Ad Hoc Networks 23 (2014) 34–51

Contents lists available at ScienceDirect

Ad Hoc Networks

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

Routing on large scale mobile ad hoc networks using bloom filters

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ARTICLE INFO

Article history:
Received 19 November 2013
Received in revised form 6 May 2014
Accepted 30 May 2014
Available online 18 June 2014

Keywords:
Routing protocol
Mobile ad hoc network
Bloom filter
Large-scale network

ABSTRACT

A bloom filter is a probabilistic data structure used to test whether an element is a member of a set. The bloom filter shares some similarities to a standard hash table but has a higher storage efficiency. As a drawback, bloom filters allow the existence of false positives. These properties make bloom filters a suitable candidate for storing topological information in large-scale mobile ad hoc networks, where there is a considerable amount of data to be exchanged. Bloom filters enable the transmission of reduced routing control messages to save available bandwidth, and they require fewer node resources than traditional data structures. Existing ad hoc routing protocols using bloom filters limit themselves to static sensor networks or small/medium-scale mobile networks. In this study, we propose and analyse a routing protocol suited for large scale mobile ad hoc networks (up to 3000 nodes) that stores and disseminates topological information through a specific type of bloom filter that is able to discard old elements. Logical overlays are then constructed with the proposed data structures to indicate the distance to the destination nodes. This process allows the routing protocol to reduce the number of control messages required to discover and maintain routes. The proposed algorithm is validated via simulation and compared with other well-known routing protocols developed for mobile ad hoc networks.

1. Introduction

The proliferation of wireless devices in recent years has led to the emergence of Mobile Ad hoc Networks (MANETs). These self-organised multi-hop networks, where each node can act as an end-system or a router, sharing the same wireless channel, have been used on military battlefields and in emergency management and rescue operations. Today, MANETs are becoming ubiquitous in many daily-life activities, and new challenges are arising with the new application domains.

In the near future, with the emergence of the Internet of Things (IoT), an enormous number of objects possessing unique identifiers and specific properties will be able to interact with each other and with humans, creating the building blocks of pervasive computing [33,1]. These objects comprise a wide variety of heterogeneous devices with different resources capabilities, such as Radio-Frequency IDentification (RFID) tags and readers, sensors, actuators, smart watches, mobile phones, tablets and laptops, among others that are not yet known. The IoT will make possible the development of a wide number of different applications targeted at different scenarios, such as transportation and logistic, personal or social activities, or healthcare with wireless body area networks [34]. Hence, an enormous number of nodes with very limited resources share the network with far more complex

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http://dx.doi.org/10.1016/j.adhoc.2014.05.016
1570-8705/

devices, providing a wide variety of services for both indoor and outdoor usage. Therefore, scalability and simplicity are major concerns due to the enormous number of heterogeneous devices that might be accessible [27].

Since MANETs appearance, routing has drawn the attention of the research community, because of the challenging issue of the frequent topology changes caused by the mobility and signal variation of the nodes. Hence, a wide variety of proposals have been put forward and surveyed by different authors [19,23,32]. Modifications to classical IP-based, table-driven routing approaches have been proposed that essentially aim quickly to frequent and unpredictable topology variations using limited resources. Despite their advantages, however, performance studies have shown that these protocols do not scale in size or density and are unable to support highly dynamic networks due to the overhead required to maintain up-to-date routing information [16,28].

Hence, other paradigms have also been explored, such as data replication at intermediate nodes to cope with intermittent connections of Delay Tolerant Networks (DTNs) [13,43] or location-based routing to support the dynamics of Vehicular Ad hoc NETworks (VANETs) [5]. In the case of DTNs' routing protocols, there is a trade-off between the amount of memory that will be used to buffer message replicas and the packet latency [13]. Even when efficient dissemination strategies are used, due to the large latencies associated with this group of protocols, this type of routing is inadequate for large networks where applications have strict time requirements. Position-based protocols have been demonstrated as more efficient for VANETs, as they have less overhead than the existing protocols [32], but they require the use of a location-service and a Global Positioning System (GPS) device in each node, precluding their indoor use or installation in very simple devices with limited capabilities.

Another paradigm developed for routing in wireless networks utilises opportunistic routing packets in duty-cycled networks. In this type of network, to conserve battery power, nodes only actively receive or transmit messages during small time intervals. Communication in these low-power, partially connected networks is extremely challenging because there is only support for special traffic patterns [12].

Although significant research efforts have been made regarding mobility and energy efficiency aspects, we claim that there is a lack of routing protocols that are able to address with the simplicity and scalability requirements arising from the advances of the IoT. A simple and scalable routing protocol is still needed that enables communication in a network that has thousands of mobile devices, some of them with very limited capabilities, and that is traffic pattern agnostic. This paper describes how our routing protocol – *Heat Routing for Ad hoc Networks (HRAN)* – fulfils these needs.

HRAN was designed to support networks composed of very simple nodes, with reduced memory, limited processing power and no GPS device, thus allowing indoor and outdoor use. The protocol relies on the use of bloom filters to store and spread topology information, and it provides very simple and efficient routing, as the manipulation of routing messages basically consists of the execution of bitwise logical operations over fixed sized buffers. To provide a scalable solution, nodes do not explicitly store and disseminate topology messages originated in other nodes. Instead, these messages are merged by each node with its own topology information, and only the result is broadcasted. Because information is stored in bloom filters, the memory requirements remain constant, independently of the amount of topological information being transferred. Additionally, to reduce the number of transmitted messages, whenever a route to a destination is requested, the protocol does not flood the network but rather uses the information stored in each node's bloom filter to discover the nodes that are candidates for the new route. This process effectively guides route queries to the destination and reduces unnecessary message transmissions, saving battery power and decreasing the overhead imposed by the protocol.

The contributions of this paper are twofold:

- First, it presents a complete and formal description of the protocol, comprising the specification of a new type of bloom filter able to address events in a timely manner.
- Second, it assesses *HRAN* performance and compares it with other well-known MANET routing protocols using networks with different sizes, ranging from 100 to 3000 nodes.

The remainder of this article is structured as follows: Section 2 presents the background and related work and lists existing routing protocol solutions for MANETs. Section 3 introduces the concept of the *Time Aware Bloom* filter and describes the proposed routing protocol. Details of the protocol's three operating phases are also included in this section. Section 4 presents the assessment of the *HRAN* performance characteristics and a comparison against other well-known routing protocols suited to MANETs environments. Finally, Section 5 draws the conclusions and lists future work.

2. Related work

This section presents the major relevant categories of routing protocols that have been proposed for MANETs. It starts by describing routing protocols that are representative of the most studied groups of protocols in this research field. The second part describes bloom-filter based routing protocols, as this is the structure type also used by *HRAN*.

2.1. Routing protocols for MANETs

This section contains a brief overview of various protocols representative of the different approaches that have been used for several types of mobile networks, namely, table-driven, epidemic and location-based routing.

2.1.1. Topology-based routing protocols

Topology-based routing protocols establish routes to forward data to the required destinations according to