A Comparison of **IP** mobility protocols

Pierre Reinbold and Olivier Bonaventure

Abstract—**This paper presents a detailed comparison, in a comprehensive framework, of Mobile IP and four of the main IP Micro-mobility protocols. We first describe the global mobility landscape and point out the important problems that must be addressed. These are mainly Handoff management, Passive Connectivity and Paging support, Scalability, Robustness, Quality of Service and Security. Based on this framework, we examine in a first step Mobile IP as a Macro-mobility protocol. In a second step, we compare four well-known IP Micro-mobility protocols: Cellular IP, HAWAII, TeleMIP and EMA.**

Keywords— **Mobile IP, Wireless networks, Cellular IP, Hawaii, EMA, TeleMIP**

Introduction

BROADBAND WIRELESS NETWORKS are quickly evolving towards all-**IP** networks. Intensive research is currently carried out to enhance **IP** to allow these networks to re-use the well-known **IP** mechanisms. In this process, many proposals have been made to enrich **IP** with the functionalities necessary to manage the mobility of users.

The most widely known of these proposals is certainly **Mobile IP** [1] which is also the oldest one. **Mobile IP** offers a mechanism allowing users to change their point of attachment in an **IP** network. Unfortunately, this protocol suffers for many weaknesses and that is the reason why the mobility problem is often divided in two parts: macro-mobility and micro-mobility. The distinction between the two depends on the scale of stations movements. The **Mobile IP** properties allow it to be used as macro-mobility management protocol.

Micro-mobility covers the management of users movements at a local level, inside a given wireless network. Many solutions have been proposed to manage this type of mobility within **IP** networks, they are often called **IP** Micro-mobility protocols. Sometimes designed for very specific issues, their heterogenous characteristics and properties do not allow to easily obtain an accurate picture of the **IP** mobility management problems.

This paper presents a detailed comparison, in a comprehensive framework, of **Mobile IP** and four of the main **IP** Micro-mobility protocols. We first describe the global mobility landscape and point out the important problems that must be addressed. Based on this framework, we examine in a first step **Mobile IP** as a Macro-mobility protocol. In a second step, we compare four well-known **IP** Micro-mobility protocols: **Cellular IP** [2], **HAWAII** [3], [4], **TeleMIP** [5] and **EMA** [6], [7].

Finally, we present our conclusions.

Due to size limitations, we cannot address all the issues in this paper. A more detailed comparison is available in [8].

I. A global **IP** mobility framework

This section will focus on the presentation of a global mobility landscape and the major issues for **IP** mobility to be investigated within this landscape.

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A. *The mobility landscape*

This paper deals with *all-**IP*** networks. These are the expected future mobile wireless networks, relying entirely on **IP**: from the mobile station to the gateway towards the Internet.

We call a *domain* a large wireless access network under a single administration authority. Such a network is composed of two kinds of machines. We call *base station* (**BS**) an equipment able to communicate directly with the mobile nodes via the radio interface. In the case of a **CDMA** based network, the so-called *Radio Access Network* (**RAN**) [1] can be seen as a single **BS** since the mobility inside the **RAN** is managed at the radio layer and is transparent to upper layers. We simply call *station* any other network machine. A station performing special tasks in the mobility management will be named *Mobility Agent* (**MA**).

We also assume that each **MN** has a *Home Network* (**HN**), a domain from which it has obtained a static[2] **IP** address: its *Home Address* (**HA**). We call *Foreign Network* (**FN**) any other domain where the **MN** can connect.

In such a context, we can reasonably propose a model of what will be the future mobility landscape, this is illustrated in figure 1.

