GSR: A Geographic Single-copy Routing Scheme in Intermittently Connected Mobile Networks

Ze Li and Haiying Shen
Department of Computer Science and Computer Engineering
University of Arkansas, Fayetteville, AR 72701

Abstract - *Intermittently connected mobile networks do not have a complete path from a source to a destination at most of the time. Efficient routing is important to high performance of the intermittently connected mobile networks. In this paper, we propose a Geographic Single-copy Routing scheme (GSR). This method relies on geographic positions of the neighbor node to find an ideal routing path using only one packet copy, which significantly reduces routing overhead, and improves routing efficiency. Simulations show that GSR provides nearly optimal performance compared with other routing methods.*

Keywords: DTN, Geographic routing

1 Introduction

In intermittently connected mobile networks, i.e. Delay Tolerant Networks (DTN), a continuous end-to-end path between a pair of source and destination nodes are not always guaranteed. Current message routing in the DTN can be classified into two groups. One group is flooding based routing [1, 2, 3]. While the other group is single-copy based routing, such as two hop direct routing [4]. However, these methods incur either high overheads due to excessive transmissions or long delay due to the incorrect choices during forwarding.

In this paper, we present a Geographic Single-copy Routing scheme (GSR) for intermittently connected mobile networks. Geographic routing is a routing principle that relies on geographic position information instead of using the network addresses. These position information can be generated by either Globe Position System or numerable location management methods [5, 6]. One requirement of geographic routing is that the source node is aware of location of the destination node. Fortunately, in wireless sensor network, the position of the sink is always available to all nodes. Therefore, after collecting data from the determined objects, these sensors route the messages to the sinks through discontinuous links.

GSR improves the performance of DTN. In GSR, wireless nodes are always able to forward bundles (i.e., blocks of several packets) to other nodes whose moving direction are approximately towards the destination nodes. In addition, the node moving towards the destination and is closest to the destination node is chosen as the last routing hop. It helps increase the "communication time" which represents the time period that a node is in the transmission range of another node so that it can transmit packets to that node.

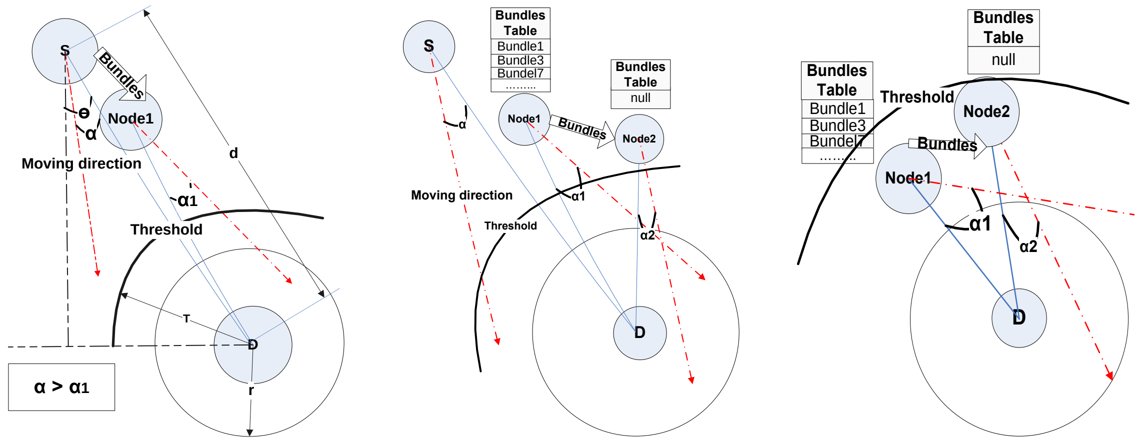
In the next section we go over existing related work. Section 3 presents GSR routing algorithm. In Section 4, we analyze the performance of GSR theoretically. Simulation results are presented in section 5. Finally, section 6 concludes the paper.

2 Related Work

Although numerous routing protocols for wireless ad hoc networks have been proposed [7, 8], traditional routing protocols are not appropriate for DTNs that are sparse and disconnected. These protocols don't work well even if the network is only "slightly" disconnected [4].

An intuitive idea to deal with connectivity disruptions in DTNs is to reinforce connectivity on demand by sending out a number of specialized nodes (e.g. robots, satellites) which are assigned to fill the "communication gap" when a disconnection happens [9].

Predicted routing is another approach for DTN [10, 11]. They determine the routing path before transmission. In [1], nodes record the history of past encounters in order to make fewer but more informed decisions. Those routing paths are predicted either by statistics of a mobility module or by a historical moving path record. However, these schemes reduce the transmission overhead of flood-based routing at a significant penalty on delivery delay.



(a) First transmission (b) $d > T$ (c) $d < T$

Figure 1. Packet routing in GSR.

