A Framework for the Evaluation of IP Mobility Protocols

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ABSTRACT

In this paper we suggest a classification scheme for IP mobility protocols and propose a framework for comparing them. We then use the framework to provide an initial comparison of recent proposals for supporting micro-mobility. The authors are part of Project BRAIN (Broadband Radio Access for IP based Networks) – a European collaborative project under the IST (Information Societies Technology) programme. One aim of the project is to propose an open architecture for wireless broadband Internet access, concentrating on issues in the access network.

1. INTRODUCTION

The interest of this paper is host mobility (also known as terminal mobility) in an IP network.

The principal problem that mobility presents to a network is:- when a mobile host[1] (MH) moves onto a new base station (BS), how do we route packets to its new destination? We would like a solution that also (amongst other things) ensures that:-

?? the break in communications during the handover is as short as possible and that no (or only a few) packets are lost. Hence all applications, including real-time ones, will be supported.

?? The overheads from the messaging to achieve the re-routing are as low as possible. Included here is minimising the signalling load and latency, and also the storage and processing requirements at each router.

?? The solution is scalable, eg we can apply it whether we have a small or large number of MHs.

?? The solution is compatible with other Internet protocols, eg it does not interact adversely with Quality of Service (QoS) protocols.

Solutions to the basic mobility problem involve establishing some sort of dynamic mapping between the MH's identifier and its location (ie what the correspondent host (CH) wants to talk to vs. how to route packets through the network between the CH and MH). The best known proposal is Mobile IP (MIP) [1], which solves the problem through using two IP addresses per MH – one acts as its permanent identifier, whilst the other acts as its temporary routable address (termed the Care-of-address, CoA) and the mapping between the two is stored at its Home Agent (HA). However, MIP[2] is a long way from the ideal solution outlined earlier, for example:-

?? Handovers may not be fast and smooth, because the MH must signal its change of CoA to the HA. This may take a long time if the HA is far away, perhaps in a different country.

?? The messaging overhead may be significant particularly if the HA is distant, as this will induce signalling load in the core of the Internet

?? MIP may interact with QoS protocols (DiffServ, IntServ), so making QoS implementation problematic. For example, MIP utilises tunnels and so packet headers – which may contain QoS information – become invisible.

However, MIP is relatively simple and robust and is likely to be ubiquitous. It thus appears to be a good way of handling global mobility and mobility between different operators. Meanwhile, more optimised solutions can be developed for regional[3] mobility. These exploit the significant 'localisation' of a MH's movement - typically, route updates travel to the nearest cross-over router[4] (as opposed to MIP where the HA is informed), thus reducing the signalling load in the core of the network and improving the re-routing latency. Our overall solution therefore consists of MIP, to handle global[5] mobility, bolted on to a specialised regional[6] mobility scheme (Figure 1). The latter are the concern of this paper.

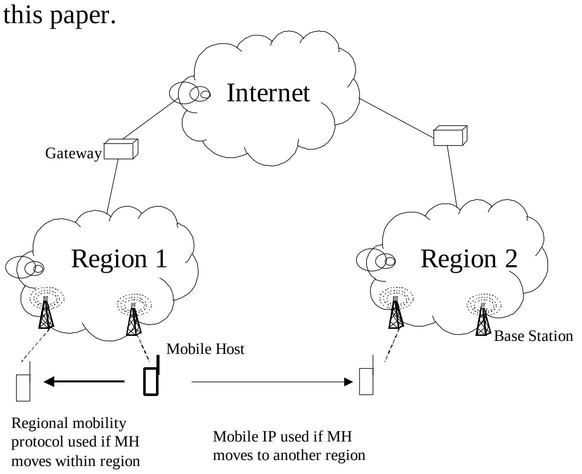

Figure 1: Global vs regional mobility management split

In this paper we compare various regional mobility proposals (**Section 4**). In order to make this analysis more effective, we have developed an Evaluation Framework (**Section 3**) – which formalises the functions a protocol must do and what criteria to use to assess how well it does them. We also believe that the evaluation

[1] also called a mobile terminal or node
[2] Some (but not all) of the problems are reduced by Route Optimisation of Mobile IP; there is not space to discuss it here.
[3] We use the rather vague term 'regional mobility', since an IP regional mobility protocol could (depending on its scalability) be suitable for a single IP domain up to the whole of an Autonomous System.
[4] Ie the last one common to the route from the CH to the old BS and the route from the CH to the new BS.
[5] There are non-Layer 3 solutions for "global" mobility, eg SIP [4], dynamic DNS.
[6] There are also Layer 2 solutions for "local" mobility, eg IAPP, L2TP.