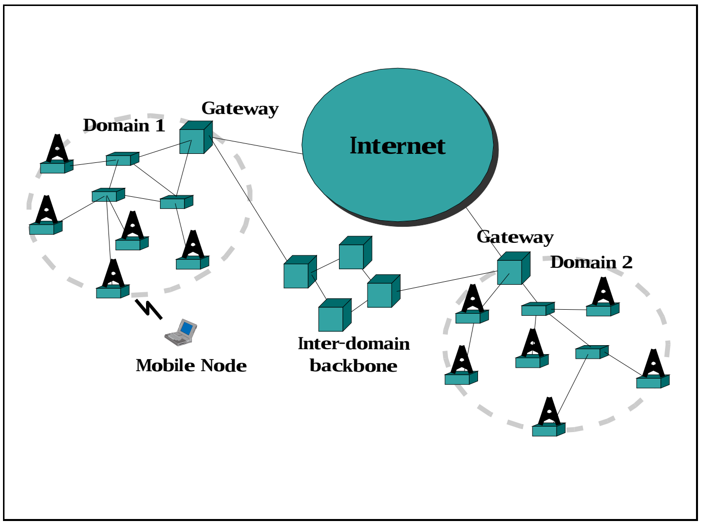

Figure 1: *Expected mobility landscape model*

B. *Major mobility issues*

We define now three major issues for the mobility management in our mobility landscape. These will be the basis for our comparison.

- **Handover management :** The handover concerns the management of the changes of point of attachment of the mobiles during their moves. This can be seen from a macro-mobility

[1] a group of transceivers under the control of a dedicated station (the *Base Station Controller*)

[2] Static meaning that the address validity is very much longer than the duration of a mobile movement.

point of view (the **MN** changes of network or subnet) or a micro-mobility point of view (the **MN** changes of *base station*). The handover management is obviously a major issue in mobility management since a **MN** can trigger several handovers during a single session as in current **GSM** networks.

- **Passive connectivity and paging :** The mobiles have very limited power capacity. Hence, their batteries must thus be spared by reducing the mobile transmissions, it is a common problem in classical mobile telephony. An ideal solution would be that the **MN** transmits nothing except when actively connected to the network (when in *active state*). But in order to allow the network to forward efficiently the incoming packets destined for it, a **MN** must periodically transmit a beacon packet to inform the network of its current location. This must be done even when not in active state and can be very power consuming. A standard solution adopted in **GSM** networks is to divide the network in geographical areas called *paging areas*. In the *idle state* (not active), the mobile transmits a beacon only when changing of paging area. this implies that the network only knows its approximative location (its current paging area). An incoming packet destined for an idle mobile triggers the network to perform a *paging* (a mechanism to find the exact location of this **MN** within its paging area) in order to deliver it.

We will also investigate some other less important topics such as support for Quality of Service and local traffic management inside a domain.

The comparison will be made with respect to these topics on the base of *performance criteria* such as , *robustness* and *scalability*.

C. *Mobile IP and the micro-mobility*

In order to introduce the comparison, we present here a quick review of **Mobile IP** and its majors drawbacks which has led to the definition of the micro-mobility approach. It implies the division of the mobility management into two different parts: mobility management at a large scale, between the different domains (macro-mobility), and, on the other hand, at a local scale, inside these domains (micro-mobility). Each type of mobility is then managed by specific mechanisms and protocols. This approach has many advantages shared by all the micro-mobility protocols.

C.1 **Mobile IP**

Mobile IP is the oldest and probably the the most widely known mobility management proposal within **IP**. It's simplicity and scalability give it a growing success within the **IETF** and it is now the matter of a entire working group. **Mobile IP** is described in a **IETF RFC**: **RFC**2002 [1]. All the related protocols are described in **RFC**2003 to **RFC**2006 [9], [10], [11], [12]. Several Internet drafts are currently published to proposed various improvement for **Mobile IP** and its counterpart designed for **IP**v6, **Mobile IP**v6 [13]. Its basic principle is that **Mobile IP** uses a *couple* of addresses to manage user's movements. Each time the **MN** connects to a foreign network, it obtains a temporary address called *Care-of-Address* (**COA**) from a **MA** in the local network called the *foreign agent* (**FA**). This address remains valid only while the **MN** stays connected to this network. The **MN** must inform its **HA** of this new address by the *registration process*. When the **HA** knows the **MN**'s current **FA**, it is able to re-tunnel towards the mobile the packets destined for it. Indeed, these packets, normally routed, will obviously arrive at the **HN** where the **HA** will intercept and encapsulate them towards the **FA**. On the basis of this principle, the **Mobile IP IETF** working group has defined several improvements and optimizations [14].

C.2 The micro-mobility problems

Mobile IP suffers from several well-known weaknesses that have led to the definition of the macro/micro-mobility architecture. In this section, we review some of these weaknesses to show the advantages of this paradigm and introduce the comparison by pointing out several important properties shared by all micro-mobility proposals.

