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Hierarchical Mobility Management for VoIP Traffic

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Abstract—A hierarchical IP-based mobility management mechanism is proposed for VoIP applications. The suggested mechanism uses the DMA architecture, based on IDMP, for managing intra-domain mobility and SIP’s dynamic binding mechanism for managing global mobility. This combination of network and application layer mobility management reduces the global signaling load, provides fast handoff for ongoing conversations, enables efficient global transport and supports IP-layer paging.

I. INTRODUCTION

IP-based mobility management solutions traditionally operate at the network layer and provide basic connectivity to mobile nodes as they change their point of attachment to the network. Mobile IP (MIP) [1], for example, ensures ubiquitous connectivity by allowing a mobile node (MN) to retain its permanent home address (PHoA) and by tunneling packets to a temporarily assigned care-of address (CoA). Such solutions are however, inadequate for Voice-over-IP (VoIP), an important application in future dynamic tactical battlefield networks. For one thing, MIP’s potentially high update latency makes it unsuitable for supporting seamless handoffs during an ongoing call. Moreover, MIP’s tunneling mechanism, which makes node mobility transparent to a correspondent node (CN), is unnecessary for UDP-based VoIP applications, which can dynamically change the destination address for an ongoing connection. SIP-based mobility management, as proposed in [2], [3] is an interesting application-layer alternative to MIP. By exposing node mobility to the application layer, SIP-based mobility management allows a mobile user to control the application response to mobility. From an architectural viewpoint, SIP’s approach to mobility management for on-

going sessions is fundamentally similar to the MIPv6 [4] solution, with the MN directly informing the CN, via a SIP Re-INVITE message, of any change in its address.

While the SIP-based approach offers several advantages over a corresponding MIP-based solution, it continues to suffer from certain drawbacks, the most significant of which is the absence of a *mobility management hierarchy*. Both SIP and MIP-based mechanisms use a flat hierarchy, whereby every change in the MN’s point of attachment requires the generation of global binding updates. Such updates can not only incur high latency, thereby making rapid handoffs impossible, but also significantly increase the mobility signaling load, especially as the number of MNs increases. This is an especially poor choice in the tactical battlefield, where the network typically exhibits a clear hierarchical structure and where bandwidth efficiency may be a key consideration. Additionally, currently proposed mechanisms offer no paging support, and hence require even an idle MN to perform mobility-related signaling for every change in subnet.

In this paper, we present a two-level management hierarchy that provides a scalable and efficient mobility management for VoIP traffic. The hierarchy uses the Intra-Domain Mobility Management Protocol (IDMP) [5] to not only localize the scope for most binding updates, but also to provide support for additional features, such as fast handoffs and paging. To manage global (inter-domain) mobility in a flexible manner, the solution re-uses the SIP mobility management mechanism. Our proposed mechanism is unique in that it *combines an application-layer solution for global mobility with a network-layer management scheme for intra-domain movement*.

The rest of the paper is organized as follows. Section II explains the advantage of a mobility hierarchy and discusses the Dynamic Mobility Agent (DMA) architecture for managing intra-domain mobility. Section III explains the implementation of our solution, which combines DMA with SIP; finally, section IV concludes the paper.

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A. Related Work

In basic Mobile IP (MIP) [1], for every change in subnet, an MN obtains a care-of address that is topologically consistent with its current point of attachment and informs a special node, called the Home Agent (HA) of this CoA. Node mobility is transparent to the CN, since all packets addressed to the MN's PHA are intercepted by the HA and forwarded (by encapsulation) to the MN's current CoA. The route optimized version of MIPv4 [6] requires the HA to inform any CN of the MN's current CoA. This mechanism removes the overhead of triangular routing by allowing the CN to directly tunnel packets to the MN's CoA. In the IPv6 version of Mobile IP, MIPv6 [4], MN directly informs any CN of a change in its CoA. The advantages and drawbacks of each of these approaches are discussed in [7].