will be more effective if we first classify different IP mobility protocols (**Section 2**), to make more sense of the already very extensive research on IP mobility. The eventual objective of our work in the BRAIN project is to contribute improved IP regional mobility protocols. However, in this paper our main aim is to present our Evaluation Framework. In order to show that the Evaluation Framework can be useful (eg to identify key differences between protocols), we also present a preliminary application of it.

2. CLASSIFICATION OF IP MOBILITY PROTOCOLS

The two major categories of *Regional Mobility* protocols are:

??***Proxy-Agent Architectures (PAA)***
??***Localised Enhanced-Routing Schemes (LERS)***

A Proxy Agents Architecture Schemes (PAA)

These schemes extend the idea of Mobile IP into a hierarchy of Mobility Agents (which are extensions of MIP's Foreign Agents (FAs) and/or HAs). A MH registers with its local Agent ('a') at the bottom level of the hierarchy ("MH is at Care-of-Address (CoA)"), which in turn registers with its nearest Agent at the next hierarchy-level ("MH is at Agent a"), and so on up the hierarchy towards the HA. This way, when the MH changes its CoA, the registration request does not have to travel up to the HA but remains 'regionalised'. Packets from a CH travel down the hierarchy, being tunnelled from one level to the next.

Examples include the initial Hierarchical Mobile IP [5] and its alternatives, which place and interconnect Mobility Agents more efficiently: Mobile IP Regional Registration [6], Transparent Hierarchical Mobility Agents (THEMA) [7], Fast Handoff Methods [8] and Hierarchical Mobile IPv6 [9].

B Localised Enhanced-Routing Schemes (LERS)

These schemes introduce a new, dynamic Layer 3 routing protocol in a 'localised' area. There are several distinctive approaches:

B1 - Per host Forwarding Schemes: Inside a domain, a specialised path set-up protocol is used to install soft-state host-specific forwarding entries for each MH. The domain, which appears as a subnet to routers outside the domain, is connected to the Internet via a special gateway, which must be pointed to by the default gateway of the routers (or packet forwarding nodes) inside the domain. Examples include Cellular IP [11] and Handoff-Aware Wireless Access Internet Infrastructure (HAWAII) [12][13].

B2 - Multicast-based Schemes: Multicast protocols are designed to support point-to-multipoint connections. So they share with IP mobility the same design goals of location independent addressing and routing and thus multicast-based mobility solutions have been proposed. A multicast-CoA is assigned to a single MH which can then be used to instruct neighbouring multicast-enabled routers to join the MH's virtual multicast group, either prior to or during handovers. This can be visualised as a multicast cloud centred on the MH's current location but also covering where it may move to. Examples include Dense mode multicast-based [15][16][17] and the recent Sparse-mode multicast-based [14].

B3 - MANET-based Schemes: MANET protocols were originally designed for Mobile Adhoc NETworks, where both hosts and routers are mobile, ie there is no fixed infrastructure. The routing is multi-hop and adapts as the MHs move and connectivity in the network changes. MANET protocols can be modified for our scenario, where there is a fixed infrastructure and only hosts can be mobile. Currently there is only one proposal in this category: MER-TORA [18].

Figure 2 shows some of the many IP mobility protocols, which category they fall into and very roughly how they relate to each other.

3. EVALUATION FRAMEWORK

In the Introduction, we listed some of the features we would like an IP mobility solution to have. In this Section, we expand on these and break them down into a more formal structure:- an Evaluation Framework. It has two dimensions:

A. Protocol Design Issues – the functional requirements for any IP-mobility protocol
B. Evaluation criteria – against which the effectiveness of a particular Solution to the Issues can be assessed.

In other words, we first decide <u>what</u> things a protocol must be able to do, and then how to assess <u>how well</u> the protocol does them.

A. Protocol Design Issues

Here we list the Protocol Design Issues, along with a short explanation / discussion of each.

