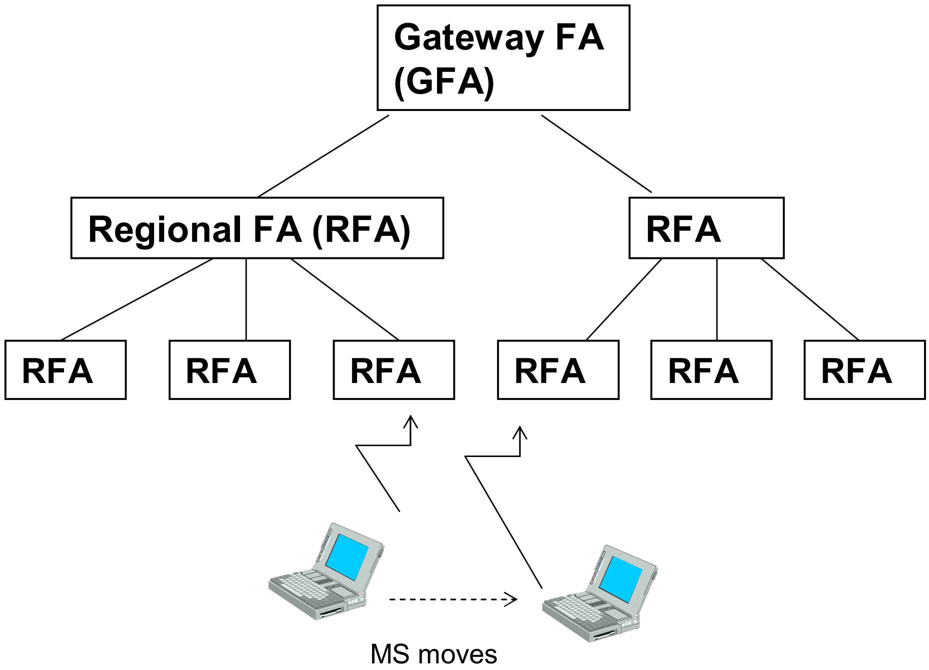

Figure 4.3: Hierarchical Mobile IP architecture

Evaluation

As seen, when the MS moves inside the domain, it has to send a registration request up to the crossover SR and the time to reach it is T_{cross}. So, the handoff latency is the sum of three elements: the interval during which the mobile detects the imminency of an handoff, T_{det}, the interval during which the MS changes point of attachment, T_{NO}, and the registration time T_{cross}: $T_{det} + T_{NO} + T_{cross}$.

After receiving a local registration for the MS, the crossover SR sends an update message along the path of the previous address of the mobile node to perform the de-registration process. The number of stations involved in the handoff mechanism is 2 N_{cross}.

When we consider a movement between two domains, T_{cross} must be replaced by T_D as the MS must register with the new DR. In this case, the number of stations involved is $2N_D + 1$, where 1 indicates the home agent, since Hierarchical Mobile IP uses Mobile IP for the macro-mobility management, which has to update its tables. The handoff latency is the same calculated before plus the time that the mobile needs to inform the home agent, T_{HAP}: $T_{det} + T_{NO} + T_{HAP}$. In this sum we don't consider T_D since Hierarchical Mobile IP works with simultaneous bindings to distribute IP routing updates during a handoff, and $T_D < T_{HAP}$.

In both cases, micro or macro movement, during the handoff process packets are lost.

Hierarchical Mobile IP does not provide a paging algorithm, so the mobile must register whenever it changes its point of attachment and whatever its state is, idle or active. Anyhow, it is always possible to consider a paging algorithm separated from the micro-mobility algorithm.

About the robustness, we can say that this architecture is quite weak, since in Hierarchical Mobile IP there is only one node that acts as a DR in a domain. The DR is the crucial node and the most heavily loaded station. In fact, it has to process all the traffic of the network, processing all packets, all updates and has to maintain table entries for all the Mobile stations inside the network.

TeleMIP

TeleMIP (Telecommunications-Enhanced Mobile IP) [14] (Figure 4.4) is not merely a protocol but a more comprehensive architectural framework for supporting intra-domain mobility in cellular wireless networks.

In TeleMIP, the elements DR and SR are called, respectively, a Mobility Agent (MA) and a Foreign Agent (FA). TeleMIP proposes a two level hierarchy architecture with the use of distributed DRs in the domain, so that a SR can be connected to more than one DR, and the assignment of a DR to a MS is done via some dynamic load balancing algorithm. In this way, the management of all the MSs present in the domain does not rely on a single DR.

