Extensions for Internet QoS Paradigms to Mobile IP: A Survey

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ABSTRACT

Mobile IP has been chosen as the core mobility management mechanism for wireless LANs, 3G cellular networks, and, most recently, aeronautical networks. It is viewed as a key element in providing a universal roaming solution across different wireless access technologies. However, Mobile IP in its basic form inherits the IP incapability to provide QoS guarantees. This results in Mobile IP's lack of support for seamless intradomain mobility. This article surveys extensions that have been proposed to enhance the QoS functionality of Mobile IP. It gives a brief overview of Mobile IP and Internet QoS paradigms, and describes their general shortcomings with regard to QoS and mobility, respectively. It then discusses the extensions that have been proposed in the literature and provides a qualitative comparison.

INTRODUCTION

INTERNET AND MOBILITY — CONVERGED

Wireless technologies have advanced to a great degree in recent years, enabling access at several scales — personal area networks (PANs), wireless LANs, and WANs, cellular and satellite networks. Such advancement also led to the emergence of new network types such as ad hoc and sensor networks. The essence of fourth-generation (4G) wireless networks is the empowerment of these wireless networks, and future types yet to emerge, with interoperability mechanisms that would enable the mobile end user to seamlessly traverse different networks while maintaining Internet connectivity.

Toward embracing such heterogeneity, the manner in which the various networks are to be interconnected must be defined in order to appropriate the techniques used in resource and mobility management. Of the many proposals that are presented, there seems to be a general consensus on interconnectivity based on Mobile IP, a mobility management IP that is proposed to provide the Internet with mobility support. It is considered the core mobility management by the 2.5G General Packet Radio Service (GPRS), Third Generation Partnership Project (3GPP), and 3GPP2, and has been proposed to be used for interoperability between different types of WLANs. It was also chosen by NASA for space and aeronautical networks.

One justification for this choice is the wide deployment of IP as the main network layer protocol for the Internet. There is also the wide range of Internet applications that rely on this very protocol. Thus, the choice of creating IP-compatible mobility management is only natural. Furthermore, IP can be viewed as a connectivity framework: it is extendible, capable of interoperating with other routing protocols, and operational over different lower-layer protocols and under different upper-layer protocols.

CHALLENGES

Initially, the design of IP did not have clear mobility support. As such, the Mobile IP (MIP) Working Group was founded in the Internet Engineering Task Force (IETF) to develop mobility support for IP. Inheriting IP's lack of quality of service (QoS) support, MIP also introduced its own set of challenges, to the extent to which it is perceived unfit to cope with mobility management on a detailed intradomain level.

In addition, the rigorously sought QoS architectures that were proposed for the Internet are not readily applicable to the agile nature of wireless networks. The maintenance of the originally proposed signaling and provisioning schemes while the mobile end user is continuously changing point of attachment to the Internet has proven to be nontrivial as well as costly.

ARTICLE OUTLINE

The following section gives a brief overview of MIP and the existing Internet QoS paradigms. Understanding both the requirements of MIP and the capabilities of the Internet QoS architectures, several proposals for implementing QoS in MIP are presented. A qualitative comparison of these proposals is then made. The final section concludes the article.

PRELIMINARIES

OVERVIEW OF MOBILE IP

Three entities take part in the basic operation of Mobile IPv4: the home agent (HA), the foreign agent (FA), and the mobile node (MN). While roaming, an MN maintains two addresses. The first uniquely identifies the MN with its origin network, the home network. The other address is acquired when the MN visits another network where it cannot be reached by the usual local means: a foreign network. As soon as the MN acquires its care-of address (CoA) at the foreign network, it registers at least with its HA. Once this registration is completed, the HA intercepts packets that are sent to the MN's home address and tunnels them toward the MN's current CoA which, depending on the CoA's type, can be either the address of the FA or a unique identifier acquired by the MN.

The above operation, illustrated in Fig. 1, results in an inherent drawback of MIPv4, triangular routing, which basically means not having a direct bidirectional route between the MN and any correspondent host (CH). Consequently, using reservation-based QoS schemes would result in either excessive or unnecessary reservations. To overcome this problem, proposals such as route optimization have been made, and were even part of the main MIPv6 protocol. Their support, however, remains optional.

The introduction of MIPv6, or rather the inherent support of mobility in IPv6, brought other innovative modifications. For example, multiple HAs can reside at the home network, and the MN can register with more than one. MIPv6 utilizes the abundant address space and neighbor discovery mechanisms of IPv6, both of which make the FA entity redundant. There is also the home address destination option, an IPv6 extension header that informs the recipient of the source's home address, avoiding session discontinuities of higher layers.