Packet Forwarding: Packet forwarding refers to the delivery of packets to and from the MH. In the 'traditional' Internet, this is based on shortest path routing (eg OSPF), where the aggregation of addresses means that routing can be prefix-based. However, this must be modified in order to cope with host mobility. Typically, the solution is based on host routes, with or without tunnelling. Tunnelling presents problems, eg its complicated interaction with some IP QoS protocols.

Path Updates: This refers to the mechanism for installing information in the fixed network so that packets can be successfully forwarded to the MH at its new point of attachment. It can consist of the intelligent transmission of specific *update* messages or the use of modified Mobile IP registration messages.

Handover Management: This Issue looks at the impact of handovers on the MH (whereas the previous Issue took a network-centric view). Handovers should be fast and smooth, ie they should be performed without significant delays and without loss of packets. Also, soft handover may be allowed, ie a MH can simultaneously communicate with more than one BS at a time.

Support for Idle Mobile Hosts: Paging reduces the frequency of refreshments/updates for an idle MH in order to achieve two goals: reduce the protocol overhead (signalling, route lookups and memory requirements) in the network and minimise a MH's power consumption.

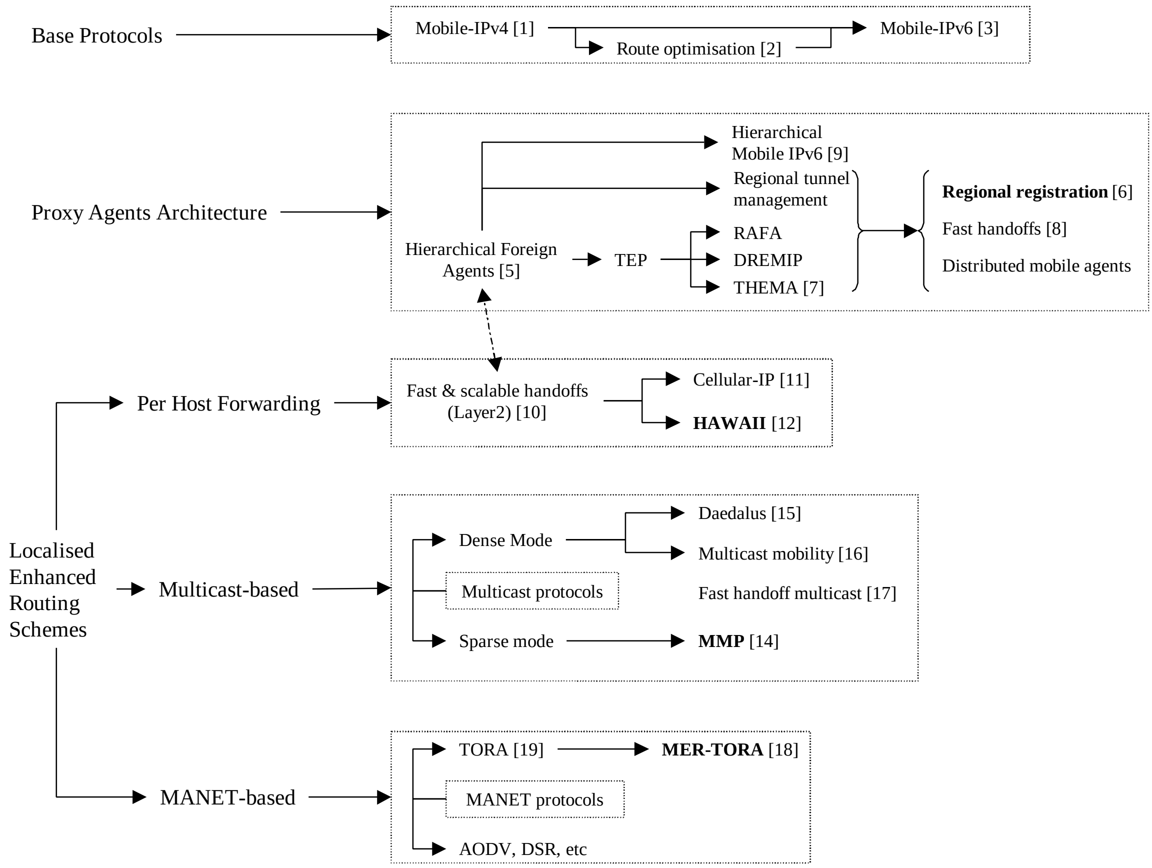

Figure 2: Classification of IP mobility proposals

Requirements for Mobile Hosts: An important decision is to what extent MHs are required to participate in the establishment and updating of the routing structure that enables mobility. A reference example can be Mobile IP where a MH is required to perform minimal operations: registering addresses, detecting movement and refreshing registrations.

