A Direction Based Geographic Routing Scheme for Intermittently Connected Mobile Networks

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Abstract

In Delay Tolerant Network, a complete routing path from a source to a destination can not be guaranteed at most of the time. Therefore, traditional routing method for ad hoc network is not applicable in these situations. Current approaches for such networks are primarily based on redundant transmissions and single copy direct routing. However, they incur either high overhead due to excessive transmissions or long delays due to the incorrect path choices during forwarding. In this paper, we propose a DIrection based Geographic routing scheme (DIG) for the intermittently connected network. Relying on the geographic location information, the packets are routed in a approximate ideal path to the destination, which significantly reduces the resource required in flooding-based algorithm and lead to decreased delay compared to the direct routing. Theoretical analyzes and simulations show that compared to the epidemic routing and direct routing, DIG provides nearly optimal delay with very low overhead .

1 Introduction

The fast development of the wireless communication techniques and electronic techniques enable almost every mobile devices to be equipped with wireless communication capabilities, which make the concept of ubiquitous computing very promising in the near future. One research area that has received increasing attention currently is mobile ad hoc network (MANET). The mobile ad hoc networks are collections of wireless mobile nodes which promise a convenient infrastructure-free communication. One special group of MANET called Delay Tolerate Network (DTN) in which source nodes and destination nodes are intermitted connected have been receiving increasing attention these years. Examples of DTN include wildlife monitoring sensor networks [8], interplanetary communication networks [2], vehicular ad hoc networks (VANETs) [22], terrestrial wireless networks. Therefore, conventional internet routing protocols (e.g. RIP, OSPF) as well as ad hoc network routing schemes cannot be applied to DTN directly.

Almost all routing schemes proposed for DTN are topology based routing, that is, the data transmissions rely on nodes' addresses. One group of topology routing is flooding based routing [8, 13, 18]. Despite their increased robustness and low transmission delay, flooding-based routing schemes (i.e. epidemic routing schemes) consume much energy, bandwidth, and memory space that are crucial to the performance of wireless network applications (e. g. wireless sensor network). While the other group is single copy based routing, such as two hop direct routing [17]. In the two hop direct routing, a source node transmits each segment of the source packets stream to several intermediate nodes. The packets are allowed to be buffered for a long time until they meet the destination node. Although these schemes bring about much lower overhead for packet transmission, they suffer from severe transmission delay if a node chooses a wrong path for the delivery.

Geographic routing is another routing category for MANET which relies on geographic position information of mobile nodes instead of using network addresses, thus it is more scalable than the address based routing. These position information can be generated by Global Position System (GPS) or numerable virtual coodination methods[10, 4]. However, one requirement of geographic routing is that the source node should aware of the location of the destination node. Fortunately, in majority application of DTN such as wildlife monitoring sensor networks [8], interplanetary communication networks [2] and etc, the position of the destination nodes (the sink nodes) are determined. The packets are routed to some location determined sinks for data collection and data processing. In addition, high power cellular interface and some localization systems [11] can also be used for destination tracking. Although geographic routing can generate much less transmission overhead and lead to high transmission scalability for the decentralize routing, i.e. MANET, current geographic routings methods proposed for the wireless ad hoc network [9] using greedy transmission strategy is not applicable to DTN. It is because in MANET, the packets can be greedily transmitted to the destination via the continuous connected link in a short time. However, because of the huge delay between each transmission in DTN, the node currently closer to the destination node can not be guaranteed to be close or can forward the packet to a closer node in the near future.

In this paper, we present the design, implementation and evaluation of direction based geographic routing scheme specific for intermittently connected mobile networks (DIG). When choosing next hop relay node, not only should we consider the distance between the next hop node and the destination node, we should also consider the moving direction of each mobile node. We assume that the destination nodes' locations are static in the DTN for analysis simplicity. Such assumption is realistic since most of the current applications [8, 2, 22] have location determined data sinks.

