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Poster Paper

Geo-mobility and Location Service in Spontaneous Wireless Mesh Networks

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Abstract: In this paper, we propose a mobility management scheme and a location service for *spontaneous wireless mesh networks*. Our mobility scheme builds upon separation between a persistent node identifier and its current address. We propose to use addresses coupled with geographical locations of nodes and maintain the mapping between identifiers and addresses in a distributed *Virtual Home Region Multi-Hash Location Service*. The paper presents the architecture for geographically based mobility and the design of the location scheme.

Keywords: Mobility management, multi-hash location service, geographic addressing spaces, virtual home region

1. Introduction

We consider the problem of supporting seamless mobility of highly mobile nodes in a *spontaneous wireless mesh network.* Such networks are characterized by an evolving, distributed, and self-organizing structure of wireless mesh routers that provide connectivity to mobile nodes. Communities of users can incrementally build such networks just by deploying additional mesh routers to increase coverage and the overall performance. Wireless mesh networks need to be *autonomic* to a great extent, because unlike the current Internet, they are not managed—they need operate without skilled personnel for configuring, connecting, and running mesh routers.

Traditional solutions for mobility management in the Internet such as Mobile IP and its variants suffer from many problems that hinder their effective deployment: high handoff latency, high packet loss during handoff, and important signalling overhead [6]. With the rapid proliferation of small handheld devices and with an increasing use of multihoming in which a node may have multiple identities, the existing proposals can be further impaired by scalability problems: as the number of mobile nodes increases, the number of binding updates increases proportionally to the number of mobile nodes. The problems of the traditional solutions may even amplify in spontaneous wireless mesh networks because of their evolving and autonomic nature.

In the paper, we propose to integrate mobility in a wireless interconnection architecture from scratch and not as a patch added to an existing architecture. Our approach is based on the following principles:

- *Separation of stable identifiers and addresses*. In the Mobile IP approach handoff latency comes from the need for acquiring a new address and registering it with a mobility agent. We propose to use an end-point identifier of a mobile node that remains unchanged wherever the node moves. At a given location, the mobile node uses the address of a nearby mesh router to become reachable from any other location in the network.

- *Distributed Location Service*. Separation of identities and addresses requires maintaining the mapping of this information for each mobile at some place. In the current Mobile IP approach this role is played by the system of Home Agents that store the information about the home address and the current care of address. To avoid important signalling overhead and scalability problems of Mobile IP and to provide the efficient mobility management inside the mesh network, we propose to use a distributed and scalable Location Service to store the mapping between the end-point identifier of a node and its current address. The location service mechanism, using multiple hash functions for robustness, is developed on the basis of the Virtual Home Region concept, but adapted to the requirements of wireless mobile networks.
- *Geographical addresses*. The current hierarchical structured form of the IP addresses enables highly scalable routing, but at the same time results in inefficient mobility handling, because a mobile node needs to acquire a new address at each topologically different point of attachment. We can improve handoff performance if addresses are bound to geographical positions of mesh routers (we explain later in the paper how we can construct a *pseudo-geographical* address space). Such addresses are topologically correct and offer a continuous coordinate system by construction, do not require time consuming checking for unicity, and can be efficiently allocated by mesh routers. With an increasing number of devices coming with GPS support, we can take advantage of precise geographical positioning of some nodes in the mesh.
- *Locality*. Using geographical addresses also results in the locality property: if a mobile node moves on short distances, the addresses of nearby mesh routers are topologically close to each other so that updating addresses can be done in a lazy way, which relieves location service from unnecessary signalling overhead.
- *Anonymity*. The problem of anonymity may arise in any system based on geographical addresses. We propose to protect mobile node anonymity by strictly separating address use—only mesh routers operate based on addresses, whereas mobile nodes only use end-point identifiers. In this way, only mesh routers, which are trusted elements, are aware of mobile node locations and all other mobiles only use virtual, location-free identifiers.
- *Geo-aware services*. A side effect advantage of building mobility support upon geographical addresses is the possibility of providing various types of location based services, such as finding users closed to a given mobile node or geo-casting—sending a message to the nodes in a geographical area.

This paper is organized as follows. Section 2 defines our mobility architecture and presents the mechanisms for mobility management. Section 3 concerns the distributed multi-hash location service mechanism and presents the design of its components. Section 4 analyzes the first research results and Section 5 concludes the paper.