Requirements for Core Network Interface: This issue defines the functionality in the gateway router of the access network. The Gateway is the transition point between the global and regional mobility and can include functions such as interworking between regional and global mobility, mapping of addresses, tunnel management, central control of mobility protocol mechanisms.

Address Management: A MH typically has to be provided with an IP address in a visited network. The way this is done can have an important impact on, for example, handover performance, scalability (because IPv4 addresses are a scarce resource), and deployability (private Home Addresses may need to be supported in corporate networks).

Routing Topology: This refers to a general static view of the access network nodes, whilst the other issues above more or less cover dynamic protocol operation. It refers to the arrangement of these nodes (eg whether they must form a tree hierarchy) and their required capabilities (eg whether they can act as normal IP routers and/or BSs). The routing topology has implications on the scalability and robustness of the system, eg robustness may be a problem if the access network hinges on a single gateway node. This Issue also relates to the reaction upon any failure of links or routers.

Security: Mobility, and wireless access in particular, introduce intricate security issues: the user's access to a visited network need to be authorised and the requests for path changes have to be authenticated; the user's privacy should be preserved; the access network's topology should be hidden from MHs; interworking of IPSec is required. The majority of IP-mobility schemes include security features or a framework for their realisation.

B. Evaluation Criteria

In the second part of our Evaluation Framework we identify the evaluation criteria. Initially we have grouped them into 3 broad topics:

a) Efficiency
   ?? minimal packet delays and handover latency
   ?? no significant packet loss, reordering or duplication, eg during a handover
   ?? good throughput
   ?? optimised routing (including MH to MH case)
   ?? small signalling load over wired and wireless links
b) Scalability and robustness
   ?? support of a large number of fast moving MHs
   ?? support of a large number of serving nodes in a domain
   ?? support of a large amount of traffic per MH
   ?? resistance to extreme cases such as link or node failures, ie no single points of failures

?? resistance to errors eg over wireless links
?? resistance to routing loops and race conditions

c) Applicability/Ease of deployment

?? simplicity
?? compatibility with the standard Internet protocols
?? ability to support int-serv/diff-serv QoS protocols
?? ability to support dumb MHs that are Mobile IP compliant
?? ability to adapt to changes in the network topology
?? applicability of the same basic approach to both IPv4 and IPv6

4. INITIAL COMPARISON OF IP-MOBILITY PROPOSALS USING OUR EVALUATION FRAMEWORK

We have made an initial application of our Evaluation Framework to compare the different classes of IP-mobility protocol described in Section 2. We decided it was easier to do this through a representative protocol from each of the different categories (Table 1), rather than to deal abstractly with the general characteristics of each category. The intention is to draw out the strengths and weaknesses of the various approaches, rather than to find the "best" in one particular class. A detailed description of how each of the selected protocols works can be found in the appropriate reference; in this paper we assume that the reader is reasonably familiar with them. Figure 3 outlines how MER-TORA operates.

Table 1: Exemplar protocol for each category

Category	Exemplar protocol
Proxy Agents Architecture	Regional Registration [6]
Per Host Forwarding	HAWAII [12]
Multicast-based	MMP [14]
MANET-based	MER-TORA [18]

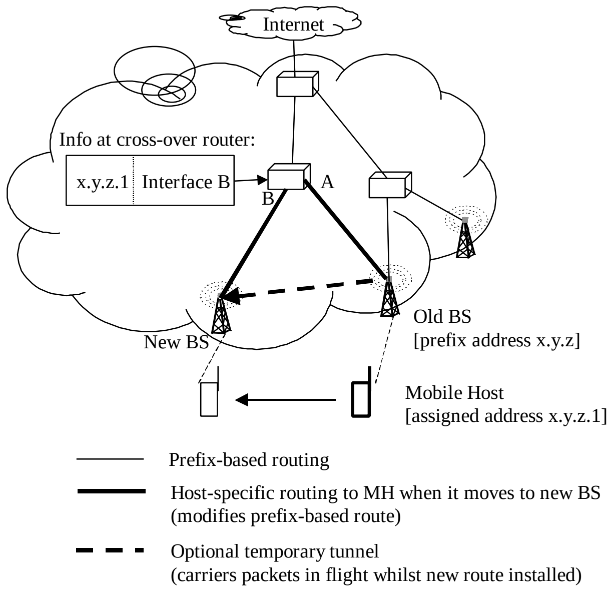

Figure 3: Mobile Enhanced Routed TORA

Table 2 summarises how our representative protocols tackle each Protocol Design Issue. This is followed by a discussion.

