A Survey On Recent Research Based On Location Management In Cellular Networks

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Abstract

It has been known for over one hundred years that radio can be used to keep in touch with people on the move. However, wireless communications using radio were not popular until Bell Laboratories developed the cellular concept to reuse the radio frequency in the 1960s and 1970s. Over the past few years, wireless mesh networks (WMN) are gaining growing interest. This trend follows the popular needs for the inexpensive, continuous wireless wide-area coverage. A seamless wireless access is a common goal of the future communication. Current deployment of the wireless mesh networks (WMN) necessitates mobility management to support mobile clients roaming around the network without service interruption.

The purpose of this paper is to survey recent research on location management in cellular networks and study major challenges to maintain service continuity based on the system model and also identify location management schemes used to access data in Wireless Mesh Networks.

1. Introduction

In the past decade, cellular communications haveexperiencedanexplosivegrowthduetorecenttechnologicaladvancesin cellular networks and cellular phone manufacturing. It is anticipated that they will experience even more growth in the next decade. In order to accommodate more subscribers, the size of cells must be reduced to make more efficient use of the limited frequency spectrum allocation. This will add to the challenge of some fundamental issues in cellular networks. Location management is one of the fundamental issues in cellular networks.

In a cellular network, a service coverage area is divided into smaller areas of hexagonal shape, referred to as cells. The cellular concept was introduced to reuse the radiofrequency. In order to accommodate more subscribers, the size of cells must be reduced to make more efficient use of the limited frequency spectrum allocation. This will add to the challenge of some fundamental issues in cellular networks. Location management is one of the fundamental issues in cellular networks. It deals with how to track subscribers on the move. This paper surveys recent research on location management in cellular networks.

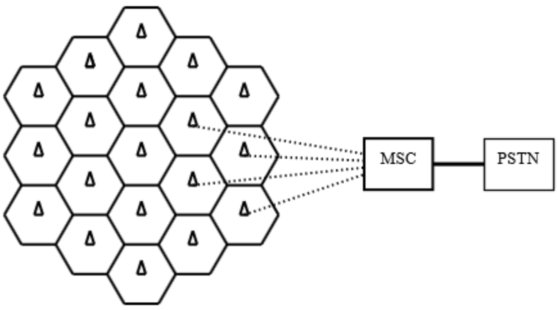

Figure 1: A Typical Cellular Network

Mobility management is not a new topic in other existing networks. In cellular systems, this part has already been a critical part to the continuous service of the mobile clients. Handoff quality is one of the most indispensable testing items in each field trial test. However, wireless mesh networks, which lack of infrastructure such as HLR and VLR, face more challenges in mobility management. Mobile IP is an approach which provides mobility support to mobile clients with IP identity. The main idea is very similar to the HLR/VLR mechanism in cellular systems. Home Agent (HA) and Foreign Agent (FA) play the roles of home database and visiting database in the IP networks, respectively. Home address is used as the ID of a mobile client and the Care-of-Address (CoA) is used to locate the current position of the moving mobile clients.

Mobile IP can provide a solution to the inter-domain movement in WMNs. However, it is not suitable for the intra-domain movement, which is much more frequent than the inter-domain movement. The reason is that if FA is implemented in every AP, signaling cost and handoff latency become the major problems to the mobility support. Therefore, the solution to cope with the local movement is required. Protocols for IP micro-mobility have been proposed to solve the mobility dilemma in small-scale networks. Though these protocols can be applied to WMNs, heavier signaling cost and longer handoff latency due to more frequent local movement in WMNs still impede the practical mobility support.

Wireless Mesh Networks (WMNs) have emerged as one of the major technologies for 4G high-speed mobile networks. The WMNs provide a ubiquitous solution for wireless Internet access and MS-to- MS communication with low deployment cost. Fig. 1 illustrates a general WMN architecture that comprises two kinds of fixed mesh nodes (MNs). The mesh backhaul is a gateway between the WMN and Internet through which all packets are delivered between the WMN and the Internet. The mesh access point (MAP) provides network access service to the mobile stations (MSs) through the wireless access links. A wireless mesh link exists between two MNs that are located within each other's radio coverage area. The MN location is stationary.

