Using local speed information as routing metric for delay tolerant networks

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Abstract: - In many practical situations, the mobility is critical factor for an intended message delivery. Recently studies have found that mobility itself affects the network performance (capacity of the network, security, connectivity, coverage, etc.). However, how to effective use these characteristics of mobility in design DTN routing protocol has not been well studied yet. In this paper, we proposed a routing protocol that uses speed of the local node as routing metric for opportunistic packet relay in DTN (Delay Tolerant Networks). Moreover, the choosing of the relay nodes is only based on the comparison of speed value. It does not require any history information, global knowledge or mobility patterns of other nodes. This makes our schemes ideal for resources limited (computational power, memory, etc.) and dynamic large-scale networks. The performance of our protocol is compared with several related works. Simulations show that our scheme has better performance.

Key-Words: DTN, n-copy routing, mobility, resources, ONE

1 Introduction

The source to destination path may not be connected at any given time instant in delay tolerant networks (DTN). Thus, data is delivered using a store-carry-forward model. Node in the network stores data locally, and upon contact with other nodes, forwards the data.

In other words, a link is established between the pair of nodes, whenever they encounter. This link is time-sensitive in that it is only valid for the duration when the nodes are in range of one another [1].

Mobile devices relay messages to neighboring devices as they come in contact with them, by taking advantage of communication opportunities that arise in the course of user mobility, until the packet eventually reaches its destination. Since mobile devices become increasingly pervasive, almost anyone with a Bluetooth device in her or his pocket becomes a potential participant in the forwarding process.

In order for the protocol to be widely accepted and deployed, relay node should reveal little private information (e.g., history information, location information, etc.), and require resource (e.g., memory space) as low as possible [2] [3].

The key idea in this paper is try to use crude information of local nodes directly instead of the utility computation, which reflects the node's probability of delivering any given packet to its known destination.

In the early protocols, such as Direct Delivery [4] and First Contact [5], only single-copy of each message exists in the network. In Direct Delivery, the node carries messages until it meets their final destination. In First Contact routing the nodes forward messages to the first node they encounter, which results in a "random walk" search for the destination node. Single-copy schemes have lowest overhead but are not so good in packet delivery [3] [6]. These observations motivated routing protocols, such as Spray and Wait [7], Epidemic [8], PRoPHET [9] and MaxProp [10] which take into account number of message copies and try to calculate utility of candidate nodes using history-based or global-knowledge. In order to enhance the routing efficiency, node's social relation is used to choose proper relay node based on its contact history [11][12]. Trust-based protocols try to stimulate selfish nodes to effectively cooperate with other nodes [13]. The fuzzy logic based protocols try to maximize message delivery with fuzzy utility computation [14]. Recently, location and moving direction of nodes are also used to calculate utility by assuming nodes with GPS function in LDPR (Location and Direction Aware Priority Routing) [15].

Epidemic replicates messages to all encountered [8]. Thus it is particularly resource hungry. Spray and Wait [7] is a variant of epidemic routing but with some additional constraints. It limits the number of message copies created to a configurable maximum “L” and distributes these copies to contacts until the number of copies is exhausted. Both variants of Spray and Wait are included: in normal mode, a node gives one copy to a relay node, in binary mode half of the copies are forwarded. Once only a single copy is left, it is forwarded only to the final recipient.

PRoPHET [9] tries to estimate which node has the highest likelihood of being able to deliver a message to the final destination based on node encounter history. MaxProp [10] sends messages to other hosts in specific order that takes into account message hop counts and message delivery probabilities based on previous encounters. MaxProp floods the messages but explicitly clears them once a copy gets delivered to the destination.

Utilizing the location and moving direction of nodes to delivery the message can improve performance to some extent, as showed in LDPR [15]. However, LDPR requires the radio transmission range of some nodes is large enough to cover certain areas. Thus, LDPR is not good at scalability.