An MN is required to update its binding at its HA whenever it changes point of attachment. Due to the MN's speed, the complexity of the foreign access network, or both, these updates might very well pose a burden on the associated networks. Accordingly, there are several intradomain enhancements, such as MIP with regional registration and hierarchical MIP (HMIP). The common idea is to have an FA hierarchy at the foreign network, with a gateway FA (GFA) assuming responsibility for contacting HAs (and CHs) on behalf of the MN while it remains within the GFA's domain.

Overview of Internet QoS Paradigms

Integrated services (IntServ) and differentiated services (DiffServ) are two technologies addressing the service differentiation problem via resource allocation. For IntServ, a signaling protocol, Resource Reservation Protocol (RSVP), was designed to facilitate reserving resources prior to establishing connections. Briefly explained, at the receiver's initial request, the sender would issue a PATH message toward the receiver. When the PATH message reaches the receiver, it understands that it can make reservations, and hence issues an RESV message. Reservations are maintained using soft states and thus require continuous exchange of PATH and RESV messages. The reliance of the IntServ framework on soft states, which require continuous refreshing, in addition to IntServ being initially aimed at per-flow granularity made the framework inherently unscalable. It also had implementation difficulties, which is why it is not widely deployed. Hence, the aggregating, and thus more scaling, DiffServ was sought. DiffServ took six of the eight type of service (TOS) bits in the IP header as the DiffServ codepoint (DSCP) or DS field, which is used to relay a per-hop behavior (PHB) between different DS domains. The DiffServ framework, however, lacks the necessary grace to control the flows at the access level. A popular notion for overcoming the shortcomings of the two frameworks is the IntServ over DiffServ model.

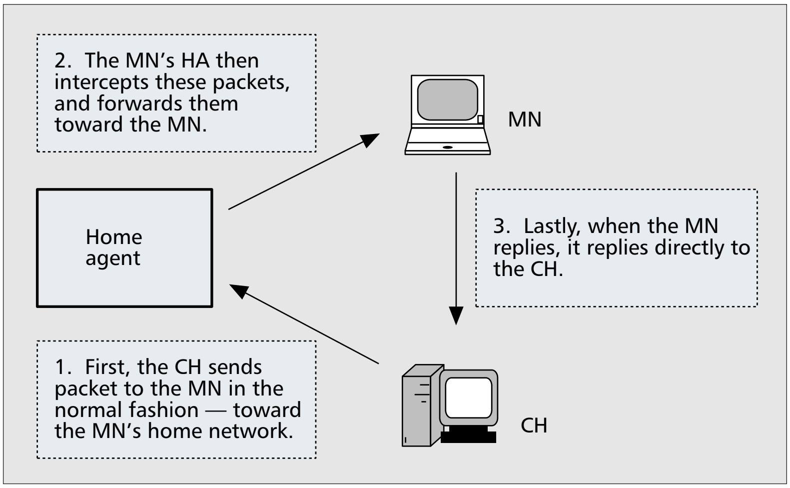

Figure 1. *Triangular routing in MIPv4.*

Multiprotocol label switching (MPLS) with its traffic engineering (TE) is a QoS technology introduced in the last decade. It was proposed to enhance the performance of the Internet's datagram model in terms of both management and delivery. MPLS is a scalable routing technique where routing is done by swapping a label on the packet instead of traditional IP destination lookup. In order to distribute the labels, a label distribution protocol (LDP) is required to maintain the coherence of label bindings across a network. Labels are then used to identify packets through a label switched path (LSP) traversing label switched routers (LSRs). MPLS's TE attempts to provide a means to manage and enhance network traffic through rigorous analytical studies.

MPLS could very well be used by DiffServ as the underlying delivery assurance framework. It also provides DiffServ with the capability of per-flow control. A more comprehensive notion is using MPLS for the IntServ over DiffServ model. In fact, RSVP mechanisms could be induced as LDPs. For example, RSVP-TE is an RSVP-based LDP with TE functionalities. Another TE LDP that utilizes hard states is constraint routing LDP (CR-LDP.)

