A Novel Path-Prediction Routing Protocol for Delay Tolerant Networks

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Summary
The objective of routing protocols in mobile ad hoc is to let nodes to communicate in the absence of network infrastructure using wireless devices. Although powerful to changes to network topologies, current routing protocols suffer from the issue of assuming the existence of a connected path from the origin node to the destination one. However, in today's networks this is not necessary the case. This is due to power limitations, the need for wireless networks with short-range, and the broad physical environment where ad hoc networks must be established. When fully connect paths between pairs of nodes are not always exist, the network is called delay tolerant.
This paper presents a new method for routing in delay tolerant networks (DTN). The proposed routing technique is based on path perdition to decide which node is more likely to deliver a message. The path perdition is done using recent locations visited by the node.
Key words:
Path Prediction protocol routing (PPR), Delay Tolerant Networks (DTN), Routing Protocols, Wireless networking

1. Introduction

Modern Transportation Systems (MTS), are state-of-the-art systems intending to support traffic management and modes of transport using vehicular connections in a novel way. The ultimate goal of such connections and systems is to provide more pleasure for drivers and to boost road security. Road security and traffic information can be exchanged between neighboring cars and roadside equipments using their wireless devices. Over the last years, the crucial applications that can be achieved in vehicular environments made their networks a common research area. According to [1], the vehicular applications are classified into two big groups:

[1] value-added applications that provide services to users, like entertainment, and
[2] security applications that boost safety of moving cars.

Vehicle-to-vehicle communications [2] (VVC) can help to reduce traffic congestion. This can be done as various degrees of traffic jams [3] can be revealed in vehicular networks using communications among vehicles. The convenience, safety, and efficiency of various transportation systems can be boosted using Inter-vehicle communication (IVC). This is applicable to trains, robots, automobiles, and planes [4]. A survey of use cases and vehicular applications is in [5], which classifies them into three groups:

[1] Management and traffic controlling applications,
[2] Road-safety applications, and
[3] Commercial applications.

IVC can be used to avoid many of the collisions caused by an accident [6], through circulation of cautioning messages. The low cost wireless networking techniques has facilitated a wide range of novel applications. Easy access to global information repositories is enabled by adaptors of wireless network placed in cellular phones (as an example of portable computing devices), laptops, and private digital assistants. The necessity of having a base station (wired) in proximity of wireless nodes and the energy/cost of moving information over large distances are among difficulties to realize this vision. The science of ad hoc wireless networking treats some of these issues via moving nodes to connect with each other with no fixed connection infrastructure system. Hence the idea is to use arbitrary moving nodes to serve as intervening routers between two nodes that may differently not be in direct communication with each other.

Recent research studies reducing power consumption [10, 11], route disclose and improve [12-18], and boosting QoS guarantees [19-21] in ad hoc networks. It is typical for current ad hoc routing methods to assume that there is always a connected way from source to goal. However, the easiness of short-domain wireless connections and the broad physical domain and factors affecting these are strong reasons that this assumption is not mostly valid in practical situations. Hence, unfortunately, using exiting ad hoc routing techniques, messages are not delivered if a network failure happens between the source and the goal when a packet is sent. Specific applications, like real-time, continuous bit connections may request an established path for guaranteed connections. However, other applications can do with ultimate and accurate arrival of packets. This

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is the case when many network failures would stop packets from ever being arriving end-to-end. We describe a few of these applications below. These applications include mobile sensor networks [22], smart dust [23], and disaster recovery/military deployment. The main objective is these applications are to develop methods for delivering application messages with high chance alike in the situation where no fully connected way from source to destination exists.

This paper presents a new technique for routing in delay tolerant networks (DTN) which are networks whose nodes are not fully connected all the time. The presented routing technique uses path perdition to decide which node is more likely to deliver a message. The path perdition is based on the recent places visited by the node. Therefore the proposed techniques requires weak connectivity for the concerned ad hoc network. This amounts to assuming that

[1] the sending node is not close enough to any base stations,
[2] the sending node does recognize the location of the target node or the optimal path to follow,
[3] the target node can be a moving wireless node, and
[4] pairs of nodes regularly are in communication range of each other due to their movement.

Organization: The rest of this paper is organized as follows. Section 2 describes the idea behind the proposed routing protocol. The system architecture and protocol details are presented in section 3 and 4, respectively. Section 5 present a brief review of related work.

