Computer Networks 100 (2016) 166–178

Contents lists available at ScienceDirect

Computer Networks

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

Sensor-free route stability metric for mobile ad hoc networks

Gin-Xian KOK[a,*], Chee-Onn CHOW[a], Yi-Han XU[b], Hiroshi ISHII[c]

[a] Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] College of Information Science and Technology, Nanjing Forestry University, Nanjing, 025, China
[c] Department of Communication and Network Engineering, School of Information and Telecommunication Engineering, Tokai University, Japan

A R T I C L E I N F O

Article history:
Received 5 June 2015
Revised 15 February 2016
Accepted 28 February 2016
Available online 5 March 2016

Keywords:
Routing metric
Mobile ad hoc networks
Link stability
Route stability
Node mobility

A B S T R A C T

The hop count routing metric is widely used in conventional ad hoc routing protocols due to its simplicity and effectiveness. With a lower hop count route, fewer transmissions are required to send a packet from the source to the destination. This can improve the network throughput because fewer transmissions results in less channel contention and interference. In spite of this, the hop count routing metric may not be ideal for mobile scenarios, where the network topology changes constantly and rapidly. Many routing metrics have been proposed to improve route stability. However, they are usually only marginally effective or incur additional cost by requiring the use of information from additional hardware such as GPS sensor and compass. In this paper we propose a routing metric to guide nodes discover/select stable paths to improve route stability. We implemented the proposed routing metric in the AODV routing protocol and proved through simulation studies that it outperforms other routing metrics.

1. Introduction

A mobile ad hoc network (MANET) is a dynamic communication network formed by a collection of mobile nodes. In unicast routing in MANETs, an end-to-end route, which may be multi-hop in nature, is established prior to data transmission. Due to the multi-hop nature of routes in ad hoc networks, an entire route becomes invalid when a single link is broken. When a route becomes invalid, data transmission is halted and the network performs self-reconfiguration where nodes update their route information using control packets. Route breakage not only causes interruptions in data transmission, the communication of control packets during network self-reconfiguration also consumes valuable transmission opportunities that are better used for data transmission. Hence, it is vital that routes that are stable are used to ensure optimum network performance.

A routing metric is used to assign a value to a path to facilitate path selection. The hop count routing metric, which minimizes the number of transmissions required to send a packet from the source to the destination, is one of the most widely used routing metrics in ad hoc routing protocols due to its simplicity and effectiveness. Due to the broadcast nature of the wireless channel, the redundant transmissions incurred when a packet traverses through a longer route means that fewer remaining transmission opportunities are available for other concurrent transmissions (inter-route contention and interference). A long route could also cause nodes belonging to the same route to be in close proximity with each other and compete with each other for transmission opportunities (intra-route contention and interference). By using shorter routes, channel contention and interference, and end-to-end delay can be reduced. Nevertheless, it is well-known that the

* Corresponding author. Tel: +60 012 6347880.
E-mail addresses: xian_kgx@hotmail.com, xiankgx@gmail.com (G.-X. KOK), cochow@um.edu.my (C.-O. CHOW), xuyihan@njfu.edu.cn (Y.-H. XU), ishii@ishiilab.net (H. ISHII).

http://dx.doi.org/10.1016/j.comnet.2016.02.025
1389-1286/

hop count routing metric does not perform well in high mobility scenarios because lower hop count routes tend to be more direct and consist of longer links, which are more prone to breakage. In higher node density scenarios, the hop count routing metric is also known to cause links to be formed through border nodes leading to short link lifetimes (the border/edge effect) [1,2]. Such a link is easily broken by a small movement from any of the two nodes forming the link.