Motivations for Extending Internet QoS to MIP

Internet QoS paradigms were sought to compensate for IP's lack of service differentiation and performance guarantees. MIP, in addition to inheriting this problem, further imposed

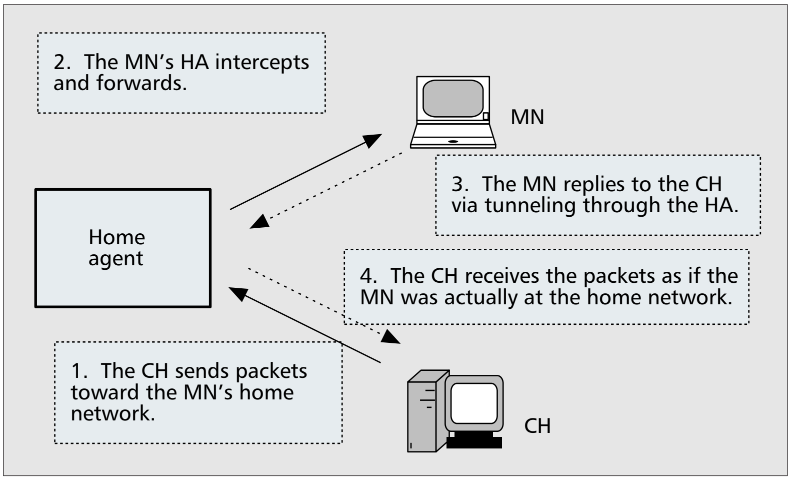

Figure 2. *Reverse tunneling in MIPv4.*

different challenges associated with mobility. As mentioned above, there are many proposals to maintain connection during handoff. However, maintaining QoS reservations during handoff and other instances needs more elaborate solutions.

For example, if a CH in MIPv4 sends a PATH message to an MN, the MN would make reservations on the direct route from the MN to the CH, even though this route will not be taken when the CH sends further packets to the MN. Although route optimization does solve this problem, it still has the issue of ingress filtering. Another solution involves reverse tunneling (Fig. 2), whereby a reverse tunnel from the MN's CoA to the MN's HA is set, In this case, RSVP over IP tunnels can be used. This, however, would result in reservations being made between the CH and HA, and between the HA and MN, regardless of the MN and CH interproximity. With MIPv6, an MN is required to use its most topologically correct address at all times. Thus, the utility of route optimization, which is intrinsic in IPv6, does not solve the ingress filtering issue. However, if the CH does not support route optimization, reverse tunneling would still be used.

QoS Extensions for MIP

IntServ Extensions

"Mobile Extensions to RSVP" [1] was one of the first attempts to extend RSVP signaling to accommodate mobility. While it does not describe a detailed mechanism, it laid out a framework that has become common in later work. First, it extends reservation classes to have *committed*, *quiescent*, and *transient* classes. Committed means both reservation and allocation, while quiescent means reservations without allocation. The transient class is a quiescent reservation that is allocated temporarily to a different user, and can be preempted by the original user. The work also defines a virtual receiver, which acts a proxy on behalf of the MN, generating refresh messages to the correspondent node while reducing the need for local refresh messages. A mobility management agent with mobility prediction capabilities is also proposed to sustain handoffs.

Mobile RSVP (MRSVP) [2] conjectures[1] that an MN, on visiting a foreign domain, always knows the addresses of the subnets it will be traversing. Accordingly, as soon as it enters the domain, it uses a *proxy discovery protocol* to acquire the proxy agents of the subnets to be visited. Once acquired, the MN will initiate a reservation protocol to these subnets so that by the time it is in a certain subnet, the reservations will have already been made. This architecture poses a burden on the network during both the proxy discovery and previsit reservation stages. It is worth noting that the work classifies reservations as either active, if the MN is using them, or passive, if they are not used by the MN, and allows the network to utilize passive reservations until preempted by the MN. A modification of MRSVP is proposed in [3] where instead of knowing the address of all the subnets to be traversed, the MN progressively acquires the addresses of the neighboring cells. With a cellular architecture in mind, this means that the MN has to keep track of only six addresses. To ensure that at least a minimum reservation can be made passively, a *rate reduction factor* parameter is introduced, and is used to inform neighboring base stations of the factor by which the resource request can be reduced if the original reservation cannot be completely satisfied.

The three proposals above do not assume any notion of hierarchy. There are, however, other proposals that either utilize a hierarchical MIP solution (e.g., HMIP) or introduce their own. The general objective of the proposals below is to localize the effect of handoff on reservations. Passive reservations are one way to counter the effect. The other way relies on separating local reservations from reservations at the core as much as possible, as long as the node is within the same domain. Consider the scenario in Fig. 3. In regular RSVP-MIP operation (Fig. 3a), when the MN moves from one foreign network to another but within the same domain, the whole path between the MN and the CH has to be established anew. However, in a hierarchical reservation scheme (Fig. 3b), a GFA would maintain one reservation connection to the CH, while only the GFA-MN reservations are to be reestablished at each handoff. The proposals below have similar GFA-CH reservation management, but differ in how local reservations are handled.