Above protocols cover the most important classes of DTN routing protocols [1]. These kind of global-knowledge or history-based routing protocols can improve the protocol performance to some extent at cost of computation. This not only leads to limitation of network size also yields a large resource requirement (e.g., memory, computation ability, etc.). Thus, these protocols may have some problems in practice.

In many practical situations, the mobility itself is critical factor for an intended message delivery. Nodes moving faster towards an intended destination are more likely to quickly deliver the particular message. For example the bus with packets on the road to bus station.

Intuitively, if the network is not too sparse, the node moving faster may have a higher chance to encounter the destination by traveling larger area. Recently studies have found that mobility can increase the capacity of the network and help security in ad hoc networks [16]. Velocity improves connectivity in clustered networks [17]. Mobility also improves coverage of sensor networks [18]. However, how to effective use these characteristics of mobility in design DTN routing protocol has not been well studied yet.

In this paper, we propose a routing protocol that uses only speed of local node directly instead of the utility computation. By this, the complexity of the protocol is constant with respect to the size of the network, making the protocol scalable for large networks.

Moreover, the choosing of the relay nodes does not require any history information, global knowledge or the mobility patterns of other nodes [19]. This makes our schemes ideal for resources limited networks.

The resulting protocol is referred to as Faster routing protocol. The performance of proposed protocol is compared with several related works. Simulation shows that our scheme performs better in terms of delivery probability, delay and overhead.

The remainder of this paper is organized as follows. In Section 2, we develop the protocol. Theoretical analysis is presented in Section 3. Simulation results are presented in Section 4. Conclusion is in Section 5.

2 The Faster Routing Protocol

Faster is composed of 2 major processes: message distribution process and message relay process. The following are given to describe the details of these processes:

2.1 Copy Message Distribution Process

Similar to the variant (binary mode) of the Spray and Wait protocol, when a message is generated the number of the message copies is limited to a quota “L”. (a configurable maximum even value). If a node (no matter source node or relay node) has a message with L>1, the node works in message distribution process.

For example, when node A carrying a message copy encounters a node B without the message, A spawns and forwards a copy of the message and half quota to B (as in Epidemic routing [8]), and keeps half for itself to continue the distribution [7]; that is, node a gives node b half of its quota, then node b takes half of the quota to continue the distribution if the quota is large than 1.

When a node has a message copy with only one quota left, the node switches to message relay process (unlike Spray and Wait works as Direct Delivery routing).

The steps of the message distribution process are summarized in algorithm 1.

Algorithm 1: When a node A with a message meets a node B at message distribution process

At a relay node A:
if (time-to-live value of the message expires)
drops the message
elseif(the message is not included in list of B)
if (the quota is large than one)
forwards the message
hands half of the quota
end if

At a node B:
receives the message
keeps half of the quota
stores and forwards the message once upon meets the destination or another node

2.2 Message Relay Process

A node works in message relay process, when there is only one quota for a message left. In this phase the message should be always forwarded to a node that moves faster. For example, when node A carrying a message copy encounters a node B without the message, B takes over message relay responsibility of node A only if B moves faster than A.

The steps of message relay process are summarized in algorithm 2.

Algorithm 2: When a node A with a message meets a node B at message relay process

At a relay node A:
if (time-to-live value of the message expires)
drops the message
elseif(the message is not included in list of B)
if (the quota is one)
compares the mobile speed of two nodes
if (mobile speed of node B is faster)
forwards the message
clears the message
end if

At a node B:
receives the message
stores and forwards the message once upon meets the destination or a faster node

3 Theoretical Analysis

In our scheme, we forward the message to a relay node that has higher mobile speed. This method can improve the protocol performance to some extent in theory.

In this section, we consider such a random mobility model and study the effect of node mobility on network. The movement of a node is characterized by its speed and direction. A node randomly chooses a direction $\theta \in [0, 2\pi)$ according to some distribution with probability density function $f_\theta^m(\theta)$. The speed of node is randomly chosen from $[0; v_{\max}]$ according to a distribution density function of $f_v^m(v)$.