Table 2: Summary of how exemplar protocols tackle each Protocol Design Issue

	Regional Registration	Multicast for Mobility Protocol	HAWAII	MER-TORA
Packet forwarding (downstream)	sequential tunnels	multicast forwarding (multicast encapsulation)	host routes for end-to-end encapsulated packets	prefix-based route to cross-over router; host-specific route below
Path updates	MIP + regional registration extensions (UDP)	CBT Join/Ack + ICMP (Instruct)	UDP Path Updates	UNICAST-UPDATE message from old-AR to new-AR for installing hard state, host-specific routes
Handover management	MIP, Route Optimisation	multicast join, advance registration, simultaneous bindings	Forwarding/Non-Forwarding schemes	localised at the edge of the network; inter-AR* tunnelling
Support for idle MHs	No	reduced signalling in wired network	paging using IP multicast	No
Requirements for MHs (in addition to basic MIP support)	I flag, registration keys as in MIP Route Optim., multiple level registrations	MIP Route Optim., multicast CoA	FA-NAI, MN-NAI, Challenge/Response, Route Optimisation	TORA, address acquisition, tunnel initiation, address return
Requirements for core network interface	HA must be able to handle the GFA IP Address extension	HA must accept registrations generated without an MN-HA authentication extension	HA must accept registrations generated without an MN-HA authentication extension	no distinction between 'global' and 'micro' mobility
Address management	Co-located CoA (bypasses the domain hierarchy), or FA-CoA	MH retains a multicast IP address within the domain. Ingress router seen as FA.	static Co-located CoA in foreign domain, Home Address in home domain	AR allocates an IP address from set it 'owns'. De-allocated at session end.
Routing topology	static configuration of enhanced MIP FAs in a tree structure	all nodes must support CBT IP multicast (sparse mode)	all nodes must be HAWAII-aware; standard routing protocols keep the default route up to date	all routers in a tree or in a mesh implement TORA (proactive prefix-routing + reactive host-routing)
Security	MIP + key distribution and authentication according to MIP-RO (FA-Key Reply extension) / DIAMETER	assumes Security Association between FA and HA	MIP + Challenge / Response or MIP-RO, password for path update messages, MN-FA and FA-HA authentication	use of existing mechanisms (RADIUS / shared keys / MIP+AAA)

(The Access Router (AR) is the first IP-aware 'box'. For simplicity it is assumed this is the BS in the discussion below.)*

We now discuss each Protocol Design Issue in turn, comparing our four exemplar protocols and drawing out points of interest. Our analysis is qualitative – thus we say only a little about the "efficiency" criteria, which is largely quantitative. We plan to remedy this later in the BRAIN project.

Packet Forwarding

The main contrast here is between, on the one hand, Regional Registration and MMP which extensively use tunnels, and on the other hand HAWAII and MER-TORA which do not. Regional Registration forwards downstream data within the domain using sequential tunnels between FAs. This may be *inefficient*, although packet de-capsulation and encapsulation can be avoided by changing the IP addresses in the encapsulating header. With MMP packets are encapsulated by the ingress router into multicast packets and are forwarded using CBT interface-based routing. However, the major concern with tunnelling is that it obscures the original header, so making *applicability* of capabilities that depend on header fields more difficult (eg QoS). For Regional Registration, HAWAII and MMP, upstream packets can be forwarded with the same mechanisms that are defined for basic Mobile IP (eg using reverse tunnelling). On the other hand, MER-TORA uses the MER-TORA protocol for up and down-stream packets. In MMP packets destined for another MH within the domain are sent up to the ingress router, which reverses them back to the target MH.