Hierarchical Mobile RSVP (HMRSPV) [4] proposes integrating RSVP with a hierarchical MIP using regional registration. It limits the request of in-advance reservations only to the case of long duration handoffs. More specifically, only when an MN resides in a coverage overlap of two base stations will an in-advance resource reservation will be made. The request is also made for passive reservations. Thus, an MN employing HMRSVP does not require any to-visit caches, nor does it make needless reservations.

HMRSVP operates as follows. When an MN first visits a foreign network, and during the initial PATH/RESV exchange with the CH, the GFA takes note and initiates a tunnel to the MN's local FA. The GFA-FA and CH-MN together constitute an active reservation. When

[1] *The authors remark, however, that the proposal can be useful in scenarios where the path to be traveled is known to a sufficient degree (e.g., traveling via trains).*

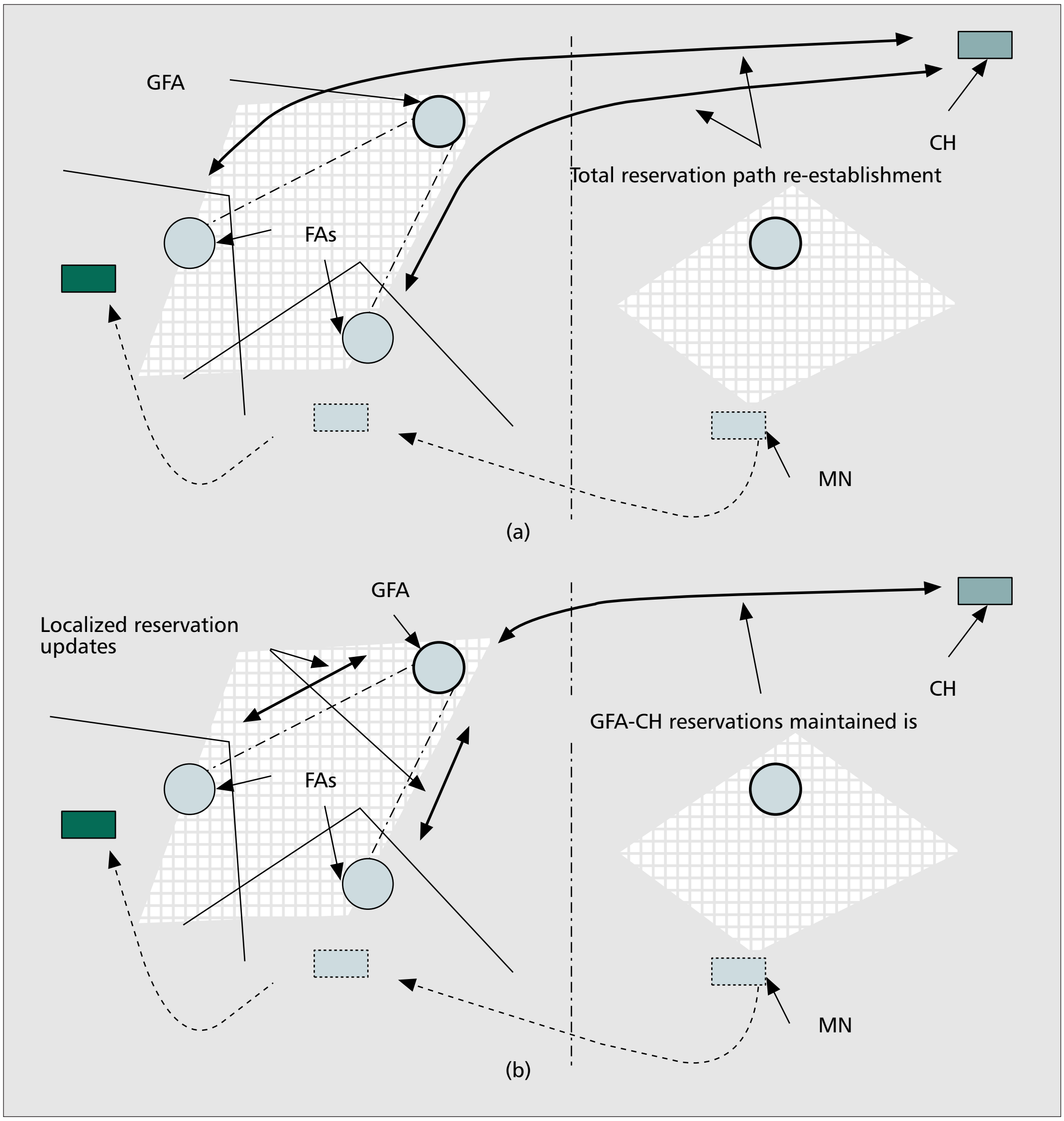

Figure 3. *Reducing the effect of handoff on reservations.*

The utility of route optimization, which is intrinsic in IPv6, does not bear the ingress filtering issue. However, if the CH does not support route optimization, reverse tunneling would still be used.