- **latency and control traffic :** in **Mobile IP**, the basic mobility management procedure is the registration to the **HA** each time the mobile changes of network. This process can take a very long time in the today's Internet and even been impossible to achieve. In the case of a quickly moving mobile which rapidly changes of network, the registration process will become totally inefficient. Moreover, this mechanism produce a lot of control traffic.
The micro-mobility approach seems to be a good solution to this problem. The **MN** obtains a local **COA** when it connects to a domain. This **COA** remains valid while it stays in this domain and the mobile will thus make only one registration at the moment it connects to the domain. The users movements inside the domain are managed by a micro-mobility protocol inside the domain and transparent to the **HA** and the rest of the Internet. Latency and control traffic across the whole network are thus extremely reduced.
- **Address space : Mobile IP** requires the availability of an entire pool of valid addresses to serve as **COA** in each domain. Unfortunately, the **IPv4** address space has now reached its limits and the fast grow of the Internet requires a large amount of **IP** addresses. This has partly led to the definition of **IPv6** which should resolve the problem by using 128 bits addresses but its deployment is very slow and we can expect that **IPv4** will remain used for many years.
The use of a micro-mobility protocol is transparent to the network outside a domain and can thus be done with a set of private addresses which represents an economic and realistic solution to this problem.
- **Quality of Service :** frequent changes of point of attachment and of **COA** make difficult to support Quality of Service for mobile users. With **RSVP**, for example, the reservations must be done again each time the **MN** changes of **COA**, along the entire path, even if the largest part of this path is unchanged! This process implies a heavy load in terms of control traffic and introduces additional delays incompatible with the Quality of Service support.
With a micro-mobility protocol, the network is not aware of the movements of the users inside a particular domain. The reservation are thus to be done again only when the mobile changes of domain. This is only possible if the micro-mobility protocol support the use of **RSVP** or other **QoS** mechanisms.

II. Short description of the different protocols

This section presents a short description of the basic principles of the different micro-mobility proposals. **Mobile IP** is not assumed to be a micro-mobility proposal but constitutes a general framework since the other proposals assumes it as macro-mobility management protocol.

A. *Cellular IP*

Cellular IP [2], [15], [16] is a micro-mobility protocol relying on **Mobile IP** for the macro-mobility management. A very specialized **MA** acts as a gateway towards the Internet and as a **Mobile IP FA**. **Cellular IP** aims to replace **IP** inside the wireless access network. **Cellular IP** routing is based on routes established and updated by the **MN** during its connection to the network. All these routes bind a mobile connected to the network and the gateway. Each station maintains a *routing cache* that allows it to forward packets from the gateway to the **MN** or from the **MN** to the gateway. The routes are established and maintained by the hop-by-hop transmission of special control packets that trigger the stations on the path to update their routing cache. A beacon is periodically sent by the gateway and floods the network. This mechanism allows each station to know which of its interfaces must be used to forward packets towards the gateway: it is the one from which the beacon was received. On the other hand, the **MN** sends *route update packets* when it connects to the network and each time it changes of point of attachment (handover). These packets, forwarded hop-by-hop towards the gateway trigger the stations on their paths to update their routing cache for the concerned **MN**. The handover is managed by two different mechanisms: hard handoff and semi-soft handoff. The hard handoff provides no guarantees while the semi-soft handoff ensures that the packet losses will be very reduced. Moreover, **Cellular IP** presents a native support for the passive connectivity with a classical paging mechanism: some stations maintain *paging caches* that are used in case of paging requests.