SIP [2] is a popular and powerful control protocol for creating, redirecting and migrating multimedia sessions. A key feature of SIP is the device-independent specification of a user, via a user-specific SIP User ID. To support user mobility, SIP merely requires the user to inform a central SIP server (via the SIP REGISTER method) of the address of the currently associated MN. If the MN moves and changes its address, the user must issue a fresh SIP REGISTER message. [3] presents an extension that uses SIP signaling to also provide mobility management for movement during a call. This update mechanism is very similar to MIPv6: the user transmits SIP Re-INVITES directly to the CN, inviting the CN to the new CoA. SIP-based mobility management is more efficient than MIP for VoIP, since it avoids the need for packet tunneling: the CN simply sends packets directly to the new CoA. Given the relatively small size of VoIP packets, this can result in a fairly significant increase in the payload efficiency¹.

TeleMIP, a two-level mobility hierarchy for next-generation cellular networks, which uses MIP for managing inter-domain mobility, was presented in [7]. [5] provides the functional and protocol description of IDMP and also provides a comparison between IDMP and other MIP-specific hierarchical mobility solutions, such as Mobile IP Regional Registration (MIP-RR) [8] and Hierarchical MIP (HMIP) [9]. The DMA architecture, which uses load balancing algorithms to distribute the intra-domain mobility load among multiple Mobility Agents (MA), and also provides QoS guarantees for MNs, is presented in [10], [11].

¹As an example, consider a G.711 VoIP packet, with a payload of 80 bytes (20 msec packetization delay). The normal IPv4 packet has a header (RTP+UDP+IP) of 40 bytes; IP-in-IP encapsulation adds a further 20 bytes. The payload efficiency for the encapsulated packet is thus $80/140 \sim 57\%$.

II. HIERARCHICAL MOBILITY MANAGEMENT

In this section, we first motivate why a flat management hierarchy is not appropriate for VoIP applications. We then provide an overview of the DMA architecture, which uses two separate CoAs to define a two-level mobility hierarchy.

A. Drawbacks of a Flat Architecture

In the absence of a hierarchy, an MN must not only refresh its configuration information (CoA) on every change in subnet, but must also generate global bindings to update remote nodes with this new CoA, for every change in subnet. This can lead to an explosive growth in the global signaling load, especially as the number of MNs increases². The absence of a hierarchy also means that every update must travel all the way to the remote node (either an HA, SIP server or CN). If the communication delay with this remote node is high, the update process can have high latency. In fact, this latency can become much higher if one considers the possibility of packet losses at intermediate hops, especially in battlefield scenarios where link loss rates may be fairly high.

To analyze the update latency distribution under packet loss, consider a situation where the MN and the remote node are separated by L hops. Let each hop have a probability p of packet loss and result in a delay of d msec. A single binding update is thus successfully received with a probability P_s , such that

$$P_s = (1 - p)^L. \quad (1)$$

Accordingly, the probability, P_L^k , that exactly k transmissions are required for successful reception of a binding update is given by:

$$P_S^k = (1 - P_s)^{k-1} P_s. \quad (2)$$

Assuming that retransmissions occur every $L*d$ msec (the latency of a successfully transmitted packet), the cumulative distribution of X , the random variable representing the time taken for the successful transmission of an update is given by:

$$F_s(kd) = Prob\{X \leq k * L * d\} = \sum_{i=1}^k P_s^i. \quad (3)$$

This is the case for MIPv4, MIPv6 and SIP. In the MIP-RO case, however, a successful transmission requires two

²Such rapid growth in signaling traffic was the driver behind the hierarchical mobility solution employed in current cellular networks.

independently successful updates, MN to HA and HA to CN. The probability of a successful transmission in exactly k overall attempts is :

$$P_{S, MIP-RO}^k = \sum_{i=1}^{k-1} P_S^i * P_S^{k-i}, \quad (4)$$

whence we can derive the cumulative distribution $F_s^{MIP-RO}(\cdot)$. Figure 1 shows the distribution of $F_s(\cdot)$, when d , the per-hop delay is 10 msecs, $S = 5$ hops and p is either 0.01 or 0.05. The figure shows that the probability of relatively large mobility-related transients is not insignificant, especially for battlefield networks where the individual hops may have moderately high packet loss probabilities.