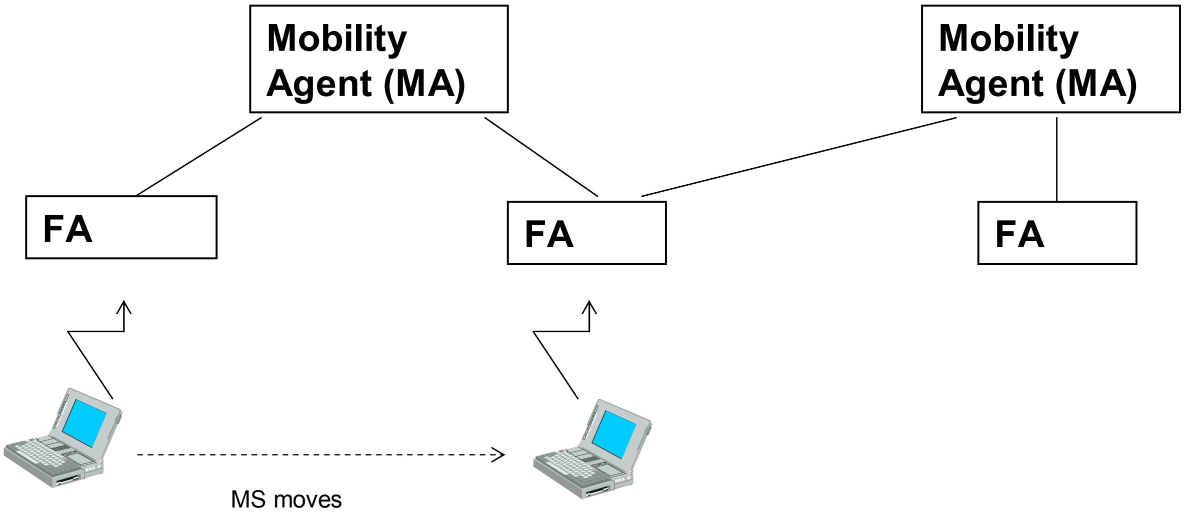

Figure 4.4: TeleMIP architecture

Evaluation

Unlike Hierarchical Mobile IP, TeleMIP is a two level network architecture and does not support a multi-level architecture, so $T_{cross} = T_D$ since DR is the crossover node. TeleMIP has the same handoff characteristics than Hierarchical Mobile IP with a two level architecture.

The only advantage of TeleMIP is its robustness properties, as it defines more than one DR in a domain and a load balancing algorithm to assign the MS to a particular DR. Thus if a DR fails it is still possible to redistribute the traffic among the remaining DRs.

IDMP

In IDMP (Intra-Domain Mobility Management Protocol) [11], [12], [13] (Figure 4.5), the elements DR and SR are called, respectively, a Mobility Agent (MA) and a Subnet Agent (SA). It is very similar to TeleMIP, in the sense that it has a two levels of hierarchy and that in the domain is possible to have more than one DR using a load-balancing algorithms to distribute the mobility load across them.

Some differences with the two schemes analyzed formerly are that IDMP supports fast-handoff and paging. Fast-handoff assumes that the IP layer has the possibility to receive information about the imminence of a handoff from the radio layer. In most cases, the radio layer is constantly doing power measurement on the signals received from its peers. On the basis of these measurements, it is possible to evaluate the signal quality for a particular node and to detect when a handoff is occurring.

In IDMP, the fast-handoff mechanism is network controlled: the mobile station informs the DR of the imminent handoff which starts to multicast in-flight packets to all SRs which are close to the old SR. The procedure works as follows:

- MS transmits an *Imminent Movement* message to the DR whenever it senses (via layer-2) the possibility of an handoff.
- DR proactively multicasts inbound packets to the SRs that are neighbors of the MS's current SR, allowing them to temporarily buffer such packets until the handoff procedure is completed.
- MS registers with one of these neighboring SRs.

- The new SR forwards cached packets to the MS as soon as this one registers to the new SR without waiting for the DR location update.

This procedure assumes that the handoff is very fast so that the buffered packets can be considered still "good".

Paging is a very efficient solution to minimize signaling in order to reduce power consumption of mobile hosts: an idle MS does not perform any registration or location update as long as it stays within a PA.

IDMP defines a Paging Area based on an explicit set of SRs that subscribe to the corresponding multicast group. When MS has to start to send packets, the mobile device will inform the DR about its location. On receipt of an incoming packet for an idle MS, the DR buffers it and multicasts a Page Solicitation to the MS's current PA, requesting the MS to re-register at the DR with a new and currently valid TCoA.

