Efficient Packet Routing in Highly Mobile Wireless Networks

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Abstract

Traditional mobile ad-hoc network (MANET) and delay tolerant network (DTN) routing schemes work properly only under the limited assumptions. MANET routing schemes are designed for densely populated networks while DTN routing schemes were developed for dealing with intermittently connected topologies. However, in a real environment, the assumption cannot be hold: the density of nodes constantly changes and a network can be separated due to node mobility even when it is composed of large number of nodes. We propose a routing scheme for maximizing the delivery rate in a network with varying density. In the proposed scheme, data packets are used to search an available path while they are delivered by DTN-based routing. If a path exists, subsequent packets are relayed along the path. Otherwise, packets are delivered continuously using DTN-based routing. Using simulation we show that the proposed scheme achieves high throughput and a low overhead in a dense part of the network, while it outperforms existing DTN routing schemes in an intermittently connected situation.

Keywords: routing, opportunistic network, wireless multi-hop network

1. Introduction

Self-configuring networks for mobile devices have been studied for decades so as to enable communication without infrastructure in a mobile environment. The mobile ad-hoc network (MANET) and delay tolerant network (DTN) are typical examples of networks without infrastructure. Both technologies are similar in that each node in the network acts as a relay node as well as an end host. However, MANETs and DTNs are different in terms of the manner in which packets are delivered because they are designed for different network environments. The MANET is designed for densely populated networks and it is assumed that every pair of nodes always has more than one connected path. Hence, if an ongoing path is broken due to node mobility, the MANET first searches for another route to the destination and then resumes the delivery of packets. In contrast, the DTN was developed for sparsely populated networks where no end-to-end path is guaranteed. Hence, packets are transmitted without a prior path setup process and a carry-and-forward mechanism is used for their delivery.

However, in a real environment, nodes are not distributed uniformly and the density of nodes constantly changes. A network could also be separated due to node mobility even when it is composed of a large number of nodes. In this situation, MANET routing algorithms [2, 3, 4] do not work properly, as the basic assumption of a MANET is no longer valid. DTN routing schemes [11, 12, 13, 14, 15, 16] are not solutions either because they generate too many redundant copies in a dense area. These redundant packets waste link bandwidth and cause serious interference problems.

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There have been attempts to reduce the number of redundant copies in DTN routing for density varying topology. In [23], a routing scheme called HYMAD has been proposed to reduce redundant copies by clustering nodes. In HYMAD, nodes are clustered by their locations. Then, MANET routing is used within a cluster to reduce overhead, and DTN routing is used to deliver packets to nodes belonging to other clusters. It can be effective when clustering is managed for a certain period of time. In DT-DYMO [21], DYMO [22] (a MANET routing) is combined to PROPHET [14] (a DTN routing) for dealing with temporal high density of nodes. HYMAD and DT-DYMO successfully reduce overhead of duplicated copies in DTN routing by employing MANET routing techniques, but it is hard to be applied for a general topology. Since they are based on DTN routing, and assume a sparse topology, they do not care about MAC layer issues such as collision and interference, which significantly impact on network performance in a dense topology.

In this paper, we propose a hybrid form of a routing algorithm for maximizing the delivery rate in a network with varying density. Here, we note that the delivery rate is different from the delivery ratio in the sense that the delivery rate is the amount of data delivered in a given time, while the delivery ratio is the ratio of sent data to successfully delivered data. Unlike MANET routing protocols, the proposed scheme does not utilize flooding control messages for searching and maintaining a path. Instead, an end-to-end path is recognized via the first packet that is delivered to the destination according to DTN-based routing. If an end-to-end path exists, subsequent packets are simply relayed along the end-to-end path without generating redundant copies. Otherwise, the packet is delivered continuously using DTN-based routing. In the proposed scheme, even when an end-to-end path is broken during the delivery of packets, packets can still be forwarded toward the destination using the DTN routing scheme instead of finding a new path using additional control messages. This approach can take advantage of partial paths in order to decrease the number of redundant copies, especially in a dense area. In a sparse area, the proposed scheme performs in the same manner as DTN routing.

