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PERFORMANCE OF MOBILITY FOR WIRELESS MESH NETWORKS

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ABSTRACT:

wireless mesh networks (WMNs) with the objective to reduce the network traffic incurred by mobility management and packet delivery is proposed. These schemes are per-user based, i.e., the optimal threshold of the forwarding chain length that minimizes the overall network traffic is dynamically determined for each individual mobile user, based on the user's specific mobility and service patterns. Analytical models based on stochastic Petri nets are developed to evaluate the performance of the proposed schemes. We demonstrate that there exists an optimal threshold of the forwarding chain length, given a set of parameters characterizing the specific mobility and service patterns of a mobile user. We also demonstrate that our schemes yield significantly better performance than schemes that apply a static threshold to all mobile users. A comparative analysis shows that our pointer forwarding schemes outperform routing-based mobility management protocols for WMNs, especially for mobile Internet applications characterized by large traffic asymmetry for which the downlink packet arrival rate is much higher than the uplink packet arrival rate.

Index Terms—Mobility management, pointer forwarding, wireless mesh networks, performance analysis, stochastic Petri net.

INTRODUCTION

WIRELESS Mesh Networks (WMNs) are gaining rapidly growing interest in recent years, and are widely acknowledged as an innovative solution for next-generation wireless networks. Compared with traditional wireless and mobile networks, e.g., Wi-Fi based wireless networks and mobile IP networks, WMNs have the advantages of low cost, easy deployment, self organization and self healing, and compatibility with existing wired and wireless networks through the gateway/ bridge function of mesh routers. A WMN consists of mesh routers and mesh clients [1]. Mesh routers are similar to ordinary routers in wired IP networks, except that they are connected via (possibly multi-channel multi-radio) wireless links. Mesh clients are wireless mobile devices, e.g., PDAs, smart phones, laptops, etc.

A major expected use of WMNs is as a wireless backbone for providing last-mile broadband Internet access [2] to mesh clients in a multi-hop way, through the gateway that is connected to the Internet. Because mesh clients may move within a WMN and change their points of attachment frequently, mobility management is a necessity for WMNs to function appropriately. Mobility management consists of location management and handoff management [3]. Location management keeps track of the location information of mesh clients, through location registration and location update operations. Hand- off management maintains ongoing connections of mesh clients while they are moving around and changing their points of attachment.

Mobility management has been studied intensively for cellular networks and mobile IP networks. A large variety of mobility management schemes and protocols have been proposed for those types of networks over the past years. Comprehensive surveys of mobility management in cellular networks and mobile IP networks can be found in [3] and [4], respectively. Due to some significant differences in network architecture, however, mobility management schemes proposed for cellular networks and mobile IP networks are generally not appropriate for WMNs. For example, the lack of centralized management facilities, e.g., HLR/VLR in cellular networks, and HA/FA in mobile IP networks, makes a large portion of the schemes proposed for those types of networks not directly applicable to WMNs, as argued in [1]. Therefore, the development of new mobility management schemes, which take into consideration of the unique characteristics of WMNs, is interesting and important. Additionally, mobility management schemes that are on a per-user basis are highly desired. A per-user based mobility management scheme can apply specific optimal settings to individual mobile users such that the overall network traffic incurred by mobility management and packet forwarding is minimized. The optimal settings of each mobile user should depend on the user's specific mobility and service patterns, and should be computationally easy to determine.

We develop two per-user based mobility management schemes for WMNs, namely, the *static anchor* scheme and *dynamic anchor* scheme. Both schemes are based on pointer forwarding, i.e., a chain of forwarding pointers is used to track the current location of a mesh client. The optimal threshold of the forwarding chain length is determined for each individual mesh client dynamically based on the mesh client's specific mobility and service patterns.

We develop analytical models based on stochastic Petri nets to evaluate the performance of the proposed schemes. Using the stochastic Petri net models, we demonstrate that for both schemes, there exists an optimal threshold of the forwarding chain length that minimizes the overall network traffic incurred by mobility management and packet forwarding, when given a set of parameters characterizing the specific mobility and service patterns of a mesh client. We show that our schemes can yield significantly better performance than schemes that apply a static threshold to all mesh clients, especially when a mesh client's mobility rate is relatively high compared to its service rate. Between the two proposed schemes, we show that the dynamic anchor scheme is better in typical network traffic conditions, whereas the static anchor scheme is better when the service rate of a mesh client is considerably high such that the advantage of the dynamic anchor scheme is offset by the extra cost.

We also carry out a comparative performance analysis to compare our schemes with a representative routing based mobility management scheme named Wireless mesh Mobility Management (WMM) [5]. To study the performance of the WMM scheme, we develop an analytical model that is also based on stochastic Petri nets for the WMM scheme. The comparative performance analysis shows that our schemes outperform the WMM scheme, especially when the network traffic is dominated by mobile Internet applications characterized by large traffic asymmetry, i.e., the traffic load on the downlink is much larger than that on the uplink.

