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A Time-slice Based Hybrid Routing for Delay Tolerant Networks

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Abstract: The non-existence of an end-to-end path poses a challenge in adapting the traditional routing algorithms to delay tolerant networks (DTNs). This paper innovatively puts forward the concept of "time-slice" to make full use of the respective advantages of single copy strategy and multiple-copy strategy thus getting a right balance between high message delivery ratio and low network overloads. We investigate making the routing decision based only on no more than one-hop information of neighbor nodes so as to enhance the practicability of our routing by reducing the complexity of neighbor discovery. Then a time-slice based hybrid routing protocol is proposed. Simulation results show that our proposed routing achieves the overall best performance than other protocols. When the network resource is constrained, our proposed routing scheme is more scalable than others. *Copyright © 2013 IFSA.*

Keywords: Delay tolerant networks, Time-slice, One-hop neighbor location information, Hybrid routing.

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1. Introduction

Delay/Disruption Tolerant Networks (DTNs) is a novel architecture facing the challenges of intermittent end-to-end connectivity, highly constrained network recourse and the mobility of nodes [1-3]. In the wide variety of work published over the past decade researchers applied this kind of communication paradigm in different heterogeneous challenged networks, such as Vehicular Ad-hoc Networks (VANETs) [4-6], Military Networks [7], Inter-Planet Networks (IPN) [8], Mobile Sensor Networks (MSN) [9]. The non-existence of an end-to-end path poses a challenge in adapting the traditional routing algorithms to such kinds of challenged networks [10], thus making routing an attractive research direction over the world [11].

To deal with the intermittent end-to-end connectivity [12] [13], routing in DTNs usually follows the "store-carry-forward" paradigm. The key problem is how to make the trade-off between efficient routing performance and the limited network resources. The straightest way to reduce the consumption of network resource is to limit the number of message replicas in the networks. However, replication strategy is very effective in enhancing the delivery ratio in such challenged networks [14] [15]. There are many research achievements that achieve good routing performance with acceptable costs by utilizing global topology knowledge, capturing the change of network topology or employing controlled ferry nodes. Nevertheless, the assumptions of pre-known knowledge oracle or the dependence on special controlled nodes lower the practicability of the routing algorithm in real network scenarios.

In this paper, we propose the concept "time-slice" so as to assist routing in utilizing both advantages of multi-copy and single-copy strategies. Besides, for the purpose of lowering the complexity of our proposed routing thus enhancing its practicability, we investigate making the routing decision by only relying on within one-hop neighbor(s)' information. Finally, based on the two above mentioned schemes we propose a Time-Slice based Hybrid routing (TSH). In summary, the paper makes the following contributions.

- We investigate making the routing decision based only on no more than one-hop information of neighbor nodes, thus raising the practicability of our routing by reducing the complexity of neighbor discovery in DTNs.
- The concept of "time-slice" is proposed to combine the advantage of multi-copy and single-copy strategies, thus seeking the balance between the consumption of network resource and the performance of routing.
- The simulation result shows that our proposed TSH routing outperforms Epidemic, FirstContact, Spray & Wait and PRoPHET in certain cases. In addition, TSH performs well in both two network scenarios with high and low node mobility.

In section 2 we give the detail of our TSH routing. Section 3 shows the simulation result. Our paper is concluded in section 4.

2. Time-slice Based Hybrid Routing

The start point of our proposed scheme is to improve the routing performance under the premise of controlling the complexity of routing in an acceptable level. [16] states that multi-copy strategy can efficiently increase the capability of communication in challenged network scenarios. In [17] the author shows that node mobility augments the throughput of the whole network. Based on these achievements, a time-slice based hybrid routing is proposed in this paper. In each period, the multi-copy and single-copy strategies are employed in turn. In the part of multi-copy period, each node tries to add message replicas to the network to raise the probability of successful delivery. In the part of single-copy period, each node focuses on seeking the destination by using its own mobility, so as to spread the message to farther areas as quickly as possible. The basic idea of TSH protocol is to take advantage of both multi-copy and single-copy strategies, while limit the overhead in an acceptable level, thus seeking the trade-off between performance and cost. Meanwhile, TSH only relies on one-hop neighbor(s)'s information to make the next hop choice for each message, which indicates that it is easy for TSH to be implemented in the real network scenarios. The routing process is illustrated in Fig. 1. The assumption that TSH based are listed as follows:

- Each node can only obtain the position information of itself. There is no assumption of network topology information.
- Each node can obtain the position information of its neighbors by broadcasting "hello" packet
- around itself. Since we only need to get the neighbor(s)'s position information, the broadcast packet is sent only within one-hop distance, which avoids the broadcast storm in the whole network.
- When the message arrived, the destination node will broadcast the admission information so as to clear the message redundancy in the network.

