Design and Evaluation of an Agenda-Based Location Service

Mathias Boc, Anne Fladenmuller, and Marcelo Dias de Amorim
LIP6/CNRS - UPMC Univ Paris 06
{boc, fladenmu, amorim}@rp.lip6.fr

Abstract—An interesting approach for the location service problem in wireless mesh networks is the one that relies on location agendas to model node displacements on an absolute time basis. To the best of our knowledge, the literature still lacks the design and evaluation of such an approach. In this paper, we introduce and analyze an agenda-based location service that reduces the overhead due to location updates. We evaluate the performance of our scheme with real mobility traces and observe that mobile nodes spend in average 80% of their time at a maximum distance of one hop from the expected locator. Furthermore, 81% of the location update messages are constrained within this radius. This drastically reduces the propagation areas when compared for instance with DHT-based approaches.

I. INTRODUCTION

An efficient location service is fundamental to any network that involves node mobility. By efficiency, we mean that the system must be able to: (i) provide accurate location information at anytime and (ii) achieve its goals at low control overhead. This latter point is particularly important in wireless networks where resources are scarce. In this paper, we focus on a self-organized IEEE 802.11 wireless mesh network (WMN) spanning a metropolitan area containing a large number of routers (dozens) providing connectivity to a large number of regular mobile users (potentially thousands). We address the problem of location service with the objective of reducing the overhead used to maintain up-to-date location information throughout the network.

There are three traditional ways to perform location management in a wireless mesh network: flooding-based, based on centralized servers, and based on distributed servers. While flooding leads to high overhead and possibly network collapse, centralized schemes (e.g., MobileIP [1]) can lead to large indirections of signaling messages. In such schemes, location updates generated by mobile nodes (MNs) and location lookups generated by corresponding nodes (CNs) must be forwarded to a location server (locator for short) that is potentially far from the nodes’ positions (triangular location). The same problem happens in promising approaches such as distributed hash table (DHT) based location services [2]. While hierarchical and grid-based approaches can reduce on the cost of location management to a local scope [3], [4], they require particular network organization and/or geographic information, which are not always available in the context of WMN.

In our scheme, we handle the functionality of locators as a mobile service. According to the mobility behavior of the MN from a per-node view, we propose to place the location functionality (and, consequently, the locators) at well-identified wireless mesh routers (WMRs). Being at anytime close to the current position of the MN, the active locator will be on or close to the shortest path between any CN and the MN, reducing then triangular location. Of course, such an approach requires the system to know the current location of each MN, which seems contradictory because this is exactly the goal of the location service. A possibility to solve this chicken-and-egg problem is to rely on some prediction of the node’s mobility behavior to define the most appropriate WMR that will play the role of locator.

Recent papers have underlined that users follow daily routines and that mobility patterns have cyclic properties (see the Mobidrive project [5] and analyses of GPS-tracked travelers [6], [7]). Based on these observations, the literature is now rich of mobility prediction models that estimate positions based on the history of users’ mobility patterns [8], [9], [10]. In a companion paper (cf., Section II), we showed that agenda-based mobility modeling could be used to predict the association point of a MN over long periods of time (at least 7 days) [11]. One key aspect of our mobility modeling is that the resulting structure, restricted in size, can be easily shared between users. This is the first step toward an efficient location service, subject of this paper.

We define an agenda-based location service and evaluate its performances with real mobility data traces. We support the key role of “agendas of locators” and the advantages offered by long-term mobility prediction and the possibilities of sharing these agendas. To validate our scheme, we performed a number of analyses using the publicly available traces collected in the Dartmouth campus [12]. The results show that over an observation period of 59 weeks, MNs spent 80% of their total time at one hop from their expected locators. Furthermore, 81% of the location updates remained within this one-hop radius. Because nodes spend most of their time directly associated to their active locators, the overhead due to forwarded location updates decreased by more than 40%.

II. AGENDA-BASED LOCATION SERVICE

In a nutshell, our objective is to have at anytime one active locator close to the mesh router the MN is currently
associated with. Because the MN and the active locator are nearby, location updates (due to high topological mobility) are localized around the mobile node, thus reducing their impact on the rest of the network (cf. Fig. 1). Meanwhile, CNs must know in advance where the active locators in charge of the location management of the MNs are positioned. Location lookups are then forwarded directly to the active locator that is the mesh router closest to the current position of the destination node. To reach this state, we use agenda-based mobility predictions to position the locators according to the temporal and spatial mobility of the MNs. We also introduce a global mapping system to support the sharing of the agendas with the other CNs.