the MN moves to an area served by a different FA under the same GFA, only a tunnel between the GFA and the new FA needs to be established. When the MN further moves to an area served by a different GFA, and has the capability of sensing and communicating in a coverage overlap, the MN initiates a passive registration that goes up to the CH, while acquiring the new COA and registering with its HA. HMRSVP also accommodates the CH itself being a mobile host. In this case, three tunnels will be activated: one inter-GFA and two GFA-FA tunnels.

The work in [5] analyzes the effect of applying different advance resource reservation mechanisms within HMRSVP in terms of localization of passive reservation messages. Considering a tree with the GFA at the root, three options are considered: one, making passive reservations in all branches; two, making passive reservations in the two neighboring FAs; and three, leaving a forwarding pointer at the old FA prior to handoff, eventually creating a pointer forwarding chain. It concludes that the third option is best. However, since the chain might lead to a nonoptimal route, especially when the node traverses between domains, chain limiting would reduce the route nonoptimality. Modified HMRSVP [6] proposes resetting the chain whenever a new domain is visited.

Figure 4 shows four HMRSVP variations. In Fig. 4a, when a node first enters the domain, passive reservations are made toward the directly neighboring FA. In Fig. 4b, when a node enters a domain, passive reservations are made toward all FAs in the domain. Figure 4c shows a flow following a pointer forwarding chain, while a limited chain is shown in Fig. 4d.

The RSVP Mobility Proxy (RSVP-MP) [7] is another approach that depends on a hierarchical MIP operation yielding two CoAs, the global CoA (GCoA) being maintained over a domain. The RSVP-MP, an RSVP enhanced edge router with mobility support, keeps track of the home address/local CoA (LCoA)/GCoA bindings in addition to their reservations. Exchange of PATH/RESV messages between the RSVP-MP and the CH is done using the GCoA, while internal exchange is done using the LCoA. After handoff, if a session is to be still maintained, the exchange is only made between the MN and the

At one level, MPLS could be viewed as a tunneling technology that outperforms the usual tunneling techniques suggested for MIP, e.g., IP-in-IP tunneling. This can be observed in the first extension presented below. At another level, MPLS could provide the grounds for improving MIP handoff