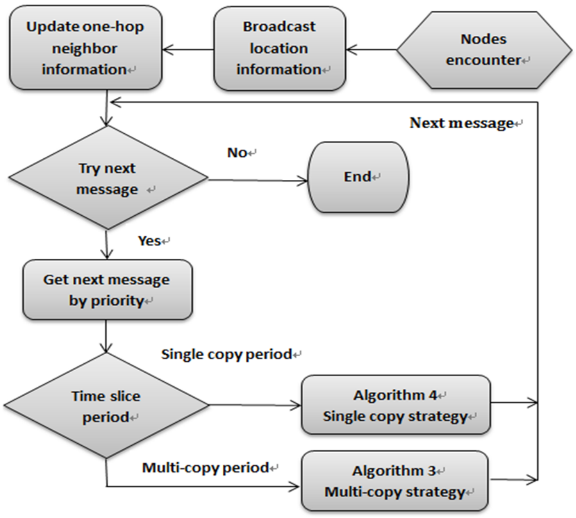


Fig. 1. TSH working process.

2.1. Choosing the Relay Nodes

By broadcasting the position information, the current node N_i can easily capture its neighbor(s)'s locations. Assuming that there are n neighbors for node N_i, we choose the two neighbor nodes as the next-hop relays that forming the largest angle with the current node N_i, as shown in Fig. 2. By using the cosine law in equation (1) and the inverse function in equation (2) we can get the degree of any of the possible C_n^2 angles. By utilizing algorithm 1, we finally choose the corresponding two nodes to forward the messages.

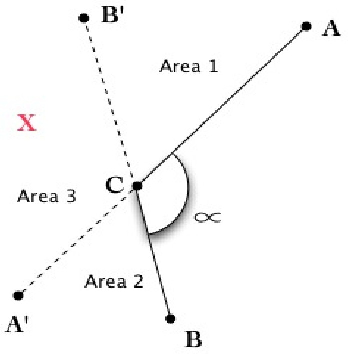


Fig. 2. The angle formed by *A*, *B* and *C*.

Algorithm 1 compute biggest angle
Input: one-hopNeighbors
Output: biggestAngle, nodeCombination

```
Initialize biggestAngle;
Initialize nodeCombination;
Update the location information of one-hopNeighbors;
for $C_n^2$ combinations of nodes in one-hopNeighbors
    compute angle of each combination by using [equation (1)] and [equation (2)];
    if angle > biggestAngle then
        biggestAngle=angle;
        nodeCombination=combination;
    end if
return biggestAngle and nodeCombination;
```

$$\cos \propto (j,k) = \frac{\overrightarrow{V_{ij}} \cdot \overrightarrow{V_{ik}}}{|\overrightarrow{V_{ij}}| \cdot |\overrightarrow{V_{ik}}|} = \frac{(x_j - x_i)(x_k - x_i) + (y_j - y_i)(y_k - y_i)}{\sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} \cdot \sqrt{(x_k - x_i)^2 + (y_k - y_i)^2}} \tag{1}$$

$$\propto (j,k) = \arccos(\cos \propto (j,k)) \tag{2}$$

2.2. Multi-copy Strategy

Algorithm 2 shows the multi-copy strategy in detail. After finishing running algorithm 1, we set the routing strategies according to the result as follows:

- We choose the two nodes that forming the largest angle $\propto$ if we have $\propto \geq \frac{2}{3}\pi$.
- We choose the node farthest from the current node, if we have $\propto < \frac{2}{3}\pi$.

When the largest angle $\propto$ is not more than $\frac{2}{3}\pi$, we find that all the neighbors locate in a sector area with the radian less than 2/3 π instead of randomly lying around the current node. In this case, there is no need to choose more than one node in this sector due to that the neighbors are too centralized. In the other case, we choose two nodes for the purpose of spreading the message to farther place, thus increase the message covering area.

Lemma1: Assuming the largest angle is $\propto$, when $\boldsymbol{\propto < \frac{2}{3}\pi}$, all the neighbor nodes locate in a sector with the radian less than 2/3 π.

Proof: As shown in Fig. 2, assuming that A, B is the two nodes that forming the largest angle $\propto = \angle ACB < \frac{2}{3}\pi$, it is obvious that there is no node X in neither area 1 nor area 2, since otherwise we would have $\angle XCB \geq \frac{2}{3}\pi$ or $\angle XCA \geq \frac{2}{3}\pi$ respectively.