2. The Proposed Path Prediction Idea

Our proposed technique, named Path Prediction Routing (PPR), aims at disseminate application packets to nodes, called hosts, inside connected regions of ad hoc networks. This allows packets to efficiently distribute over connected regions of the network. The path prediction Routing then counts upon hosts that are more likely (using coordinates history) to meet the target node. This allows packets to spread into other connected regions of the network using node mobility. Therefore, the packet visits an additional isolated region of nodes. This style of transitive transmission of packets allows packets to enjoy high probability of finally arriving their goals.

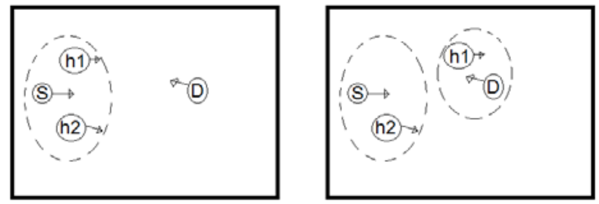

Fig. 1 A description of the path-prediction routing.

Figure 1 describes the path prediction (PP) routing at an abstract view, with the network nodes drawn as letters in circles. The wireless coverage area of the source node in the LHD figure and of the source and destination nodes in the RHD figure are represented using dotted ovals. The arrow associated with every node shows the direction of its predicted motion evaluated by the recent places visited by the nodes.

In Figure 1(LHS), the source, *S*, needs to send a packet to the destination, *D*, however the connection between the two nodes is not available. However *S* has two nodes (h_1 and h_2) in its wireless coverage area. Form the motion directions; it is obvious that h_2 is more likely to meet *D* than h_1. Therefore *S* transmits its packet to h_1 rather than h_2. As shown in Figure 1(RHS), at some later time, h_1 becomes in the wireless coverage area of *D* and delivers the packet to its final destination, node *D*. nation.

We present in this paper an extended version of the epidemic routing protocols [9] in which the random exchange of packets among nodes allows all updates to be seen by almost all nodes in a relatively small amount of time. Therefore the system eventually arrives at a consistent state. More specifically, the objective of epidemic routing is to deliver a packet with reasonable probability to a *specific* destination. Rather than the destination, it is desirable to reduce the set of nodes hosting a specific packet to reduce needed system resources (i.e., network bandwidth, memory, or power) to deliver the packet. Although not explored in details in this paper, our proposed protocol can easily be extended to support packet multicast/broadcast in delay tolerant (partially connected) ad hoc networks.

The ultimate objective of our proposed PP routing is to increase number of packet delivered and reduce average delivery time, and reduce also the accumulated system resources needed for packet delivery. We achieve this by fixing an upper bound on the number of nodes visited by a specific packet on its way for the destination. This bound is determined by the importance level of the packet. Another bound is put on the per-node buffer space which is the amount of storage dedicated to host other's nodes packets. This bound depends on the nature of the hosting node. Of course these bounds are proportional to the probability that a packet will successfully arrives its destination in swapping using higher accumulated consumption of resources.

3. The Path Prediction System Architecture

The aims of the PP routing are to:

[1] Effectively disseminate packets among nodes of ad hoc networks that are partially connected in a prediction style,
[2] Reduce resources usage in delivering packets, and
[3] Boost the number of packets are eventually arriving their destination.

The underlying protocol for the PP routing has to consider the following interesting issues:

Resource Allocation*:* In the PP routing, it is common and maybe convenient to simultaneously have many copies of a packet in transit. Therefore, the system has to compromise minimizing resource usage and maximizing packet delivery. For instance, a single packet has to use reasonable buffer space on Internet while ensuring its earliest timely delivery. On the other hand, copies of a packet may be hosted by many nodes to increase the likelihood that a specific packet is ultimately delivered.

Routing Under Uncertainty*:* inaccurate information about locations of nodes in the network is owned by packet senders. Therefore, a main issue is to decide if it convenient to give a packet upon arriving into domain of a potential carrier. For instance, the system may rely on the nodes that the target node is more likely to meet according (in terms of the coordinates of recent locations of nodes).

Reliability*:* Due to the prediction style in delivering packets in our protocol, specific applications may require acknowledgments for packet-delivery success. For instance, the source node and all hosts may release resources allocated for a specific packet upon ensuring the successful delivery at the intended node.

