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SURVEY ARTICLE

A Survey on Knowledge Based Classification of Different Routing Protocols in Delay Tolerant Networks

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Abstract— Now a days, current wireless networks have provided a wide range of applications making it possible to successfully interconnect devices and systems, such as a mobile phone to a powerful server all around the world. Modern Internet protocols exhibits inefficient performance in those networks where the connectivity between end nodes has intermittent property due to dynamic topology such as Mobile Ad-hoc Networks (MANET) or Vehicular Ad-hoc Networks (VANET). The network environments where the nodes are characterized by opportunistic connectivity are referred to as Delay Tolerant Networks (DTNs). DTNs have been one of the growing areas of interest characterized by the significant amount of research efforts invested in this area over the past decade. Routing is one of the major issues affecting the overall performance of DTN networks in terms of resource consumption, data delivery and latency. Over the past few years a number of routing protocols have been proposed for DTN networks. This paper mainly focuses on classification and description of these routing protocols.

Key Terms: - Delay Tolerant Network, Routing in DTNs, Deterministic Routing, Stochastic Routing.

I. INTRODUCTION

Delay Tolerant Network is also referred as the Intermittently Connected Mobile Network [1]. It is the wireless network in which at any given time instance, the probability that there is an end-to-end path from a source to destination is low. Since most of the nodes in a DTN are mobile, the connectivity of the network is maintained by nodes only when they come in to the transmission ranges of each other. If any node has data to send but it is not connected to another node, it stores the message until an appropriate communication opportunity arises. A communication opportunity between two nodes is called a contact in DTN's. Since DTN represents a large group of networks several different kinds of contact have been identified. A contact can be persistent i.e. the contact is always available, on-demand i.e. a contact can be initiated when needed, scheduled i.e. the contact and its characteristics is known in advance or opportunistic contacts, called opportunistic DTN.

Generally, MANET routing protocols are built with the assumption that the network is dense enough so that it is fully connected i.e. that there always exists a path between every node in the network or that paths are down for a very short period of time. So, traditional routing protocols for MANETs do not work well for DTNs [2], since they try to discover a full path before sending any data. If no path between the sender and the destination exists, these protocols will not succeed to send any data.

To overcome the problem with intermittent connectivity and partitions in the network, DTN routing protocols utilize the mobility of the nodes and buffering of messages, this makes is possible for a node to carry a message and in that Way Bridge partitions in the network. It is also known as store-carry-forward (SFC) [3]. When a message is created it gets stored at the source node, when a contact becomes available to a next-hop node the message is sent over this contact. The message gets stored at the new node until the next-hop in the path is found and so on, until the destination is found. This results in a path from the source node to the destination without a guarantee for a contemporaneous path.

Although the connectivity of nodes is not constantly maintained, it is still desirable to allow communication between nodes. Therefore, it is necessary to provide a routing protocol which tries to route packets throughout the times the link is available among the nodes. But this cannot be done by standard routing algorithms which assume that the network is connected most of the times.

This paper is organized as follows: First the routing problems in traditional networks are discussed in section II. In section III, the knowledge based classification is explained. A detailed explanation of deterministic routing and stochastic routing are given in section IV and V. A concluding remark is given in section VI.

II. ROUTING PROBLEMS IN TRADITIONAL NETWORKS

The existing TCP/IP based Internet, operates assuming end-to-end communication using a concatenation of various data-link layer technologies. The set of rules specifying the mapping of IP packets into network specific data link layers frames at each router provides the required level of interoperability. IP protocol still makes a number of key assumptions regarding the lower layer technologies making seamless IP layer communications smooth. These are: (i) there is an end to end path between two communicating end systems. (ii) The round trip time between communicating end systems is not absurdly high and (iii) the end to end packet loss probability is rather small. Unfortunately, in DTN networks one or more of the above mentioned assumptions are violated due to mobility, power conservation schedule or excessive bit error rate. As a result, classic protocols of the TCP/IP protocol stack are not appropriate for such environments [2].

A key reason why end to end communication is difficult in DTNs topology is that IP packet delivery works only when the end to end path is available. In general, according to classic IP routing mechanism an IP packet is dropped at the intermediate system where no link to the next hop currently exists. Such design restricts the end to end communication to those scenarios, where intermediate nodes have to buffer received packets to deliver them whenever they have an opportunity to contact their destinations.