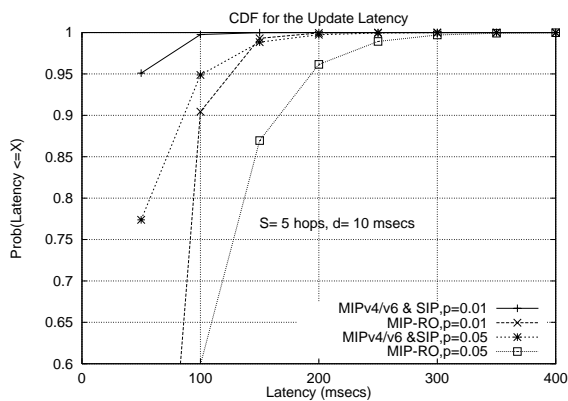


Figure 1: Update Latency Distribution for MIP/SIP

B. The DMA Architecture

The DMA architecture is based on a two-level mobility management hierarchy, with individual subnets aggregated into *domains*. IDMP [5] is used as the protocol for managing mobility within a domain. Figure 2 depicts the functional layout of IDMP. The Mobility Agent (MA) is similar to a MIP Foreign Agent (FA), except that it resides higher in the network hierarchy (than individual subnets) and acts as a domain-wide point for packet redirection. A Subnet Agent (SA) is similar to a MIP FA and provides subnet-specific mobility services. Under IDMP, an MN obtains two concurrent CoAs:

- *Global care-of address (GCoA)*: This address resolves the MN's current location only up to a domain-level granularity and hence remains unchanged as long as the MN stays within a single domain. By issuing global binding updates that contain this GCoA, the MN ensures that packets are routed correctly to its present domain.
- *Local Care-of Address (LCoA)*: This is similar MIP's CoA in that it identifies the MN's present subnet of

attachment. Unlike MIP's CoA, the LCoA in IDMP only has local (domain-wide) scope. By updating its MA of any changes in the LCoA, the MN ensures that packets are correctly forwarded within the domain.

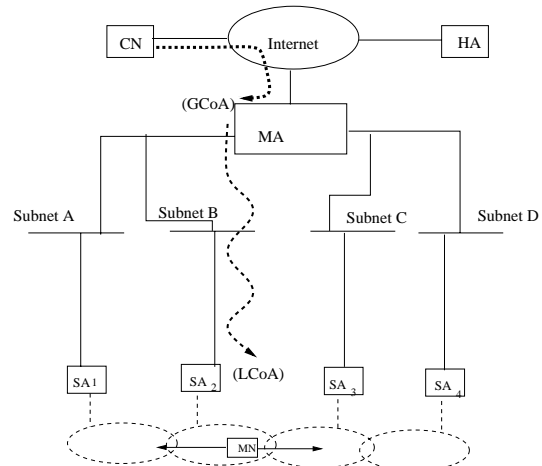


Figure 2: IDMP Logical Elements & Architecture

Under IDMP, packets from a remote CN are forwarded (with or without tunneling) to the GCoA and are intercepted by the MA. As shown in figure 2, the MA then tunnels these packets to the MN's current LCoA. Since global binding updates are generated only when the MN changes domains and obtains a new GCoA, this approach drastically reduces the global signaling load.