In DIG, the bundles (blocks of several packets) are greedy forwarded to nodes whose moving directions and location distances are towards to the destinations when the distance between the packets and destinations are larger than a threshold. Otherwise, the nodes whose moving direction are closest to the destination nodes are chosen for the next hops. It helps increase "communication time" which represents the time period that a node is in the transmission range of another node, therefore, more packets can be transmitted to the destination in one interaction. The term "buffer" is used to refer to a queue in the mobile nodes to store received packets. A buffer management strategy is also being implemented In DIG to reduce packet transmission delay. We also build a module to theoretically analyze the performance of DIG. Theoretical and simulation results show that:

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

2 Related Work

Since the routing protocols for MANET are not appropriate for DTNs, in which the communication links are intermittently connected, serval routing methods for DTNs are proposed in these years.

An initial method 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 [24, 12]. However, such method need a global monitoring in the network. Therefore, it is not applicable to a self-organized DTN network.

Predicted routing is another approach for DTN [7, 2]. They determine the routing path before transmission. In [8], 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. In [5], Dubois-Ferriere *et al* proposes an idea based on encounter ages to improve the route discovery process of regular ad hoc networks. in [5], instead of searching for the destination, the source node searches for any intermediate node that encountered the destination more recently than did the source node itself. In [13], the author pointed out that consulting the age of the last node encountered when making forwarding decision results in superior performance than flooding.

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 message all the way to the destination [15]. Although these schemes can achieve high throughput performance, the delay will be very long. A faster way to perform routing in DTN is flooding based epidemic routing [19]. The basic idea of this algorithm is to forward the packets between two nodes when they contact with each other until the packet arrive at the destination. This scheme can guarantee a short delay by locating a shortest routing path at the cost of high network resource consumption. There are a number of improved approaches proposed to reduce the overhead of the epidemic routing [23, 13, 21, 16, 20]. In [23], a message is "gossiped" to other nodes instead of flooding in which a message is forwarded to partial neighbors. In [16], nodes remove redundant copies of certain message when that message has been transmitted.

3 Direction Based Geographic Routing Scheme

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

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

(2) In order to reduce transmission delay, unlike existing topology based single copy schemes [14, 15], DIG practically uses location information of each node to assist packet forwarding and make sure that a package is forwarded towards the destination in a comparatively optimistic way.

(3) In order to achieve high scalability, unlike the work in [13], DIG does not require to maintain a large routing

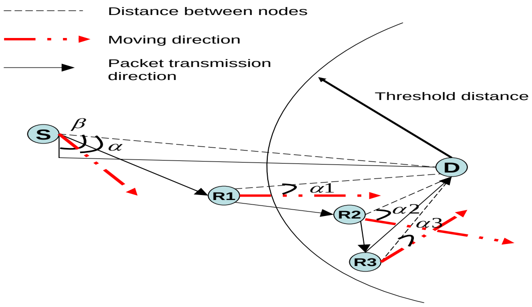


Figure 1. Transmission process

table containing the information of all the nodes, but a number of location information of its current neighbor nodes .

(4) In order to increase messages delivery throughput and reduce message dropping rate, DIG uses a packet handoff management scheme to manage the buffer.

3.1 Mobility Models

We use Uniform Mobility Model [1] as the theoretical analyzing scenario for DIG. In this model, each of the m mobile nodes move at speed v inside a unit circular disk. At time $t = 0$, the positions of these nodes are distributed uniformly at random inside the disk. The directions of motion of the m nodes at time $t = 0$ are identical independent distributed (i.i.d.) in $[0, 2\pi)$. We assume that the destination nodes are static or they have regular mobility routines to simplify the analysis. There are a number of real environments, such as interplanetary network, terrestrial network, wireless senor network, that satisfy the assumption.

