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TLSR: A tree link state routing protocol using message aggregation based on a skewed wait time assignment for infrastructure-based mobile ad hoc networks

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ABSTRACT

The existing protocols for the Internet connectivity of Mobile Ad Hoc Networks suffer from a high overhead since they often rely on flooding in executing mobility management and/or route discovery. In this paper, we propose a tree link state routing protocol in which a mobility management protocol builds topology information at the Internet Gateway (IG) as well as manages mobile nodes using tree topology and a routing protocol exploits the topology information, tackling the inherent problem of the excessive control overhead which appears in link state routing protocols. The activities of routing protocol including the delivery of data packet and control message also help the update of the topology information. In this way, mobility management and routing protocol collaborate with each other to increase convergence speed of topology and reduce control overhead. In addition, the progressive path discovery and the message aggregation technique based on the skewed wait time assignment are employed to reduce control overhead of the nodes near the Internet Gateway that process much more data packets and control messages. Simulation results show that the proposed method far outperforms AODV-Hybrid and OLSR+.

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1. Introduction

The provision of Internet connection is an essential service for extending the usability of Mobile Ad Hoc Networks (MANETs). This service can be implemented by integrating an Internet Gateway into MANETs, referred to as Infrastructure-based mobile ad hoc networks (abbreviated to IFMANET). In IFMANET, one mandatory requirement is that IGs have to manage the mobility of the MNs via multi-hop to provide uninterrupted connections for them [1] while they moves freely, thereby causing high control overhead. Furthermore, the routing protocols for IFMANETs can be designed with a new approach to take advantage of powerful IGs.

A lot of researches have been conducted for the provision of Internet connectivity for MANET. In [1], Sun et al. discussed how Mobile IP and AODV can cooperate to discover multi-hop paths between MNs and IGs. Ratanchandani and Kravets [2] proposed a hybrid scheme that combines some techniques, such as agent advertisements, TTL scoping, and the detection of agent advertisements, eavesdropping, and agent solicitation. Khan et al. [3] studied the IFMANET based on the extended DSDV [4] protocol in which it used one of the mobile hosts as Mobile Internet Gateway (MIG) to act as a bridge between the MANET and the Internet, thus data communication between two parties is done through the MIG. M. Benzaid et al. [5] proposed a hierarchical architecture that uses a proactive scheme to integrate Mobile IP and OLSR routing protocol. In this approach, the control overhead can be reduced by utilizing Multipoint Relays (MPRs) technique to limit the number of retransmissions of topology control as well as advertisement messages. Recently, some adaptive gateway discovery algorithms have been considered in IFMANET. T - C. Huang and Wu [6] proposed an adaptive scheme in which based on the information received, IGs can estimate the ratio of reactive overhead to proactive overhead of the network, and the TTL of the advertisement message can be adjusted to optimize control overhead using this ratio. A. J. Yuste et al. [7,8] proposed an adaptive scheme in which IGs dynamically adjust the interval between two consecutive advertisement messages to decrease network congestion and achieve lower end-to-end delay. In [7] the adjustment is determined based on a genetic algorithm, while in [8] the tuning is determined by the analysis of the spatial distribution of nodes in the network and relative positions of nodes that impact on the route lifetimes. Bouk, S.H. et al. [9] uses the hybrid scheme for gateway discovery; nodes base on the combination of QoS parameters such as path availability period, available capacity and latency to select a potential gateway.

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In the aforementioned approaches, node mobility management for IFMANET mostly relies on the existing ad hoc routing protocols such as AODV [10], DSR [11], OLSR [12], DSDV [4], etc. Despite their advantages using existing routing protocols for IFMANETs, they use flooding for mobility management which causes a high overhead. Furthermore, if both mobility management and routing use flooding, the performance will be worsen due to the double impact of control overhead caused by two sources of flooding. On the other hand, a tree-based approach for both mobility management and routing was proposed [11], in which a number of small trees are managed to reduce tree maintenance cost and every MN in the tree maintains its own tree information, consisting of its descendants, its parent, and its IG. The improvement of this approach is to reduce control overhead greatly; however, flooding technique has been used for route discovery, although the utilization degree is restricted.