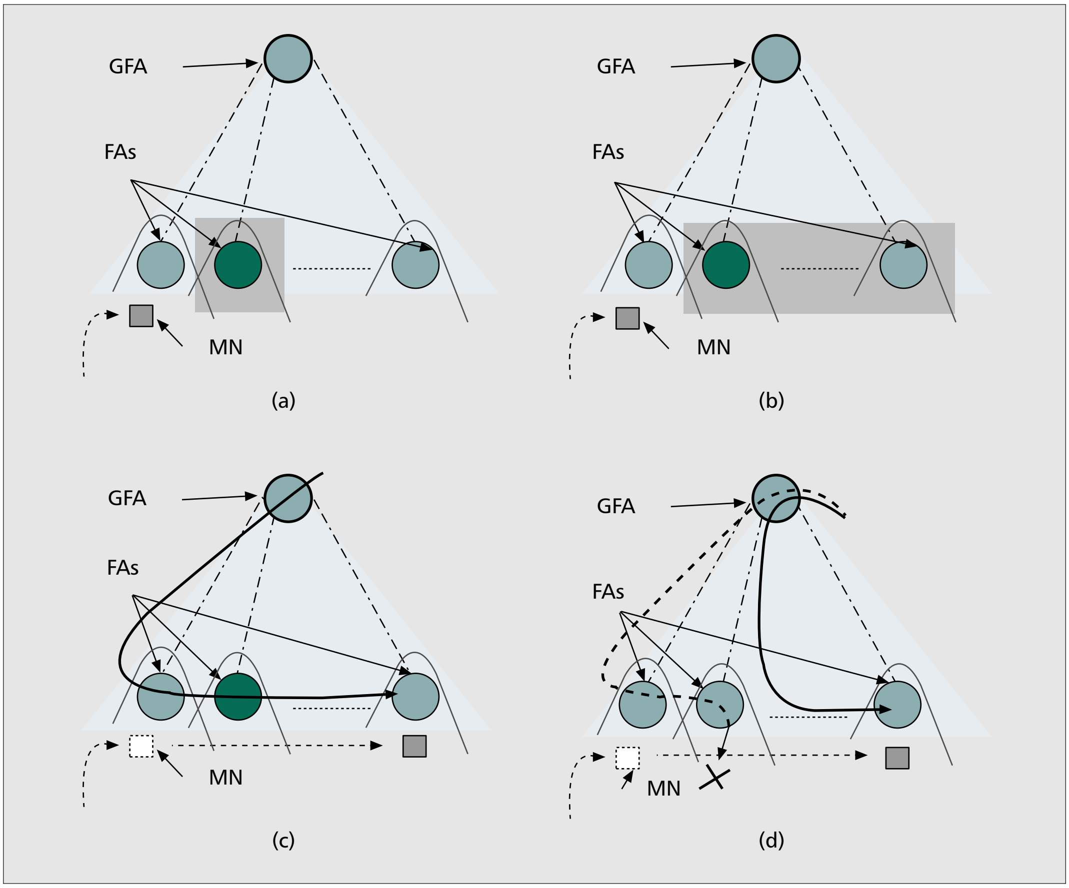

Figure 4. *Variants of HMRSVP route recovery.*

RSVP-MP through the new access router. On its part, the RSVP-MP will maintain state-refreshing correspondence. The work also describes regulations for having more than one RSVP-MP in a given domain.

In Localized RSVP [8], an attempt is made to separate local reservations from reservations in the local network. The authors define a new message, PATH REQUEST, used to request a PATH message from a local RSVP proxy, another new entity that assumes responsibility for maintaining local reservations. Operation of upstream transfers is similar to normal RSVP operation. For downstream transfers, the end host would send the PATH REQUEST message to the correspondent node. The CH would then reply with a PATH and, accordingly, the end host would initiate the reservation. After handoff, an end host would issue a PATH message from its new location, and the PATH would be intercepted by a crossover router located at the intersection of the old and new routes to the end host. For downstream transfers, the MN would send a PATH REQUEST to the CH. As the CH responds with a PATH, the end host's RESV would be intercepted by the crossover router. As an enhancement, the crossover router can also intercept the PATH request.

The above solutions assume a mobility agent at the foreign network, and hence are more geared toward MIPv4. As described earlier, since MIPv6 utilizes neighbor discovery, an FA is no longer required, and an MN will always have a *collocated* CoA while roaming. The work in [9] describes extensions to enable RSVP in MIPv6. The authors suggest a modification for RSVP daemons at the correspondent and foreign networks such that they acknowledge the MIPv6 addressing scheme. They also outline advanced solutions that provide smooth handoffs. To avoid re-reservations whenever an MN moves to a different foreign network, and acknowledging that the home destination option remains only an option, it proposes using a new RSVP object. By including the MN's home address, this object relays to the intermediate routers that this is the same MN but with a different CoA, and thus maintains the previously reserved states. Also, since RSVP and PATH refresh messages might be delayed during handover, the work suggests that the arrival of the binding update at the CH would trigger a PATH message. A different solution that does not depend on objects and triggers is flow extension. Basically, this mechanism extends the existing RSVP flows that are applied on typical MIP routers to the new MIP router. This is coupled with a simultaneous binding option that has to be applied for the roaming MN, and packets will be sent to both the old and new CoAs.

DiffServ Extensions

DiffServ cannot be applied at the access level without a signaling protocol. Earlier, it was mentioned that an IntServ over DiffServ framework is highly viable. In this case, any of the RSVP signaling proposals described above could become a candidate if such a framework were employed for MIP. However, there have been two proposals that are not dependent on RSVP in their signaling.

The work in [10] introduces three ICMP messages: Report, Reply, and Modify. Report messages convey local parameters like bandwidth or power requirements; Reply messages acknowledge reservation requests. Modify messages are designed for bandwidth changes. The work also utilizes class-based queuing and extends it with capability to recognize the DSCP entry in the DS field. It also presents packet dropping extensions, class allocation changes, and the capability to change the priority of a certain class to another. Beyond the access network, the work assumes regular DiffServ operation.