Although mobility management has been studied intensively for other types of networks, e.g., cellular networks and mobile IP networks, it is relatively unexplored for WMNs. As suggested in [6], existing mobility management schemes proposed for WMNs fall into three categories, i.e., tunneling-based, routing-based, and multicasting-based.

Tunneling-based Schemes

Ant [7] is a Mobility management protocol that supports intra-domain mobility within a WMN. Although the use of MAC-layer events can help Ant speedup handoff, the signaling cost of location updates in Ant is considerably high, because a location update message has to be sent to a central location server every time a mesh client changes its point of attachment. This is especially as average problem if the average mobility rate of mesh clients is high.

Huang et al. [8] proposed a mobility management for WMNs called M^3, which combines per-host routing and tunneling to forward packets to mesh clients. The gateway hosts the location database and user profiles in M^3. Like our schemes, M^3 is based on pointer forwarding. However, M^3 adopts a periodic location update approach, and the location update interval is uniform for all mesh clients. In that sense, M^3 is not a per user based mobility management scheme, and therefore cannot guarantee optimal performance for every mesh client.

Routing-based Schemes

iMesh [9] is an infrastructure-mode 802.11-based WMN. iMesh adopts a cross-layer approach for mobility management and develops a routing-based mobility management scheme. A link layer handoff is triggered when a mesh client moves out of the covering area of its current serving mesh router. After the link-layer handoff is completed, the routing protocol used in iMesh, the Optimized Link State Routing (OLSR) protocol, broadcasts an HNA message announcing the new route of the mesh client. Mobility management in iMesh therefore incurs significant overhead due to the broadcasting of the HNA message.

MEsh networks with Mobility management (MEMO) [10] is the implementation of an applied WMN with support of mobility management. MEMO uses a modified AODV routing protocol, called AODV-MEMO, for integrated routing and mobility management. Like the Ant scheme, MEMO also adopts MAC-layer triggered mobility management (MTMM). Although this cross layer design (Layer 2 and 3) helps reducing the handoff latency, the use of flooding by mesh clients to inform correspondence nodes about location handoffs leads to high signaling cost and bandwidth consumption.

A common problem of iMesh and MEMO is that both of them are based on routing protocols proposed for mobile ad-hoc networks that rely on broadcasting for route discovery or location change notification, thus excessive signaling overhead is incurred.

WMM [5] is a novel routing-based mobility management scheme proposed for WMNs. Location cache is used in combination with routing tables in the WMM scheme for integrated routing and location management. Because location update and location information synchronization can be done while mesh routers route packets, the WMM scheme does not incur significant signaling overhead, as in tunneling-based and multicasting based schemes. Additionally, as discussed, the WMM scheme can be virtually viewed as a variant of mobility management schemes based on pointer forwarding, since relevant operations in the WMM scheme resemble forwarding pointer setup and reset operations in pointer forwarding approaches.

Multicasting-based Schemes

SMesh [11] offers a seamless wireless mesh network system to mesh clients, in the sense that mesh clients view the system as a single access point. Fast handoff in SMesh is achieved by using a group of mesh routers to serve a mesh client and multicast traffic to the mesh client during the handoff. This incurs a high signaling cost, which is especially a severe problem when the average mobility rate of mesh clients is high. Management of multicasting groups is also a major source of signaling overhead in SMesh.

SYSTEM MODEL

A WMN consists of two types of nodes: mesh routers (MRs) and mesh clients (MCs). MRs are usually static, and form the wireless mesh backbone of WMNs. Some MRs also serves as wireless access points (WAPs) for MCs. One or more MRs are connected to the Internet and are responsible for relaying Internet traffic to and from a WMN, and such MRs are commonly referred to as gateways. We assume that a single gateway exists in a WMN.

In the proposed mobility management schemes, the central location database resides in the gateway. For each MC roaming around in a WMN, an entry exists in the location database for storing the location information of the MC, i.e., the address of its anchor MR (AMR). The AMR of an MC is the head of its forwarding chain. With the address of an MC's AMR, the MC can be reached by following the forwarding chain. Data packets sent to an MC will be routed to its current AMR first, which then forwards them to the MC by following the forwarding chain. Packet delivery in the proposed schemes simply rely on the routing protocol used. The concept of pointer forwarding [12] comes from mobility management schemes proposed for cellular networks. The idea behind pointer forwarding is minimizing the overall network signaling cost incurred by mobility management operations by reducing the number of expensive location update events. A location update event means sending to the gateway a location update message informing it to update the location database. With pointer forwarding, a location handoff simply involves setting up a forwarding pointer between two neighboring MRs without having to trigger a location update event.

The forwarding chain length of an MC significantly affects the network traffic cost incurred by mobility management and packet delivery, with respect to the MC. The longer the forwarding chain, the lower rate the location update event, thus the smaller the signaling overhead. However, a long forwarding chain will increase the packet delivery cost because packets have to travel a long distance to reach the destination. Therefore, there exists a trade-off between the signaling cost incurred by mobility management vs. the service cost incurred by packet delivery. Consequently, there exists an optimal threshold of the forwarding chain length for each MC. In the proposed schemes, this optimal threshold denoted by K is determined for each individual MC dynamically, based on the MC's specific mobility and service patterns. We use a parameter named the service to mobility ratio (SMR) of each MC to depict the MC's mobility and service patterns. For an MC with an average packet arrival rate denoted by λp and mobility rate denoted by σ, its SMR is formally defined as $SMR = \lambda p/ \sigma$.