The IFMANET requires the periodic registration of MNs with an IG in terms of mobility management to enable packet routing between two parties, MN and a host in the Internet. Meanwhile, the link state routing protocol requires the maintenance of the entire network topology to calculate a path. Thus, if every MN sends its link state instead of its ID to an IG periodically, this activity can not only help MNs to register with the IG but also allow for the construction of entire network or tree topology at the IG. Then, an MN can request a path calculation from the IG by sending a path calculation request message along tree path that also piggybacks the change of its link state. In this way, the topology maintenance activity that is a key barrier in realizing the link state routing protocol due to the convergence delay and high control overhead can be absorbed into the two required activities of the IFMANET, registration and routing. Based on this idea, in this paper we propose an efficient tree-based approach in which mobility management utilizes tree topology. During mobility management, a gateway can build and update tree topology by having every node send a registration message including its link states to the gateway periodically. The constructed topology information is used later when a routing function explores a routing path. Thus, the proposed approach does not pay additional cost in building the topology information for routing. Since the nearer to an IG a node is, the more the amount of topology information that it maintains is, path calculation is performed from source up to the IG progressively until a path is found. A node that finds a path can respond immediately with a found path to the source. This approach is different from its previous version [13], but is similar to the link state protocols such as FISHEYE [14], and OLSR [12] in that mobile nodes in the considered network manage a partial or full network topology and a shortest path is calculated based on topology information.

Furthermore, we use some other techniques to reduce control overhead and collision in this type of network. Every MN only uses unicast mechanism in handling node mobility, topology management, and path acquisition by making use of topology information. Note that broadcasting tends to increase the probability of message collision in the IEEE 802.11 MAC [15]. Also, nodes surrounding an IG often suffer from congestion due to receiving and processing many messages delivered from their descendants, referred to as the funneling effect [16]. We employ an efficient message aggregation technique that relies on the skewed time synchronization between nodes at different depths. According to the analysis in [17], it was proven that message aggregation not only reduces collision but also improves throughput.

In what follows, Section 2 gives the network model, followed by message and graph definitions. Section 3 details the tree link state routing protocol with a message aggregation technique. The performance of our approach is evaluated in Section 4. Finally, Section 5 concludes the paper.

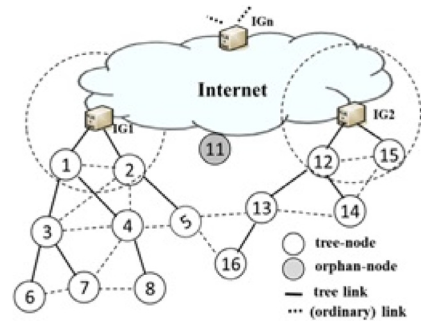

Fig. 1. A Network with tree topology.

2. Preliminary

2.1. The network model

The network considered in this paper consists of multiple stationary Internet Gateways (IGs) and a number of mobile nodes (MNs). We assume that IGs share all their information through a wired backbone network. Every MN acts as a router that can forward a message received from one node (MN or IG) to another node. An IG is equipped with two network interface cards so that it can communicate with MNs using one network interface card and also communicate with a wired host in the Internet using another network interface card. The wireless transmission range of the IG is the same as that of an MN. The wireless transmission range is limited because the longer transmission distance increases interference among MNs. An MN can not only initiate communication with any wired host but also be requested for connection from wired hosts in the Internet or MNs in other wireless networks via an IG. Thus, we assume that an MN should do its best to register with the IG, although it may not want to initiate communication.

The network forms a tree topology as shown in Fig. 1 where every MN has a parent node. A connection between two MNs is said to be an *ordinary link* and especially a connection between an MN and its parent is said to be a *tree-link*. A node is said to a *tree-node* if it belongs to a tree; otherwise it is an *orphan-node*.

2.2. Motivation

The routing protocol efficiency (PE) in IFMANETs is determined largely by *mobility management efficiency* (MME) and *route management efficiency* (RME). That is, the efficiency of a protocol A can be expressed as follows:

$PE(A) = MME(A) + RME(A)$

In IFMANET, each node is required to send its registration message (REG) to an IG at regular intervals. In this case, a considerable amount of overhead is created since a flooding is used to establish and maintain paths between IGs and mobile nodes. This overhead is one of the major constraints in improving the performance of a routing protocol. A tree-based mobility management technique which does not use flooding was proposed to reduce control overhead [18], where every node sends REG messages to an IG along tree path.

In this paper, we present a tree-based link state routing protocol (TLSR) in which mobility management and route management collaborate with each other. In MANETs, the link state protocols have been less attractive since they cause an excessive control overhead or the low convergence speed in constructing and maintaining topology information. To improve these problems, the link state protocols such as OLSR [12] and PCDV [19] have been proposed; however, the overhead problem still remains to hinder its broad application.

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