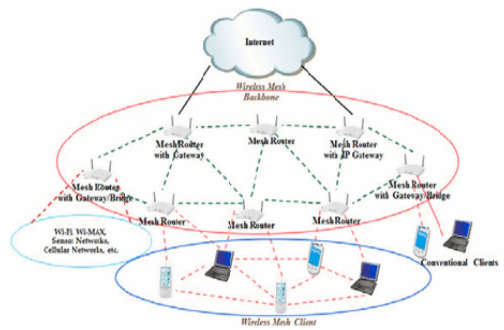

Figure 2: WMN Typical Structure

In this paper, we study how to develop two per-user-based mobility management schemes for WMNs.

2. Location Management

Location management deals with how to keep track of an active mobile station within the cellular network. A mobile station is active if it is powered on. Since the exact location of a mobile station must be known to the network during a call, location management usually means how to track an active mobile station between two consecutive phone calls. There are two basic operations involved with location management: location update and paging. The paging operation is performed by the cellular network. When an incoming call arrives for a mobile station, the cellular network will page the mobile station in all possible cells to find out the cell in which the mobile station is located so the incoming call can be routed to the corresponding base station. This process is called paging. The number of all possible cells to be paged is dependent on how the location update operation is performed. The location update operation is performed by an active mobile station. A location update scheme can be classified as either global or local. A location update scheme is global if all subscribers update their locations at the same set of cells, and a scheme is local if an individual subscriber is allowed to decide when and where to perform location update. A local scheme is also called individualized or per-user based. From another point of view, a location update scheme can be classified as either static or dynamic. A location update scheme is static if there is a predetermined set of cells at which location updates must be generated by a mobile station regardless of it mobility. A scheme is dynamic if a location update can be generated by a mobile station in any cell depending on its mobility. A global scheme is based on aggregate statistics and traffic patterns, and it is usually static too. Location areas and reporting centres are two examples of global static schemes. A global scheme can be dynamic. For example, the time varying location areas scheme is both global and dynamic. A per-user based scheme is based on the statistics and/or mobility patterns of an individual subscriber, and it is usually dynamic. The time-based, movement based and distance based schemes are three excellent examples of individualized dynamic schemes. An individualized scheme is not necessary dynamic. For example, the individualized location areas scheme is both individualized and static. Location management involves signalling in both the wireline portion and the wireless portion of the cellular network. However, most researchers only consider signalling in the wireless portion due to the fact that the radio frequency bandwidth is limited while the bandwidth of the wireline network is always expandable. This chapter will only discuss signalling in the wireless portion of the network. Location update involves reverse control channels while paging involves forward control channels. The total location management cost is the sum of the location update cost and the paging cost. There is a trade-off between the location update cost and the paging cost. If a mobile station updates its location more frequently (incurring higher location update cost), the network knows the location of the mobile station better. Then the paging cost will be lower when an incoming call arrives for the mobile station. Therefore both location update and paging costs cannot be minimized at the same time. However, the total cost can be minimized or one cost can be minimized by putting a bound on the other cost. For example, many researchers try to minimize the location update cost subject to a constraint on the paging cost. The cost of paging a mobile station over a set of cells or location areas has been studied against the paging delay. There is a trade-off between the paging cost and the paging delay. If there is no delay constraint, the cells can page sequentially in order of decreasing probability, which will result in the minimal paging cost. If all cells are paged simultaneously, the paging cost reaches the maximum while the paging delay is the minimum. many researchers try to minimize the paging cost under delay constraints.

