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Network Traffic Reduction In 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 and 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.**

Index Terms*—Mobility management, pointer forwarding, wireless mesh networks, performance analysis.

I. 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. 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 wireless links. Mesh clients are wireless mobile devices, e.g., PDAs, smart phones, laptops, etc

A. Need of Mobility in Wireless Mesh Networks

The mobility management provides packet delivery without delay to their destinations and routing protocol is the basic requirement. Mobility management include two schemes [1] i.e. location management and handoff management. The location management keeps track of the location information of the mesh client, through location registration and location update operations. The Handoff management maintains ongoing connections of mesh clients while they are moving around and changing their points of attachment.

B. Concepts of Mobility

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. 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 and can be found in [3] and [4],respectively. Due to some significant differences in network architecture mobility management cellular networks and mobile IP networks are generally not appropriate for WMNs. For example, the lack of centralized management facilities. Therefore, the development of new mobility management schemes takes into consideration of the unique characteristics of WMNs. Additionally, mobility management schemes that are on a per-user basis are highly desired.

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 show that our schemes 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.

II. RELATED WORK

A. *Tunneling-based Schemes*

ANT [7] is a Actor Network Theory 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 [8] proposed a mobility management for WMNs called Mesh Mobility Management (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.and it 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.

B. *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. Mobility management in iMesh therefore incurs significant overhead due to the broadcasting of the Host Network Announcement (HNA) message.

Mesh networks with Mobility management (MEMO) [10] is the implementation of an applied WMN with support of mobility management. Like the Ant scheme, MEMO also adopts MAC layer triggered mobility management (MTMM).

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.

C. *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. This incurs a high signaling cost, which is especially a severe problem when the average mobility rate of mesh clients is high.

III. 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 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. 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 reduces location update event, thus the smaller the signaling overhead. However, a long forwarding chain will increase the packet delivery cost .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 $SMR = \lambda p/ \sigma$.

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IV. 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*.

A. Location Handoff

When an MC moves across the boundary of covering areas of two neighboring MRs, it disassociates 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 The new session request from 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 are routed directly to the AMR of MC2, which then forwards them to MC2 by following the forwarding chain.

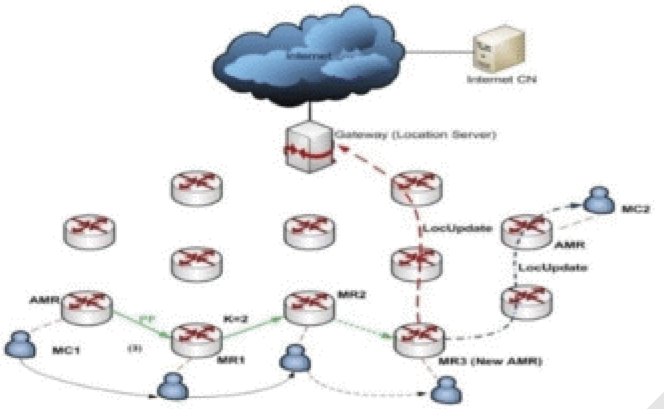

Fig. 1 The handling of location handoffs in the pointer forwarding.

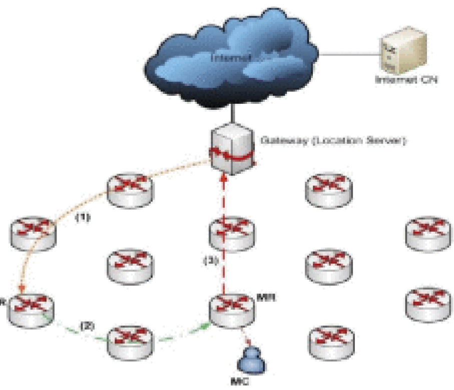

Fig. 2 The location search procedure for newly arrived Internet sessions in the dynamic anchor scheme.

1) Internet Session

Internet sessions initiated toward an MC always go through the gateway, i.e., they are always routed to the gateway first before they actually enter into the WMN. Because the location database resides in the gateway, the gateway always knows the location information of an MC by performing queries in the location database. Therefore, routing an Internet session toward an MC is straight forward. Once the location information of an MC is known, i.e., the address of the MC's AMR is queried, the gateway can route data packets to the AMR, which then forwards them to the MC by following the forwarding chain.

2) Intranet Session

Unlike Internet sessions, which always go through the gateway where the location database is located, an Intranet session initiated toward an MC Within a WMN must first determine the location information of the destination MC through a location search procedure. Suppose a mesh client MC1 initiates an Intranet session toward another mesh client MC2. Upon receiving 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.

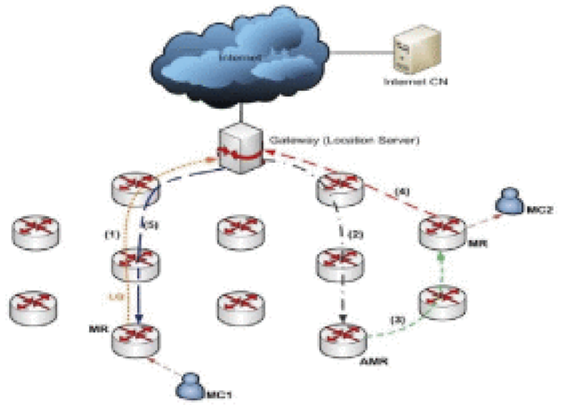

Fig. 3 The location search procedure for newly arrived Intranet sessions in the dynamic anchor scheme.