2. Geo-mobility in Wireless Mesh Networks

We start with the definition of the main elements in our mobility architecture. As in many fundamental contributions in this domain [5, 9, 11], we distinguish between the following entities:

- *Node*: it is an entity capable of communicating and computing. It may be mobile (mobile node) or stable (mesh router).
- *End-point*: it is a logical communicating entity corresponding to a single node.
- *End-point identifier* (EID): it is a short binary identifier for an end-point. It is persistent, i.e. it does not change when a node changes its position.

- *Name*: it is a human readable unique identifier associated with an EID.
- *Address*: it is a locator: a short binary identifier used for locating an end-point in the mesh network so that routers can forward packets to it. The address may change when a node changes its position and its network interface.
- *Community*: it is a group of nodes that share a common trust relationship.

Figure 1 presents the mobility architecture of the wireless mesh. Mesh routers form the interconnection infrastructure for mobile nodes moving inside and getting connectivity from the nearest mesh router. The mesh network runs two core services: the *naming* service and the *location* service. The naming service provides the mapping between the name and the EID of a node like in the standard DNS service (it is not specific to mobility so it is not presented in the figure). The location service supports mobility and provides the information about the mapping between EIDs and addresses in a dynamic and robust way.

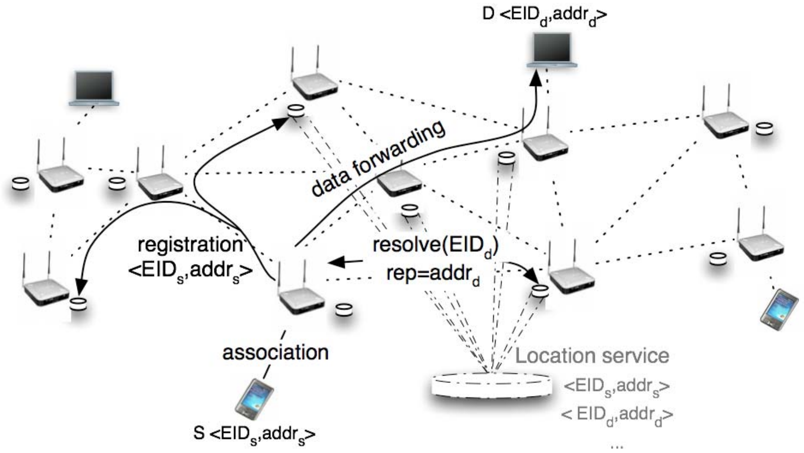

Figure 1: Mobility mesh architecture

Our approach to mobility is based on the assumption that an address reflects the position of a mesh router and of any other mobile nodes attached to the router. When a mobile node joins the mesh, it associates with a nearby mesh router that registers the mapping between its own address (the address of the router $addr_S$) and the node EID (EID_S of node S) in the location service. To communicate with destination node D, node S first resolves its name to get the corresponding EID (EID_D of node D) and starts sending packets to the destination EID via the mesh router. The latter resolves the EID by querying the location service that returns the address of the destination mesh router ($addr_D$). Then, it forwards packets to the destination address using a geographical long-distance routing (the description of the routing scheme is outside of the scope of the present paper). Finally, the destination mesh router delivers packets to the destination mobile node. So, the communicating nodes only see forwarding packets between their respective EIDs and mesh routers make use of geographical addresses to actually forward packets to the destination. Conceptually, the location service is a database maintaining the global location information that we have designed as a distributed service involving mesh routers.

As EIDs are persistent, the transport layer can use them across different network interfaces and across different locations to maintain long-lived transport connections in spite of mobility. We can construct EIDs in several ways: we can derive them from a public key like in HIP [9] or we can take into account a person that uses a node and derive EIDs from the public key of the node user.

2.1 –Pseudo-geographical addressing space

We propose to define a *coordinate address space* for assigning addresses to EIDs in an autonomous and a distributed way. Such a coordinate space may be either virtual or real one based for example on the GPS position of a node. Many proposals considered addressing and routing in virtual coordinate spaces [4, 7, 10]. Their advantage is a relative ease of generation compared to the requirement of GPS positioning. However, they present several drawbacks. The first one is related to merging two subnetworks. Imagine that two regions of the networks develop in a independent and unplanned way. Each part creates its addresses in a given portion of the virtual subspace (for instance, P2P approaches for constructing a virtual space such as CAN can be used). The problem is how to merge two parts when we place a mesh router interconnecting them. One part needs to change its addresses to accommodate for the addresses of the other part. We can also face address clashes if the parts allocate addresses from intersecting portions of the coordinate space. The second problem is that if we want to handle mobility, the distance in the addressing space needs to be correlated with the real world distance, because nodes physically moves in the real space. When the distances in the addressing space reflect real movements, the most common mobility of a node will be in its neighborhood, so changing addresses will only be limited to this part of space.