3.1 Searching Area

We assume that, at time $t = 0$, the locations of these nodes are uniformly and independently distributed in the region. Under this assumption, the node locations can be modeled by a stationary Poisson process. Denote the density of the underlying Poisson point process as λ. The communication range of each node is r.

At any given time instant t, the fraction of area being searched is expressed as Eq.1 [18][21].

$$f_a(t) = 1 - e^{-\lambda\pi r^2}, \qquad \forall t \geq 0 \tag{1}$$

During time interval [0,t), the mobile node searches a shape of a racetrack whose expected area is

$$a = E\left[\pi r^2 + 2rv_m t\right] = \pi r^2 + 2rE\left[v_m\right]t. \tag{2}$$

Where $E[v_m] = \int_0^{v_m^{\max}} f_v^m(v)dv$ represents the expected node speed. As pointed out in [18][19][20], area coverage depends on the distribution of the random shapes only through its expected area. The fraction of area that has been searched at least once during time interval [0,t) is

$$f_i(t) = 1 - e^{-\alpha\lambda} = 1 - e^{-\lambda\left(\pi r^2 + 2rE[v_m]t\right)}. \tag{3}$$

Note that the area searched during a time interval does not depend on the distribution of the node's movement direction. The faster the node moves, the more area will be searched. Due to node mobility, the fraction of the area that has ever been searched increases and approaches one as time goes to infinity. Therefore, node mobility itself can be exploited to search more area before TTL expiration of message.

That is, the rate at which the searched area increases over TTL depends on the expected speed of node. Thus, by virtue of utilizing node mobility, our scheme may improve the probability to encounter the potential destination node when searching larger area.

3.2 First Meeting Time

Consider a destination located at a random position outside of the communication range of the node that is carrying the message. The first meeting time of the destination is defined to be the time at which the destination first enters the communication range of the node.

v_m : speed of node that is carrying the message
v_d : speed of destination node
$v(\theta_i)$: relative speed of the node to destination

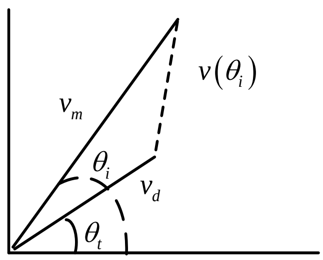


Fig. 1. Relative message mobile speed to destination node

The first meeting time is a function of the copies of message direction distribution density, node speed, and destination moving direction. It depends not only on the mobility behavior of the nodes but also on the movement of the destination itself. In this work, we will not consider specific movement patterns.

Let c be the ratio of the destination node speed to the node speed that carries the message.

$$c = \frac{v_d}{v_m} \quad (4)$$

Let $v(\theta_i)$ be the relative speed of node to the destination as illustrated in Fig. 1.

$$v(\theta_i) = \sqrt{\left(v_m \cos(\theta_i - \theta_d) - v_d\right)^2 + v_m^2 \sin^2(\theta_i - \theta_d)} \quad (5)$$

With Eq.(4) and some derivations, $v(\theta_i)$ is given by

$$v(\theta_i) = v_m (1+c)\, w(\theta_m - \theta_d) \quad (6)$$

where $w(u)$ is expressed as:

$$w(u) = \sqrt{1 - \frac{4c}{(1+c)^2} \cos^2 \frac{u}{2}} \quad (7)$$

Eq.6 gets the maximum value of Expression (8) if the node and the destination move in the same direction.

$$v(\theta_i) = \left| v_m - v_d \right| \quad (8)$$

The results show that the node should move as faster as possible to shorter the first meeting time if they move at the same direction. Thus, our method may effective when nodes move as some movement model (e.g., map based movement model, shortest path map model, etc.) where they are more likely to move along specific path.