3.2 Algorithm

In DIG, two nodes exchange their current locations, moving directions information and packets when they meet. Figure 1 shows an example of packets (bundles) routing from a source node to a destination node in DIG. Basically, when the packets are far from the destination node (i.e. beyond a threshold distance denoted by T), they will be forwarded to the mobile nodes whose positions and moving direction are closest to the destination. As the packets are moved close to the destination node, they are forwarded to a mobile node whose moving direction is closest to the destination node even the distance of that node to the destination is longer. Because of the limited communication time between nodes, the closer moving direction to the destination can guarantee a longer communication time with the destination node.

Specifically, as figure 1 illustrate, SD denotes the line joining the source node and destination node; θ is the slope of SD; d is the length of the packets segment to the destination; α is the moving direction of a node relative to destination node. The DIG scheme consists of following three steps.

First, when a source node wants to send packets to a destination node, it forwards each part of the packets stream to a number of neighbor nodes when it meets. The positions of these neighbor nodes should closer to the destination node than the source node. There is no specific requirement for the direction of the next hop at this phrase, since the source node should send out the source packet as soon as possible to increase the capacity of DTN network.

Second, When $d > T$, the node seeks to find a next hop relay node whose position is closer to the destination node while its moving direction is between $[\theta - \xi, \theta + \xi]$, where

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

τ is a weight value increasing with time and $\tau > 1$; n is a constant value where $n \in (0, 1)$. That is, the angle ξ increases with time if a node cannot find an qualified next hop node for packet forwarding. By this means, the node can have more choices for next hop selection. However, the largest value of ξ is $\pi/2$, which means the next hop node should at least do not move in an opposite direction to the destination node. On the other hand, every time when a relay node successfully finds another node for packet transmission, τ is resumed to 1. That is ξ is resumed to $\arcsin(r/d)$. We call this phrase "macro-control of transmission," because packets are forwarded greedy with a loosing direction constrains to the destination node in this phrase.

Third, when $d < T$, the mobile node only forwards packets to another node whose moving direction to the destination node $\alpha 3$ is smaller than its own direction $\alpha 2$ as figure 1 shows, even if the location of that node is longer to the destination node at that time. If there is no nodes nearby satisfied this requirement, the node continually carry the packets by itself until reach the transmission range of destination node. We call this phrase "micro-control of mobility".

Because the mobile nodes serving as relay nodes always try to find a next hop with a closest moving direction, it is possessible to consume more time than macro-control in a forwarding phase. However, the micro-control can guarantee more communication time between the mobile node and the destination node, which reduces the total delay in a long term. In DTN, a communication happens only during communication time, i.e. when the nodes are within each other's transmission range. Since the communication time of two nodes in DTN is limited, each mobile node may not be able to send all packets to the destination node at one time. Meanwhile, since the meeting opportunity of two nodes is rare, it may take a long time for the undelivered packets to be sent. DIG macro-control gathered the packets destined to the same destination nodes to a number of certain mobile nodes and DIG micro-control phase grantees more communication time between those mobile nodes and destination nodes. Hence, the total packets transmission delay can be reduced.

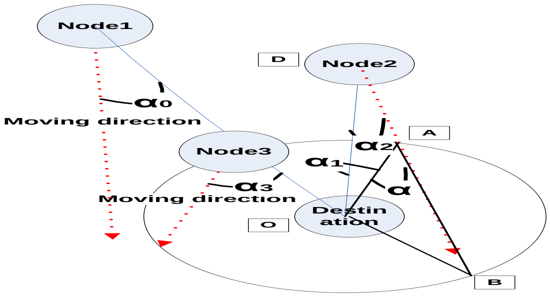


Figure 2. Calculation of the communication time.