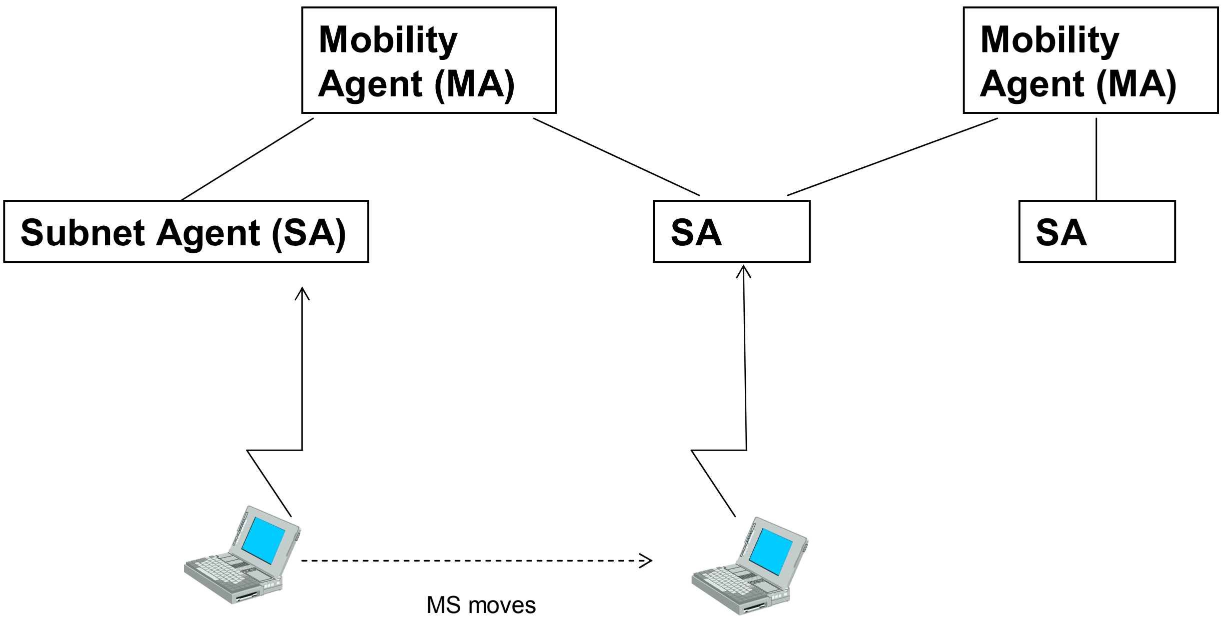

Figure 4.5: IDMP architecture

Evaluation

The fast handoff scheme supported by IDMP should allow us to obtain an handoff delay lower than using TeleMIP or Hierarchical Mobile IP and no loss of in-flight packets. Infact, the mobile device (MS) uses a layer-2 trigger to inform the DR of an incoming handoff, the DR multicasts all packets to all SRs that are neighbors to the SR to which the MS is attached. When the MS performs a local registration with the new SR it already starts to receive the buffered packets, without having to wait for the registration process with the DR to complete. So the handoff delay is $T_{det} + T_{NO}$.

As we can see the number of stations involved in the handover process is higher than the one calculated for Hierarchical Mobile IP, with a two level network architecture. In addition to the nodes considered in Hierarchical Mobile IP, we must consider the number of SRs which must buffer the packets sent by the DR.

Another important feature of IDMP is the paging management, the support of this feature is explicitly included in the protocol, which allows a mobile device to register its new location only when it is working in active mode, saving power. With the paging mechanism the price to be paid is the delay linked to the intradomain location update process. In IDMP this delay is about $2T_D$ as it is the sum between the time that the DR needs to send the *Page Solicitation* message (T_D) and the time that the MS registers with the DR (T_D).

For the robustness we can say that, as for TeleMIP, there is the possibility to have more than one DR in the network, managed by a load balancing algorithm, avoiding, in this way, to overload this crucial node.

Cellular IP

In a Cellular IP network, location management and handoff support are integrated with routing. To minimize control messaging, regular data packets transmitted by mobile node are used to refresh location information of the nodes. Paging is used to route packets to idle stations.

Cellular IP [15] [16] associates a MS with a single DCoA, which actually is the address of the DR, here called Gateway (GW). In this architecture the SRs are switches with particular capabilities, that we will describe later.

The GW uses the Mobile Station's permanent home address as the unique identifier inside the domain, without requiring additional tunneling. Packets to the MS are routed to its current SR on a hop-by-hop basis where each node only needs to know on which of its outgoing ports to forward the packets. Mappings are created by packets transmitted by an MS. As the MS approaches a new SR, it redirects its data packets from the old SR to the new one. The first of these redirected packets will automatically configure a new path of routing for the host. This handoff procedure is called hard handoff.

Cellular IP supports two different mechanisms to manage the handoff process: the hard handoff mechanism and the semi-soft handoff mechanism. The hard handoff mechanism is the basic handover management and is the one described earlier. It is based on a simple approach that trades off some packet loss for minimizing handoff signaling rather than trying to guarantee zero packet loss

Cellular IP semi-soft handoff exploits the notion that some mobile nodes can simultaneously receive packets from the new and old point of attachment during handoff. It is based on level-2 triggers received by the mobile that warns it of an imminent handoff and that allows the MS to send a special packet to the old and the new point of attachment to establish a bicasting of the traffic. Semi-soft handoff minimizes packet loss, providing improved TCP and UDP performance over hard handoff.

While the semi-soft packet ensures that the mobile host continues to receive packets immediately after handoff, it does not, however, fully assure a smooth handoff. Depending on the network topology and traffic conditions, the time to transmit packets from the cross-over point to the old and new base stations may be different and the packet streams transmitted through the two base stations will typically be not synchronized at the mobile host. If the new base station "lags behind'' the old base station, the mobile host may receive duplicate packets. Reception of duplicate packets in this case is not disruptive to application operations. If, however, the new base station "gets ahead'' then packets will be deemed to be missing from the data stream observed at the receiving mobile host. The second component of the semisoft handoff procedure is based on the observation that perfect synchronization of the two streams is not necessary. The condition can be eliminated by temporarily introducing into the new path a constant *delay* sufficient to compensate, with high probability, the time difference between the two streams. This can be best achieved at the cross-over switch that understands that a semi-soft handoff is in progress due to the fact that a semi-soft packet has arrived from a mobile host that has a mapping to another interface. The mapping created by the semi-soft packet has a flag to indicate that downlink packets routed by this mapping must pass a "delay device'' before transmission. After handoff, the mobile host will send data or route-update packets along the new path which will clear this flag and cause all packets in the delay device to be forwarded to the mobile host.