Existing mobility (location) management schemes can be classified largely into two categories: tunnel-based schemes and routing-based schemes. Examples of tunnel-based mobility management schemes include Mobile IP, MIPRR, HMIP, and IDMP proposed for Mobile IP networks, and Ant and M3 proposed for WMNs. The basic idea of tunnel-based schemes is that mobile hosts explicitly register or update their location information to some centralized location servers, e.g., home agents in Mobile IP or gateway foreign agents in MIP-RR, through location registration/update messages. Such messages incur significant signalling cost for highly mobile clients. This is particularly a severe problem if location registration/update messages are sent upon every location change. For example, in Ant, a location update message has to be sent to a central location server every time a mobile host changes its serving MR. Routing-based schemes represent another class of mobility management schemes proposed for various types of IP-based networks. Typical examples of routing-based mobility management schemes include Cellular IP and HAWAII proposed for Mobile IP networks, and WMM, iMesh, MEMO, and the scheme in WMNs. The basic idea of routing-based schemes is that mobility management is integrated with routing such that location information of mobile hosts can be propagated throughout the network through regular packet routing.

In Cellular IP, HAWAII, and WMM, in addition to routing tables, routers also maintain location caches that store location information of mobile hosts for which they have routed packets. One of the most distinct characteristics of these routing-based schemes is that data packets originated from a mobile host carry the current location information of the sender. Therefore, the location information of the mobile host kept in a router's location cache can be updated when the router processes data packets originated from the mobile host. In this way, the host-specific route of the mobile host is updated when it sends data packets.

Because the update of location information and the maintenance of host-specific routes in these routing-based schemes solely rely on packet routing, they are essentially opportunistic. Specifically, for idle mobile hosts that are not sending any data packets, their location information may become outdated and consequently their host-specific routes may become obsolete. This leads to a major performance deficiency of these routing-based schemes. LMMesh proposed in this paper uses pointer forwarding to solve the above problem, and at the same time, minimizes the overall network traffic incurred by mobility management and packet delivery.

In both schemes, each domain is identified by a single gateway and the entire domain is constructed to a tree-like structure. Both schemes require each router to maintain a routing entry for each mobile client in the downstream APs' coverage. When handoff occurs, the corresponding routing entries will be updated in all the routers involved from the new AP to the crossover router which is shared by the new AP and old AP. The invalid routing entries in the routers of the old path need to be removed. Due to the major feature of per-host routing, this type of schemes is called mobile-specific routing approach. Another important type of IP micro-mobility protocols is the hierarchical tunnelling approach, an example of which is Mobile IP Regional Registration (MIP-RR). Hsieh et al. proposed another scheme, namely, Hierarchical Mobile IPv6.

This type of schemes replaces the mobile-specific routing by introducing the tunnelling technique. Through the hierarchical registration procedure, the higher-level FA knows the location information (ID of the lower-level FA) of the mobile clients and encapsulates the data packets with the destination address of this lower-level FA. Per-host routing entry is not required for the routers in these schemes while per-host location information is still stored in FAs. Due to the extra processing of encapsulation and decapsulation as in Mobile IP, larger delay is introduced to each flow. Additional cost of this type of schemes is that two or more CoAs have to be used. When handoff takes place, the registration with a different CoA also adds extra delay. The intuitive idea of this approach is to extend the Mobile IP mechanism to local movements.

3. LMMesh

In this section, we study the proposed location management scheme, namely LMMesh. In next sections we discuss the protocol behaviour when an MC is within a gateway zone. We discuss the protocol behaviour when an MC moves from one gateway zone to another. Finally, we address the scalability of LMMesh.

a. Routing-based Location Update and Pointer Forwarding,
b. Integration and its impact
c. Location Search Procedure
d. Data Packet Routing
e. Multiple Gateways
f. Scalability of LMMesh

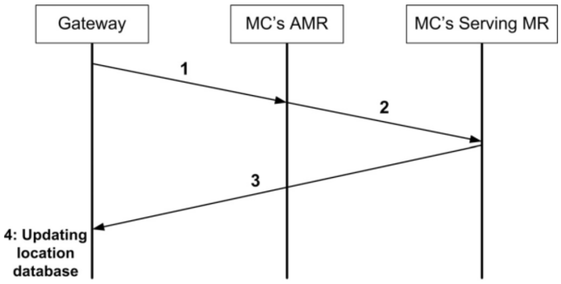

Figure 3: The Location Search Procedure for Internet Sessions.