B. *HAWAII*

Like **Cellular IP**, **HAWAII**[3], [4] is a micro-mobility protocol relying on **Mobile IP** for the macro-mobility but, unlike **Cellular IP**, **HAWAII** does not replace **IP** but works above **IP**. Each station in the network must thus act as a classical **IP** router but also have specific **HAWAII** features. The basic working of **HAWAII** is very similar to the **Cellular IP** principles. Each station maintains a routing cache to manage the mobility. The hop-by-hop transmission of special packets on the network triggers the stations to updates their caches. As in **Cellular IP**, the network is supposed to be organized as a tree and a single gateway is located at the root of this tree. **HAWAII** defines two different handover mechanisms adapted to different radio access technologies. These two mechanisms present different properties and can be chosen to optimize the network with respect to packets losses, handoff latency or packet reordering. Like **Cellular IP**, **HAWAII** supports the passive connectivity with a paging mechanism. The geographic paging areas are composed of stations belonging to the same **IP** multicast group. The paging messages are thus transferred to the stations by using the classical multicast mechanisms of **IP**. To support efficiently Quality of Service, **HAWAII** defines a native integration of **RSVP** adapted to the user's mobility. In a natural way, **HAWAII** ensures that the resource reservations due to path changes will be reduce. At handoff, assuming that the **MN** is a receiver, nothing will be made in the unchanged part of the path [3] and the network will make a reservation only on the changed part of the path (roughly the path from the cross-over router to the new base station currently serving the **MN**). This is possible with **HAWAII** for two reasons:

- the **COA** of the **MN** remains unchanged as long as the mobile stays in the same domain,
- **HAWAII** is working over **IP**; this allows the deployment of **RSVP** in **HAWAII** networks.

C. *TeleMIP*

TeleMIP [5] is a very simple protocol, well adapted to **CDMA** networks with **RAN**. **TeleMIP** relies on **Mobile IP** for the macro-mobility management and defines a new type of mobility agent: the **TeleMIP** Mobility Agent (**TMA**). The **TeleMIP** network is composed of a set of subnets and a set of **TMA** machines. Each subnet has a central machine acting as a **Mobile IP FA** and several *base station*s are directly connected to it[4]. The different **FA** are connected to one or more **TMA** of the wireless domain. When a mobile connects to the network, it connects to a subnet and obtains *two* temporary addresses from the local **FA**: its local **COA**, which remains valid as long as the mobile stays in the domain, and a temporary address only valid for the time it stays connected to the stations *of this subnets*. The first of these addresses is registered to a **TMA** of the network [5] and this **TMA** will act as gateway and **Mobile IP FA** to the global Internet *for this mobile*. Each time the mobile changes of subnet, it obtains only a new local address from the new **FA** which will warn the **TMA** of the new location of the **MN**. On this basis, the working of **TeleMIP** is very simple. When an incoming packet arrives for a mobile located in the domain, its destination address is the **COA** of this mobile. The concerned **TMA** intercepts it and forwards it to the **FA** of the subnet where the mobile is currently connected. On the basis of a mapping between **COA** and local addresses, the **FA** can finally deliver the packet to its destination.

D. *EMA*

EMA [6], [7] aims to define a generic framework for the mobility management within a wireless domain. The authors discuss the possibility of using the **TORA** [17], [18] ad-hoc network routing protocol with **EMA**. This choice seems to ensure a good scalability to the system while the **EMA** architecture allows to adapt **TORA** to the management of standard wireless access network which have specific properties with respect to ad-hoc networks. Without any assumption on the radio access technology, **EMA** defines a handover mechanism completely transparent to the upper layers. **EMA** aims to allow two types of routing: prefix routing (as in classical wired **IP** networks) and

[3] The latter being hopefully the main part of the path since handoff is managed locally.

[4] so a subnet can be seen as **CDMA RAN**.

[5] The **FA** can choose this **TMA** on the base of load balancing algorithms.

host specific routing. When its connects to the **EMA** domain, the mobile obtains a **COA** from to the local subnet. In such a way, the traffic destined for this mobile can be routed based on its prefix while it remains in the subnet. When the **MN** changes of subnet, specific routes are injected in the network to reach it. **TORA** is very well adapted to work this way.

III. A COMPARISON OF IP MOBILITY PROTOCOLS

In this section, we review the different micro-mobility proposals and compare them with respect to the context described in the previous section.

A. Handoff

We investigate the handoff management on the base of the simple network model shown in figure 2with respect to three parameters:

- **handoff latency:** the time needed to complete the handoff inside the network,
- **packet losses:** the amount of possibly lost packets due to the handoff process,
- **updates:** the amount of updates to be processed by the network stations to perform the handoff.

We assume here that n_{gate} is the average hop distance between a **MN** and the gateway. The delay between these two hosts is $t_{gate}\, msec$. Similarly, n_{prev} is the number of hops between a **MN** and its previous *base station* (delay: $t_{prev}\, msec$). t_{cross} is the average delay in $msec$ between the **MN** and the so-called *crossover base station* for a given handoff value.