The agenda-based mobility model is based on the mobility rhythm of the MNs [11]. The period (or cycle) of prediction is typically one week. This period is sliced into one-hour periods and each time period indicates a specific WMR. This approach relies on observed associations and durations of association. To integrate the generated agendas in our location system, we define two levels of services that we call functionalities, as they should be played by any of the WMRs.

The first service is operated through the locator functionality. The purpose of the locator is to store current positions of the nodes it manages by receiving pro-active location updates. In the same way, locators receive and respond to location lookups from other CNs. A locator manages the location of a node for a certain period of time specified in the MN’s agenda. A MN sends location updates to the locator indicated in the agenda for a particular time slot. Of course, a WMR can play the role of locator for one or several nodes at the same time.

The second service can be defined as a global mapping system. The purpose of this service is to share agendas among nodes. We propose the use of a DHT-based approach for performance, reliability, and scalability issues. By hashing the identifier of each node (unique network address or through a naming system), each server of the global mapping system is in charge of a set of nodes. By collecting agendas from all the nodes under its responsibility, the mapping server acts as a repository system. When the server receives a location query, it returns a copy of the current valid agenda of locators of the node. In this way, correspondent nodes are able to identify the current locator of the MN.

### A. Node position dissemination

Whenever a node is in the network, its current position has to be registered at its active locator and a valid agenda must be available through the global mapping service. These are the requirements for the coherence of the location system. Along time, the active locator changes and the agenda have to be renewed at each cycle of predictions. In this way, each node must provide the network with the necessarily information to maintain this coherent state at specific steps:

- **At the beginning of each cycle.** Agendas of locators are valid until the end of the current cycle of predictions. At the beginning of each cycle, the node has to generate a new agenda taking into account its recent and past mobility information. Once updated, it sends the new agenda to the global mapping server (arrow 1 in Fig. 1).
- **At the beginning of each time period and at each association.** The MN sends a location update to the locator in charge (arrows 2 and 3 in Fig. 1). In this message, the node provides the network address of the WMR it is associated with, as well as the corresponding validity period. While location updates generated at each association have a mobility tracking purpose, by doing this at the beginning of each time period, MNs indicate that they are still present in the network, as a heartbeat system does. This is also useful for nodes that remain static during several consecutive time periods.

### B. Nodes localization

Nodes follow the succession of locators provided in their agendas to disseminate their current position. To be able to retrieve such information, a CN must first fetch a copy of the agenda of the destination node from the global mapping system. Two situations may occur:

- **The destination node’s agenda is unknown.** To obtain the agenda of a MN, the CN sends an agenda – request to the WMR it is associated to, providing the identifier of the destination node. The WMR applies a hash function on the identifier of the destination node to identify the mapping server in charge. Once determined, it forwards this agenda request to the resulting mapping server. This latter returns a copy of the agenda to the node if the agenda is valid for the current cycle of predictions. If it is not valid, this means the destination node is not yet associated in the network. Then the server returns an error message.

- **The CN already has a valid copy of the MN’s agenda.** The CN is then able to determine the current active locator for the destination node. To obtain the current position of the node, it sends a location request to this locator. The locator responds with a location – response providing the current position of the destination node. It replies with an unreachable – node message if the MN has not updated its current position.
Now that we have described the architecture of our location service, we present an evaluation using real data traces collected in the Dartmouth campus.

III. EVALUATION SETUP

To evaluate the performance of our location service, we need real mobility data traces from an environment where we will be able to observe nodes mobility according to a fixed infrastructure. Due to the lack of data traces focused on nodes mobility behaviors in real WMNs, we chose to extrapolate a WMN topology from a conventional IEEE 802.11 wireless network. The dataset we use represents 3 years (2001-04-11 to 2004-06-30) of collected information about all wireless adapters connected to the wireless access network of Dartmouth campus. The campus is composed of 188 buildings covered by 566 official access-points (APs) on 200 acres and about 5,500 students. From this dataset, we chose a subset of 4,961 mobile nodes over an observation period of 59 weeks (between the first Monday of January 2003 to the last Sunday of February 2004).