Cellular IP supports paging. Some specific nodes in the network domain maintain the two sets of mappings: Paging Caches (PCs) and Routing Caches (RCs). PCs are used to find an idle MS when there are data packets to be routed to it, while RC mappings are maintained for MNs currently receiving or expecting to receive data.

Cellular IP defines an *idle mobile host* as an host that has not received data packets for a system specific amount of time *active-state-timeout*. In this respect, idle mobile hosts allow their respective soft-state routing cache mappings to time out. These hosts transmit *paging-update packets* at regular intervals defined by *paging-update-time*. The paging-update packet is an empty IP packet addressed to the gateway that is distinguished from a route-update packet by its IP type parameter. Similar to data and route-update packets, paging-update packets are routed on a hop-by-hop basis to the gateway. Base stations may optionally maintain *paging cache*. A paging cache has the same format and operation as a routing cache except for two differences. First, paging cache mappings have a longer timeout period called *paging-timeout*. Second, paging cache mappings are updated by any packet sent by mobile hosts including paging-update packets. In contrast, routing cache mappings are updated by data and route-update packets sent by mobile hosts. This results in idle mobile hosts having mappings in paging caches but not in routing caches. In addition, active mobile hosts will have mappings in both types of cache. Packets addressed to a mobile host are normally routed by routing cache mappings. Paging occurs when a packet is addressed to an idle mobile host and the gateway or base stations find no valid routing cache mapping for the destination. If the base station has no paging cache, it will forward the packet to all its interfaces except for the one the packet came through. Paging cache is used to avoid broadcast search procedures found in cellular systems. Base stations that have paging cache will only forward the paging packet if the destination has a valid paging cache mapping and only to the mapped interface(s). Without any paging cache the first packet addressed to an idle mobile host is broadcast in the access network. While the packet does not experience extra delay it does, however, load the access network. Using paging caches, the network operator can restrict the paging load in exchange for memory and processing cost. Idle mobile hosts that receive a packet move from idle to active state, start their active-state-timer and immediately transmit a route-update packet. This ensures that routing cache mappings are established quickly potentially limiting any further flooding of messages to the mobile host.

For paging, the stations are grouped in paging areas and only one station per area maintains a PC, while the MSs are distributed into *Idle* and *Active* states.. When mobile node wants to transmit data, it changes state into active state.

In Cellular IP networks, SRs are switches with particular capabilities. They have to support the paging management and must contain a delay device, for the semi-soft handoff mechanism.

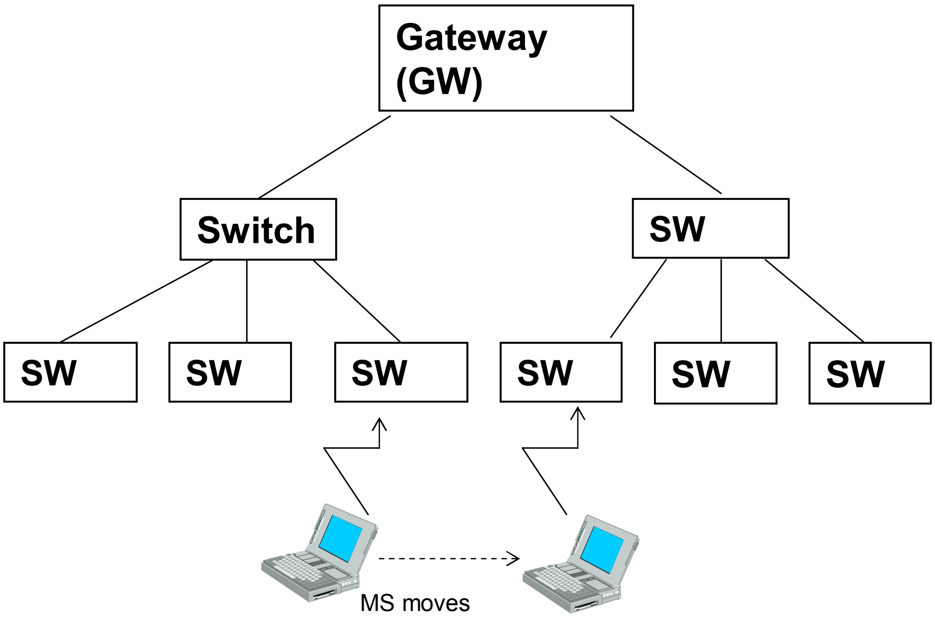

Figure 4.6: Cellular IP architecture

Evaluation

In Cellular IP, the MS sends a packet that is forwarded hop-by-hop towards the DR, to inform this node of its new location, and this packet must be acknowledged. The handoff latency is thus $2T_D$ and the number of stations involved in the process is N_D. It is expected that during the semi-soft handoff no packet loss will occur, while during the hard handoff packets are lost during the interval $T_{det} + T_{NO} + T_D$.