In general, we can assume that $t_{gate} \geqslant t_{prev} \geqslant t_{cross}$. We call n_{TORA} the average number of updates required in a **TORA** network for routing to converge after a modification (this number depends on the network topology [17]). We assume that this convergence is done in $t_{\text{TORA}} msec$. t_{HA} is the average time needed to reach the **HA** in classical **Mobile IP** registration mechanism. τ is the mean throughput for a **MN**.

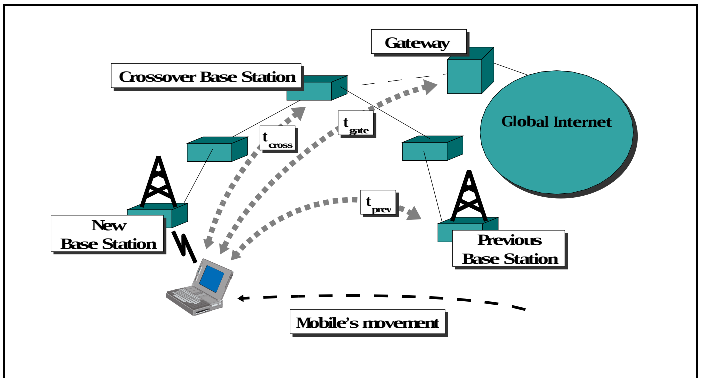

Figure 2: *A simple model for handoff parameter comparison*

With **Cellular IP**, the handoff mechanism triggers the **MN** to generate a packet that is forwarded hop-by-hop towards the gateway which must acknowledge it. The latency is thus $2t_{gate}$ (time to reach the gateway and to receive its acknowledgment) with n_{gate} updates in the network stations (in each station on the path to the gateway). We can expect that no loss will occur with semi-soft handoff since the **MN** waits to receive the packets from the both *base station*s before effectively triggering the handover [6]. Hard handoff generates τt_{cross} losses since packets are lost from the moment the mobile changes of station to moment the route update message reaches the crossover *base station*.

HAWAII handoff mechanisms are both exchanges between the old and the new *base station*s. Their total latency is thus $2t_{prev}$. The forwarding scheme generates τt_{prev} losses since packets are lost until the update message reaches the old *base station*. 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 **HAWAII**, only the stations on the path between the two concerned *base station*s perform a routing update. This very "local" handoff management generates thus n_{prev} updates in the network.

TeleMIP handoff mechanisms simply consist in sending an update message to the **TMA** in the case of an handoff between subnets and performing a classical **Mobile IP** registration in the case of an handoff between **TMA**[7]. We assume here that the **TMA** is as far from the **MN** as the gateway. The handoff latency is thus $2t_{gate}$ or $2t_{HA}$ since updates messages must be acknowledged. In the case of the subnet handoff, the losses only occur during the time needed to reach the **TMA**: τt_{gate}. In the case of a change of **TMA**, the packets are lost until the **HA** is reached: τt_{HA}.

From a theoretical point of view, **EMA** defines mechanisms sufficient to avoid packet losses if the handoff can be anticipated (as it will be the case in **CDMA** networks). The handoff latency is the time needed to perform the three way handshake followed by the network routing convergence time. Indeed, **TORA** will build new routes to the **MN** each time it changes its point of attachment since the three way handshake is finished when the **MN** injects its new **TORA** height in the network. Many stations will be aware of the handoff and perform routing updates in addition to that located between the concerned *base station* and the **MN** itself.

The table I summarizes this discussion.

TABLE I

COMPARATIVE CHART FOR HANDOFF PARAMETERS

Protocol	**Handoff type**	**Latency**	**Losses**	**Updates**
Cellular IP	semi-soft handoff	$2t_{gate}$	0	n_{gate}
	hard handoff	$2t_{gate}$	τt_{cross}	n_{gate}
HAWAII	forwarding scheme	$2t_{prev}$	τt_{prev}	n_{prev}
	non-forwarding scheme	$2t_{prev}$	τt_{cross}	n_{prev}
TeleMIP	between subnets	$2t_{gate}$	τt_{gate}	2 **(TMA, FA)**
	between **TMA**	$2t_{HA}$	τt_{HA}	3 **(TMA, FA, HA)**
EMA (using soft-state tunnels)	Make Before Break	$3t_{prev} + t_{\text{TORA}}$	0	$n_{prev} + n_{\text{TORA}}$
	Break Before Make	$3t_{prev} + t_{\text{TORA}}$	0	$n_{prev} + n_{\text{TORA}}$

[6] Assuming that the delay device defined in **Cellular IP** is efficient

[7] when the new **FA** is not connected to the current **TMA**.