III. KNOWLEDGE BASED CLASSIFICATION OF ROUTING PROTOCOLS IN DTN

It has been almost a decade since the initiating talk [2] of Kevin Fall about delay tolerant networks. The primary focus of researchers studying on DTNs has been routing problem. Many studies have been performed on how to handle the sporadic connectivity between the nodes of the DTN and provide a successful and efficient delivery of messages to the destination. This paper mainly focuses on classification of routing algorithms which is decided according to the broadness of the knowledge of the network available at nodes. In some studies, it is assumed that each node in the network has exact knowledge of node trajectories, or node meeting times and durations. Therefore, the messages are routed over predetermined paths deterministically. But these algorithms which assume the existence of oracles giving future information are unrealistic because the intermittent connectivity between the mobile nodes in delay tolerant networks does not allow nodes to have such information. On the other hand there is also significant number of studies assuming zero knowledge about the aforementioned features of the nodes. These algorithms either forward the message randomly or use the meeting history of nodes and forward the message over different paths in a nondeterministic manner [4].

Based on the knowledge routing in DTNs could be classified as Deterministic Routing and Stochastic Routing. In deterministic routing the network topology and/or its characteristics are assumed to be known. Contrarily, for stochastic routing no exact knowledge of topology is assumed.

IV. DETERMINISTIC ROUTING

The main idea in computing the optimal route from a source to a destination in deterministic routing protocols is based on completely knowledge or predictable information about nodes future mobility patterns and links availability between them. Deterministic routing protocols could be divided into following four approaches. Most of those are special modification of well-known algorithms.

A. *Oracles Based Routing*

Several oracle-based deterministic routing algorithms taking the advantage of predictable information about network topology and traffic characteristics have been suggested by jain et al. (2004). Based on the amount of information they need to compute routes, the oracle-based algorithms are classified into complete knowledge and partial knowledge. Complete knowledge protocols utilize all information regarding traffic demands, schedules of contacts, and queuing in the forwarding process. However, in practical applications this knowledge is partially missing and routing needs to utilize available information. The author in [5] purposed their routing framework by modifying the Dijkstra's shortest path algorithm assuming four knowledge oracles: (I) contact summary oracle provides the knowledge about aggregated statistics of contacts. (ii) Contact oracle maintains information regarding the links between two nodes at any given time. (iii) Queuing oracle presenting the queuing information in each node instantaneously, and (iv) traffic demand oracle provides the knowledge about the current and future traffic characteristics. Oracle-based algorithms are mostly suitable for networks with controlled topology or with existing full or partial information about that [5][6].

B. *Link State Based Routing*

Gnawali et al. (2005) presented a modification of link state routing (LSR) protocol for use in deep-space networks, entitled “positional link-trajectory state” (PLS) protocol. PLS is a position based routing mechanism that predicts the satellite or other spacecraft’s moving paths to make routing decision. In the suggested routing protocol, flooding is performed at first and then the predicted trajectory of nodes. Links availability and their characteristics such as latency, error and rate through the network and link states are updated. Finally, each node independently re-computes its own routing table using a modified Dijkstra algorithm [7].

C. *Space Time Based Routing*

Merugu et al. (2004) suggested a routing framework, which unlike conventional routing tables using only connectivity information, provides a space-time routing table relying on information about destination and arrival time of messages. These two metrics are used to choose the next hop in a route. The underlying reason behind this approach is that in wireless networks with mobile nodes, the network topology changes with time and choosing the best route depends not only on destination but also on the topology evolution. The forwarding table in each intermediate node is a two dimensional matrix composed of destination address and instances of time when this route has been obtained. The forwarding decision is a function of both destination and time [8].

D. *Tree Based Routing*

Handorean et al. (2005) presented a tree based routing algorithm based on the knowledge about motion and availability patterns of mobile nodes. Depending on how the routing information is obtained they classified the path selection mechanism into three cases: (i) the source node initially has complete information about speed and direction of motion of all other nodes and has the ability to estimate route trees for data delivery to destination nodes. (ii) The source originally has no information about other nodes motions and each node exchanges its own information with its neighbours and learns the path to a destination whenever they meet. The second method is useful in applications where nodes have highly mobile patterns and obtaining the global knowledge is difficult. (iii) The future trajectory of nodes is predicted relaying on the past recorded knowledge [9]. The tree based routing protocol requires maintenance algorithms to somehow keep the tree alive.