This simple idea has the following advantages: 1) Under the dense part of the network, the proposed algorithm achieves a level of performance similar to that obtained with the MANET routing algorithm in terms of overhead, delay, and throughput, and 2) in an intermittently connected situation, the proposed algorithm outperforms pure DTN routing schemes in terms of throughput and delay performance. As the packet is not cached during delivery along a partially connected path, the amount of duplicate packets in the network becomes much smaller when compared to that in pure DTN routing schemes. Consequently, buffer space can be used more efficiently in the proposed scheme, which leads to a high achievable throughput and low delay. In contrast to previous works, we describe the implementation details of the proposed scheme, including media access control (MAC) layer operation, and outline an ns-2 [24] module for the proposed scheme. In order to validate the proposed scheme, we compare the proposed scheme with other representative schemes using ns-2 simulator. The simulation is performed by changing various network parameters as well as with a real trace of Shanghai taxi [34].

The remainder of this paper is organized as follows. Related works are introduced in more detail in Section 2, while the problem is defined in Section 3. The proposed routing scheme is described in Section 4 and techniques for performance enhancement are proposed in Section 5. In Section 6, the proposed scheme is evaluated through an extensive ns-2 simulation. Finally, conclusions are presented in Section 7.

2. Related Work

The traditional MANET is discussed under the assumption that the network is composed of a high density of nodes sufficient to guarantee more than one end-to-end path for every communication pair. When the ongoing path is broken due to node mobility or a dead battery, packets can be delivered along alternative paths to the destination in MANET environments. Hence, finding an alternative path fast and efficiently is one of the main topics in MANET research. In previous work [5, 6], schemes to maintain multiple ad-hoc on-demand distance vector (AODV) routing paths were suggested. Mainly, when a node detects a link breakage, it immediately uses another path, which minimizes the path recovery time. In other studies [7, 8], an opportunistic routing scheme that relays packets via broadcasting was proposed. As the packet is relayed to the destination by the broadcast, packets can be successfully delivered so far as the end-to-end path assumption is valid. All of these MANET schemes work well under the MANET assumption, but the problem is that the MANET assumption is not valid in reality.

In order to deal with an intermittently connected topology, the DTN [1] was introduced. Since an end-to-end path cannot be guaranteed in a DTN, each node carries data, which are turn forwarded if the nodes meet neighbors.
This store-carry-forward approach enables packet delivery even under harsh network conditions. A typical example of DTN routing is epidemic routing [10]. In epidemic routing, a list of data is exchanged when nodes encounter each other. All missing packets are then requested and exchanged during the connected period. Ideally, epidemic routing can achieve maximum possible performance in a DTN environment. However, the limited buffer size and wasting of link bandwidth due to the generation of redundant copies lead to poor throughput performance in a real setting. Several schemes [14, 11, 12, 13, 16] have been proposed to minimize the number of meaningless copies in a network. In previous work [14, 12, 16], a history of contact patterns was used to calculate the predictability of delivery, and a packet was only relayed to nodes that show a higher predictability value. In other research [17, 18], only one copy was maintained in a network based on perfect knowledge of the future contact pattern. However, as most of these previous studies are largely dependent on the periodicity of node mobility, their applicability is limited in a real setting.

In a real network environment, the MANET assumption cannot be guaranteed. Also, in a dense part of a network, DTN schemes cannot achieve reasonable performance due to redundant copies of data. There have been DTN routing schemes [23, 21] to adopt MANET routing techniques in order to eliminate useless copies. In one study [21], the authors designed a DT-DYMO scheme that extends a DTN routing scheme such as ProPHET using the predictability of delivery based on historic data by adding a MANET routing, DYMO. If an end-to-end path exists, DT-DYMO works in the same way as DYMO. When a node fails to find a path to the destination using DYMO, it sends the packet to the node that seems to encounter the destination most frequently. That node then delivers the packet to the destination via a store-carry-forward approach. However it also has the well-known problems of ProPHET such as dealing with frequently changed patterns of nodes and setting the initial value that can converge to reasonable delivery probability. Like ProPHET, dependency on the periodicity of node mobility has a limitation in a real networks. HYMAD [23] a group-based DTN routing scheme to use spatial locality in order to decrease redundant copies. In HYMAD, a group is created by nodes that have connections to each other. Since an end-to-end path exists within a group, MANET routing is used for packet delivery. The nodes belonging to the same group periodically exchange the list of packets that they have. Hence, each node recognizes the list of all files maintained within a group. When the nodes belonging to different groups meet, they exchange missing files for each group as a delegate. Missing files are then distributed within the group using the MANET. A large overhead is incurred with HYMAD because a group must be maintained and metadata concerning a list of file information must be exchanged between nodes belonging to different groups.