However, one issue is raised in these transmission phases. The problem is that a smaller α can not always guarantee a closer moving direction from a wireless node to a destination node. Figure 2 shows that although $\alpha 0 < \alpha 3$, the moving direction of $node3$ to the destination node is much closer than $node1$'s. The reason is that in a such situation, the transmission range r of the $node1$ is so large that $node1$ and $node3$ can communicate in a long distance. According to the geometry calculation, the long distance between two mobile nodes will affect the accuracy of using moving direction to predict their future communication time with the destination node. On the other hand, if the transmission range of the mobile nodes is small, the two nodes can only communicate with each other when they are close. Then, the distance will not affect the moving direction α significantly, and the communication time prediction between the mobile node and the destination node can be totally based on moving direction α. If the α of the new meeting node is smaller, the packets will be forwarded to this node.

To deal with this problem, we can use another angle calculation method for the moving direction comparison when the transmission range of mobile nodes is so large that it affects the accuracy of angle prediction method. In Figure 2, we use v to denote the moving speed of the wireless node, and use L to denote the length from point A to point B, represented by $AB = L$. Then, L/v is the transmission time of mobile nodes within the range of the destination node. Similarly, we define the following representation: $AO = BO = R, OD = D, \angle OAB = M, \angle OAB = \alpha 2, \angle AOD = \alpha 1$. From the figure, we can get $\alpha = \alpha 2 + \alpha 1$. Therefore

$$\sin(\alpha) = \frac{d}{r} \cdot \sin(\alpha 2) = \frac{\sqrt{r^2 - (\frac{L}{2})^2}}{r}$$

$$\Rightarrow T_{comm} = \frac{2\sqrt{r^2 - d^2 \sin^2(\alpha 2)}}{v},$$

where T_{comm} denotes the predicted communication time of the node with the destination node. Packets should be forwarded to a node with larger T_{com}.

3.3 Packet Handoff Management

To ensure short transmission delay, a packet should be delivered to the destination node as soon as possible. However, a rely node may have several packets with various destinations at a time. In addition, when a rely node meets another relay node along its way, it can hand over very few packets, since the duration during which they are in each other's communication range is very small. Hence, DIG needs a scheme to decide which packets have higher priority to be transmitted during communication time.

In addition to the traditional field such as the IDs for source node and destination node, DIG includes two new fields into each packet's head : *priority* and $time\_stamp$. *Priority* is used to indicate the delivery urgency of packets indicated by the applications. $time\_stamp$ is used to record the elapsed time since packet creation. In a node's buffer, the packets are arranged in decreasing order of *priority* . Within each level of priority, the packets are sorted in decreasing order of $time\_stamp$. When two nodes meet each other, the bundles are delivered based on the sequence in the buffer. The employing of $time\_stamp$ guarantees that the longer a bundle stays in a buffer, the higher priority it has to be delivered. It avoids the worst delay in the communication in which a packet always stays in a buffer.

4 Theoretical Analysis

4.1 Transmission throughput

Handoff nodes denote the meeting nodes that the packets can be delivered to. We now discuss the number of encounters (i.e. number of handoff nodes) that a certain mobile node M_1 has in a time period t. As in [1], a node M_i can be a *handoff node* of M_1 if

(1) M_i moves in the direction α where $\alpha \in [\theta - \xi, \theta + \xi]$.

(2) M_i encounters M_1 at sometime during the time period $[t_0, t_0 + t]$.

Theorem 4.1 *Let M be some mobile node seeking for handoff nodes and Y_i be a Berboulli random variables, where $Y_i = 1$ if M_i is a* handoff node. *For any $\theta \in [0, 2\pi)$, the number of encounters satisfies:*

$$\sum_{i=0}^{i=(m-1)} E[Y_i] > 2mt^2|v|^2 \cdot o(\sigma),$$

which indicates that the number of encounters of a mobile node during a time period depends on the density and moving speeds of mobile nodes.