As described, Cellular IP supports a paging architecture where the load of paging management is assigned to one node per paging area. This, obviously, creates problems related to robustness.

HAWAII

HAWAII (Handoff-Aware Wireless Access Internet Infrastructure) [17] is very similar to Cellular IP, but unlike Cellular IP, it does not replace IP addresses inside the domain, but rather works above the IP layer. Each SR maintains a routing cache to manage the mobility; the hop-by-hop transmission of special signalling packets in the network allows the nodes to update their cache. In HAWAII the root of the tree architecture is called Domain Root Router (DRR).

HAWAII defines two different handover mechanisms (called forwarding and non-forwarding scheme) adapted by different radio access technologies. In the first one, the MN can communicate with more than one base station at the same time while in the other this cannot happen.

In the forwarding schemes, packets are first forwarded from the old access point to the new one before they are diverted at the crossover SR, while in the non-forwarding schemes data packets are diverted at the crossover SR to the new access point, resulting in no forwarding of packets from the old to the new SR.

Each one of these mechanisms define two different path setup schemes that control the handoff between the SRs. The appropriate path setup scheme must be selected by the network operator depending on his priorities between eliminating packet loss, minimizing handoff latency and maintaining packet ordering.

HAWAII also supports a paging mechanism. Each paging area corresponds to an IP multicast group. The paging requests are transmitted to the multicast group corresponding to this area. The paging mechanism is managed by a load balancing algorithm that chooses a particular station to perform each paging, taking into account the current load of each node.

Each node inside the domain is an IP router with special functions: management of the mobility and multicast enabled.

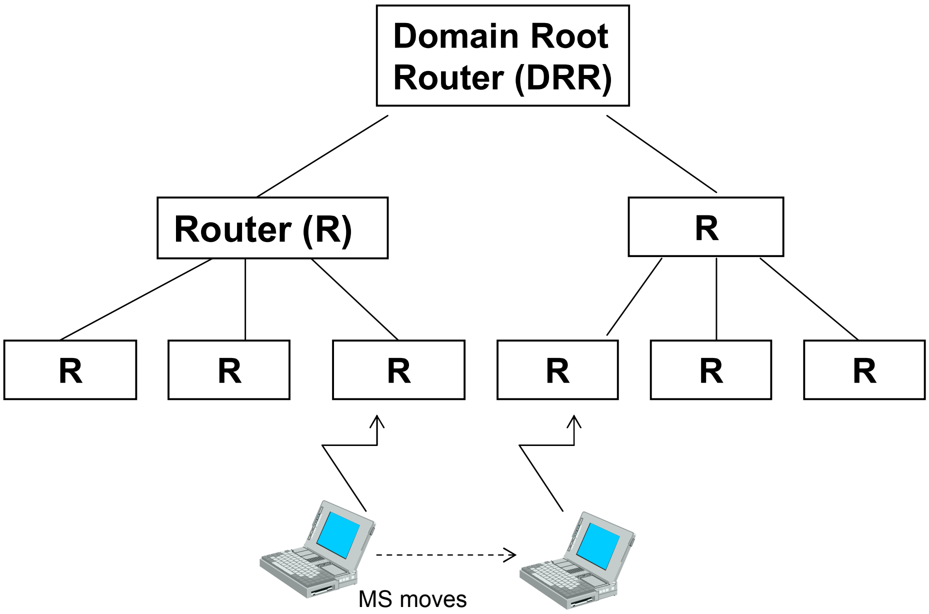

Figure 4.7: HAWAII architecture

Evaluation

As seen, the handoff mechanism in HAWAII is based on the exchange of special signalling packets between the old and the new SR and the acknowledgment of the path setup message to the mobile host. The handoff latency is thus $2T_{cross}$ and the number of stations involved in the mechanism is N_{NO} as only the stations located on the path between the old and the new SR perform a routing update. Routing update messages do not have to be propagated higher in the hierarchy, to the DR, as in Cellular IP, but only towards the crossover node.

Packet losses are different in the two handoff schemes. The forwarding schemes rely on the wired network to buffer packets and forward them to the new SR, so the interval during which is possible to lose packets is given by the time that the mobile needs to move and to discover the new point of attachment, $T_{det} + T_{NO}$, and the time that the update message sent by the new SR needs to reach the old SR, $2T_{cross}$: $T_{det} + T_{NO} + 2T_{cross}$. The non forwarding scheme is faster since the packets are correctly forwarded as soon as the crossover station is aware of the handoff (this is similar to the hard handoff in Cellular IP). In the non-forwarding scheme packets are lost from the time the mobile changes station until the update message reaches the crossover node, $T_{det} + T_{NO} + T_{cross}$.

HAWAII supports a paging mechanism as well, but here the paging algorithm dynamically balances the paging load among the SRs, that is, nodes are roughly equally loaded.