If addresses are derived from geographical positions of nodes, the problem of merging does not exist, because nodes in different locations use different addresses. However, this approach requires the knowledge of the exact positions of all nodes, which may be too difficult or too expensive to obtain. We propose to build a *topologically consistent addressing space* by only requiring that a small portion of nodes (e.g. of the order of 10%) know their exact geographical positions. We can easily achieve this, if some roof routers operate GPS devices and a few others, for instance indoors, learn their positions through manual configuration at deployment. All other routers estimate their relative positions to form a global topologically consistent addressing space. The resulting addressing space is *pseudo-geographical* in the sense that the coordinate space is virtual and relative, but anchored in the real world through the exact geographical positions of some nodes. We describe the details of the pseudo-geographical address space elsewhere.

2.2 –Handoff

When a mobile node moves, it can prepare to change mesh routers based on the information about the layer 2 characteristics of neighbor routers, for example choose a lightly loaded one. As the mobile node always uses the same EID independently of its position, it is up to mesh routers to perform all the required modifications during handoff, in particular, to update the location service with the address of the new mesh router that will handle the mobile node after handoff.

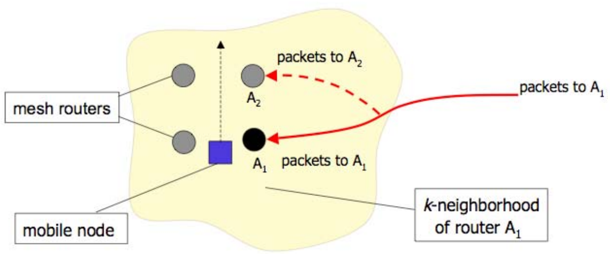

Figure 2: Handoff

Handoff performance depends on the update rate of the location service—this rate should be kept low for an efficient handoff. We can achieve this objective by updating the location service in a lazy manner when a mobile node moves inside a *k*-neighborhood. We call a *k*-neighborhood the closed vicinity of the mobile node composed of all routers *k* hops apart. As the mobile node moves in the real geographical space, the address of the next mesh router will be topologically close to the address of the previous one, the proximity depending on the distance and the speed of the movement. Imagine that the mobile node associated with router A_1 moves near router A_2 (cf. Figure 2). It chooses A_2 based on the available information and sends a *handoff* request to its current router A_1 that relays it to router A_2. Router A_2 registers the association with the mobile node and starts forwarding its packets. At the beginning, router A_1 can forward packets destined for the mobile host to A_2. At the same time, it will disseminate the information about the handoff in the *k*-neighborhood so that the mesh router at the border of the *k*-neighborhood can divert packets to the new address as shown in the figure. In this way, packets are re-routed via the shortest path to the new mesh router as soon as they enter in the *k*-neighborhood. Such a scheme does not require any notification of corresponding nodes about changed addresses, because they still send packets to the address of the previous mesh router A_1.

At some time however, router A_1 needs to update the location service. It can make the decision based on the progress of the mobile node, for instance when it approaches the border of the k-neighborhood. At that instant, router A_1 updates the EID binding with the address of the current mesh router with which the mobile node is associated and notifies the mesh routers of corresponding nodes about the change in the destination address. In this way, packets sent by corresponding nodes start coming to the current mesh router.

3. Distributed Location Service for Wireless Mesh Networks

Having a location service is fundamental for the correct operation of the proposed geo-mobility architecture. Its main requirements are the following ones: *scalability, robustness, accuracy (provision of the most recent address), low overhead, and low implementation complexity*. Moreover, it needs to fit the nature of wireless mesh networks and build upon its spontaneous cooperative structure.

We have considered some features of location services already designed for ad hoc networks [3, 8], but we have found that the ideas of the Virtual Home Region Location Service [1, 13] better match the above requirements. We have adapted them to design the *Virtual Home Region Multi-Hash Location Service,* a location mechanism that operates in the pseudo-geographical addressing space. Its main idea is to determine the geographic position of the location server maintaining EID-to-address mapping by means of one (or more) hash function known to all nodes. The hash function takes an EID as an argument and returns the physical position of the location server that can provide the address corresponding to the EID. As wireless mesh routers are much more stable than mobile nodes and are not energy constrained, we take advantage of these characteristics and distribute the address information throughout multiple mesh routers. Moreover, each mesh router only stores a part of the global location information. We adopt a *proactive* approach in which mesh routers periodically exchange address information to reduce the overhead that reactive location management schemes generate and to provide accurate information.