Proof The number of encounters during time t equals to the average number of encounters when $\alpha \in [\theta + \xi, \theta - \xi]$ in time period t. That is,

$$E[Y_i] = \int_{\alpha=\theta-\xi}^{\alpha=\theta+\xi} E[Y_i|d_i = \alpha] Pr[d_i = \alpha]$$

Relative to M, the speed of M_i is $|2|v|sin\frac{\alpha}{2}|$. Thus, given that $d_i = \alpha, Y_i = 1$ iff M_i lies in a region of area

$$\pi L^2 = \pi \cdot t^2 |2 \cdot |v| \cdot sin\frac{\alpha}{2}|^2$$

$$E[Y_i] = \frac{1}{2\pi} \int_{\alpha=\theta-\xi}^{\alpha=\theta+\xi} \pi L^2 = \pi t^2 |2 \cdot |v| \cdot sin\frac{\alpha}{2}|^2 \cdot d\alpha.$$

Supposed $\theta = 0$, we can get $= 2t^2|v|^2(\xi - sin\xi)$. Suppose $\xi - sin\xi > o(\sigma)$, we can get

$$\sum_{i=0}^{i=(m-1)} E[Y_i] > 2mt^2|v|^2 \cdot o(\sigma).$$

Based on theorem 4.1, the amount of data that can be delivered to other mobile nodes during a time period t can be calculated, which reflects the throughput of the system.

Theorem 4.2 *Let λ_{mm} denotes the bandwidth allocated for data transmission, then the amount of data that a mobile node can handoff to other nodes during time period $[t_0, t_0 + t]$ is at least $\lambda_{mm} r_0 m t^2 |v| \sigma$. where r_0 denotes the moving distance of mobile node in a time period t.*

Proof Consider the motion of a mobile node M_2 relative to a mobile node M_1, M_2 moves at speed at most $2|v|$ if they move in opposite directions. Moreover, if M_2 covers a distance of at least r_0 during their encountering, the time duration of the transmission is $\frac{r_0}{2|v|}$. Hence, the expected amount of data delivered during an encounter is at least $\frac{\lambda_{mm} r_0}{2|v|}$. Followed by the Theorem 4.1, the amount of data that a mobile node can handoff to other nodes in $[t_0, t_0 + t]$ is at least $\lambda_{mm} r_0 m t^2 |v| \sigma$.

4.2 Transmission bound of DIG

In the uniform mobility model, mobile nodes are initially uniformly distributed, moving at a constant speed v, and the directions of the motion are i.i.d. in the range $[0, 2\pi]$, Suppose in a big square where the side length of each square cell is a. Among the total number of mobile nodes m, a fraction of them, n_S, are randomly chosen as senders, while the remaining nodes n_R function like possible receiving nodes [6]. For a finite a and a finite m, connectivity is guaranteed if $\frac{1}{a} > \frac{2log(m)}{m}$[3]. $\bar{L}$ denotes the mean distance between the source node and destination node. Given that each cell hop has an average size of $1/a$, the average number of hops traversed by a bundle to the destination is $\frac{O(\bar{L})}{1/a}$.

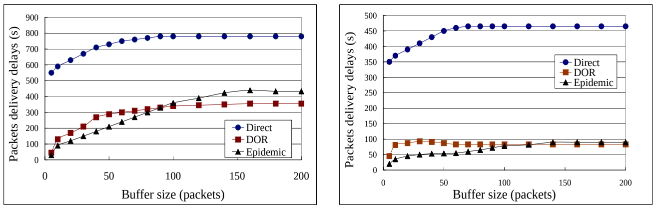
To ensure that all required traffic can be carried to the destination node, the throughput of packets transmission is less than total channel bandwidth. That is,

$$\frac{O(\bar{L}) n_S \cdot Th(m)}{1/a} \leq n_S \lambda_{mm}. \Rightarrow Th(m) \leq \frac{\varepsilon \lambda_{mm}}{a}.$$

where $Th(m)$ denotes the throughput of the network with m mobile nodes. Therefore, $Th(m) = \frac{1}{a} O(1)$.