Fig. 3 illustrates the pointer forwarding method using an example in which $K = 2$, described below:

a) When the MC moves from its current AMR, which is also its current serving MR, to MR1, a forwarding pointer is setup between its AMR and MR1 and the forwarding chain length is one,

b) The MC moves to MR2 after employing MR1 as its serving MR for some time, and a forwarding pointer is setup between MR1 and MR2 and the forwarding chain length becomes two,

c) The MC again moves, this time to MR3, after being associated with MR2 for some time. This third movement causes the forwarding chain being reset because $K = 2$;

d) MR3 becomes the MC's new AMR, and a location update message is sent to the gateway to update the MC's location information stored in the location database.

The use of routing-based location update has a positive effect of reducing the signalling traffic of explicit location update messages in pointer forwarding. The reason is that LMMesh relies less on the explicit location update messages in pointer forwarding for location management when an MC is actively sending data packets. On the other hand, when an MC does not have active network sessions or is not sending data packets, the use of pointer forwarding addresses the problems associated with routing-based location update. Particularly, the costly location query procedure based on broadcasting as in is avoided by using the pointer forwarding method. Fig. 4 illustrates the location search procedure for a new Internet session initiated towards an MC, which is described as follows:

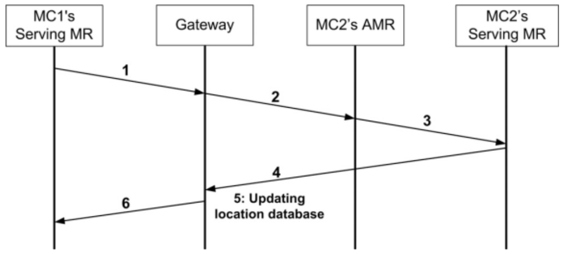

Figure 4: The Location Search Procedure for Intranet Sessions

i) When an Internet session initiated by an Internet host towards an MC arrives at the gateway, the gateway sends a location request message to the MC's current AMR (the gateway keeps the address of the MC's AMR in the location database);

ii) The AMR forwards the message to the MC's current serving MR;

iii) Upon receiving the location request message, the MC's current serving MR sends a location update message back to the gateway, making itself the new AMR of the MC;

iv) The gateway updates the location information of the MC in the location database, and the location search procedure is completed.

4. Performance Evaluation

In this section we study common assumptions to evaluate the performance of location management schemes in detail.

The network topology can be either one-dimensional or two dimensional. In one-dimensional topology, each cell has two neighbouring cells if they exist. Some researchers use a ring topology in which the first and the last cells are considered as neighbouring cells. The one dimensional topology is used to model the service area in which the mobility of mobile stations is restricted to either forward or backward direction. Examples include highways and railroads.

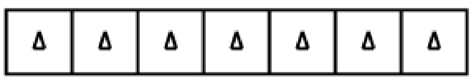

Figure 5: One-dimensional Network Topology

The two-dimensional network topology is used to model a more general service area where mobile stations can move in any direction. There are two possible cell configurations to cover the service area, hexagonal configuration and mesh configuration. In hexagonal cell configuration where each cell has six neighbouring cells. Although eight neighbours can be assumed for each cell in the mesh configuration, most of researchers assume four neighbours (horizontal and vertical ones only). Although the mesh configuration has been assumed for simplicity, it is not sure whether the mesh configuration, especially the one with four neighbours, is a practical model.

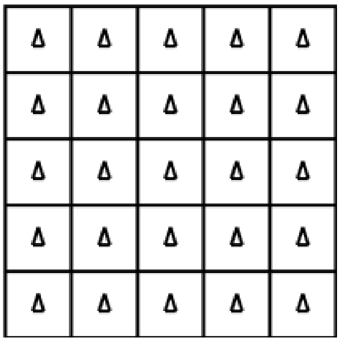

Figure 6: Two-dimensional network topology with the mesh configuration.

