J. Parallel Distrib. Comput. 122 (2018) 109–121

Contents lists available at ScienceDirect

J. Parallel Distrib. Comput.

journal homepage: www.elsevier.com/locate/jpdc

A multi-hop pointer forwarding scheme for efficient location update in low-rate wireless mesh networks☆

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HIGHLIGHTS

- MPFS improves the probability of success in forwarding pointer setup, resulting in lowering the location update overhead significantly.
- Pointer forwarding success probability and average chain length are analyzed in terms of suitability of MPFS for resource-constrained LRWMNs.
- Using ns-2, we show that MPFS significantly reduces the number of location update events, location update delay and signaling overhead, and packet losses during location updates.
- With real-world test-bed, feasibility of MPFS is validated.

ARTICLE INFO

Article history:
Received 16 November 2016
Received in revised form 21 April 2018
Accepted 9 July 2018
Available online 30 July 2018

Keywords:
Mobility management
Location management
Handoff
Pointer forwarding
IEEE 802.15.4
6LoWPAN
Wireless mesh networks

ABSTRACT

Recently, a pointer forwarding scheme (PFS) was proposed to reduce location update overhead in wireless mesh networks. Using PFS, a location update is replaced with a simple forwarding pointer setup between two neighboring mesh routers (MRs). However, in PFS, if the two MRs are not one hop neighbors, PFS fails to set up a forwarding pointer, thus increasing location update overhead. To improve PFS, we present a multi-hop pointer forwarding scheme (MPFS). MPFS allows forwarding pointers to be constructed over multi-hop at once even if MRs are not one hop neighbor by using logical tree distance constructed during network formation. The tree distance is used to relay forwarding pointer packets over multi-hop links without additional control overhead during forwarding pointer setup and to estimate hop distance between two MRs. By doing so, MPFS improves the probability of success in forwarding pointer setup while ensuring $k \leq k_m$, resulting in lowering the location update overhead. Also, we analyze pointer forwarding success probability and average chain length and discuss why MPFS is suitable for resource-constrained LRWMNs. Using ns-2, we show that MPFS significantly reduces the number of location update events, location update delay and signaling overhead, and packet losses during location updates. With real-world implementation, we also confirm feasibility of MPFS.

1. Introduction

Wireless mesh networks (WMNs) [21] are a promising technology as an innovative solution for next-generation wireless networks. WMNs enable low-cost and rapid construction of wireless backbone comprised of mesh routers (MRs) in order for mesh clients (MCs) to access the Internet. WMNs are established with several wireless technologies such as WMAN, WLAN, and WPAN [21]. Among them, WPAN based on IEEE 802.15.4 is the low-end branch of WMNs in terms of data rate, which we call low rate wireless mesh networks (LRWMNs).

Typical applications of LRWMNs are building automation, health care, smart grid, and so forth. In these applications, an MC may move in a WMN and change points of attachment (i.e., MRs) frequently when playing a role of mobile sinks or mobile sensors [6,26]. This fact highlights the need for mobility management in LRWMNs. In general, mobility management consists of handoff management and location management. In this paper, we focus on the location management which is to keep track of location information of an MR to which MCs are attached.

In LRWMNs, mobile MCs typically broadcast location update messages right after changing associated MRs so that other static sensors or gateways keep track of mobile MCs. However, as the

☆ The early version of this paper appears in the Proceedings of IEEE Wireless Communications and Networking Conference (WCNC), 2012.

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https://doi.org/10.1016/j.jpdc.2018.07.012
0743-7315/

number of mobile MCs increases, the location update events result in frequently broadcasting location update messages, incurring broadcast storm problem [34]. Meanwhile, each node involved in broadcast maintains a broadcast transaction table (BTT) in order to prevent rebroadcasting of duplicate messages. For instance, the ZigBee standard[1] employs this scheme. For that reason, in resource-constrained LRWMNs, sources of traffics may not be able to update the current location of mobile MCs if MRs responsible for rebroadcasting the location update events do not have sufficient memory to store broadcast transactions. Thus, minimizing location update events is an important design factor for mobility support in LRWMNs since resources like memory even at MRs are relatively small (e.g., a few kilobytes).

In this paper, we first propose that a pointer forwarding scheme (PFS), which was originally proposed for PCS [14], can reduce frequent location update events for resource-scarce LRWMNs. That is, an MC does not trigger a location update event in which an associated MR sends location update messages. Instead, PFS simply constructs a forwarding chain between two neighboring MRs as long as MC's current forwarding chain length k is less than or equal to k_m, resulting in lowering a location update frequency.