The average delay of DIG is the sum of the delay of bundles routing to the destination cell square and the delay of the last relay reaching the destination. The former is the product of the number of hops traversed and the delay on each hop. The size of the DTN is fixed in our analyze model, thus, the speed of the nodes is scaled down as $v = O(1/\sqrt{m}))$ [3]. Thus,

$$O[(\frac{\bar{L}}{1/a} \frac{1}{v}) \frac{1}{a}] = O(\sqrt{m}).$$



(a) Range = 50m (b) Range = 100m

Figure 3. Packet delivery delay.

If the destination node is a static node, the transmission delay is only $O(\sqrt{m})$. If the destination node is a mobile node, the delay is caused by two phases: transmission phase and locating phase. The delay of transmission phase is $O(\sqrt{m})$, and the delay of the locating phase is bound by O(m/a) [6]. Since $O(m/a) >> O(\sqrt{m})$, the total delay is $O(m/a) + O(\sqrt{m}) \approx O(m/a)$, which is a little better than direct routing but longer than the epidemic routing. From the analyze about we can find, the DIG with single routing will lead to a longer delay in the scenario that the destination node is a randomly mobile node. However, in the scenario that the destination node is a static, the delay performance of DIG is the best.

5 Performance Evaluation

This section demonstrates the distinguishing properties of DIG through simulation built on OMNeT++ [13]. We used Epidemic routing scheme [19] to represent flooding-based schemes, and used Direct routing scheme [6] to represent sing-copy routing scheme, and compared DIG with them. The simulation is based on Uniform Mobility Model. This model consists of a $1500m \times 1300m$ 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. The mobile nodes move at the speeds of $0 - 20m/s$. A subset of 47 nodes generate one message per second for 2000 seconds to one of the three destination nodes, and the simulation is then run for another 2000 seconds to allow messages to be delivered. The distance threshold T in the DIG 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. The simulations in our previous tests indicated that these values were the “sweet spot” for the parameters. Transmission range r is the distance that the signal of a mobile can reach. We conducted experiments in two cases: $r = 50m$ and $r = 100m$ in order to see the impact of transmission range on the routing performance. In the simulation, dropped packets will not be re-transmitted again. In order to get a comparatively high accuracy for the moving direction comparison, the angle calculation method is used for the simulation. Three simulation metrics were used in the simulation:

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

(2) *Number of successfully delivered messages.* 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 message to another node in the routing. This metric reflects the transmission overhead and the resource consumption of a routing scheme.

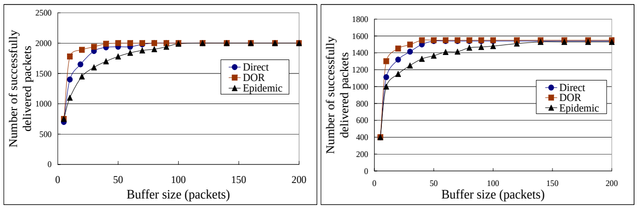
5.1 Message delivery delay

Figure 3 plots the message delivery delay versus buffer size. The figure shows that Direct generates much longer delay than others. It is because in Direct, the packets transmission delay is based on the meeting probability of the packets relay node and destination node. Since only a singe copy of the packet is used in the system, the low probability of the meeting chance of packets relay node and destination lead to a high transmission delay in Direct. In contrast, flooding based Epidemic takes full advantage of all routing path to the destination results in a low transmission delay. Such delay should the lower bound of the delay performance in DTN, if the buffer size of the mobile nodes in the DTN are large enough to store a considerable amount of packet replicates. Although DIG also use single copy routing, instead of waiting relay node to meet destination node by chance, the packets in DIG are routed in a determined way base on the location information of nodes. DIG reduces the transmission delay of Direct significantly.