3. Problem Definition

In previous work [27], achievable throughput in an ad-hoc routing scheme, \( E[U] \), was formulated as follows,

\[
E[U] = \frac{U_{max}}{1 + \frac{E[T_{pr}]}{E[T_{pd}]}}
\]

(1)

where \( E[T_{pr}] \) is the expected value of the path recovery time, \( E[T_{pd}] \) is the expected duration time of a connected path, and \( U_{max} \) is the best achievable throughput during the path duration time when the path from a source to a destination becomes available.

As \( U_{max} \) is a function of the possibility of end-to-end connectivity; it can be expressed as

\[
U_{max} = E[\frac{Traffic}{P_{path}}] \cdot E[P_{path}]
\]

(2)

where \( E[P_{path}] \) is the expected value of the probability of end-to-end path existence. As \( E[P_{path}] \) is impacted by the density of nodes and the transmission range, \( P_{path} \) can be represented by

\[
P_{path} = f(N, A, R)
\]

(3)

where \( N \) is the number of nodes, \( A \) is the network area, and \( R \) is the transmission range of a node. If \( A \) and \( R \) are constants, \( P_{path} \) is determined by \( N \).

Similar to previous research on connectivity [32], we estimate \( P_{path} \) according to \( N \) using a simulation. Figure 1 shows the probability of existence of an end-to-end path when mobile nodes move around in an area with a size of 1500 m x 1500 m. If the number of nodes is smaller than 30, the probability that an end-to-end path exists decreases to below 50%.
If we set $E[T_{pf}]$ to be a constant, $E[T_{pd}]$ is another factor to determine $E[U]$. According to previous research [31], $E[T_{pd}]$ is inversely proportional to the speed of the nodes. Hence, if the density of nodes becomes low or the speed of the nodes is too high, MANET routing protocols cannot work properly.

On the other hand, the DTN cannot function in a network with a high density of nodes. According to a previous study [29], the expected number of copies for a single packet up to the point when the packet is delivered to the destination may be expressed as $\frac{N-1}{2}$. If we define link stress, $L_s$, as the number of redundant transmissions, it may be written as

$$L_s = GTN \frac{N - 1}{2} (1 + I(N))$$

where $G$ is the packet generation rate and $T$ is the average time for a packet to be delivered to the destination. Since redundant transmissions also act as interference, $I(\ast)$, the number of blocked transmissions caused by a redundant transmission is added to (4). Obviously, $I(\ast)$ is an increasing function of the density of nodes. In order to compensate for the aforementioned malfunctions of the MANET and DTN, we present a new routing scheme that is applicable under all network conditions that occur in real setting.

4. Routing

4.1. Routing overview

In the proposed scheme, data packets are delivered to the destination by either forwarding or replicating. If a node has a route entry for the destination, it simply forwards a packet to the next hop without generating a copy of it. Otherwise, a node replicates a packet and disseminates it to the neighboring nodes in order to increase the reachability to the destination. When a node has a route entry but fails to reach the next hop described in the route table, the MANET protocol discards the packet and starts setting up a new path before resending that packet from the source node. However, the proposed scheme keeps forwarding packets by replication while eliminating the outdated route entry.

To ensure that nodes are aware of the reachability to the next hop, each node broadcasts a HELLO message periodically, as is the case with most on-demand routing protocols. However, the HELLO message in the proposed scheme carries a list of files in the packet buffer. Such a list is necessary for delivery via replication. Hence, each node can periodically recognize what packet it should exchange with neighbors by replication.

In the proposed scheme, the functionalities of the bundle layer adopted in the DTN are minimally implemented in the IP layer for delivery via replication. Hence, we must add two additional option fields in the IP header: packet identifier and creation time of packet. packet identifier is a 32-bit hash value to which three keys are mapped: source address, destination address, and timestamp for the packet that was created so it can be identified in the network layer. Also, an additional buffer (referred to as a packet buffer) should be implemented in the network layer for packets that will be delivered by replication.
4.2. Route Discovery

If a node does not have a route entry for the packet or it fails to send the packet to the next hop described in the route table, it inserts the packet into the packet buffer and waits for an opportunity to relay that packet to upcoming contacts by replication as shown by a flow chart in Figure 2. The packet could then be relayed to the destination by replication, or it could be relayed by forwarding after it meets a node with a route entry to the destination. In either relay scheme, each intermediate node puts its address in the packet header (path lists), which allows an end-to-end path to be recognized by the destination node.