The work in [11, 12] describes another DiffServ framework for MIP users. For intradomain movement in the home network, an MN first signals the bandwidth broker (BB) its QoS requirements, CoA address, and so on. After checking that there are enough resources in the network, the BB reconfigures the DiffServ network. If both the admission and reconfiguration are successful, the BB sends a confirmation message to the MN. For interdomain mobility, the service level specification of the MN needs to be transferred. Thus, the MN first requests the foreign BB to acquire the MN's SLS from the home BB. The home BB then sends the MN's SLS and releases the associated reservations at the home network. The foreign BB then reconfigures its network and informs the MN of either the success or failure of the message.

MIP-Specific MPLS Extensions

At one level, MPLS could be viewed as a tunneling technology that outperforms the usual tunneling techniques suggested for MIP (e.g., IP-in-IP tunneling). This can be observed in the first extension presented below. At another level, MPLS could provide the grounds for improving MIP handoff, something that can be realized through hierarchy. The problem of LSP establishment after handoff is quite similar to the problem of restoring reservations in RSVP. Hence, the hierarchical proposals in this section attempt to separate the maintenance for the GFA-HA and LSPs from the maintenance of the GFA-MN LSP. Another important level at which MPLS could be applied is its accommodation of service differentiation solutions, which has been proposed in the literature.

In [13] the authors suggest integrating the architectures of MPLS and MIP. They first describe an architecture where the FA and HA are edge LSRs and belong to the same MPLS domain. In this architecture, when the MN detects that it is in a foreign network, and after it registers with the local FA, the FA configures its entries, forwards the registration to the HA using regular IP routing, and awaits the HA's LDP request. After the HA adjusts its MN's binding, it issues the LDP request to the FA, and the LSP is eventually set up. When the MN visits a new FA, the same procedure is repeated. The article also describes the procedure for deregistration when the MN returns to its home network and having multiple CHs, each with different QoS requirements. For FAs and HAs that are not edge LSRs of the same domain, two scenarios are pictured. One is when the home and foreign MPLS domains are interconnected by an MPLS-aware cloud, in which case the procedure described above applies without modifications. The other case is where an MPLS-unaware cloud separates the home and foreign MPLS networks. In this case it is suggested that the MPLS tunnels be extended by IP tunnels, and a hierarchical MIP is utilized. However, the authors note that their scheme performs best when the whole network is MPLS-aware.

The work in [14], Mobility-Aware MPLS, proposes using MPLS at the access network level, having either MIP or an MPLS-aware domain at the core. The authors assume a gateway (GW) for the domain through which the core is accessed. Two types of LSPs are configured between the base stations and the GW. Static LSPs, both uplink and downlink, are preconfigured LSPs that are set up by the network administrator for the purpose of predefined forward error codes (FECs). Dynamic LSPs, on the other hand, are initiated by the MN, and are set up on registration between the MN and the network's GW. If the MN is in a foreign network, the registration is extended to the GW at the MN's home network. Static LSPs implement the DiffServ/MPLS framework, while dynamic LSPs are used for RSVP signaling.

Static LSPs, both uplink and downlink, are preconfigured LSPs that are set up by the network administrator for the purpose of predefined FECs. Dynamic LSPs, on the other hand, are initiated by the MN, and are set up on registration between the MN and the network's GW.

Since static LSPs are initially set up, M-Aware MPLS reduces the problem of handoff to changing the MN association at the GW. For RSVP sessions, the MN initiates handoff by sending a new RESV message, relayed by the base station, and route only up to the first crossover LSR. Dynamic LSPs are maintained by RESV and PATH refresh messages.

Hierarchical Mobile MPLS [15] extends the MIP/MPLS integration proposal described above to where the entire network is MPLS-aware. It proposes a two-tier hierarchy with a new mobility agent, called the foreign domain agent (FDA), at every MPLS domain. Responding to an FA advertisement, the MN would respond with a registration request to be sent to the MN's HA via the FDA. The HA consequently issues a label request to the FDA. The FDA would then simultaneously respond to the HA with a mapping and issue a label request to the FA. As the HA and FA respond to the FDA with the registration reply and label mapping, the FDA will issue a registration reply to the MN via the FA. During handoff, a local registration request is sent up to the FDA, which will maintain its tunnel with the HA independent of the internal tunnel. Also, the MN can issue a binding update to the old FA so that it forwards any in-flight packets. Lastly, a notion of active and passive reservations is used to improve the delivery of reservations during handoff.