It is intriguing to see that the transmission delay increases as the queue size increases. It is because the low transmission delay is resulted from the fact that less packets is transmitted to the destination. Since no retransmission function is implemented in the simulation , the packets dropping caused by the channel congestion in the DTN with small buffer size lead to a short transmission time between source node and destination node. While as the buffer size increase, the dropped packets in small buffer size case are able to reside in the queues until they are delivered to their destination which increase the transmission time.

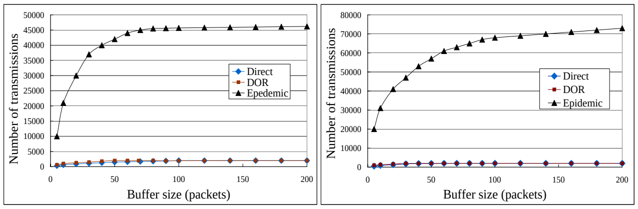
Furthermore, the figures show that the delay of DIG is not as sensitive to the buffer size as Epidemic. Since the DIG is only single copy transmission which does not depend on the buffer storage as flooding in Epidemic, the performance of DIG will remain almost the same.

Comparing Figure 3(a) and (b), we can find out that as the transmission range increase, the transmission delay of all routing schemes decrease. Intuitively, larger transmission range makes it easier to find other neighbor nodes, which may be either the destination nodes or promising relay nodes, thus leading to shorter delay. Moreover, the speed of the electromagnetic wave moves much faster then the moving node, thus message delivery delay with larger transmission range is shorter.



(a) Range = 50m (b) Range = 100m

Figure 4. Number of delivered packets.



(a) Range = 50m (b) Range = 100m

Figure 5. Number of transmissions.

5.2 Message delivery capacity

Figure 4 depicts the number of successfully delivered messages versus buffer size. It shows that as the queue size increases, so does the number of the successfully delivered message to their destinations due to the same reason observed in Figure 3. Larger queue size means that more messages can be buffered and less message droppings, resulting in more successfully delivered messages.

Figure 4 also shows that the DIG and Direct are less sensitive to the queue 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. DIG 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 DIG leads to more delivered messages than Direct with small Queue size. This is due to the transmission delay of DIG is much less than direct transmission, it is more likely that the DIG has more free buffer at all the time, therefore, as the queue size is small, the DIG will has less possibility to experience the data congestion than direct transmission.

Moreover, Figure 4 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. DIG performs the best among the schemes with regards to the message delivery ability.

Comparing Figure 4 (a) and (b), we can observe that as the transmission range increases, the successfully delivered messages also increases. The result is consistent with Theorem 4.1, which shows that with the increase of the transmission range, the communication time between two mobile nodes will increase, which subsequently increases the possibility of a mobile node meeting the destination node or promising forwarding nodes, and hence increases the number of successfully delivered messages.

5.3 Transmission overhead

Figure 5 shows the number of transmissions versus the buffer size. The figure shows that DIG and Direct incurs much less transmissions, hence much lower communication overhead than Epidemic. It is because Epidemic is based on flooding in which a node sends all possible messages to nodes it encounters. In contrast, DIG 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.

In conclusion, the experiment results show DIG has the merits of both epidemic routing which has an optimal delay and direct routing which has a low overhead in the transmission. It achieves an optimized tradeoff between Epidemic and Direct.

6 Conclusions

In this work, we investigated the problem of efficient routing in intermittently connected mobile networks. Current approaches in such networks are primarily based on redundant transmissions or single copy routing. However, they incur either high overhead due to excessive transmissions or long delay due to incorrect choices during forwarding. We proposed a Direction based Geographic routing scheme (DIG), which overcomes the shortcoming of epidemic routing, and reduce the transmission delay of the single copy routing scheme. Depending on the location information that facilitates nodes to be aware of each other's position and moving direction, DIG outperforms the epidemic routing and directing routing with respect to successful transmission ability, transmission delay and overhead.

Acknowledgements

This research was supported in part by U.S. NSF grants CNS-0834592 and CNS-0832109.

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