We make the extension cord CA' of AC and CB' of BC, then we have

$$\angle XCA = \pi - \angle XCA' \tag{3}$$

$$\angle XCB = \pi - \angle XCB' \tag{4}$$

$$\angle XCA' + \angle XCB' < \frac{2}{3}\pi \tag{5}$$

Assuming that there is a node X existing in area 3 with $\angle XCA < \frac{2}{3}\pi$ and $\angle XCB < \frac{2}{3}\pi$, then from (3) we have

$$\angle XCA = \pi - \angle XCA' < \frac{2}{3}\pi \Rightarrow \angle XCA' > \frac{1}{3}\pi$$

and thus from (5) we have

$$\angle XCB' < \frac{1}{3}\pi$$

Finally from (4) we have $\angle XCB \geq \frac{2}{3}\pi$, which is conflict to our original assumption.

Algorithm 3 single copy strategy
Input: forwardingBundle, one-hopNeighbors
Output:

```
update the location information of one-hopNeighbors;
if one-hopNeighbors contain destination of forwardingBbundle
    if destination has received forwardingBundle
        delete forwardingBundle from Ni;
    else
        transfer forwardingBundle to destination;
        delete forwardingBundle from Ni;
    end if
else
    Ni still carry forwardingBundle;
end if
return;
```

Algorithm 2 multi-copy strategy
Input: forwardingBundle, one-hopNeighbors
Output:

```
update the location information of one-hopNeighbors;
if one-hopNeighbors contain destination of forwardingBbundle
    transfer forwardingBundle to destination;
    delete forwardingBundle from Ni;
else if one-hopNeighbors.size()==1
    select the only one-hop neighbor as next hop;
else
    compute biggestAngle by using Algorithm 1;
    if biggestAngle < $\frac{2}{3}\pi$
        if some node of one-hopNeighbors have carried forwardingBundle
            return;
        else
            select the farthest node as next hop;
        end if
    else
        select the nodeCombination from Algorithm 1 as forwarding nodes;
    end if
end if
return;
```

The multi-copy strategy of TSH is dependent of the network topology information. All we need is the one-hop neighbor(s)'s location. From this point, our proposed TSH protocol is easy to implement in the real networks.

2.3. Single-copy Strategy

The single-copy strategy is illustrated in algorithm 3 in detail. To save the bandwidth and the consumption of energy, the primary goal of our single-copy strategy is to find the destination node and coping with the message redundancy after the successful delivery detected.

3. Simulation

The metrics for comparison include delivery ratio, overhead ratio, average hop count and the number of drop packets. We simulate the routing protocols in two different mobility model, random walk and random waypoint.

The core idea of our proposed TSH is the concept of time-slice. By adjusting the length of either period of the whole time-slice, we can easily control the balance between delivery ratio and the network overloads. In the default case, we set the multi-copy period to be 10 % of the total time-slice.

3.1. Simulation in Random Walk Model

Table 1 shows the simulation settings in the random walk model. The protocols in comparison consist of FirstContact, Epidemic, Binary Spray & Wait and TSH.

Table 1. Simulation settings of RandomWalk.

Parameter	Default value	Range
Area size	500 m × 500 m	-
Number of nodes	20	-
Size of time slice	100 s	-
Transmit radius	100 m	-
Message size	500 K	-
Message interval	40 s	-
Transmit speed	250 Kbps	-
Moving speed	0.5-1.5 (m/s)	-
Node buffer size	20 M	2-10 M
Time-To-Live(TTL)	20 min	20-60 min
Simulation time	4 hours	-

3.1.1. Varying the Buffer Size

Fig. 3 shows the simulation result of varying the buffer size. Regarding the result in Fig. 3 (a), the delivery ratio of TSH is clearly higher than Binary Spray & Wait and FirstContact. When the buffer size is less than 9M, the delivery ratio of TSH keeps higher than Epidemic. This shows that TSH outperforms the others in delivery probability when the buffer resource is highly constrained. When the buffer size is more than 4M, there is no increase on the delivery ratio of both FirstContact and Binary Spray & Wait, which indicates that the network resource would not be sufficiently used. On the contrary, the delivery ratio of Epidemic is the lowest when the buffer resource is limited, thus making it hard to be implement in the real network scenarios with limited available buffer space in each node.

Fig. 3 (b) compares the overhead ratio of all protocols. The overhead ratio of Epidemic is approximately 2 times of the other three protocols. Nevertheless, the overhead ratio of our proposed TSH is slightly higher than the message-limited scheme Binary Spray & Wait and FirstContact, which verifies the advantage of TSH in lowering the cost of routing. The time-slice based scheme effectively takes the trade-off between the routing performance and routing cost, by combining the multi-copy and single-copy strategies.

In Fig. 3 (c), the average hop count metric is illustrated. For the reason that no forward operation in the wait phase of Binary Spray & Wait limits the maximum hop count of each message, we only take the other three protocols into consideration in this comparison. Regarding Fig. 3 (c), the average hop count of TSH keeps stable. When the buffer size is less than 6M, the average hop count of Epidemic is lower than FirstContact, which indicates that the energy consumption of Epidemic is higher.