Path Updates

There are some interesting contrasts here. HAWAII and MMP both use soft-state path updates that are aggregated / merged as they travel up the tree, whilst MER-TORA uses hard state path updates[7]. Both methods aim to improve *scalability*. A quantitative comparison between them will be carried out later. Next, compare what happens as a MH changes its point of attachment: in MER-TORA it results in more host-specific state being installed (which 'over-rides' the prefix-based routes); whilst this is not so for the other schemes, essentially because their routing is entirely host-specific. Again, this will impact on the *scalability*, and the comparison may depend on how frequently the MH moves to another BS (for example). For both Regional Registration and HAWAII, a raceless (*robust*) and yet simple path management scheme is difficult to achieve if handoffs occur quickly [6] [24]. Because Regional Registration reuses the existing Mobile IP protocol messages, it can leverage on the recent enhancements to Mobile IP (e.g., for authenticating path updates), making its *deployment* easier. On the other hand, the scheme does not directly fit into the IPv6 mobility framework.

[7] more accurately, hard state updates for the mobility related changes in topology, and both hard and soft state updates for non-mobility related changes.

Handover Management:

All the protocols suggest conceptually very similar mechanisms for supporting fast and smooth handovers. Essentially, packets are forwarded from the old to the new base station after a handover and/or a route is set up to the new BS before the connection via the old one is lost. There is no obvious reason why one class of protocol should inherently perform better than another class. MMP has inherent support for simultaneous bindings through its advance registration feature, which may prevent packet loss during handovers; whilst HAWAII can optionally use dual-casting from the cross-over router, and it appears that this capability could also be added to MER-TORA if required. Regional Registration uses standard MIP move detection mechanisms, extended if necessary with fast handover support [20] [26] [27], and smooth handovers as specified in MIP Route Optimisation [2]. Similarly, both HAWAII and MER-TORA can optionally deliver, from the old to the new BS, packets that would otherwise be lost during handover. There are differences, however: in the Single Stream Forwarding sub-scheme HAWAII uses what it calls 'interface-based forwarding' which means that the outgoing interface (on which to forward the packet) is determined by both the IP address and the incoming interface, whilst MER-TORA uses a temporary tunnel. However, in MER-TORA if there is no tunnel when the link to the MH is lost (eg because handover is not predicted), then a virtual link is constructed to the MH from the old BS. It retains this for some time in the hope that it will be notified of the MH's new location. This virtual link should improve *robustness*, compared to the routing loops that can transiently appear in some HAWAII sub-schemes. There has been some work to try and quantify the *efficiency* of handover schemes, eg [24] compared HAWAII to basic and route optimised MIP. However, there are no similar papers comparing all four of our protocol classes. We hope to address this within the BRAIN project.

Support for Idle Mobile Hosts

Apart from HAWAII, paging seems to have received relatively little attention. Its proposal uses administratively scoped IP multicast [13] to distribute paging requests to BSs. This should push paging to the edge of the access network, which assists in *scalability* and *robustness*. A similar scheme is probably widely applicable to other IP mobility protocols. MMP naturally tracks MHs as they move, through the standard messages to join to / prune from the multicast tree. It is suggested that the location management overhead may be able to be reduced for idle hosts by reducing the refresh frequency of the CBT "soft state" mechanism. A paging protocol has also been proposed for Regional Registration [28]. The protocol aims at independence of link layer technologies; the MH agrees a 'sleep pattern' with the network, which requires synchronised sending of Paging Agent Advertisements from FAs belonging to the same Paging Area.

Requirements for Mobile Hosts

HAWAII and MMP appear to have the *simplest* requirements on MHs, ie only MIP capability with extensions. However, a dumb MH might not be able to accept a multicast IP address as a CoA. In HAWAII the MH must be able to acquire a co-located CoA in a foreign network; in MER-TORA, [18] suggests that a FA-CoA must be acquired. In Regional Registration the leaf FAs support basic MIP which guarantees the *compatibility* with dumb MHs.

Requirements for Core Network Interface

The objective is to minimise changes to the standard IP protocols (eg at MIP HAs). All schemes seem to make some additional requirements on HA operation (limiting *applicability*); for instance, a HAWAII BS refreshes registrations with the HA on behalf of the MH, and these registrations do not contain a 'mobile home authentication extension', which might not be acceptable to a HA. MER-TORA can have several gateways (aiding *robustness* and *scalability*), whereas the others appear to be able only to have one. However, a deployment issue is that the backward *compatibility* of MER-TORA with MIP has only received limited consideration so far.