The DMA architecture defines a dynamic technique for assigning an MA to an MN when it first moves into the domain. The architecture assumes the presence of multiple MAs and applies a load balancing technique for distributing the mobility load across the multiple MAs. A central node called the Mobility Server (MS) implements different load balancing and MA-allocation strategies. The architecture also uses the Differentiated Services framework to dynamically provision domain resources and provide an MN QoS guarantees as it moves within the domain. Dynamic resource provisioning is accomplished by leveraging the Bandwidth Broker [12] architecture, whereby a centralized Bandwidth Broker (BB) dynamically changes the allocation of resources at different nodes, based on a knowledge of the traffic and service profiles. The MAs and SAs interact to ensure that the MN's QoS profile is seamlessly transferred across subnets, without the need for explicit QoS renegotiation at each change in subnets. Figure 3 provides the logical organization of elements in the DMA architecture; see [11] for further details on the mechanism for assuring QoS guarantees to individual MNs.

C. Network Mobility and DMA

Battlefield networks are not only subject to individual *host mobility*, but also *network mobility*, where groups of nodes in one or more hierarchies exhibit collective movement. For example, as a tank brigade changes location, platoons of soldiers located at a lower hierarchy also exhibit collective movement. DMA's mobility hierarchy leads to lower signaling overhead during such network mobility and is compatible with automated network reconfiguration techniques (e.g., DCDP [13]) under investigation. If network mobility is confined to a single mobility domain, then DMA simply requires each MN to obtain a new LCoA. Its GCoA would, however, remain unchanged; consequently no global update messages are required. Contrast this with the flat MIP (or SIP) architecture, where all the nodes comprising the mobile network would have to generate global updates. For example, a platoon of 200 soldiers, each communicating with 5 CNs, would generate *1000 simultaneous global binding updates* under a flat MIPv6/SIP approach. The DMA approach would, however, lead to the generation of only *200 local updates* in a similar scenario.

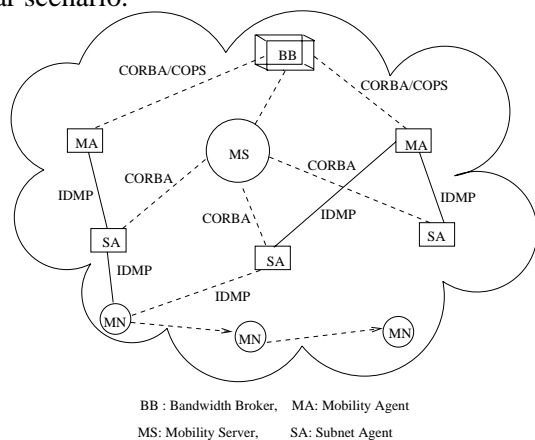


Figure 3: Elements of the DMA Architecture

III. A MULTI-LAYER MOBILITY SOLUTION FOR VOIP

To provide a scalable and efficient mobility solution for VoIP traffic, we proposed to combine DMA's two-level hierarchy with SIP-based global mobility management. The architecture thus combines mobility solutions defined at different layers: while the DMA approach makes intra-domain mobility transparent to individual applications, the SIP mobility mechanism provides an application control over its response to global (inter-domain) mobility. The key features of the mechanism are:

- *Unique GCoA*: The MN uses the globally co-located (GC) mode of IDMP. In this mode, every MN is as-

signed a unique GCoA, which is different from the address of the MA. This mode assumes that each MA has a pool of unique global addresses, and allocates each MN a unique address from this pool. This removes the need for global tunneling, since an MA can simply use this unique GCoA to determine the identity of the target MN.