The Multi-Hash Location Service is based on the concept of a *Virtual Home Region* that we modified for better efficiency. A node has several virtual home regions that we call *HomeGeoClusters* (HGCs). Wireless Mesh Routers (WMRs) inside these regions store the information about the address of the node. The distinguishing features of the Location Service are the following:

- We use multiple hash functions (pre-defined and well-known by all nodes in the network) to increase robustness. Each function returns exactly one *HomeGeoCluster* for a given EID.
- The source can choose the best (e.g. based on geographical proximity) HGC from its point of view to reduce query overhead.
- We define a Visited Geographic Region called *VisitedGeoCluster* (VGC) for the case when geographic routing is used. The geographical address of a mobile node in a VGC changes when the node moves to support fine-grained mobility. In this way, mesh routers in VGC are able to forward packets to the node without having to modify the

address stored in the location table of the source node. This concept increases robustness and accuracy (up-to-date information) of address as well as it reduces the overhead of location updates.

- We maintain the proactive location database inside the clusters according to the soft-state principle to avoid maintaining stale entries.
- We define policies for triggering updates to reduce overhead.

3.1 –Building blocks of the Virtual Home Region Multi-Hash Location Service

The location service relies on two main concepts: a *HomeGeoCluster* and a *VisitedGeoCluster*. The *HomeGeoCluster* of node *n* is the geographical region defined by the address obtained by applying a hash function to the EID of node *n*. A node has more than one *HomeGeoCluster*: multiple hash functions are defined over the space of node EID and return the geographical positions of several different cluster centers.

More specifically, the HGC_i of node *n* is the subset of mesh routers forming the geographical neighborhood (cluster) around the location returned by the *i*-th hash function applied to the EID of node *n*, *i*=1,…, *k*, *k* being the total number of hash functions used. All mesh routers inside the HGC of node *n* maintain an entry for the node EID in their *location database*.

The *VisitedGeoCluster* is related to the geographical region around the current position of node *n*. The VGC of node *n* is the subset of mesh routers forming the geographical neighborhood (cluster) around node *n*. All mesh routers within the cluster maintain an entry for the node EID in their location database. Therefore, the location database of an arbitrary mesh router *x* contains an entry for the EID of node *n* if $x \in HGC_i(n)$ (for any *i*=1,…,*k*) or $x \in VGC(n)$. We call a mesh router with a location database a *location server*. To avoid stale information, location servers maintain soft-state entries, i.e. an entry disappears if a periodic message does not refresh its information.

Thus, each node has several *GeoClusters*, some HGCs and one VGC, as shown in Figure 3 in which *k*=2. The size of *GeoClusters* is defined in accordance with reliability requirements of the network in such a way that each *GeoCluster* maintains approximately a constant number of location servers. It is assumed that the routing protocol allows reaching these servers inside a cluster.