The destination node maintains end-to-end path information for each source. If a new path lists is informed, the destination node selectively responds with a "NEW ROUTE" message, as shown in Figure 3. The "NEW ROUTE" message also carries path lists to ensure that the message traverses along the reverse path described in path lists. Since the "NEW ROUTE" message is used to create a routing entry for forwarding, it is relayed to the source node only by forwarding. If the next hop node is not reachable, the "NEW ROUTE" message is simply discarded. Whenever each node relays a "NEW ROUTE" message, it creates a route entry for the destination node.

Here we note that replication makes multiple duplicate packets delivered to the destination via different paths. In this case, the first packet to arrive carries along the optimal end-to-end path in terms of delay. Hence, the destination node updates the path information with that of first packet and ignores path lists in subsequent duplicate packets.

A "NEW ROUTE" message is sent when a packet from a new source node is delivered; it is recognized simply by looking at the first node in path lists. The "NEW ROUTE" message is also sent when an existing path becomes unavailable. In order to indicate the availability of an existing path, a packet header has a replication flag that is turned on when a packet is relayed by replication. If a packet is delivered by forwarding along the existing path, the replication flag of the received packet is 0. However, if the existing path becomes unavailable, the packet has been relayed by replication in some parts of the end-to-end path and the destination node receives a packet with a value of 1 in the replication field. In this case, the destination node sends a "NEW ROUTE" message back to the source node along the reverse path. The intermediate node in the new path can then create a routing entry to the destination. Figure 4 and Figure 5 respectively represent a route discovery and a route maintenance process.

4.3. Route entry structure

Each node maintains a routing table entry that has the following structure: destination, next hop and expire time. As the "NEW ROUTE" message carries the path lists from the source node to the destination, each node can recognize...
Figure 3. NEW ROUTE format

(a) First packet is spread by replication  
(b) Destination generates a NEW ROUTE message 
(c) Route path is established

Figure 4. Route discovery
the next hop to the destination node. If a node receives a new "NEW ROUTE" message carrying a different path list to the same destination, the node updates the (next hop) field based on the "NEW ROUTE" message since the latest available path is included in the "NEW ROUTE" message. In addition, the expiration time of the entry is newly calculated and registered in the (expire time) field.

4.4. Hello message

In the proposed scheme, a "HELLO" message is periodically broadcast. As mentioned before, the "HELLO" message serves two functions: 1) recognizing active neighbor nodes and 2) exchanging a summary vector between neighbor nodes. The format of the "HELLO" message is ⟨source address⟩⟨summary vector⟩ and its size is limited to 400 Bytes. Hence, identifiers with a maximum of 99 packets can be included in a single "HELLO" message.

It may seem that the periodic broadcast of summary vectors leads to a large overhead, but this is an efficient manner of exchange in highly populated sectors of the network. In the DTN, a node exchanges a summary vector with its neighboring node when they meet. After that, the nodes start exchanging missing packets during the contact time. This is a reasonable sequence of operations in the DTN environment, where the contact of nodes occurs intermittently and packets in the buffer are rarely changed by other neighbor nodes during the contact period. However, in a densely populated environment, a node can have contact with multiple neighbors concurrently and new packets can be delivered from other nodes after exchanging a summary vector. Therefore, periodic exchange of the latest summary vector is necessary for efficient replication. In the DTN, the summary vector is exchanged by unicast communication. As unicast communication is more reliable than multicast or broadcast communication, it is an effective way of exchanging summary vectors in a sparsely populated environment. However, in a densely populated environment, unicast communication incurs multiple transmissions of the same summary vector to each neighbor node. This is obviously a waste of network resources. Thus, we use the broadcast of a "HELLO" message to exchange summary vectors.
5. Performance Enhancement

5.1. Physical broadcast

In order to prevent a node from repeatedly sending the same packet to different neighbor nodes, we exploit physical broadcasting, as described in previous research [30, 33]. In wireless networks, packets are physically broadcast even when they are sent to a single node in a unicast manner. Hence, other neighbor nodes within the transmission range can overhear the unicast packet. The overhearing mechanism based on unicast is superior to the broadcast scheme in terms of reliability, as broadcasting does not allow packet recovery by ACK. Using a physical broadcast, neighbor nodes overhear the packet on the transmission and if they do not have that packet, they add it in their receiving queues. The efficiency of a physical broadcast is determined by the number of neighbor nodes within a transmission range. When more neighbor nodes exist within the communication range, bandwidth can be used more efficiently. However, battery consumption is an expected cost, as every packet in the air should be decoded.