The call arrival probability plays a very important role when evaluating the performance of a location management scheme. If the call arrival time is known to the called mobile station in advance, the mobile station can update its location just before the call arrival time. In this way, both costs of locate update and paging are kept to the minimum. However, the reality is not like this. Many researchers assume that the incoming call arrivals to a mobile station follow a Poisson process. Therefore the inter arrival times have independent exponential distributions with the density function. Some researchers assume the discrete case. Therefore the calls inter arrival times have the geometric distributions with the probability distribution function.

The mobility pattern also plays an important role when evaluating the performance of a location management scheme. A mobility model is usually used to describe the mobility of an individual subscriber. Sometimes it is used to describe the aggregate pattern of all subscribers. The following are several commonly used mobility models.

- Fluid Flow
- Random Walk
- Markov Walk
- Cell Residence Time Based
- Gauss Markov
- Normal Walk
- Shortest Path
- Activity Based

5. Location Management Schemes

In this section we study the propose and analyze an adaptive per-user per-object cache consistency management (APPCCM) scheme for mobile data access in wireless mesh networks.

APPCCM supports strong data consistency semantics through integrated cache consistency and mobility management. The objective of APPCCM is to minimize the overall network cost incurred due to data query/update processing, cache consistency management, and mobility management. In APPCCM, data objects can be adaptively cached at the mesh clients directly or at mesh routers dynamically selected by APPCCM. APPCCM is adaptive, per-user and per-object as the decision regarding where to cache a data object accessed by a mesh client is made dynamically, depending on the mesh client's mobility and data query/update characteristics, and the network's conditions. We develop analytical models for evaluating the performance of APPCCM and devise a computational procedure for dynamically calculating the overall network cost incurred. We demonstrate via both model-based analysis and simulation validation that APPCCM outperforms non adaptive cache consistency management schemes that always cache data objects at the mesh client, or at the mesh client's current serving mesh router for mobile data access in wireless mesh networks.

There are two caching modes in APPCCM, namely CCM and DPM. In CCM, a data object accessed by an MC is cached directly by the MC, whereas in DPM, the data object is cached by a data proxy running on an MR. A data proxy is essentially a data cache maintained by an MR. Modern MRs have sufficient computing power and storage capacity to perform both routing and data caching. The rationale of using data proxies to cache data objects is that it incurs less network cost than always caching data objects directly at the MCs, under certain circumstances. More specifically, when a data object is updated more frequently than being accessed by an MC such that the invalidation cost is dominating, it may be beneficial to cache the data object at a data proxy rather than locally at the MC to reduce the invalidation cost and hence the total communication cost. On the other hand, if a data object is accessed more frequently by the MC than being updated such that the access cost is dominating, it may be beneficial to let the MC cache the data object directly to avoid the additional cost of accessing a data proxy. Therefore, there exists a tradeoff between the access cost and invalidating cost. APPCCM exploits this tradeoff and adaptively decides on a per-user per object basis where to cache a data object based on the data object's QUR and the MC's mobility characteristic. The decision is made independently for each data object accessed by each individual MC. Therefore APPCCM is an adaptive per-user per-object cache consistency management scheme.

In APPCCM, each MC maintains a *caching status table* that keeps the caching status of each data objects it has accessed.

When an MC receives a new data query from an application, it first checks its caching status table to see whether an entry for the queried data object exists or not in the table, and if an entry is found, it determines where the data object is currently cached and if the cached copy is still valid. Depending on the result of this table lookup, the query is answered accordingly in different ways. The pseudo code presented below describes the query processing algorithm.

6. Conclusion

The cellular network was introduced to reuse the radio frequency such that more people can take advantage of wireless communications. Location management is one of the most important issues in cellular networks. It deals with how to track subscribers on the move. Wireless Mesh Network became a ubiquitous solution wireless internet access and communication with low deployment cost. WMNs are interesting not only in the context of small community networks but also in the area of enterprise wide networks. Tunnel based schemes and routing based schemes became more efficient existing mobility management schemes.

Network topology, call arrival probability, and mobility patterns have a great impact on the performance of a location management scheme.

7. References

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