The third transmission approach for DTN is opportunistic routing. A simplest approach is direct routing that lets the source or a moving relay node carry the packet all the way to the destination [12]. A faster way to perform routing in DTN is epidemic routing [13] based on flooding. This scheme can guarantee a short delay by locating a shortest routing path at the cost of high network resource consumption. There are some improved approaches proposed to reduce the overhead of the epidemic routing [14, 2, 15]. In [14], a packet is "gossiped" to other nodes instead of flooding in which a packet is forwarded to partial neighbors. In [15], nodes remove redundant copies of certain packet when that packet has been transmitted. In [2], the author points out that consulting the age of the last node encountered when making forwarding decision results in superior performance than flooding.

3 GSR: GPS-based Routing Algorithm

Based on the previous exposition, we identify a number of desirable design goals for a routing protocol in DTN and propose GSR routing scheme.

(1) In order to reduce transmission overload and resource consumption, rather than relying on flooding, GSR uses single-copy routing scheme to avoid traffic congestion in the system.

(2) In order to reduce transmission delay, unlike existing opportunistic single-copy routing and flooding-based routing, the package in the GSR is forwarded towards the destination in a control path.

3.1 Algorithm

Figure 1 shows a routing path of packets (bundles) from a source node to a destination node in GSR. Basically, when the packets are far from the destination node (i.e. beyond a threshold distance denoted by T), they will be forwarded among the mobile nodes whose position *distances* are closer to the destination. When the packets move closer to the destination node (i.e. within threshold distance T), they are forwarded to a mobile node moving towards and the *direction* is closer to the destination node.

We let SD be the line joining the source node and destination node in figure 1, let θ be the slope of SD, d be the length of SD, and α be the moving direction of a node relative to destination node. The GSR scheme consists of the following three steps.

First, as shown in Figure 1 (a), when a source node wants to send packets to a destination, it first transmits the packets to another mobile node whose position is closer to the destination and its moving direction α is in $[\theta - \xi, \theta + \xi]$, where ξ is the deviation angle from the θ. Initially, ξ is equal to $\arcsin(r/d)$, where r denotes the transmission radius of the destination node.

Second, as shown in Figure 1 (b), if $d > T$, the relay node seeks to find another relay node whose position is closer to the destination node and its moving direction is between $[\theta - \xi, \theta + \xi]$, where

$$\xi = \tau^n \cdot \arcsin(r/d) \leq \pi/2,$$

in which τ is a weight value increasing with time and $\tau >= 1$, n is a constant value and $n \in (0, 1)$. That is, ξ increases with time if the relay node cannot find another node for packet forwarding. The largest value of ξ is $\pi/2$. On the other hand, every time when a relay node

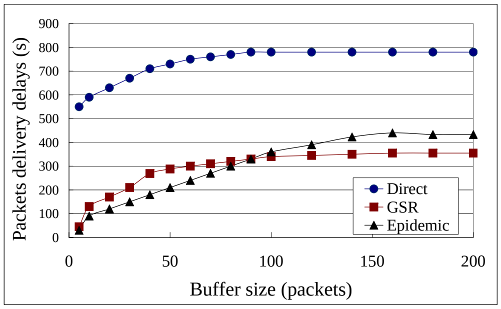


Figure 2. Packet delivery delay.

successfully finds another node for packet transmission, τ is resumed to 1. That is ξ is resumed to $\arcsin(r/d)$. We call this phase "macro-control of transmission," because packets can be transmitted comparably faster to the destination node in this phase.

Third, as shown in 1(c), if $d < T$, the mobile node only forwards packets to another node whose moving direction $\alpha 2$ to the destination node is smaller than its own $\alpha 1$, even if the position of that node is farther to the destination node. If there is no such nodes nearby, the node will continually carry the packets by itself until reaching the destination node. For more details of the GSR protocol, Please refer to [16].

4 Performance Evaluation

This section demonstrates the distinguishing properties of GSR through simulation built on OMNeT++ [2]. We used Epidemic routing scheme [13] to represent flooding-based schemes, and used Direct routing scheme [17] to represent sing-copy routing scheme, and compared GSR with them. The simulation is based on Uniform Mobility Model [18]. This model consists of a $1500m \times 300m$ space area where 50 nodes are i.i.d. placed. Three of the 50 nodes are randomly chosen to be static nodes serving as destination nodes whose locations are known by other nodes. The mobile nodes move at the speeds of $0 - 20m/s$ and the pause time is $0 - 5$s. A subset of 47 nodes generate one packet per second for 2000 seconds to one of the three destination nodes, and the simulation is then run for another 2000 seconds to allow packets to be delivered. The distance threshold T in the GSR is set to be $2r$, where r denotes the transmission range of mobile node, if the transmission range of the mobile nodes changed, the T will be changed. The TTL in the Epidemic was set to be 5 hops and $\tau = 2$. Our previous tests indicated that these values were optimal choices for the parameters. The transmission range of the node is 50m. In the simulation, dropped packets will not be re-transmitted again. Three simulation metrics were used in the simulation:

(1) *Packet delivery delay*. It is the average time latency of a packet to be delivered. This metric represents the efficiency of a routing scheme in fast routing.

(2) *Number of successfully delivered packets.* It is the number of packets that can be delivered to the destination. This metric represents the robustness and delivery capacity of a routing scheme.

(3) *Number of transmissions.* A transmission occurs when a node forwards a packet to another node in the routing. This metric reflects the transmission overhead and the resource consumption of a routing scheme.