4 Simulation Results

In order to observe performance variation of DTN routing protocol that was affected by memory size and number of nodes, we performed simulations in ONE 1.41 simulator.

4.1 Performance Metrics

Protocol performance was evaluated in the simulation with following metrics [1]:

Delivery Probability is the ratio of data packets being successfully received by the destination nodes versus data packets being sent by the source nodes.

Latency represents the average message delay from creation to delivery.

Overhead Ratio is the difference between the number of relayed packets and number of delivered packets over the number of delivered packets. It's some measure of how much "overhead" there was in relation to delivered messages. So if every message was delivered directly from the source to destination without relaying through intermediate nodes the overhead would be zero.

4.2 Simulation Configuration

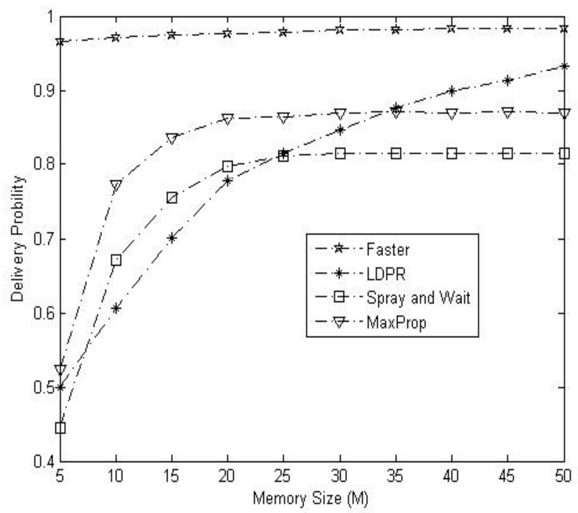
Table 1 shows the parameters of the simulation.

Table 1: Simulation configuration

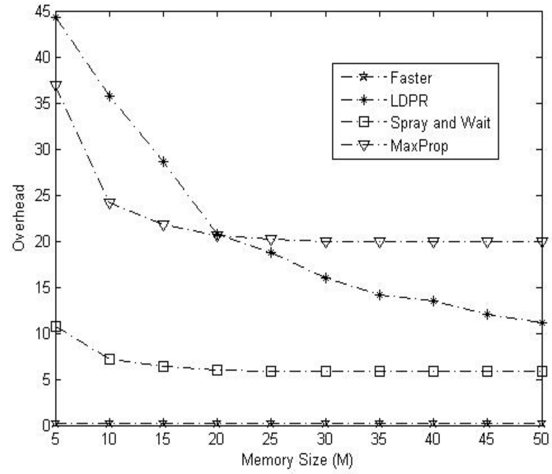
Parameters	Values
Simulation time	43200s
Movement model	Shortest Path Map, Random Way Point
Buffer size	5M-50M
Wait time	0-120
Interfaces	Bluetooth
Number of Groups	6
Maximum Number of Nodes	480
Maximum Speed	20m/s
Message TTL	18000s
Transmit speed	2 Mbps, 10Mbps
Transmit range	10m
Event generators	1s- 35s
Message copies(L)	6
Message sizes	500KB - 1MB

4.3 Varying Memory Size

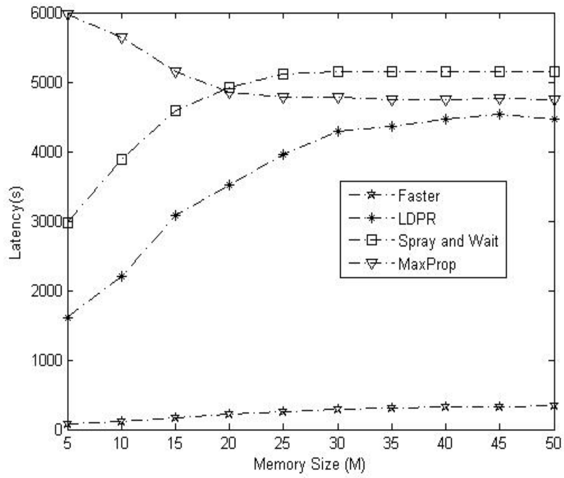
With 125 nodes are randomly displaced. The messages are sent between randomly chosen sources and destinations at generation rate of 1 packet every 25s-35s. The results shows that memory constraints can severely affect the performance of DTN routing schemes.