V. STOCHASTIC ROUTING

When there is no information about nodes mobility patterns obtained via deterministic predictions or historic information stochastic routing mechanism needs to be used. Depending on whether nodes dynamically adapt their trajectories or mobility patterns to improve the routing process, routing protocols based on stochastic techniques could be classified into passive or active protocols.

A. Active Routing Protocols

In this category of routing protocols, moving paths of some nodes are controlled in order to increase the message delivery probability. In these schemes mobile nodes act as natural “message carriers” and after picking up and storing the messages from the source node move toward the destination node to deliver them. Very often the active routing methods are more complicated and costly in terms or resources that are not related to communications compared to the passive routing techniques. However, they may drastically improve the overall performance of system in terms of delay and loss metrics [8]. Active routing techniques could be implemented in those DTNs where no direct communication opportunities between end systems are expected by default. e.g. emergency and military networks. Buses, unmanned aerial vehicles (VAV) or other types of mobile nodes can be used as ferry nodes in different DTN environments [10].

A.I. Meet and Visit Routing

Burns et al. (2005) suggested the so-called meet and visit strategy for forwarding messages in structures with mobile source and fixed destination nodes. This scheme actively explores information about meeting of peer nodes and their visiting locations. The knowledge regarding meetings and visiting places is stored at each node and used to estimate message delivery probabilities. Three important assumptions are introduced in the meet and visit protocol: (i) nodes have unlimited buffer space. (ii) there is infinite link capacity and (iii) destination nodes are fixed [11].

A.II. Message Ferrying (MF) Routing

Zhao et al. (2004) described the so-called message ferrying method which uses mobile nodes with stable mobility patterns as collections and carriers of messages. The ferry nodes could provide connectivity among nodes in a network, where there are no possibilities for direct communication between end systems. Because of fixed moving path of ferry nodes, each node can save information about the ferries' mobility patterns and may adapt its future trajectory to come into contact with ferry nodes to have sending or receiving messages. Depending on the entity initiating transactions, two forwarding schemes can be used for message delivery: node-initiated message ferrying (NIMF) and ferry-initiated message ferrying (FIMF). According to the first approach the ferry nodes chooses their path using a predefined mobility pattern known by other nodes. Whenever the nodes want to send message via the ferries, they need to adjust their trajectories to move towards the ferry nodes. The nodes can be informed about ferries' path using broadcasting messages originated by ferry nodes or using predefined schedules. In the FIMF, nodes broadcast call-for-service request whenever they need to send or receive messages. The nearest ferry node is responsible for responding them and moving towards the nodes to pick up the messages [12].

B. Passive Routing Protocols

Protocols falling in to this category assume that the moving path of nodes does not change in order to dynamically adapt to the routing and forwarding process of messages. The basic idea of these mechanisms is to combine routing with forwarding by flooding multiple copies of a message to the network by a source and waiting for successful reception. Obviously, the more the copies of the message on available links, the more the probability of the message delivery will be. As one can see this scheme may provide low delay at the expense of worse resource utilization. This approach is useful in those networks, where forwarding and storage resources of nodes mobility.

B.I. Epidemic Routing

Epidemic routing algorithm was the method which firstly introduced by Demers et al. [6] to synchronize database which use replication mechanism. This algorithm was modified by Vahdat et al. (2000) and proposed as a flooding-based forwarding algorithm for DTNs. In the epidemic routing scheme, the node receiving a message, forwards a copy of it to all nodes it encounters. Thus, the message is spread throughout the network by mobile nodes and eventually all nodes will have the same data. Although no delivery guarantees are provided, this algorithm can be seen as the best effort approach to reach the destination. Each message and its unique identifier are saved in the node's buffer. The list of them is called the summary vector. Whenever, two adjacent nodes get opportunity to communicate with each other, they exchange and compare their summary vectors to identify which message they do not have and subsequently request them. To avoid multiple connections between the same nodes, the history of recent contacts is maintained in the nodes caches [13].