4.1 Packet Delivery Delay

Figure 2 plots the packet delivery delay versus buffer size. The figure generally shows that Direct generates much longer delay than others, and the delay performance of GSR and Epidemic are almost the same. The reason is that due to Direct's single-copy feature, the possibility of a successful transmission between two node depends on the possibility they can meet, leading to a long delay. In contrast, relying on flooding, Epidemic increases the possibility to meet destination node, therefore it can deliver packets more quickly. Although GSR also uses single-copy routing as Direct does, since this copy can always be forwarded to the destination node in the right direction, the delay can be very small. Note that the flooding based Epidemic routing can reach the optimal transmission delay in DTN, which means GSR was also reaching the optimal transmission delay.

It is intriguing to see that the delay increases as the buffer size increases. It is because smaller buffer size leads to more packet droppings, resulting in less packet delivery, hence less delay. The increased delay is resulted from those extra delivered messages which were dropped at smaller queue sizes. Therefore, we can see from Figure 2 that when the buffer size is small, a considerable number of packets are dropped by Epidemic routing resulting in a less delay than GSR. However, when the buffer size is big, the delay of GSR is shorter than Epidemic. It is because, when the transmission range of nodes are small, it is unlikely that the packet can be replicated to many nodes, which affect its transmission performance.

Furthermore, the figures show that the delay of GSR is not as sensitive to the buffer size as Epidemic. Since the GSR is only single-copy transmission which does not depend on the buffer storage as flooding in Epidemic, the performance of GSR will remain almost the same.

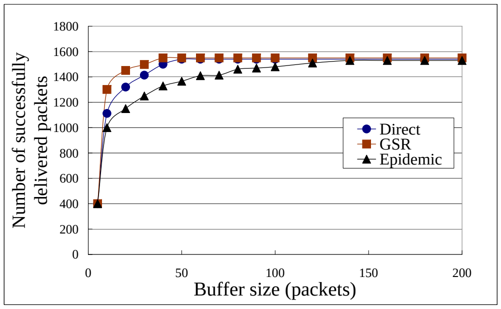


Figure 3. Number of delivered packets

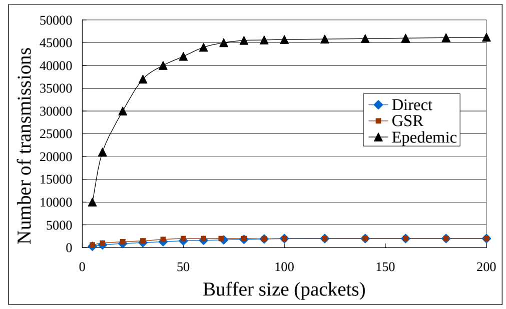


Figure 4. Overheads rate versus number of source nodes

4.2 Packet Delivery Capacity

Figure 3 depicts the number of successfully delivered packets versus buffer size. It shows that as the buffer size increases, so does the number of the successfully delivered packet to their destinations due to the same reason observed in Figure 2. Larger buffer size means that more packets can be buffered and less packet droppings, resulting in more successfully delivered packets.

Figure 3 also shows that the GSR and Direct are less sensitive to the buffer size than Epidemic. Buffer congestion occurs when the buffer size is not big enough for all the packets, and some packets should be dropped off. GSR and Direct don't have buffer congestion problem due to their single-copy routing, whereas the Epidemic with the flooding nature suffers from the buffer congestion severely especially when the buffer size is small. Furthermore, we can see that GSR leads to more delivered packets than Direct with small buffer size. This is due to the transmission delay of GSR is much less than Direct, and it is more likely that the GSR has more free buffer at all the time. Therefore, as the buffer size is small, the GSR will has less possibility to experience the data congestion than Direct.

Moreover, Figure 3 indicates that when the buffer is large enough for all the packets, the delivery ability of all routing schemes are almost the same. It is because there is no buffer congestion during their transmission. GSR performs the best among the schemes with regards to the packet delivery ability.

4.3 Transmission Overhead

Figure 4 shows the number of transmissions versus the buffer size. The figure shows that GSR and Direct incurs less transmissions, hence lower communication overhead than Epidemic. It is because Epidemic is based on flooding in which a node sends all possible packets to nodes it encounters. In contrast, GSR and Direct only forward one copy of the packets in the network. That is also why Epidemic will come across packet congestion in a high loaded network.

5 Conclusions

In this work, we investigate the problem of efficient routing in intermittently connected mobile networks, which can be found in very sparse mobile networks where nodes meet only occasionally to exchange information, or in wireless sensor networks where nodes sleep most of the time to conserve energy. We propose a Geographic Single-copy Routing scheme (GSR), which reduces the routing overhead by a single copy, and improve the routing delay by forwarding message in the destination direction. Experiment results show that GSR outperforms other routing schems with respect to successful transmission ability, transmission delay and overhead.

In the future work, we will theoretically analyze the performance of the GSR routing method. In addition, we will investigate whether the transmission delay can be further improved with GPS-based multi-copy routing.

Acknowledgements

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