5. Evaluation Summary

The basic idea which leads to develop the micro-mobility approach is handoff management. The handoff is the most important problem to manage in IP mobility, as it must be as fast and as efficient as possible in order to reduce the risk of packet loss. Expecially in a scenario where movements occur frequently, micro-mobility protocols are very advantageous since they decrease the handoff delay. Infact the home network could be very far from the mobile node visiting network, with the micro-mobility approach the mobile node must perform the home registration only when connecting to a new domain otherwise it has to send routing updates only to the nodes inside that domain. Inside the domain the handoff delay is due to three sources of latency, the move detection latency, the address acquisition latency and the IP routing update latency, that could cause packet losses. IP handoff always begins after the radio handoff and usually is based on routers advertisement. Some protocols, such as Hierarchical Mobile IP, TeleMIP, Cellular IP with hard handoff, remain totally independent of the radio layer doing nothing to prevent packet losses during the handoff inteval. Other protocols, as IDMP, Cellular IP with soft-handoff, and HAWAII, utilize layer-2 trigger to detect an impending handoff and attempt to complete the IP handoff before the radio handoff, to avoid or at least to decrease packet losses.

An improvement of the micro-mobility approach is the paging scheme. It is a very well known efficient solution to save power since the mobile devices have no batteries with infinite capacity. HAWAII, together with IDMP and Cellular IP, explicitly include the support of this feature. The basic idea used by these protocols comes from the classical cellular telephone concepts of location areas. The stations are grouped into paging areas and the network must perform paging to find the actual location of an idle mobile node.

The major difference in paging between IDMP, HAWAII, and Cellular IP is that Cellular IP does not have the ability to distribute the paging load among all the stations in the network (paging is performed by one node per paging area).

All the protocols analyzed here rely on a tree-like architecture, defining a hierarchical network structure. This structure reduces the routing update latency since it restricts the number of nodes involved in handoff management to a small set composed of the nodes closest to the old and the new MS point of attachment. The major drawback of a hierarchical architecture is the decreased robustness. The problem is that such a structure is very vulnerable to a failure of one of the stations at the higher levels of the hierarchy because these stations are the most heavily loaded in the network. TeleMIP and IDMP try to solve this problems defining more than one root station (the gateway station), in the tree architecture, to which a leaf station can be linked and using a load balancing algorithm to assign the mobile station to a particular gateway station. In this way the user load is balanced among the highest level stations.

Table 2 summarizes some of the characteristics of the different micro-mobility protocols.

Protocol	FA-based Architecture	Paging explicitly included	Load Balancing	Layer-2 Trigger	Type of Station	Packet Loss Interval
Hierarchical Mobile IP	Yes, with multi-level hierarchy. One DR in the network	No	No, tree structure more loaded around the root (DR)	No	Classic Mobile IP FA with various enhanced capabilities	$T_{det} + T_{NO} + T_{cross}$
TeleMIP	Yes, with two-level hierarchy. More DRs in the network and SRs connected to more DRs	No	Yes, load-balancing algorithms to distribute the mobility load across DRs	No	Advanced Switch with mobilitiy capacities	$T_{det} + T_{NO} + T_{D}$
IDMP	Yes, with two-level hierarchy. Multiple DRs in the domain	Yes	Yes, load-balancing algorithms to distribute the mobility load across DRs	Yes	Advanced Switch with mobility capacities	No Packet Loss
Cellular IP	No, but hop-by-hop based architecture. It replaces IP addresses inside the domain	Yes	No, tree structure more loaded around the root (DR)	Yes, in the semi-soft handoff scheme	Advanced switch with particular capabilities (es. paging management)	Hard Handoff: $T_{det} + T_{NO} + T_{cross}$ Semi-Soft handoff: No Packet Loss
HAWAII	No, but hop-by-hop based architecture. It works above the IP layer	Yes	Yes, only for the paging	Yes	IP router with mobility and multicast features	Forwarding: $T_{det} + T_{NO} + 2T_{cross}$ Non Forwarding: $T_{det} + T_{NO} + T_{cross}$

Table 2. Comparison of the micro-moblity protocols

6. Conclusions

One of the biggest issues in IP mobility is handoff management. It is very important that this handoff is fast to reduce packet loss. The two major solutions to IP mobility, Mobile IP, and SIP, are very similar to each other and to the GSM solution. The general idea is to perform a registration process with the home network everytime that the mobile node changes its IP address. This can take a long time as the mobile station can be far away from the home network; this solution is not acceptable expecially considering scenarios where the mobile device experiences frequent handoffs. To solve this problem, micro-mobility approaches have been introduced that allow the mobile node to inform the home network about its current location only when connecting for the first time to a foreign domain.

Several solutions have been proposed in literature for the micro-mobility, but all of them can be described considering one architectural model which relies on a tree-based hierachical network architecture. The choice of a hierarchical network structure results in a reduction of the routing update latency, but unfortunately, this presents drawbacks in respect to robustness. To improve this situation a good solution would be using a more redundant, more fault-tolerant, structure (an example of this is the use of load balancing in TeleMIP or IDMP).