5.2. Anonymous request to send (RTS)

In the proposed scheme, replication is performed after the periodic exchange of summary vectors using a "HELLO" message. Therefore, the interval between two successive "HELLO" messages is a dominant factor in determining the end-to-end delay. In order to minimize this delay, we introduce an anonymous request to send (RTS) mechanism. Instead of waiting to send the next "HELLO" message, a node puts the ID of the newly received packet in the RTS frame and sends it via a MAC broadcast. When the node does not have the packet described in the received RTS, it sends a clear to send (CTS) packet in order to request that packet immediately. As multiple neighbor nodes can send CTS frames at the same time, the CTS frame is not sent right after the short interframe space (SIFS) interval. Instead, transmission is deferred for a random amount of time in order to avoid a collision. Here, we note that since the proposed scheme exploits physical broadcasting, the delivery of one CTS frame is sufficient for all neighbor nodes that are ready to send a CTS packet. Therefore, all other nodes discard the CTS frame in their transmission queues after overhearing the CTS frame. When the node that sent the RTS frame receives the CTS frame, it immediately transmits the packet. If anonymous RTS is used, a "HELLO" message is used to detect the neighbor nodes and a summary vector is exchanged using the "HELLO" message only when a new neighbor node is detected.

6. Performance Evaluation

In this section, the results of a performance evaluation for the proposed routing algorithm are presented. To evaluate our algorithm, a simulation was conducted using the ns-2 simulator [24]. In the simulation, nodes are placed in a 1500 m x 1500 m area and a random mobility model is employed to model the mobility.

Epidemic routing and the proposed routing algorithm were implemented in the ns-2 and the IEEE 802.11 MAC protocol and interface queues were modified. Parameters related to IEEE 802.11 were also configured so that IEEE 802.11g could be used [25]. The transmission range is 150 m and the size of the packet buffer is 500 packets. We randomly picked pairs consisting of a source node and a destination node. Unless otherwise noted, ten flows were used. Each source node generates CBR (Constant Bit Rate) traffic at an interval of 0.2 s, and the simulation was run for 300 s. For a proper evaluation, we compared the performance of our algorithm to that of the epidemic routing, AODV, and spray-wait[11] schemes. Spray-wait is a DTN routing scheme, which set a limit on the number of packet copies, L (it is limited to 4 and 15 in this simulation). $U_{max}$ described in Section 3 was also compared, which presents the delivery rate of opportunistic routings such as ExOR since it can deliver packets only when more than one end-to-end path exist. Here we note that authors in [23, 21] do not describe their MAC layer implementations, even though their schemes are greatly dependent on them. Hence, unfortunately, DT-DYMO and HYMAD cannot be included in our simulation study.

Three performance metrics were studied: packet delay, delivery rate, and packet overhead. Packet delay is the duration from the time generated in the source node to the time of arrival at the destination node. In the case of AODV routing, the routing discovery duration is included in the delay. If several packets are lost due to link failure and a packet subsequently arrives at the destination, the delay experienced by lost packets is added to total delay of the packet delivered. The delivery rate is defined as the amount of data delivered in a given time, and packet overhead is the sum of the data packets and control packets transmitted in all nodes.
Figure 6. Trace of a flow
6.1. Trace of a flow