- *SIP for Global Mobility*: For providing handoff support during inter-domain mobility, the application sends SIP Re-INVITE to inform the CN of the MN's new GCoA. The CN can then send packets directly to this GCoA, without suffering from the overheads of triangular routing or packet encapsulation. To provide user mobility, our solution requires the user to update appropriate servers with the GCoA of his/her current mobile node. Soldiers in the battlefield can thus use any available node, rather than having their identity tied to a single device.
- *Fast Handoff and Paging*: IDMP provides mechanisms for faster and low loss handoffs, as well as network-layer paging. Such fast handoff mechanisms significantly improve the quality of voice conversations by eliminating the losses associated with handoffs, especially in bandwidth-constrained military environments. Nodes can also use the optional paging mechanism to significantly lower their mobility-related signaling. This is an especially big benefit for highly mobile users who have very low call-to-mobility ratios.
- *Scalable Security*: By making a clean separation between the intra-domain and global mobility mechanisms, our solution provides a very robust security and authentication infrastructure. Alternative solutions, such as MIP-RR, use the intermediate agents for relaying global binding updates and require the home network to transfer security and authentication information (such as registration keys) to these intermediate agents. In the DMA-SIP solution, however, the MN performs a completely independent *end-to-end* global update. This solution thus works even in scenarios where the home network has no pre-established security association with the foreign domain and is not willing to share authentication-related keys with the MA.

A. Signaling Flow

Figure 4 shows the exchange of mobility-related signaling when an MN first moves into a domain. The MN not only obtains a unique GCoA. In addition, MN requests an initial LCoA, the MN also uses IDMP's QoS extensions

to inform the network of its bandwidth requirements for any subsequent voice call. The SA first queries the MS, which uses this QoS information to dynamically assign an MA to the MN. The MN then performs an intra-domain update to register itself with the designated MA and obtain a unique GCoA. Finally, the SIP User Agent generates global binding updates (SIP Re-INVITE or SIP REGISTER), asking for call redirection to this GCoA. The signaling flow for subsequent movement within the domain is then easy to construct. The MN merely informs its MA of its new LCoA. To support the QoS assurances over the new path, the MN may need to interact with the BB.

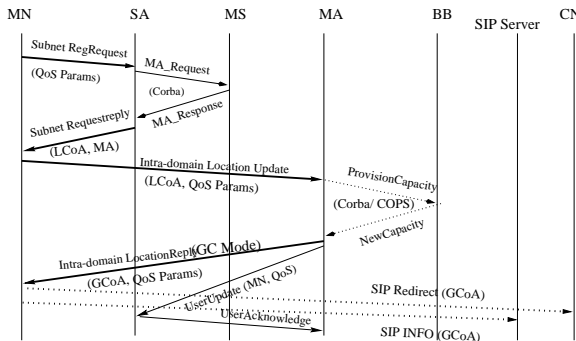


Figure 4: Signaling Flow for VoIP Mobility

B. Prototype Implementation and Ongoing Work

We have implemented a prototype of IDMP as a user level process in Redhat Linux and demonstrated its functionality in our testbed. The current code is based on enhancements to Stanford University's MosquitoNet [14] Mobile IPv4 code and integrates IDMP with Mobile IP. Such a combination is useful for certain TCP-based applications in mobile battlefield environments and is discussed in [15]. IDMP's MA daemon is a modified version of the HA, while the mobile client code has been modified to incorporate support for two separate CoAs. In the current version of our code, the MN uses DHCP as the configuration protocol for obtaining an LCoA, as well as the address of an MA. We are currently working on completing the development of the SA code, (to enable an MN to perform local registration using an SA), and on integrating our IDMP code with the SIP client code.

IV. CONCLUSION

In this paper, we showed the need for a hierarchical mobility solution in battlefield networks, especially for real-time applications, such as VoIP. We then explained our solution that combines DMA's network-layer intra-domain mobility management technique with SIP's application-layer global binding mechanism. Our solution is an attrac-

tive approach for supporting VoIP in dynamic, security-conscious battlefield topologies. The mobility hierarchy ensures that most binding updates, whether due to node or network mobility, remain confined within the domain, thereby significantly reducing the transients associated with the update latency. An MN can also use IDMP's fast handoff and paging mechanisms to further reduce the mobility-related transient and to minimize its mobility-related signaling load. Also, by completely separating intra-domain and global authentication and security mechanisms, IDMP allows for authenticated mobility management, even when the MN visits potentially untrusted foreign domains. *

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