To reduce the move detection latency and the packet losses, some proposals assumes that it is possible to receive a layer-2 handoff trigger which indicates an imminent radio handoff. Actually, it seems realistic to have a simple trigger informing the IP layer that a radio layer is about to happen, but it is difficult to have such information sufficiently in advance to avoid packet loss.

The last consideration is about the paging management. Some proposals explicitly include the support of this feature and others not. But the basic idea is taken from cellular networks and it should be possible to adapt this mechanism in the different protocols to the utilization of such a scheme.

It would be interesting to evaluate the different micro-mobility proposals in a standard and realistic network model with intensive simulations, but such analysis has not yet
been attempted.

References

[1] C. Perkins, "IP Mobility Support for IPv4", RFC 3344, August 2002.

[2] J. Rosenberg, H. Schulzrinne, G. Camarillo et al., "SIP: Session Initiation Protocol", RFC 3261, June 2002.

[3] D. Johnson, C. Perkins, J. Arkko, "Mobility support in IPv6", RFC 3775, June 2004.

[4] E. Wedlund, H. Schulzrinne, "Mobility Support Using SIP", Mobile Computing and Communications Review, Vol. 4, No. 3, July 2000, pp. 47-57.

[5] W. Xing, H. Karl, A. Wolisz, H. Muller, "M-SCTP: Design and Prototypical Implementation of an End-to-End Mobility Concept", in Proc. 5th Intl. Workshop The Internet Challenge: Technology and Applications, Berlin, Germany, October 2002.

[6] S. J. Koh, "Mobile SCTP (mSCTP) for Internet Mobility", IETF Internet draft, draft-sjkoh-msctp-00.txt, March 2005.

[7] R. Stewart, Q. Xie, K. Morneault, C. Sharp, H. Schwarzbauer, T. Taylor, I. Rytina, M. Kalla, L. Zhang, V. Paxson, "Stream Control Transmission Protocol", RFC 2960, Network Working Group, October 2000.

[8] R. Stewart, R. Ramalho, Q. Xie, M. Tuexen, P. Conrad, "Stream Control Transmission Protocol (SCTP) Dynamic Address Reconfiguration", IETF Internet draft, draft-ietf-tsvwg-addip-sctp-11.txt, February 2005.

[9] E. Gustafsson, A. Jonsson, C. Perkins, "Mobile IPv4 Regional Registration", IETF Internet draft, draft-ietf-mip4-reg-tunnel-00.txt, November 2004.

[10] H. Soliman, C. Castelluccia, K. El Malki, L. Bellier, "Hierarchical Mobile IPv6 Mobility Management (HMIPv6)", IETF Internet draft, draft-ietf-mipshop-hmipv6-04.txt, December 2004.

[11] A. A. Misra, S. Das, A. Mcauley, A. Dutta and S. K. Das, "IDMP-Based Fast Handoffs and Paging in IP-Based 4G Mobile Networks", IEEE Communications, vol. 40, pp. 138-145, March 2002.

[12] S. Das, A. McAuley, A. Dutta, A. Misra, K. Chakraborty, S. K. Das, "IDMP: An Intradomain Mobility Management Protocol for Next-Generation Wireless Networks", IEEE Wireless Communications, June 2002, pp.38-45.

[13] S. Das, A. McAuley, A. Dutta, A. Misra, S. K. Das, "IDMP-Based Fast Handoffs and Paging in IP-Based 4G Mobile Networks", IEEE Communication Magazine, March 2002, pp. 138-145.

[14] S. Das, A. Misra, P. Agrawal, S. K. Das, "TeleMIP: Telecommunications-Enhanced Mobile IP Architecture for Fast Intradomain Mobility", IEEE Personal Communications, August 2000, pp. 50-58.

[15] A. T. Campbell, J. Gomez, and A. Valko, "An overview of cellular IP," in IEEE Wireless Communications and Networking Conf. (WCNC), Sept. 1999, pp. 606–611.

[16] A. G. Valko, "Cellular IP: A New Approach to Internet Host Mobility", Comp. Commun. Review, vol. 29, no. 1, January 1999, pp. 50-65.

[17] R. Ramjee, K. Varadhan, L. Salgarelli, S. R. Thuel, S. Y. Wang, T. La Porta, "HAWAII: A Domain-Based Approach for Supporting Mobility in Wide-Area Wireless Networks", IEEE/ACM Transactions on Networking, Vol. 10, No. 3, June 2002, pp. 396-410.

[18] Q. Wang, M. A. Abu-Rgheff, A. Akram, "Design and Evaluation of an Integrated Mobile IP and SIP Framework for Advanced Handoff Management", IEEE Communication Society 2004, pp. 3921-3925.

[19] Q. Wang, M. A. Abu-Rgheff, "Integrated Mobile IP and SIP approach for Advanced Location Management", London Communications Symposium, 2002.

[20] A. Peddemors, H. Zandbelt, M. Bargh, "A Mechanism for host Mobility Management supporting Application Awareness", MobiSys '04, pp. 231-244.

[21] L. Patanapongpibul, G. Mapp, "A Client-based Handoff Mechanism for Mobile IPv6 Wireless Networks", in Proceedings of the Eighth IEEE International Symposium on Computers and Communication (ISCC), June 2003, pp. 563–568.

