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Organized topology based routing protocol in incompletely predictable ad-hoc networks

Jian Shen[a,b,c], Chen Wang[c], Anxi Wang[c], Xingming Sun[a,c], Sangman Moh[d], Patrick C.K. Hung[c,e,*]

[a] *Jiangsu Engineering Center of Network Monitoring, China*
[b] *Jiangsu Collaborative Innovation Center on Atmospheric Environment and Equipment Technology, China*
[c] *School of Computer and Software, Nanjing University of Information Science & Technology, Nanjing, 210044, China*
[d] *Department of Computer Engineering, Chosun University, Gwangju, Republic of Korea*
[e] *Business and Information Technology, University of Ontario Institute of Technology (UOIT), Canada*

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ABSTRACT

Nowadays, ad-hoc networks are becoming increasingly popular and has been put into practice in many kinds of applications. However, in some environments, such as ground temperature monitoring or medical and health care, the traditional routing protocols are not proper, due to the fact that the topologies of these networks are relatively stable in a very long period. Such networks are defined as the incompletely predictable network. Nodes in such networks move only in a limited range from the basic positions which are initiated at the very beginning. In this paper, we propose a new protocol named Organized Topology Based Routing (OTBR) to adapt to the environments mentioned above. It is worth noting that the concept of Organized Topology (OT) can be divided into two different situations: one is called the Static Organized Topology (S-OT) and the other is called the Dynamic Organized Topology (D-OT). Moreover, a new concept named "anti-pheromone" is put forward to achieve high energy efficiency. In particular, a Static Organized Topology Based Routing using Anti-Pheromone (APS-OTBR) is presented on the basis of the characteristic of S-OT. In addition, according to the feature of D-OT, Dynamic Organized Topology Based Routing using Greedy Algorithm (GrD-OTBR) is proposed. Simulation results show that APS-OTBR has proper utilization ratio of nodes to achieve energy efficient, and GrD-OTBR has a stable performance when network size changes. Last but not least, to achieve higher node utilization, a new concept of equilateral triangle topology is proposed.

1. Introduction

A wireless ad-hoc network (WANET) [1,2] is a self-configuring, decentralized type of wireless network. With every node that participates in routing, the main characteristic of ad-hoc network is the complete lack of pre-existing infrastructure such as routers in wired networks. There are a lot of papers talking about time-evolving and predictable networks [3–5], where the positions of nodes and link status are predictable in a long period of time. However, the predictable network has certain limitation due to the preset network structure.

In this paper, we construct several models for one kind of ad-hoc networks which has no need for nodes to move or whose nodes move in a very limited area around the basic position that has been initially settled at. We call such networks the incompletely predictable ad-hoc networks. In this kind of network, the movement of the nodes and information interaction is not such complicated as that in the classic ad-hoc models. What's more, repairing link failure is not so difficult as well. It becomes less necessary to use the traditional excellent routing algorithms, such as Dynamic Source Routing (DSR) [6], Destination-Sequenced Distance Vector Routing (DSDV) [7], Ad-hoc On-demand Distance Vector Routing (AODV) [8], and other novel routing, protocols [9–17], which could greatly waste CPU computing resources of each node and cause too much overhead. Hence, for an incompletely predictable network, the corresponding lightweight algorithms are required to be constructed. This paper can be divided into several main parts. Section 2 gives the related works. Section 3 interprets several important related concepts as well as the concept of "incompletely predictable networks". In addition, we construct Model I to describe the network whose nodes are

* Corresponding author.
E-mail addresses: s_shenjian@126.com (J. Shen), wangchennuist@126.com (C. Wang), Anxi_wang@126.com (A. Wang), sunnudt@163.com (X. Sun), smmoh@chosun.ac.kr (S. Moh), patrick.hung@uoit.ca (P.C.K. Hung).

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fixed as a specific topology and Model II to represent the network whose nodes move in a limited range around basic positions. Section 4 further elucidates the structure named Static Organized Topology (S-OT), and presents Static Organized Topology Based Routing (S-OTBR). After the description of the process of S-OTBR, we propose the concept of “anti-pheromone” referring to Ant Colony Optimization algorithm [18,19], to maintain the network energy consumption equilibrium. Static Organized Topology Based Routing using Anti-Pheromone (APS-OTBR) is designed on the basis of “anti-pheromone”. Mainly aimed at discussing the situations where nodes move in certain ranges around the basic positions, Section 5 deeply parses Model II named Dynamic Organized Topology (D-OT). Besides, combined with greedy algorithm [20,21], Dynamic Organized Topology Based Routing using Greedy Algorithm (GrD-OTBR) is proposed to adapt the environment described by D-OT [22,23]. In our simulation in Section 6, we figure out that APS-OTBR shows a reasonable node utilization frequency. Moreover, GrD-OTBR has a stable performance when network size changes and performs better in a relatively small size of the network. Last but not least, Section 7 records some improvement methods. In the view of the imbalance problem of area coverage frequency caused by node movement, we propose a concept of a equilateral triangle network structure. Section 8 draws the conclusion.