A, Delivery probability



B, Overhead ratio



C, Latency

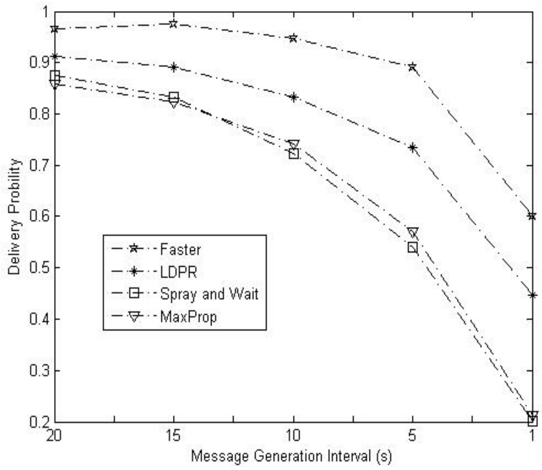
Fig. 2. The performance of varying memory size: A, Delivery rate; B, Overhead ratio; C, Latency.

Performance is relatively good with increasing memory size, as shown in Fig. 2. With very small memory size, the stress of memory requirement is relative heavy. Our scheme is effective in such scenarios because there is not much requirement on the packet storage and computation cost.

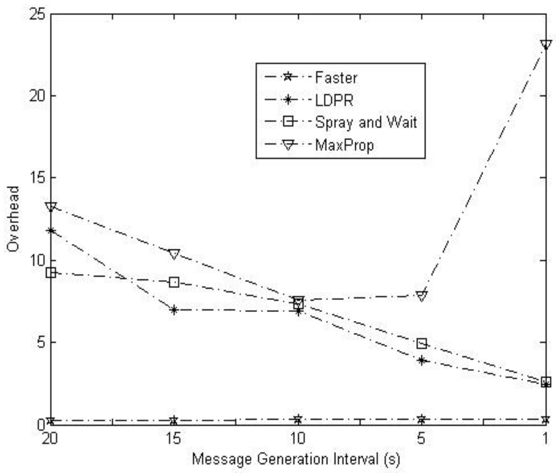
Since the latency increasing is mainly caused by the storage time of the message in larger memory, the latency slightly increases in Faster protocol with increasing memory size.

4.4 Varying Traffic Load

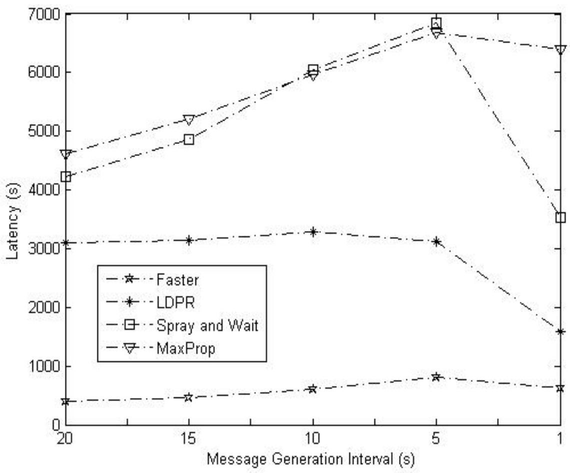
We decrease every message generation interval from 20 seconds to 1 second. Fig. 3 shows performance with varying message generation interval. Performance degrades in all the cases with