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V. DYNAMIC ANCHOR SCHEME

In the dynamic anchor scheme, the current forwarding chain of an MC will be reset due to the arrival of new Internet or Intranet sessions. The idea behind this scheme is to reduce the packet delivery cost by keeping the AMR of an MC close to its current serving MR when the service to mobility ratio is high, thus relieving the problem of triangular routing (gateway-AMR-MC) of the static anchor scheme, with the extra cost of resetting the forwarding chain upon a new session arrival. The handling of location handoffs in the dynamic anchor scheme is the same as in the static anchor scheme.

A. Internet Session

In the dynamic anchor scheme, when a new Internet session toward an MC arrives at the gateway, the gateway will not route the session to the AMR of the MC immediately. Instead, a location search procedure is executed to locate the MC's current serving MR, which may be different from its AMR. Fig. 2 illustrates the location search procedure for newly arrived Internet sessions. Specifically, the gateway sends a location request message to the AMR of the MC,which forwards the location request to its current serving MR. Upon receiving the location request message, the MC's current serving MR sends a location update message to the gateway, announcing that it is the new AMR of the MC. When the gateway receives the location update message, it updates the location information of the MC in the location database. After the location search procedure, the forwarding chain is reset and subsequent data packets will be routed to the new AMR of the MC. The gain is that the routing path is shortened, thus reducing the packet delivery cost

B. Intranet Session

When a new Intranet session is initiated toward an MC, a location search procedure similar to the one above is executed to locate the current serving MR of the destination MC. Fig. 3 illustrates the location search procedure for newly arrived Intranet session.Let MC1 and MC2 denote the source mesh client and destination mesh client, respectively. When a new Intranet session initiated toward MC2 by MC1 arrives at the current serving MR1,its sends a location request message to the gateway, which queries the location database and routes the location request message to the AMR of MC2, which forwards the location request message to MC2's current serving MR2.Upon receiving the location request message, MR2 replies to the gateway with a location update message, announcing that it is the new AMR of MC2. The location information of MC2 in the location database is updated by the gateway after it receives the location reply. The updated location information of MC2 is sent to MR1 in response to the location request and the location search procedure is completed. After the location search procedure, subsequent data packets will be routed to the new AMR of MC2 directly.

VI. PERFORMANCE MODEL

We develop analytical models for evaluating the performance of the proposed schemes. Table 1 summarizes the parameters and notations used in the following sections

TABLE I

The parameters and Notations used in Performance Modeling and Analysis

parameter	Notation
σ	Mobility rate
λ_I	Internet session arrival.
λ_L	Intranet session arrival.
λ_{Pu}	Average uplink packet arrival rate of Intranet session
λ_{Pd}	Average downlink packet arrival rate of Intranet session
N	Number of MRs in a WMN.
N_L	Instantaneous average number of active Internet correspondence nodes per MC.

A. Performance Metrics

We use the total communication cost incurred per time unit as the metrics for performance evaluation and analysis. The total communication cost includes the signaling cost of location handoff an update operation, the signaling cost of location search operations, and the packet delivery cost. For the static anchor scheme, the signaling cost of location search operations is incurred when a new Intranet session is initiated toward an MC. For the dynamic anchor scheme, the signaling cost of location search operations represents the cost for tracking the current serving MR of an MC and resetting the forwarding chain when new sessions are initiated toward an MC. In the following, we use C_{static} and $C_{dynamic}$ to represent the total communication cost incurred per time unit by the static anchor scheme and dynamic anchor scheme, respectively. $C_{location}$, C_{search}, and $C_{delivery}$ are used to represent the signaling cost of a location handoff operation, the signaling cost of a location search operation, and the cost to deliver a packet, respectively.

For the static anchor scheme, the total communication cost incurred per time unit calculated as

$$C_{static} = C_{location} * \sigma + C_{search},L * \lambda L + C_{delivery},I * \lambda_{pd} + C_{delivery},L * \lambda_{pL}.$$

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For the dynamic anchor scheme, the total communication cost incurred per time is calculated as

$$C_{dynamic} = C_{location} * \sigma + C_{search},I * \lambda_I + C_{search},L * \lambda_L + C_{delivery},I*\lambda_{pd} + C_{delivery},L*\lambda_{pL}$$

B. Algorithm for Mobility

Begin

Get the mobile client ID

Get the mobile router IDs

Attach the mobile client to router

Update the log entry of the router

If

Threshold value is reached for mobile client

Update gateway table entry

Update router table entry

Else

Update pointer table entry

End if

C. Gateway table entries

Begin

If

Mobile client reached threshold value

Write to gateway log entry

End if

End

IV. PERFORMANCE ANALYSIS

In this section, we analyze the performance of the proposed schemes, in terms of the total communication cost incurred per time unit. Additionally, we compare the proposed schemes with two baseline schemes. In the first baseline scheme, pointer forwarding is not used. Thus, it is essentially the same as having K=0 in the proposed schemes. In the second baseline scheme, pointer forwarding is employed, but the same threshold of the forwarding chain length is preset for all MCs, e.g., K=4 for all MCs.

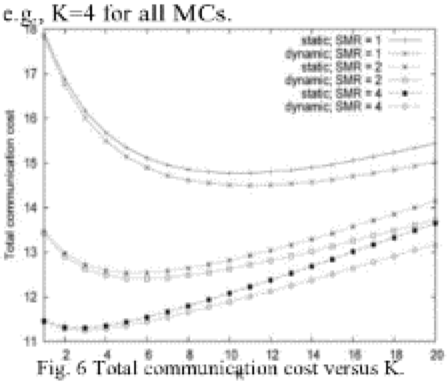

Fig. 6 Total communication cost versus K.

VII. 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 and also show that 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 our schemes perform significantly better than the baseline schemes, especially when SMR is small.

In the future, we plan to investigate how our proposed Schemes can be extended to WMNs that have multiple gateways. 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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