2. Related works

Ad hoc networks are widely studied in recent decades. For instance, Delay Tolerant Networks (DTNs) [24], Wireless Sensor Networks (WSNs) [25], Vehicular Ad hoc Networks (VANETs) [26] are specific categories of Ad hoc networks. A large number of new protocols have been proposed in these fields. Tripp et al. [27] utilize the information retrieved by the sensors to make forwarding decisions, which increases packet delivery ratio and decreases end-to-end delay. A real-time X-layer protocol is proposed by Mouradian et al. [28] to guarantee a bound on the end-to-end delay. Basurra et al. [29] utilize a one hop clustering algorithm splitting the network into zones by reliable leaders to achieve network stability and energy efficiency.

In this paper, OTBR is designed for incompletely predictable ad-hoc networks. OTBR is a general designation of routing protocols which are named as APS-OTBR and GrD-OTBR. APS-OTBR can be utilized into applications in which nodes are static, and GrD-OTBR can be applied to dynamic environment. The proposed protocols can be widely used in all aspects of real life, such as smart home, environmental monitoring, intelligent medical system, intelligent transportation and military defense.

3. Concepts and models

3.1. Predictable networks

Time-evolving and predictable networks are widely mentioned in DTNs [30] and WSNs [31,32]. Fig. 1 illustrates an example of such time-evolving and predictable network. Fig. 1(a) shows the situation of the nodes and the link state of the network at the specific moment. Fig. 1(b) can be seen as a Time-Space graph which shows the locations of the nodes and the relationship between them in the form of a sequence of snapshot of the network. The concept of this kind of network is based on a theory that human mobility model can achieve a 93% potential predictability [33,34].

3.2. Static organized topology (S-OT) model (model I)

Under the circumstances as is described with predictable networks, there is a specific situation that the positions of the nodes and the link status of the network are fixed. To simplify and present that, Model I named as Static Organized Topology (S-OT) is constructed.

In our first model, as shown in Fig. 2, nodes are orderly distributed in the test area (each intersection point has a node settled there), just like the layout of the chessboard. Nodes are fixed at the specified positions and attempt to communicate with other nodes from time to time. The distances between every two adjacent nodes are all the same, which can be represented as L. Clearly, we can draw the first lemma.

Lemma 1. *The geographical locations of all nodes, which can be expressed in coordinates, could be calculated with one location of a certain node in the topology obtained by GPS.*

3.3. Dynamic organized topology (D-OT) model (model II)

As stated earlier, there is still a 7% of human mobility that cannot be accurately predicted [33]. In other words, the network related to human mobility model is an incompletely predictable network. Dynamic Organized Topology (D-OT) is designed to adapt such situation as Model II. The basic structure of Model II is the same as Model I. The positions that the nodes are settled at when the S-OT network is initialized are defined as Basic Positions (BPs). What distinguishes D-OT from S-OT is that all nodes of D-OT move randomly around BPs in a limited range. In our simplified model of D-OT, the activity area of a node is a circular area whose center is BP and radius is R_{act}. According to the feature of Model II, we can draw Lemma 2 by referencing Lemma 1. Model II can be illustrated with time-space graph which is shown Fig. 3.

Lemma 2. *The geographical locations of the BPs of all nodes in Model II, which can be expressed in coordinates, could be calculated with one position of the BP of a certain node in the topology obtained by GPS.*

As seen from Fig. 3, at the very beginning, nodes are set initially at the BPs. At the following time slots, nodes move in the area near BPs. This is so-called **the incompletely predictable ad-hoc networks** in our paper.

4. Static organized topology based routing protocol

4.1. Overview of S-OTBR

In the fields of marine monitoring [35], meteorological monitoring [36] (such as ground temperature monitoring [37], intelligent agriculture [38], etc.), fixed nodes, evenly distributed in a certain area, might be required. Information interaction and real-time monitoring of these nodes plays a very significant role in such applications. For that reason, we propose an energy-efficient transmission strategy that is suitable for the situations perfectly, which is named Static Organized Topology Based Routing (S-OTBR) Protocol. In addition, combined with the concept of “anti-pheromone”, Static Organized Topology Based Routing using Anti-Pheromone (APS-OTBR) is proposed to achieve energy efficiency.

4.2. Static organized topology (S-OT) model (model I)

In order to simplify the problem, we first assume that the node transmission radius is equal to the distance between two adjacent nodes, which can be expressed as $R_{trans} = L$. When it comes to the situation that the transmission radius $R_{trans} = L$, a certain S-D pair indicates a certain length of the shortest route(s) between the source and the destination. For example, as seen in Fig. 2, assuming that the coordinates of S and D are $(L, 0)$ and $(4L, 4L)$, the shortest route(s) for S and D to communicate with each other include 7 hops.