A, Delivery probability



B, Overhead ratio



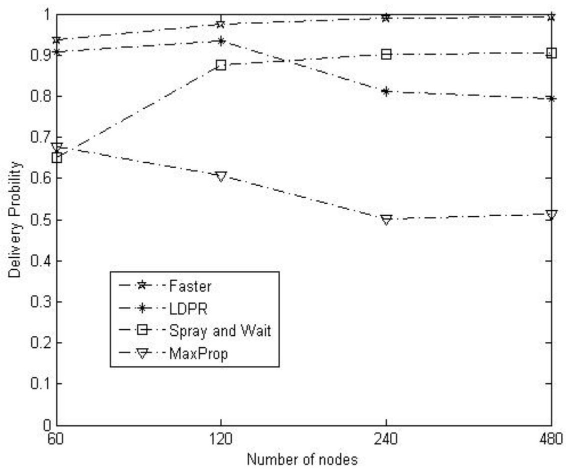
C, Latency.

Fig. 3. The performance of varying traffic load: A, Delivery rate; B, Overhead ratio; C, Latency.

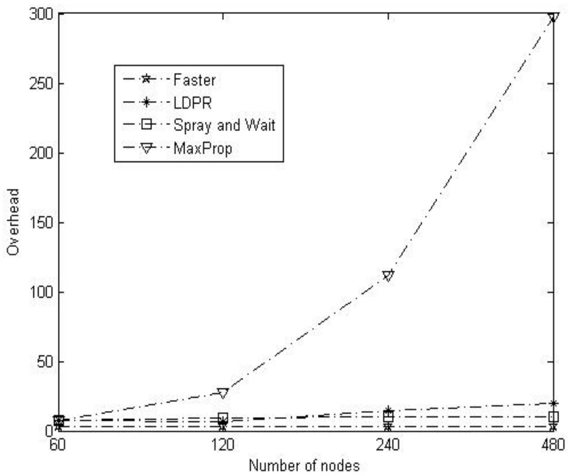
decreasing message generation interval (increase offered load). With very long message generation interval, the stress of relay a message is relative light. All the protocols perform comparable to each other. With very short message generation interval, relative performance gain with our scheme increases. This shows that our scheme by virtue of utilizing potential mobility of relay nodes has a better ability to handle the stress of messages delivery of the nodes, as shown in Fig. 3.

4.5 Varying Number of Nodes

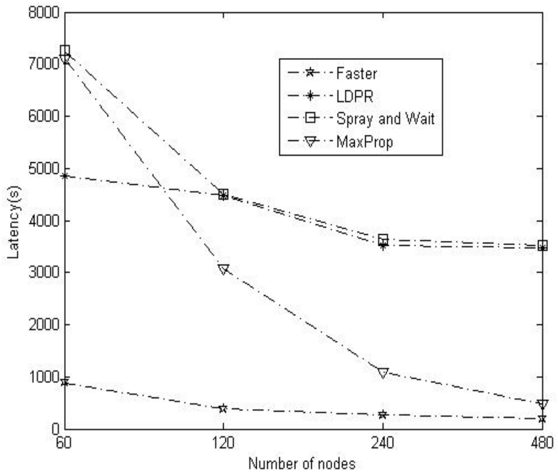
We study the behavior of our scheme while the number of the stations in the network grows. Different experiments are executed where the number of the associated nodes in the network increases from 60 to 480. There is no synchronization on the time that each node starts its transmission.



A, Delivery probability



B, Overhead ratio



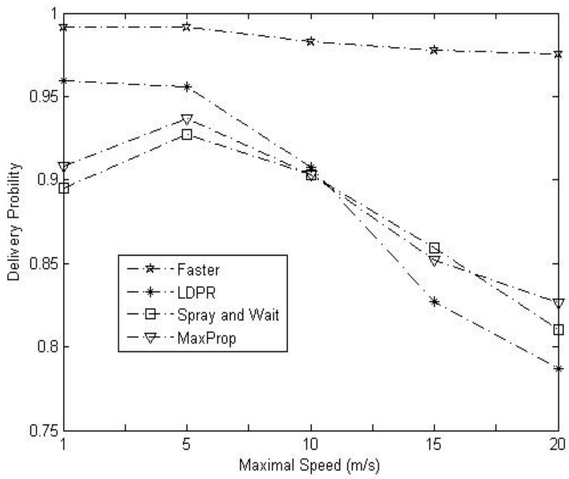
C, Latency.