[22] M. G. Choi, Y. Xu, "A New Multimedia Network Architecture Using 3G CDMA2000", IEEE VTC 2000, pp 2937-2944.

[23] F. Chiussi, D. A. Khotimsky, S. Krishnan, "Mobility Management in Third-Generation All-IP Networks", IEEE Communications Magazine, September 2002, pp. 124-135.

[24] A. Rajkumar, P. Feder, S. Benno, T. Janiszewski, "Seamless SIP-Based VoIP in Disparate Wireless Systems and Networks", Bell Labs Technical Journal, Volume 9, Issue 1, May 2004, pp. 65-82.

[25] N. Nakajima, A. Dutta, S. Das, H. Schulzrinne, "Handoff Delay Analysis and Measurement for SIP based mobility in IPv6", International Conference on Computers and Communications, IEEE, 2003.

[26] Q. Wang, M. A. Abu-Rgheff, 2003, "Next-generation mobility support", IEEE Communications Engineer, February 2003, pp. 16-19

[27] J. Z. Sun, J. Sauvola, "Mobility and Mobility Management: A Conceptual Framework", in Proc. 10th IEEE International Conference on Networks, Singapore 2002, pp. 205– 210.

[28] C. E. Perkins, "Mobile Networking Through Mobile IP", IEEE Internet Computing 1998, pp. 58-69.

[29] S. Uskela, "Mobility Management in Mobile Internet", 3G Mobile Communication Technologies 2002, pp. 91-95.

[30] Y. B. Lin, H. C. H. Rao, I. Chlamtac, "General Packet Radio Service (GPRS): architecture, interfaces, and deployment", Wireless Communications and Mobile Computing 2001, pp. 77-92.

[31] B. Sarikaya, "Packet Mode in Wireless Networks: Overview of Transition to Third Generation", IEEE Communication Magazine, September 2000.

[32] S. M. Faccin, P. Lalwaney, B. Patil, "IP Multimedia Services: Analysis of Mobile IP and SIP Interactions in 3G Networks", IEEE Communications Magazine, January 2004.

[33] N. C. Lobley, "GSM to UMTS-architecture evolution to support multimedia", BT Technology Journal, Vol 19, n. 1, January 2001.

[34] P. J. McCann, T. Hiller, "An Internet Infrastructure for Cellular CDMA Networks Using Mobilr IP", IEEE Personal Communications, August 2000.

[35] J. McNair, I. F. Akyildiz, M. D. Bender, “Handoffs for Real-Time Traffic in Mobile IP Version 6 Networks”, Global Telecommunications Conference, 2001, GLOBECOM '01. IEEE, Vol 6, pp. 3463-3467.

[36] A. Dutta, F. Vakil, J. C. Chen, M. Tauil, S. Baba, N. Nakajima, H. Schulzrinne, “Application Layer Mobility Management Scheme for Wireless Internet”, 3G Wireless, 2001.

[37] P. Y. Hsieh, A. Dutta, H. Schulzrinne, “Application Layer Mobility Proxy for Real-time Communication”, World Wireless Congress, 3G Wireless (San Francisco), Delson, 2003.

[38] T. Dreibholz, A. Jungmaier, M. Tuxen, “A New Scheme for IP-based Internet-Mobility”, in Proceedings of the 28th Annual IEEE International Conference on Local Computer Networks (LCN’03).

[39] M. Ratola, “Which Layer for Mobility? - Comparing Mobile IPv6, HIP and SCTP”, HUT T-110.551 Seminar on Internetworking Sjökulla, 2004.

List of Initials and Acronyms

AAA Autentication, Autorizzation, Accounting

ADDIP Dynamic Address Reconfiguration

BA Binding Acknowledgement

BU Binding Update

CN Correspondent Node

CoA Care-Of Address

DCoA Domain CoA

DR Domain Router

DRR Domain Root Router

FA Foreign Agent

GFA Gateway Foreign Agent

GSM Global System for Mobile telecommunication

GW Gateway

HA Home Agent

HAP Home Anchor Point

HAWAII Handoff-Aware Wireless Access Internet Infrastructure

HLR Home Location Register

HMIP Hierarchical Mobile IP

IDMP Intra-Domain Mobility Management Protocol

IETF Internet Engineering Task Force

IMSI International Mobile Subsriber Identity

MA Mobility Agent

MAP Mobility Anchor Point

MIPv4 Mobile IPv4

MIPv6 Mobile IPv6

MS Mobile Station

MSC Mobile services Switching Center

M-SCTP Mobile SCTP

MSISDN Mobile Station ISDN

MSRN Mobile Station Roaming Number

PA Paging Area

PC Paging Cache

QoS Quality of Service

RC Routine Cache

RFA Regional Foreign Agent

SA Subnet Agent

SCTP strema Control Transmission Protocol

SIP Session Initiation Protocol

SR Subnet Router

SW Switch

TCoA Throughway CoA

TCP Transmission Control Protocol

TeleMIP Telecommunications-Enhanced Mobile IP

UDP User Data Protocol

VLR Visitor Location Register

WLAN Wireless LAN