In this subsection, we show how the proposed routing algorithm operates by tracing a CBR flow during a simulation. The simulation is conducted with 20 nodes moving at a maximum speed of 30 m/s, and only one pair consisting of a source and destination exists in a topology. The manner in which a flow reacts to network changes for the first 50 s is shown in Figure 6; node 18 is a source node while node 19 is a destination node. In the beginning, node 18 sends out packets by replication in order to find a path. Figure 6(a) shows the conditions of the packet buffer in nodes on the path at the moment that packet 4 reaches a destination (node 19) for the first time. Node 19 generates a NEW ROUTE message that is forwarded in the direction opposite to the path along which packet 4 has passed. A node receiving the NEW ROUTE message also forwards the message and its buffered packets to the destination. Node 8 wants to forward the NEW ROUTE message to node 18, but it failed. As a result, the path is only maintained from node 8 to node 19. As shown in Figure 6(c), node 18 sends out packets by replication, as it still does not have a path. At 19.637 s, a link failure is detected by node 3. This node makes the route entry down and stores receiving packets in its buffer. Buffered packets are transmitted again by replication. Packet 16 reaches the destination and a new path is established at 33.205 s.

6.2. Varying node density

Since network connectivity depends on the node density, a simulation with various numbers of nodes in the networks was run in order to examine the effect of network connectivity. In the simulation, the number of nodes was varied from 15 to 55, the speed of each node was between 15 m/s and 30 m/s, and the pause time was 0. Figure 7 shows the average delivery rate during the simulation. The AODV scheme should establish an end-to-end path to deliver the packet, but the path exists with low probability in the sparse networks. Thus, AODV routing can only deliver 2.5 packets/s with 15 mobile nodes. As a result, only 50% of the generated packets are successfully delivered. As the node density increases, networks are more connected and the AODV scheme can deliver more packets. AODV scheme delivers much more packets than $U_{\text{max}}$ since it uses a buffer to store packets during route discovery. In the sparse networks, epidemic routing shows a higher delivery rate than the AODV scheme since the carry-and-forward mechanism is used for data delivery. However, when more than 35 nodes are deployed, the delivery rate of epidemic routing rapidly decreases. As shown in Figure 9, epidemic routing spreads an excessive number of copies over the networks as the node density becomes high. This causes an increasing amount of contention and interference, which in turn leads to a low delivery rate. The delivery rate of spray-wait routing does not decrease due to interference since it puts limitations on the number of copies. The proposed routing scheme always has the highest deliver rate. Even in the sparse networks where there are 15 nodes, more than 4 packets/s are delivered. Our approach delivers packets according to the mobility of nodes, as in the epidemic routing and spray-wait schemes, but it can deliver more packets since it forwards packets along a partial path if the path exists. When compared to the AODV scheme, the proposed routing approach can carry packets even if there is no end-to-end path.
Figure 8 shows the average delay of eventually delivered packets. The average packet delay of AODV routing and the proposed routing scheme becomes low as the number of nodes increases. In particular, when more than 30 nodes are used, the average delay of the two approaches is less than 1 s. A high node density guarantees an end-to-end path with high probability and thus, the time spent for route discovery is short. Furthermore, nodes along a path to the destination forward packets immediately. In contrast, epidemic routing and spray-wait should wait for the next exchange of summary vectors to transmit packets. Epidemic routing spreads as many packet copies as possible, which results in a lower delay than spray-wait routing.

Figure 9 shows how many packets nodes transmit during the simulation time. Since the AODV scheme never replicates packets, only a small amount of overhead is incurred. Epidemic routing spreads copies of packets over the networks so they can eventually be delivered. The number of copies generated by epidemic routing is proportional to the number of nodes. As shown in Figure 7, this leads to an undesirably low deliver rate. On the other hand, since packets carried by spray-wait have a limitation on the number of copies, the node density does not have a big impact. The proposed routing scheme uses a partial path in the connected portion of the networks and thus, it can reduce packet overhead.

6.3. Varying the number of active flows

A simulation was performed with various numbers of active flows in networks consisting of 40 mobile nodes. The speed of each node was chosen so as to be between 15 m/s and 40 m/s. Figure 10 shows the delivery rate for
different numbers of active flows. Replication-based routings such as epidemic routing and spray-wait are influenced by contention and interference due to the increasing number of packets. Thus, the delivery rate in these schemes decreases with increasing traffic. Since epidemic routing copies with no limitation, its delivery rate is drastically reduced. AODV routing always delivers about 4.5 packets/s regardless of the number of flows. The delivery rate of the proposed routing scheme decreases by 3% with 20 active flows, but it is still higher than AODV routing by about 7%. Our approach can always deliver more packets than other routing schemes.