Fig. 4. The performance of varying number of nodes: A, Delivery rate; B, Overhead ratio; C, Latency.

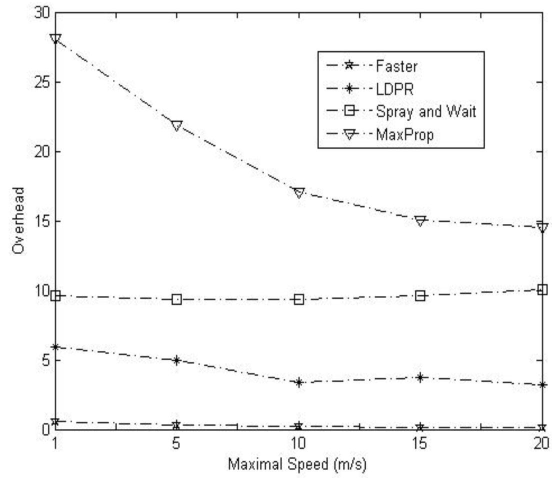
The difference of all modes is not very noticeable with a few nodes. However, with increase in the nodes, our scheme tends to perform better relatively, as shown in Fig. 4. This shows that our scheme scalable for large networks by simplifying the complexity of the route strategy.

4.6 Varying Mobile Speed

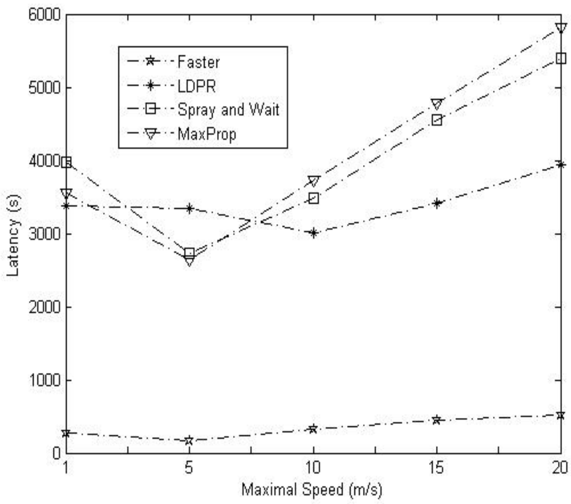
All the nodes move in the model of random way point. The maximal node speed was increased from 1m/s to 20m/s. As can be observed from Fig. 5, increasing mobility deteriorates all of them due to the increasing amount of route changes. As mobility increases, more history knowledge will become invalid and new re-quests are required. Our scheme has relative better performance by virtue of utilizing node mobility to encounter potential destination.



A, Delivery probability



B, Overhead ratio



C, Latency.

Fig. 5. The performance of varying mobile speed: A, Delivery rate; B, Overhead ratio; C, Latency.

5 Conclusion

In order for the protocol to be widely accepted and deployed, relay nodes should reveal little private information (e.g., history information, location information, etc.), and require resources (e.g., memory space) as low as possible[2][3].

In this paper, we proposed a routing protocol that only uses speed of the local node as routing metric for opportunistic packet relay in delay tolerant networks. The choosing of the relay nodes does not require any history information, global knowledge or the mobility patterns of other nodes.

This makes our schemes ideal for resources limited (computational power, memory, etc.) and dynamic large-scale networks. The performance of our protocol is compared with several related works.

Simulations show that our scheme has better performance.

6 Acknowledgment

This work was supported in part by a grant from the foundation of NanJing Forestry University.

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