Performance*:* A particular packet delivery and routing protocol can be examined using a various number of parameters. The parameters include the average time in delivering packets, the average amount of buffer consumption and communication power in handing over a packet, and the amount of power needed to deliver the packet to its target. The power consumption parameter is specifically related to mobile nodes as a node must consider the power usage of carrying a particular packet. It is essential to note that carrying and delivering packets use power as well as classical performance parameters like memory, CPU power, and network bandwidth. Therefore it is important to compromise among all system resources in delivering packets to their final goals.

Security: A packet typically goes through an arbitrary path of nodes to reach its ultimate goal. Different receivers require guaranteeing different levels of authenticity of packets. This depends on the sensitivity of the packet-information and the nature of the concerned application. Well-known cryptographic techniques [7] may be used to provide the required guarantees. Investigating the full path that a packet travels to arrive the destination may also be beneficial. This allows receivers to know whether a packet has been hosted by (even in encrypted format) untrusted nodes. Hence with guidance of the sensitivity of information carried by a particular packet, untrusted hosts can be removed from the set of potential hosts.

4. Path Prediction Routing Protocol

The PP routing ensures the ultimate delivery of packets to arbitrary goals with specific conditions regarding the connectivity and structure of the concerned network. More specifically, the protocol works as follows. The protocol succeeds by the transitive dissemination of packets in the ad hoc networks to nodes that are on paths to meet the destination nodes. Every node stores its own and other's packets. For efficiency, a B-tree is used to index the list of packets in a specific node. Each packet has its own key in the form of a unique identifier. Every node also has its own register that stores the root of the B-trees. We assume the author is familiar with the B-trees data structures. Related protocols use other data structures like vectors, however the B-tree has the advantage of considerably minimize the space overhead due to the summary vector. When two nodes become close enough, the node with undelivered packets requests an *exchange period* with the other node. To reduce unnecessary communications, every node keeps a record of *"bad"* nodes that have low percentage of success in delivering packets. An *exchange period* is not to be established with nodes in this list.

Over an exchange period between nodes A and B, the two nodes swap their B-trees so that every node A (B) can decide which packets in node B (A) can be delivered by A. Then, every node asks for copies of packets that it has a chance to meet their destination. The hosting node can decide later not to host a specific packet for different reasons like: the packet is very large; the content of the packet, its source, or its destination is not trusted.

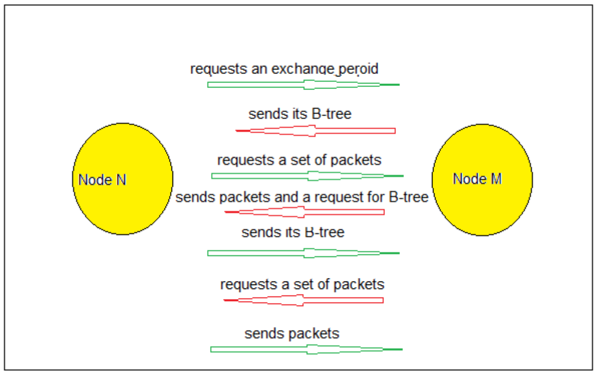

Fig. 2 A description of exchange steps between nodes.

Figure 2 describes the packet exchange in the path prediction routing protocol. Node N has undelivered packets and becomes close enough to node M. Hence node N requests and exchange period with Node M. When Node M receives the request, it starts to send its B-tree to the node N. Upon receiving the B-tree node N then decides which of the packets hosted by node M have chance to be delivered by the node N. Node N then asks for these packets. Node M then replies to node B with the required packets and a request for the B-tree of Node N. Upon receiving the B-tree node M then decides which of the packets hosted by node N have chance to be delivered by the node M. Node M then asks for these packets. This technique is repeated transitively by nodes N and M upon coming close enough to other nodes. B comes into contact with a new neighbor. Large storage spaces in nodes and enough number of exchange periods guarantee ultimate packet delivery using this technique of pair-wise packet exchange.

The design for PP routing assigns each packet a unique identifier, and a time-before-exchange filed. The packet ID is a 64-bit number. The source node ID contributes to the packet ID. Practically, it is necessary to assign ID's to moving nodes. The way out packet Id is built allows to recognize packets produced by nodes on the ad hoc network and having identical subnet mask.