Discussion

The RSVP-MIP initiatives can be compared on the following grounds: whether a given proposal considers intradomain mobility; whether it relies on passive states reservations; what are its pre-

	Considers intra-domain mobility?	Relies on passive states?	Prereservation basis?	MIPv6-compatible?	Route recovery for handoff?
Mobile Extensions to RSVP	No	Yes, but could be temporarily reassigned.	Generic	No: heavily relies on an FA.	N/A
Mobile RSVP	No	Yes	Node knows whole path a priori.	Yes	N/A
Mobile RSVP with modifications	No	Yes	Six neighboring cells.	Yes	N/A
HMRSVP	Yes	No	Only during coverage overlaps.	Yes	Up to GFA for local movements. Total path when GFA changed.
Modified HMRSVP	Yes	No	Only during coverage overlaps.	Yes	Up to GFA for local movements. Total path when GFA changed.
RSVP-MP	Yes	No	–	Yes	None
Localized RSVP	Yes	No	–	Yes	Only up to a crossover router.
RSVP for MIPv6	No	No	–	Yes	Only up to a crossover router.

Table 1. *Comparison of RSVP extensions.*

reservation bases; if it is not initially aimed at MIPv6, whether making such a modification is feasible; and whether the proposed scheme performs any post-handoff route recovery. Table 1 presents this comparison. Note that post-handoff reservation recovery is better made possible by inducing hierarchy. It could still be implemented in a nonhierarchical solution, but this would result in more processing at either the FA or MN, depending on CoA type. Another noteworthy observation is that none of the hierarchical solutions implements a passive reservation mechanism. This could be the result of distributed resource management. However, this tradeoff requires a more quantitative evaluation. Finally, it should be noted that in order for an MN to initiate reservation in coverage overlaps, as proposed in HMRSVP, it has to be adequately capable at the physical level.

The two proposals made for extending DiffServ do not provide a solution capable of sustaining high mobility at the access level. Initial requirements of a signaling protocol for DiffServ in MIP must provide an adequate level of reservation robustness and adaptability, capable of handling access level flows at fine granularity while providing aggregation compatible with DiffServ mechanisms at the core. We note, however, that [11, 12] suggested that the MN's SLS be acquired from the BB at the MN's home network rather than from the MN. This raises the issue of verifying the MN's authenticity at the expense of delay in delivering the desired QoS.

Similar to RSVP extensions, MIP-Specific MPLS initiatives differ in their scope, reliance on passive reservations, and MIPv6 compatibility. They also differ in number of tiers and how intradomain LSPs are re-established on handoffs. Noting that MPLS is a performance assurance technology that could provide service differentiation, we note which proposals had such provisions. Observations similar to the ones made in comparing RSVP-MIP initiatives could be made. It is also important to note that any of the proposed solutions could accommodate an IntServ over DiffServ architecture, or utilize DS-based LDP like RSVP-TE or CR-LDP. However, proposals for such accommodations were only found for HM-MPLS.

CONCLUSION

From an architectural point of view, the collective problem of mobility and resource management in IP networks needs further solutions for interdomain mobility. For example, interdomain handoff under MIP still suffers great delay. Such a solution requires reevaluating gateway protocols, both internal and external, in order to facilitate seamless mobility with end-to-end QoS delivery considered. This includes frameworks for autonomous systems to become dynamically aware not only of their networks' status, but also other autonomous systems engaged in service delivery.

The interest in MPLS-based MIP solutions is based on the traffic engineering capabilities of MPLS, including constraint-based routing, survivability, and recovery. More important, MPLS provides a level of abstraction and scale through which a unified, but robust, solution could be applied at several network levels, from access to core level operations. Thus, MPLS has potential to solve MIP's operational and architectural shortcomings.

In September 2003, the International Telecommunication Union — Telecommunication Standardization Sector (ITU-T) consented on Recommendation Y.1281, "Mobile IP Services over MPLS." The Recommendation discusses the architectural details of implementing MIP over MPLS for both MIPv4 and v6. It also

	Considers intra-domain mobility?	Reliance on static LSPs	MIPv6-compatible?	Route recovery for handoff?	Notes
MPLS/MIP	No	No	No: requires FA functionality.	Total path.	–
Mobility Aware MPLS	Yes	Yes	Yes: GW could be an edge LSR.	Only up to a crossover router.	–
HM-MPLS	Yes: two-tier only.	No	No: requires FA functionality.	Only up to a crossover router.	Extended for IntServ over Diff-Serv solution and RSVP-TE
MMPLS-Based Hierarchical MIP	Yes	No	Yes	Total path.	

Table 2. *Comparison of MPLS extensions.*

discusses the implementation for an HMIP solution. Having described the architectural aspects of implementation, attention can now be channeled to problems that require elaborate solutions, such as label management; labels represent different resources collectively and hence need to be managed properly.

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