B. Passive connectivity and Paging

Only two proposals include explicitly the support for these features: **Cellular IP** and **HAWAII**. It seems to be ignored by **TeleMIP** and **EMA**. **Cellular IP** and **HAWAII** use the classical cellular telephony concepts of *location area* and *paging*. As in **GSM** networks, the stations are grouped in *paging areas* and a router must perform a *paging* to find the actual location of the **MN** in the network (*i.e.* its current point of attachment).

A major difference between **Cellular IP** and **HAWAII** is the paging algorithm. In **Cellular IP**, the arrival of a packet destined for an idle **MN** triggers the paging from the gateway. This paging request is propagated inside the network by stations with *paging caches* in charge of the concerned paging area. The stations that are to perform the paging requests are thus defined by the network manager and only these machines will maintain paging information. **HAWAII** defines an algorithm to dynamically balance the load of paging among the stations of the network. Based on the current load of each router, a particular station is chosen to perform the paging each time it is needed. The paging information is thus distributed throughout the network to ensure that any station can perform a paging.

C. Intra-network traffic

In this section we focus on the traffic between the **MN**s connected to the same wireless network. This kind of communication is a large part of today's **GSM** communication and we can expect that it will remain an important class of traffic in future wireless networks. The effective support of this type of traffic seems thus an important concern.

With **Cellular IP** all the traffic coming from a **MN** *must* pass through the gateway, even if the **MN** is communicating with another host in the same wireless network! Far from an optimal path, this kind of routing increases unduly the processing load of the gateway and the neighboring stations. **HAWAII** works over **IP** and this traffic will hopefully benefit from classical routing. **TORA** allows **EMA** networks to forward in an efficient way this traffic to the concerned hosts if the network implements all the **TORA** features[8]. In the case of **TeleMIP**, all the traffic coming from a **MN** must pass through the **MA** currently serving this **MN**. Except for very simple topologies, this can have the same effects as the **Cellular IP** routing.

D. Scalability and robustness

Current **GSM** networks support millions of connected users communicating at the same time. We can expect that future large wireless access networks will have the same constrains in terms of users load. The **CISCO** 7206 **GPRS** router acting as **GGSN** is able to manage 90,000 simultaneous user contexts [19]. These facts are to be related to the increasing load of today's Internet routers: routing tables containing a few hundreds of thousands entries have become a critical management problem.

Cellular IP and **HAWAII** use a tree-like architecture within the wireless access network. A dedicated machine acts as a gateway[9] and is the root of this structure. All routing/paging updates arrive to it[10]. A direct consequence is that the closer to the gateway a station is, the more loaded it is. This increasing load is due to traffic processing and soft table handling in memory. The gateway is thus the more loaded station in the network, processing *all* updates and maintaining tables entries for *all* the **MN**s within the network! This table may thus contain millions of entries, making its handling by a single machine almost impossible. **Cellular IP** defines stations working with advanced layer two switch capabilities, **HAWAII** assumes classical **IP** routers with extended features. **HAWAII** stations must hence act as **IP** routers (including maintaining a routing table and actually routing the traffic) in addition to the management of the mobility. Finally, in the case of semi-soft handoff, **Cellular IP** base stations must support delay device mechanisms. Such devices can be difficult to implement efficiently and, with this last feature, **Cellular IP** *base station*s become actually closer to routers than switches.

These architectures are weak since they rely on specific routers such as the gateway and the surrounding stations. In the case of **Cellular IP**, the paging mechanism aggravates this weakness since only a few stations maintain the paging information, making the network extremely vulnerable to a crash of these stations. **HAWAII** distributes the paging information inside the network and assigns dynamically the paging processing. This increases its robustness in comparison to **Cellular IP** but at the cost of a far greater load on the routers memory. Furthermore, **Cellular IP** basically manages link failure or station crash with two kinds of refresh mechanisms: the beacon periodically transmitted by the gateway and the routing refreshes sent by the **MN**. On the other hand, **HAWAII** works *over* **IP** and benefits from the existing **IP** recovery mechanisms.