We measure path lengths between position of the MNs and their predicted locators. The infrastructure of the wireless network of the Dartmouth campus is composed by APs (that will represent our WMRs). To evaluate our system in a wireless mesh network context, we virtually interconnect the overall topology by wireless links between the APs. The algorithm that we used to obtain a wireless mesh topology from the known topology of the campus network and from the roaming events of the MNs is based on three steps:

- **Interconnect APs with coordinates.** We have the coordinates of 506 APs out of the 590 visited (cf. Fig. 2). The first step of the algorithm is then to interconnect these 506 APs on the basis of average radio coverage.

- **Interconnect APs involved in short-term handoffs.** The second step is to attach to the obtained topology the APs that do not have coordinates but that have been involved in roaming events where the duration of handoffs was less or equal to 1 second. In this step, 45 APs have been included to the topology.

- **Interconnect the remainder APs.** In this step, we only link the remainder APs that have been involved in roaming events with the already obtained topology.

The interconnection is made on the basis of the smallest duration of handoff and we consider this link as obtained with the use of directional antennas.

With this algorithm, we obtained a wireless mesh topology, which have a diameter of 19 hops.

IV. RESULTS

We evaluate the accuracy of locator determination and the cost of the signaling messages in terms of number of hops according to our generated topology. We evaluate the two functionalities of the approach: global mapping system and locator functionality.

To evaluate the DHT-based global mapping system, we assign to each node one global mapping server according to a MD5 operation on its identifier. We compare the performances with different number of servers as \( n \)-DHT systems (with \( n \) varying from 1 to 512 servers randomly placed throughout the network). We ran one hundred times each setup.

We evaluate the accuracy of locator predictions through both the duration of association that nodes have spent at different distances from the locator position and the path lengths of all location updates. We compare our system with a pure DHT approach.

A. Locators positioning

We observed node mobility over a period of 59 weeks. During this period, all nodes have not been active every week. The proportion of active users varied along the observation period. Each week, the number of predicted locators indicates that we catch fairly well current places of interest.
This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE "GLOBECOM" 2008 proceedings.
represents here 12,677,457 location updates. With the normal behavior it has been 19,035,169 location updates that have been generated which represent 6,357,712 added signaling messages. 64% of the overhead messages have been generated when the nodes were directly associated with their active locators and 21% when they were at one hop. Then 85% of the overhead messages have not been forwarded through more than one hop.

This figure also comforts the fact that, with our system, problematic location updates are well handled. Indeed, as nodes stayed most of the time associated to their active locator, the high number of generated location updates at 0 and 1 hop indicate that they have had high micro-mobility between the active locator and the WMRs around at one hop.

Finally, because nodes have spent large amount of time directly associated to the active locators, we reduced the number of forwarded location updates when the nodes are directly associated to their active locators. Quantitatively, 44% of the location updates have disappeared with our approach in the normal behavior and 34% without the overhead messages.

V. SUMMARY AND OUTLOOK

In this paper, we designed and evaluated an agenda-based location service. The view in this proposal was to reduce the cost of location management by optimizing the position of the locator between the MN and potential CNs. To reduce triangular location and to contain the propagation of highly frequent location updates, we propose to position the locator close to the current position of the MN. To obtain prior information on where the MN is and will be in the long term, we used agenda-based mobility modeling to provide a list of WMRs that will play the role of locator for the node.

In our system, one MN follows mobility prediction to create an agenda that informs other nodes about the position of the locator to contact for location lookups. The dissemination of the agendas is supported by a global DHT-based mapping system.

The analyses that we performed using publicly available traces collected in the Dartmouth campus showed that our location service is efficient (nodes stayed 80% of their time at one hop radius from the expected locator) and that the improvements can be considerable: 81% of the location updates contained to a one hop radius and the proportion of forwarded location updates decreased by more than a third.

Because, with a high probability, we know that the mobile node will be very close of the active locator, we are currently investigating how to combine our agenda-based location service with an adaptive routing strategy to reduce even more the cost of location lookups.

REFERENCES