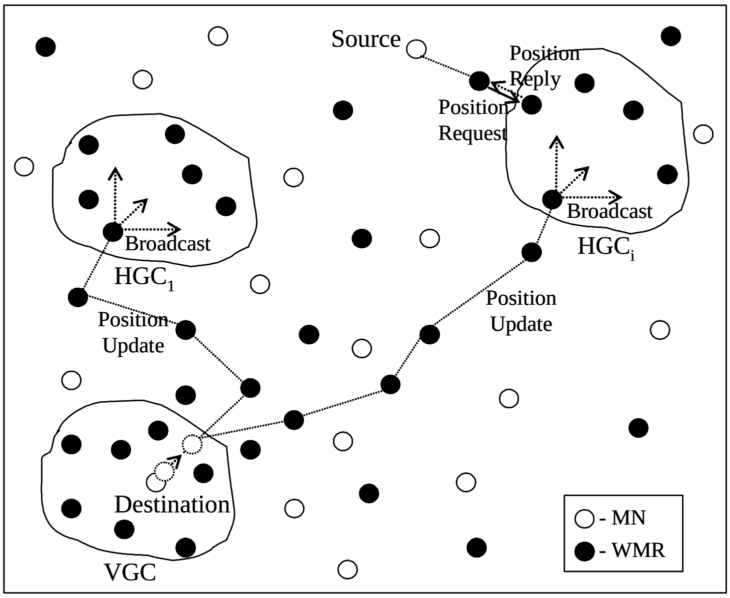

Figure 3: Multi-Hash Location Service

3.2 – Operation of the Virtual Home Region Multi-Hash Location Service

Node *n* triggers the update of the location database in the following cases: 1) at network initialization, 2) when joining the mesh, 3) when moving, 4) upon timeout to refresh the soft-state. Updating (or refreshing) location servers inside the VGC is different from that of location servers inside HGCs. In the case of the VGC, the WMR to which node *n* is attached, i.e. WMR_n, broadcasts updates to its neighborhood using the local knowledge of location servers inside its VGC. To update HGCs, the WMR sends *geo-broadcast* updates [12] to the addresses obtained from the multiple hash functions applied to the node EID. So, once an update message reaches the first location server of a *HomeGeoCluster*, it is flooded inside the *GeoCluster*. The location server also acknowledges the update to WMR_n. Note that WMR_n updates address information in parallel to all HGCs to increase system robustness even if it may lead to a slightly increased overhead. If there is no ACK from any of the HGCs, WMR_n repeats the process until all HGCs successfully receive the updated position. Location updates can be initiated in several different ways, e.g. movement-based, distance-based, timer-based, and so on [13]. When a node does not move, it periodically triggers refreshing of all HGCs and VGC. As a rule, VGCs are refreshed more often than HGCs, as they maintain fine-grained mobility information.

When a source node wants to send a packet to a given destination EID, it first passes it to its WMR (WMR_s) that initiates *location resolution* by querying the location service: it obtains the current geographical address of the WMR to which the destination node is attached (WMR_d). The packet stays in the buffer of WMR_s until the node obtains the address. The location resolution proceeds as follows. First, WMR_s checks its local cache to find an entry for a given destination EID. If the entry is not found, the router applies all hash functions to the destination EID to obtain the positions of all the HGCs and chooses the closest one. Then, it sends the location resolution query to this HGC using a *geo-anycast* [12]: the location query message is forwarded using geographic routing to reach *any* location server inside the HGC as shown in Figure 3. Then, the server that has received the query sends a unicast with the address of the destination. The reply uses geographical routing to reach WMR_s.

After receiving the location reply, WMR_s puts the geographical address of the destination node into the packet header and sends the packet to WMR_d through intermediate mesh routers using a geographical long-distance routing protocol. When the packet reaches an intermediate mesh router inside the *VisitedGeoCluster* of the destination node, it uses the local reachability knowledge of mesh routers in the VGC to reach the final destination, WMR_d.

After the initial location resolution phase, the source and destination nodes can communicate without new location requests. But, as they may be mobile, their WMRs need to apply *location tracking* [2], i.e. data packets must periodically piggyback the current addresses of communicating nodes. If there are no data to send, WMRs must periodically send on behalf of their attached nodes location update messages with their addresses. In this way, communication can continue based on accurate geographical addresses.

4. Analysis of Initial Research Results

At this stage, we have finished the design of the geo-mobility scheme and the supporting location service. Our goal was to propose mobility management mechanisms suitable for mobile nodes in a spontaneous wireless mesh and integrate them from scratch in the interconnection architecture. The main contribution is the definition of the architecture based on the separation of logical identifiers and geographical addresses as well as the design of the location service required for managing the location information. The proposed Multi-Hash Location Service is *transparent* and *flexible* from the viewpoint of the main underlying packet forwarding strategies for location-based routing that may include geographical greedy forwarding, restricted directional flooding, or hierarchical approaches combining both geographical forwarding for wide area routing and non-position based approaches for local area routing [8]. Therefore, the proposed mechanism for the location service fits the geo-mobility architecture defined in Section 2 fairly well, even if the routing scheme uses a combination of coarse-grained location-based routing for distant nodes and fine-grained topological routing for delivery in a *k*-neighborhood. In fact, in this case, the functions of the VGC to support robustness and fine-grained mobility are fulfilled by means of the fine-grained topological routing in the *k*-neighborhood. Mesh routers in the *k*-neighborhood perform all the required location updates when a mobile node moves. A moving node triggers location update for HGCs when it leaves the *k*-neighborhood of the mesh router that last updated its address information in its HGCs.

5. Conclusions

In this paper, we have described a geo-mobility scheme for mobility management. It is based on separation between logical identifiers and current addresses. It requires a distributed location service and a geographical addressing space. The proposed scheme presents several advantages for spontaneous wireless mesh networks: proper integration of mobility with forwarding and routing, improvement for the most frequent case of short distance movements in a close vicinity, and suitable support for location-aware geographical services. The design of the location service results in an increased scalability, robustness, and high accuracy of location information. Its distributed structure contributes to load sharing over multiple servers. We have started to validate the design through simulation and implementation of the main elements of the architecture.

Acknowledgments

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