Address Management

Address management is a key issue and a significant contrast between the protocols. With HAWAII, MMP and MER-TORA a MH keeps its IP address throughout the lifetime of the session (or longer), at least while it is in the same domain. This would (for example) ease the *applicability* of RSVP-based QoS support. By contrast, in Regional Registration the CoA changes at each handover. HAWAII requires that in a foreign network a MH acquires a publicly routable co-located CoA. Given the scarcity of public IPv4 addresses, this is a major drawback from the point of view of *scalability*. Also, because the CoA must be unique within a domain, a co-ordinated address allocation mechanism must be available. Regional Registration can also use a co-located CoA, and then similar comments would apply. But it can also use a FA-CoA and then IPv4 address exhaustion is not a problem. Within the domain, private CoAs can be used since they are not visible outside the domain. In MER-TORA, a MH is allocated an IP address by the BS (more accurately, the Access Router) where it starts a 'session', from the IP address block that the BS 'owns'. The pros are: fully prefix-based routing until the MH moves so minimising host-specific routing, and consistent address allocation across domain is *simple* since each AR owns its own address block. The cons are: more addresses are probably needed than for a IP mobility scheme with flat addressing across the domain, and more frequent address de-allocation is required (for *scalability* the IP address should be returned as soon as possible, eg at the end of an active session and not just when the MH powers down). If the number of MHs is large and their sessions short, then clearly a good, scalable DHCP implementation is needed. In MMP, the MH acquires a multicast CoA, so the shortage of IPv4 multicast addresses appears to be a major *deployment* problem. This should be less so in IPv6.

Routing Topology

Clearly, the relevant routing protocol capability needs to be *deployed* in the nodes in the network. The effort is probably greatest for MER-TORA, because standard unicast routing (eg OSPF) is replaced by TORA. However, [18] argues that it will give *scalability* advantages. *Robustness* is probably best for MER-TORA, since TORA was originally designed for mobile ad hoc networks (MANETs) so it will react immediately to any failure of links or routers. HAWAII relies on standard routing protocols for detecting failures; by integrating HAWAII with a routing daemon, a change in default route can trigger soft-state refreshes to HAWAII paths. Regional Registration and MMP would also rely on standard protocol recovery mechanisms to adopt to changes and failures. Regional Registration uses a central routing tree, whilst the others can have a tree or mesh topology.

Security

Security has received limited consideration, especially for MMP and MER-TORA. In general, it is suggested that existing mechanisms can be used; for example, Regional Registration mostly refers to the existing Mobile IP related security infrastructure ([21] [22] [23]). In MMP and HAWAII, the access network sends Registration Requests on behalf of the MH. These requests do not contain a Mobile-Home Authentication extension.

5. CONCLUSIONS

In this paper we have proposed a Framework for the evaluation of IP mobility protocols, including the identification of Protocol Design Issues (which are the basic functional requirements) and the identification of Evaluation Criteria (against which the Issues can be assessed). We have suggested a classification scheme for IP mobility protocols, in order to recognise common characteristics of a particular Category and hence its strengths and weaknesses. Also, we assume it will allow a new protocol to be easily assigned to a Category.

We have presented an initial application of our Evaluation Framework. Rather than dealing abstractly with the general characteristics of each Category, we chose a representative protocol from each Category: Regional Registration, HAWAII, Mobile Multicast Protocol, and Mobile Enhanced Routing TORA. The results presented are only an initial examination using the Framework, due to early stage of our work. In particular, quantitative criteria are mostly out of the scope of this study. For example, efficiency is difficult to evaluate because it should involve quantitative measures or simulation. We plan to deal with this later in our work.

From the discussion of the Protocol Design Issues it can be deduced that some bear more importance and complexity than others. Handover mechanisms and the interface between the mobile host and the access network entities appear surprisingly similar, whilst address management is a key differentiator.

Our goal is to use the Evaluation Framework to extract the best protocol mechanisms from all the investigated mobility protocols and to produce a clear perspective of the functionalities that need to be achieved by a new (or evolved) IP-mobility protocol, which we plan to propose at the final stage of our project. Another possible future direction could be designing a standard interface, or a standard architectural approach to IP micro-mobility. Already there is some effort in this direction: the Edge Mobility Architecture (EMA) [18] and Open Base Station Architecture (OBAST) [25], both of which aim to create a common approach to IP mobility whatever the wireless link technology.

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