Various methods have been proposed to improve route stability in MANETs. Unfortunately, they are only marginally effective or incur additional cost by requiring the use of additional hardware. For instance, some methods require information from sensors such as GPS sensor and compass. In this paper we propose a routing metric for discovering and establishing stable routes that can be used without sensors. We show through analysis and simulation studies that the proposed routing metric is effective and outperforms the hop count and other related routing metrics. The contributions of this paper are summarized as follows:

1. The design of a routing metric that uses link length information and node mobility information to facilitate the selection of stable paths for improved network performance.
2. The proposal of a method to estimate the information used in the proposed routing metric so that the routing metric can be used without additional hardware (sensors) to reduce cost and node hardware complexity.
3. The proposal of a method to store a node's neighbor set, which is required to estimate the link length information used in the proposed routing metric, compactly in Route Request (RREQ) and Route Reply (RREP) packets.

The remainder of this paper is organized as follows. Related work is reviewed in Section 2. In Section 3 we provide further details of our routing metric. Results and discussion are provided in Section 4. Finally, we conclude our work in Section 5.

2. Related work

Route instability is one of the key problems affecting unicast routing in MANETs. Several routing metrics for wireless mesh networks (WMNs) are reviewed in [3], such as Expected Transmission Count (ETX) [4], Expected Transmission Time (ETT) [5], Weighted Cumulative Expected Transmission Time (WCETT) [5], and Metric of Interference and Channel Switching (MIC) [6]. However, these routing metrics were not designed for route stability; hence, they are not suitable for the problem that we seek to solve.

Many attempts have been made to resolve the route instability issue. These methods can be broadly categorized into two categories: (1) methods using information from sensors, and (2) methods using only readily available information. Methods from the first category usually offer good performance gains; however, they incur additional cost as additional hardware is required. While methods from the second category reduce cost, they usually offer only negligible performance gains when compared to the hop count routing metric, which does not consider route stability.

2.1. Methods using information from sensors

Node location information and node velocity information are used to estimate the remaining time before a link breaks called Link Expiration Time (LET) in the Flow Oriented Routing Protocol (FORP) [7]. In FORP, the path with the highest Route Expiration Time (RET), which is the minimum LET of the LETs of the links in a path, is preferred over other paths. In addition to LET, the Power and Mobility Aware Routing (PMAR) [8,9] protocol also employs RREQ propagation control using node location information. This method was first used in location-aided routing protocols such as LAR [10] and PMLAR [11].

In the AODV-Reliable Route Selection (AODV-RRS) [12] routing protocol, only nodes that are inside stable zones forward RREQs during a route discovery. This reduces the number of RREQ transmissions and results in the discovery of routes with short links. However, as some RREQs are dropped in a route discovery, a route between a pair of nodes might not be discovered even if multiple paths exist between these two nodes.

In the work in [13], link length is mapped onto a value called Link Availability, and the path with the highest path availability, which is the minimum link availability of all the link availabilities in a path, is chosen for data transmission. A possible consequence of selecting the max–min path is that a much longer path might be chosen over a shorter one with only slightly lower path availability.

Node heading direction information, which can be obtained using compass, is used in the Heading-direction Angles Routing Protocol (HARP) [14]. The main idea is to propagate RREQs along a single direction from the source to the destination. As the nodes in a route established in such a manner move in the same direction, the links in the route are less prone to breakage.

The Node Stability Factor (Nsf) and Link Stability Factor (Lsf) are used in the On-demand Bandwidth and Stability based Unicast Routing (OBSUR) protocol [15]. Nsf is an aggregate metric that takes into account a node's own mobility, the mobility of its neighbors, and its remaining buffer ratio while Lsf maps the estimated remaining lifetime of a link to a value in the interval [0, 1].

In Link Stability based Multicast Routing Scheme in MANET (LSMRM) [16], a metric called Stability Factor, which is a value computed for a link based on power level, distance, and Bit Error Rate (BER), is used to measure link stability. However, the use of BER information means that support from lower layers is required.

2.2. Methods using only readily available information

In the Associativity-Based Routing (ABR) protocol [17], link stability is measured using associativity ticks, which is the measure of time the two nodes of a link are connected. A node can measure the associativity of a neighbor by counting the number of beacon packets it received from the neighbor. It was claimed that links that are stable for