More importantly, we point out that the PFS frequently fails to set up a forwarding pointer. This is because the PFS succeeds if and only if a new MR (nMR) of the MC is a symmetrically one-hop neighbor of an old MR (oMR) with which the MC has associated right before handoff. As reported in this paper, the probability that an MC selects a nMR which is the one-hop neighbor of the oMR is merely about 0.26. To cope with this, we propose a novel multi-hop pointer forwarding scheme (MPFS) for LRWMNs, improving the probability that a forwarding pointer is successfully set up. Unlike the existing PFS based on a single-hop forwarding pointer setup, the MPFS allows forwarding pointers to be set up over multi-hop at once.

Enabling MPFS has two key design issues: how to minimize additional signaling control overhead for relaying forwarding pointer setup messages over multi-hop and how to satisfy a constraint $k \leq k_m$. To achieve this, we exploit a tree address structure constructed during network formation. The tree address structure provides a means to multi-hop packet forwarding without additional control overhead. Besides, the tree distance, which is derived from the tree addressing structure without message exchanges, provides a means to estimating a logical hop distance, which allows each MC to always satisfy the constraint. As a result, even if the nMR which is selected by the MC is not one-hop neighbor of the oMR, MPFS allows construction of a multi-hop forwarding pointer without additional control overhead during forwarding pointer setup. Therefore, MPFS results in reducing the number of location update events, subsequently lowering the location update overhead.

To show the ratio of improvement, we analyze the success probability of forwarding pointer setup for PFS and MPFS by combination of mathematical model and simulation analysis. The result shows that MPFS achieves significant improvement over the PFS. Also, we analytically show average chain lengths of PFS and MPFS and is influence to location update failures.

We also run extensive simulations based on ns-2 [28] and show that the MPFS results in reduction of the number of location update events, location update delay, and packet losses during the location update. With real-world implementation on a 6LoWPAN test-bed we also verify MPFS is suitable to support mobility in resource-scarce LRWMNs.

The rest of this paper is organized as follows. Next section explains network architecture and a basic mobility management scheme in LRWMNs, followed by PFS applied to LRWMNs and its problems in Section 3. Section 4 describes our proposed MPFS followed by analysis of probability that forwarding pointer setup succeeds for both PFS and MFPS in Section 5. Sections 6 and 7 present the simulation results and MPFS implementation, respectively. Related works are presented in Section 8. Finally, we conclude this paper in Section 9.

[1] ZigBee website: www.zigbee.org.

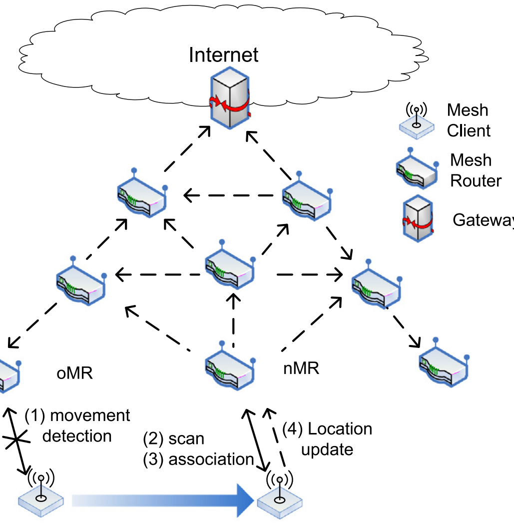

Fig. 1. A mobility management in a LRWMN.

2. Preliminary

This section describes network architecture that we assume throughout this paper. Also, since we deal with mobility management in LRWMNs, we explain a basic mobility management scheme.

2.1. Network architecture

In a LRWMN as depicted in Fig. 1, there are two types of nodes: mesh routers (MRs) and mesh clients (MCs). MRs and MCs operate based on non-beacon enabled mode in IEEE 802.15.4 [12] where MRs are quasi-stationary and always powered on with constant power, and MCs are either mobile or static with sleep operations. Every MC is allowed to communicate with other nodes only through its associated MR. MRs are in charge of relaying packets over multi-hop links for both itself and its associated MCs by using routing protocols. For instance, when an MC sends a location update message via broadcast, MC's location update message is first forwarded to its associated MR, which in turn broadcasts the message on behalf of the MC.

The MCs periodically wake up and send a polling packet (i.e., data request command messages defined in IEEE 802.15.4) to its associated MR to receive data packets queued at its associated MR. In this paper, we assume that a single gateway exists in a LRWMN.

A node has both identifier (e.g., IEEE address) and network address (also known as short address). The identifier is a globally unique number that can be distinguished from others during the lifetime of the node. For ease of presentation, we assume that each node has a single identifier. The network address of a node can be dynamically changed every time it changes its MR (i.e., a point of attachment). As far as routing is concerned, data packets are relayed by using the network address. Throughout this paper, we interchangeably use short address and network address unless we specify otherwise.