The time-before-exchange variable is necessary to determine an upper bound for the allowed time before the node that is to receive the packet is expected to meet the destination node. Another bound on the number of exchanges is forced by TTL field of IP packets. It worth noting that packets with a time-before-exchange variable of zero will only be handed to their destination nodes. Unfortunately, such packets are more likely to be ignored due to restrictions on available local-buffer space. The largest the time-before-exchange value is, the quickest packets dissemination is. This result in increasing resources required to packet delivery, but will as well reduce average packet delivery time. Therefore the packet priority affects (increases) the time-before-exchange value for the packet. Using the network configuration, practically most packets are assigned a time-before-exchange value close to the expected time of all exchanges to get the packet delivered.

Every node fixes an upper bound on the number of packets hosted by its buffer. The buffer size affects the amount of resources consumed through our PP routing technique. As a general practice, nodes sacrifice older packets to host newer ones when reaching their buffer's limit. Typically, there is a classical tradeoff between packet delivery time (rate) and resource usage. Practically, letting a subset of nodes to enjoy buffers of sizes close to the anticipated count of packets in a delivery process at any given time, ensures ultimate arrival of packets to their destinations. Elseways, it is likely that older packets will be dismissed from buffers ahead of arrival to their destinations.

Classical management techniques can be applied the per-node packet local buffer. The most common technique is FIFO: first-in-first-out. This technique is straightforward for implementation and reduces the time that a specific packet is expected to remain "around" hosted by at least one node. Upon the arrival of enough count of new packets into the network, older packets are expected to be dismissed from most node buffers. It is convenient to use FIFO when the buffer capacity on most nodes is bigger than the anticipated count of packets being delivered at any given time. On the other hand if buffer capacity is small compared to the packets number, FIFO is convenient in term of quality of service (QoS) and fairness. For instance, a node's growing buffer usage is affected by the number of packets treated by the node. Moreover, FIFO does not consider the packets priorities; FIFO assumes that all packets are of equal priorities. An example, of more accurate queuing techniques, is Weighted Fair Queuing (WFQ) [9], which allots free buffer places among competing nodes. This applies only if QoS is differentiated on a per-packet communication.

5. Related and Future Work

The path prediction routing utilizes techniques in both consensus protocols and ad hoc routing ones. Many ad hoc routing techniques exist [12, 13, 14, 23, 24, 16, 17, 18]. These techniques have relative weaknesses and strengths and were assuming different environments [25, 26, 27]. However, our proposed technique is conveniently orthogonal to the nature of the delay tolerant ad hoc routing protocols. This is so as this paper focuses completely on methods for treating the scenario where a connected way does not exist between source and destination. Practically classical techniques (assuming end to end ad hoc routing) are first applied. If a path does not exist, path-prediction routing (PPR) is then more appropriate to apply.

For future work, it may convenient to use geographical maps to improve the path prediction process. Combined with the factor of routes conditions, considering the geographical conditions is expected to lead to significant improvements to the routing process. The expected improvement is in terms of power consumptions and delivery latency.

A number of proposals investigate multicast support in ad hoc routing protocols [21, 28]. Once again, these techniques are appropriate in the case where the network is connected. We observe that Epidemic Routing, by its very nature of widely distributing messages in partially connected networks, is appropriate for supporting multicast in partially connected networks. While strong real-time guarantees cannot be provided for timely delivery, eventually delivering messages to a group of receivers can provide benefits for many applications.

Epidemic algorithms [8] are the basis of our proposed routing technique. These techniques were basically developed to arrange ultimate compatibility for replicated databases providing the absence of all replicas. All messages are ultimately arrive at all replicas due to the arbitrary pair-wise disseminations of packets among couples of replicas. Other applications of Epidemic techniques are weakly-connected situations and group membership [30, 31, 31]. Our proposed technique presents an extension of the general idea of epidemic techniques via utilizing advantage of the nature of our specific connection domain. This amounts to having individual packets ultimately seen by different nodes rather than assuming all packets to be ultimately seen by all replicas.

Other research [14, 15] utilizes global positioning system (GPS) to minimize the search space accompanying the ad hoc route establishment. This is another direction for our future work as the use of location information may help in restricting resource consumption characterizing Epidemic Routing.

Query localization [29] utilizes the concept of spatial locality to minimize regions of the network examined by conscious protocols of ad hoc routing. More specifically, when a specified path “fails” (because of movements of nodes), new paths orders are only disseminated if they vary by less than an upper bound of nodes from the old path.

An interesting direction for future work is to establish theoretical methods [33, 34, 35, 36] to ensure the correctness of the routing protocols. Such methods could be in the form of mathematical semantics to the routing steps. This has the advantage of proving interesting properties for the routing process in DTNs.

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