Assuming sufficient resources such as node buffers and communication bandwidth between nodes, the epidemic routing protocol finds the optimal path for message delivery to destinations with the smallest delay. The reason is that the epidemic routing explores all available communication paths to deliver messages [7] and provides strong redundancy against node failures [14]. The major disadvantage of epidemic routing is wastage of resources such as buffer, bandwidth and nodes power due to forwarding of multiple copies of the same message. It causes contentions when resources are limited, leading to dropping of messages. It is especially useful in those conditions when there are no better algorithms to deliver messages.

B.II. Spray and Wait Routing

Wasteful resource consumption in the epidemic routing, could be significantly reduced if the level of distribution is somehow controlled. Spyropoulos et al. (2005) proposed the spray and wait mechanism to control the level of spreading of messages throughout the network. Similar to the epidemic routing, the spray and wait protocol assumes no knowledge of network topology and nodes mobility patterns and simply forwards multiple copies of received messages using flooding technique. The difference between this protocol and the epidemic routing scheme is that it only spreads L copies of the message. The authors in [15] proved that the minimum level of L to get the expected delay for message delivery depends on the number of nodes in the network and is independent of the network size and the range of transmission.

The spray and wait method consists of two phases, spray and wait phase. In the spray phase the source node after forwarding L copies of message to the first L encountered nodes, goes to wait phase, waiting for delivery confirmation. In the wait phase all nodes that received a copy of the message wait to meet the destination node directly to deliver data to it. Once data is delivered confirmation is sent back using the same principle.

To improve the performance of the algorithm Spyropoulos et al. (2005) purposed the binary spray and wait scheme. This method provides the best results if all the nodes' mobility patterns in the network are independent and identically distributed with the same probability distribution. According to the binary spray and wait, the source node creates L copies of the original message and then, whenever the next node is encountered, hands over half of them to it and keeping the remained copies. This process is continued with other relay nodes until only one copy of the message is left. When this happens the source node waits to meet the destination directly to carry out the direct transmission [15].

B.III. PROPHET Routing

The probabilistic routing protocol using history of encounters and transitivity (PROPHET) is a probabilistic routing protocol developed by Lindgren et al. (2003). The basic assumption in the PROPHET is that mobility of nodes is not purely random, but it has a number of deterministic properties e.g. repeating behaviour. In the PROPHET scheme, it is assumed that the mobile nodes tend to pass through some locations more than others, implying that passing through previously visited locations is highly probable. As a result, the nodes that met each other in the past are more likely to meet in the future [16]. The first step in this method is the estimation of a probabilistic metric called delivery predictability *P(a,b)*. This metric estimates the probability of the node A to be able to deliver a message to the destination node B. Similar to epidemic routing, whenever a node comes in to contact with other nodes in the network, they exchange summary vectors. The difference is that in the PROPHET method the summary vectors also contain the delivery predictability values for destination known by each node. Each node further requests messages it does not have and updates its internal delivery predictability vector to identify which node has greater delivery predictability to a given destination [16]. The operation of PROPHET protocol could be classified in two phases: Calculation of delivery predictabilities and forwarding strategies.

B.IV. MobySpace Routing

Leguay et al. (2005) suggested a mobility pattern space routing method called MobySpace. The major principle behind their proposal is that the two nodes with similar trajectories will meet each other with high probability. According to this method, each node forwards the received messages to the encountered nodes provided that they have similar mobility patterns with the destination node. The title of this protocol comes from a virtual Euclidean space used for taking decision on the message forwarding process. In this virtual space each nodes is specified using its mobility pattern, called MobyPoint and routing is done towards nodes having similar MobyPoint with the destination node [17]. Each axis in the MobySpace defines the possible contact and the distance from each axis presents the communication probability between nodes. In the MobySpace the closer nodes have higher probability to communicate with each other , so in the routing process the messages are forwarded toward the nodes that are as close to the destination node as possible [10][18].

The MobySpace protocol demonstrates better results whenever nodes' mobility patterns are fixed. However, two nodes with similar mobility patterns may never communicate if they are separated in time. In other words, the nodes with similar trajectories could meet each other provided that is in the same time dimension [10].

VI. CONCLUSION

Research on routing in DTN is still in its infancy. Much progress has been achieved by the research community in bridging the gap of disconnection and enabling communication in DTNs. However several areas in DTN routing that requires research attention. We have made an in depth study of the various routing protocols, proposed for DTN and we have tried to classify them according to knowledge based classification. It is not possible to classify each of the schemes into exactly one of the many classes. Most approaches are hybrid in nature and may fall into more than one category.

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