6.4. Shanghai Taxi Trace

For the evaluation of the proposed scheme under real environment, we perform simulation with GPS traces of Shanghai taxies [34] that is the largest vehicular GPS trace available. The trace records the location information of taxies within an area of 102 km² for 28 days. The total number of taxies recorded is about 4300. Since taxies are frequently in and out in the boundary area, to obtain stable results, our simulation is performed with the 3000m x 3000m core area. Each simulation is performed with various numbers of nodes in the network from 50 to 120 for 300 seconds. In the simulation, a half of the nodes are selected as senders and the others become receivers. The pair of a sender and receiver is randomly selected in each simulation. We repeat the simulation 5 times with a number of nodes, and plot the average value in the graph. The sender node generates CBR traffic, and its generation rate is 5 packets/second.

The results are presented in Figure 13. Figure 13(a) shows the average delivery rate of each routing scheme. As the number of nodes increases, the probability of end-to-end connectivity increases. AODV that operates upon the
Figure 12. Packet overhead for different number of active flows

Figure 13. Evaluation with Shanghai taxi trace
The end-to-end connection achieves a higher delivery rate with the increased number of nodes. In epidemic routing, an increased number of nodes incurs much traffic to be exchanged, which results in congestion and collision. Therefore, the performance of the delivery rate is inversely proportional to the number of nodes. In spray and wait where the maximum number of copies is set as 15, the delivery rate is rather increasing slightly unlike epidemic routing. This is because the spray and wait successfully increases the delivery rate by limiting the maximum number of copies. The proposed scheme works similar to epidemic routing when the node density is low. As the number of nodes increases on the network, the proposed scheme exploits the end-to-end connectivity, and it forwards packets without replication. It lessens the amount of exchanged packets on the network as well as the amount of buffered packets on each node. As a result, fewer congestion and collision are observed, and packet buffer can be used more efficiently. All of these contribute to the maximum delivery rate in the proposed scheme.

Figure 13(b) shows the average delay of delivered packets. The minimum delay is observed in AODV, since every delivered packet is routed along the pre-established end-to-end path. Both epidemic and spray-wait show much longer delay than the other comparative ones. This is because replication-based delivery observes additional carrying time. Here we note that the average delay in spray-wait is much larger than that in epidemic routing. In spray-wait, the limited number of copies makes messages diffused more slowly than in epidemic routing, and a larger average delay is observed. In the proposed scheme, a small number of nodes incurs a large value of delay. This implies that the proposed scheme works like epidemic routing under the low node density. As the node density becomes high, the delay is decreasing in contrast to both epidemic routing and spray-wait. This result indicates that more packets are delivered via simply forwarding rather than via replication, and the network becomes less congested. Figure 13(c), that shows the average values of the minimum 300 delays, also indicates that the proposed scheme successfully exploits a pre-established end-to-end connection. Here we note that delays of epidemic routing and spray-wait are reversed. Since spray-wait observes less congestion and collision than epidemic routing, the minimum 300 delays are smaller.

Figure 13(d) shows the overhead. The overhead of all schemes are dependent on the connectivity but epidemic routing and spray-wait. In epidemic routing, the amount of exchanged traffic sharply increases in proportion to the number of nodes, since more nodes incur higher contact rates. In spray-wait, as the number of maximum copy is limited, the rate of increase in packet overhead is not as significant as that in epidemic routing. If the connectivity is enhanced, more packets are forwarded along the pre-established path in both AODV and the proposed scheme. In the case of the proposed scheme, less packets are replicated under higher density of nodes. Hence, the overhead does not keep increasing unlike in the other schemes.

7. Conclusion

Traditional MANET and DTN routing schemes work normally only under the limited assumptions. However, the assumptions cannot be hold in a real environment and a more generalized routing algorithm is required for various and dynamically changing node density. In this paper, we design a new routing scheme for the realistic adhoc network environments. In the proposed scheme, data packets themselves are used to search an available end-to-end path while they are delivered by replication. If the end-to-end path becomes available, subsequent packets are relayed by simple forwarding. Otherwise, they are replicated to the destination, while searching an end-to-end path. This approach introduces low overhead and high throughput in a dense part of the network, while it outperforms existing DTN routing schemes in a sparse environment. Via ns-2 simulations, we verify superiority of the proposed scheme by comparing the proposed scheme with the well-known MANET and DTN routing schemes.

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