TeleMIP does not define exactly a routing system but the multiplicity of **TMA** and their interaction with the **FA** allows to distribute the load across the network so that each machine maintains a reduced forwarding table only. With very simple topologies, the **TMA** and **FA** can act as advanced switches and remain quite simple. On the other hand, **TeleMIP** does not define anything if the network becomes more complex than a set of wireless radio networks directly connected to the different **TMA**s.

EMA relies on **TORA** to manage the mobility but aims also at providing a classical prefix-based routing by establishing both subnet and destination specific routes. This seems to be a good compromise with respect to the size of the tables in each station. However, **TORA** is designed to be an ad-hoc network protocol and provides more than one route to each destination. Each node situated on a route towards a given host must maintain information about this route (its "height" with respect to this destination). In large networks, the route multiplicity may become a problem because many nodes will maintain redundant informations about **MN**s or subnets. Moreover, this information will mainly be useless since the greatest part of the network is *fixed and wired* in contrast with ad-hoc wireless network where the availability of more than one route is an extremely valuable feature. On this basis, the tables to be maintained within each sta-

[8] That is the assumption we have made in this report but the **EMA** draft is not very clear about this…

[9] the *Gateway* with **Cellular IP** and the *Domain Root Router* with **HAWAII**

[10] **HAWAII** seems to be slightly better than **Cellular IP** since handoff is treated locally. With **Cellular IP** a route update is sent hop-by-hop to the gateway at each handoff!

TABLE II

COMPARATIVE CHART FOR THE DIFFERENT STATIONS REQUIREMENTS

Protocol	Type of station	Tables sizes (worst case)	Load balancing
Cellular IP	Advanced switch with paging functions and delay device	At the gateway, one entry for each **MN** currently connected to the network	no, tree structure more loaded around the root (the gateway)
HAWAII	**IP** router with mobility functionalities	Similar to **Mobile IP**	yes
TeleMIP	Advanced switch with mobility capabilities (**FA** and **TMA**)	At a **TMA**, one entry for each **MN** it serves currently	yes, between the different **TMA**
EMA	Ad-hoc router	Same as **Cellular IP** with redundant routing informations within all stations	yes, all the informations are distributed and duplicated

tion may become bigger than with other proposals (especially at the gateways) and most of this load will be unnecessary because of the specificity of the wireless access network.

The table II summarizes the different stations requirements for each protocol.

CONCLUSION

We can easily see, at the end of this comparison, that all proposals have their strengths and weaknesses with respect to the important points described in our framework. We can now make some conclusions on the micro-mobility management from a more general point of view. We make then some general concluding remarks.

First of all, the handover management will obviously remain the most important point for the micro-mobility. It must be fast, efficient and affect only the very concerned stations. The control traffic must be reduced. The passive connectivity is extremely valuable unless the mobile devices have infinite capacity battery. The paging is an improved and very efficient solution to this problem. A micro-mobility proposal must thus include a paging support. The future broadband wireless networks are expected to support millions of customers. Robustness and scalability will be a major concern for such networks. The micro-mobility proposals must be capable to handle such a load with appropriate mechanisms. Finally, the traffic between two mobiles *inside* the same domain constitutes today an important part of the wireless communications. This traffic must be efficiently supported by the micro-mobility proposals. All these features must be optimized to preserve the costly bandwidth of the radio interface but also of the wired part of the wireless domain.

One of the biggest remaining question is the "technological integration". The radio interface is now clearly oriented towards **CDMA** and its variants. But the research is intensive and **CDMA** seems to be able to provide many more services at layer two than those expected initially. The services that this layer will provide are thus still to be defined and it is clear that we can not conceive the upper layer (**IP**) without taking these services capabilities in account. **GPRS** is being deployed by mobile operators and **UMTS**, which is its natural continuation, will soon arrive on the market. Future all-**IP** wireless networks will be evolutions of these systems. Their architecture must be defined in that way. Finally, it is now clear that the lack of numerical data and realistic simulations is a major weakness of the current Micro-mobility approaches. It is important to be able to evaluate these proposals in a standard and realistic network model with intensive simulations. To our knowledge, such analysis has not yet been done.

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