As discussed in [13], Internet traffic, i.e., the traffic between MRs and the gateway, dominates peer-to-peer traffic in WMNs because WMNs are expected to be a low-cost solution for providing last-mile broadband Internet access. Thus, we assume that for any MC, the Internet session arrival rate is higher than the Intranet session arrival rate, and the average duration of Internet sessions is longer than that of Intranet sessions. We use a parameter γ to signify the first assumption, and another parameter δ to signify the second assumption. More specifically, γ denotes the ratio of the Internet session arrival rate to the Intranet session arrival rate, and δ denotes the ratio of the average duration of Internet sessions to the average duration of Intranet sessions. We show that δ is also the ratio of the Intranet session departure rate to the Internet session departure rate, using a *M/M/∞* queue to model the session arrival process towards an MC.

STATIC ANCHOR SCHEME

In the static anchor scheme, an MC's AMR remains unchanged as long as the length of the forwarding chain does not exceed the threshold *K*.

Location Handoff

When an MC moves across the boundary of covering areas of two neighboring MRs, it de-associates from its old serving MR and re-associates with the new MR, thus incurring a location handoff. The MR it is newly associated with becomes its current serving MR. For each MC, if the length of its current forwarding chain is less than its specific threshold *K*, a new forwarding pointer will be setup between the old MR and new MR during a location handoff. On the other hand, if the length of the MC's current forwarding chain has already reached its specific threshold *K*, a location handoff will trigger a location update. During a location update, the gateway Fig. 1. The handling of location handoffs in the proposed pointer forwarding schemes (*Loc Update* means a location update message, and *PF* means pointer forwarding) is informed to update the location information of the MC in the location database by a location update message. The location update message is also sent to all the active Intranet correspondence nodes of the MC. After a location update, the forwarding chain is reset and the new MR becomes the AMR of the MC. Fig. 1 illustrates the handling of location handoffs in the proposed schemes. The new session request from MC1, the serving MR of MC1 (MR1) sends a location query for MC2's location information to the gateway, which performs the query in the location database and replies with the location information of MC2, i.e., the address of the AMR of MC2. After the location search procedure, data packets sent from MC1 to MC2 can be routed directly to the AMR of MC2, which then forwards them to MC2 by following the forwarding chain.

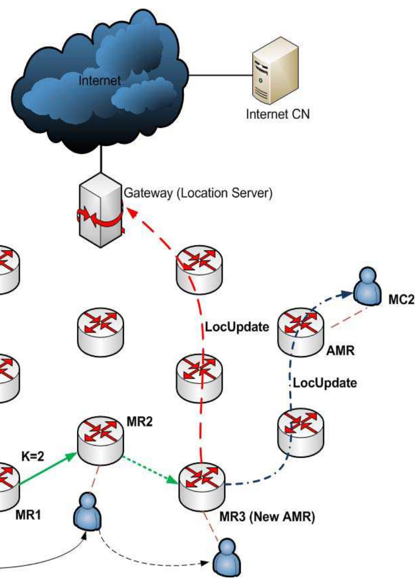

Fig. 1. The handling of location handoffs in the proposed pointer forwarding schemes (*LocUpdate* means a location update message, and *PF* means pointer forwarding).[24]

CONCLUSION

In this paper, we propose two mobility management schemes based on pointer forwarding for wireless mesh networks, namely, the static anchor scheme and dynamic anchor scheme. The proposed schemes are per-user based, in that the optimal threshold of the forwarding chain length that minimizes the total communication cost is dynamically determined for each individual MC, based on the MC's specific mobility and service patterns characterized by SMR.

We develop analytical models based on stochastic Petri nets to evaluate the performance of the proposed schemes. We also compare the proposed schemes with two baseline schemes and with the WMM scheme. Analytical results show that 1) the dynamic anchor scheme is better than the static anchor scheme in typical network traffic conditions, whereas the static anchor scheme is better when the service rate of an MC is comparatively high such that the advantage of the dynamic anchor scheme is offset by the extra cost; 2) our schemes perform significantly better than the baseline schemes, especially when SMR is small; 3) the dynamic anchor scheme is superior to the WMM scheme when the network traffic is dominated by mobile Internet applications characterized by large traffic asymmetry for which the downlink packet arrival rate is much higher than the uplink packet arrival rate.

In the future, we plan to investigate how our proposed schemes can be extended to WMNs that have multiple gateways. In addition, we plan to investigate the proposed schemes under more realistic mobility models other than the random walk model. We will also investigate how caching of location information of MCs can be used to reduce the signaling cost incurred by our proposed schemes.

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