Regarding the result in Fig. 3 (d), the number of dropped messages of Epidemic is nearly 3 times of the others, which shows that the flooding strategy leads to torrent redundancy in the network. When the buffer size is limited, these redundant messages compel the nodes to drop the newly arrived messages. Our proposed TSH controls the amount of redundancy message in an acceptable level by utilizing the next-hop relay choosing algorithm, as stated in section 3. Thus the number of dropped message of TSH is slightly higher than FirstContactand Binary Spray & Wait. When the buffer size is less than 4M, the number of dropped message of both Epidemic and TSH increase. However, that of TSH decreases slower than Epidemic, which indicates that TSH is more stable.

In conclusion, FirstContact and Binary Spray &Wait can be viewed as good choice when the network resource is highly constrained. When the network resource is relatively sufficient, our proposed TSH can take advantage of both multi-copy and single-copy strategies and thus make the trade-off between the routing performance and routing cost.

3.1.2. Varying the Message Time-to-live

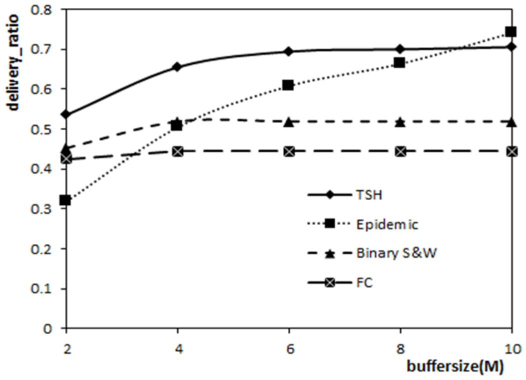
Fig. 4 shows the result of varying the message time-to-live. As shown in Fig. 4 (a), the delivery ratio of TSH is much higher than FirstContact and Binary Spray & Wait.

While the message time-to-live is more than 25 minutes, the delivery ratio of TSH is higher than Epidemic. The result shows the effectiveness of TSH in enhancing the delivery performance. The employed time-slice scheme takes advantage of both single-copy and multi-copy strategies, which ultimately increases the probability of meeting the destination for each message. With the increase of message time-to-live, the delivery ratio of FirstContact and Binary Spray & Wait arises slowly, since that the number of each message is strictly limited. The deficient amount of message leads to the message delivery ratio under a very low level. However, we can cope with this problem by increasing the message time-to-live value, thus giving each message enough time to survive before arriving the destination. When the message time-to-live is less than 20 minutes, Epidemic has the highest delivery ratio. However, the delivery ratio declines with the message time-to-live increase, for the reason that there is no strategy to control the blind flooding for Epidemic protocol and consequently introducing large amount of redundancy in the network. In this case, the buffer resource becomes the bottle neck factor for routing. When the message time-to-live is less than 40 minutes, the delivery ratio gradually decreases, because TSH only choose several relays with high utility values. However, there is no strict limit for the number of message replicas in TSH. So with the extending of the message time-to-live, there will be excessive message redundancy at last, thus increasing the number of dropped message and lowering the delivery ratio.

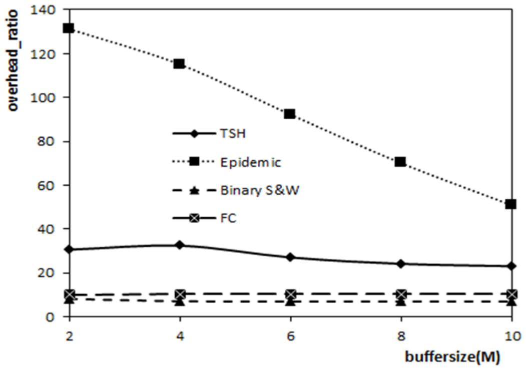
Regarding the result in Fig. 4 (b), the overhead ratio of FirstContact and Binary Spray & Wait are under a very low level. The overhead ratio of TSH is slightly higher than FirstContact and Binary Spray & Wait and is much lower than Epidemic. With the increase of the message time-to-live, the overhead ratio of both Epidemic and TSH augments. However, the growth rate of TSH is much slower than that of Epidemic, thus leading a relatively lower overhead ratio.

In Fig. 4 (c), we compare the average hop count metric among FirstContact, Epidemic and TSH. We can see from the result that TSH has the lowest average hop count value, from which we can infer that the next-hop choosing method of TSH is efficient in such network scenario. The average hop count values of all the three protocols increase along with the message time-to-live, since that the longer survive time of each message leads to the more forward operations, thus increasing the average hop count.

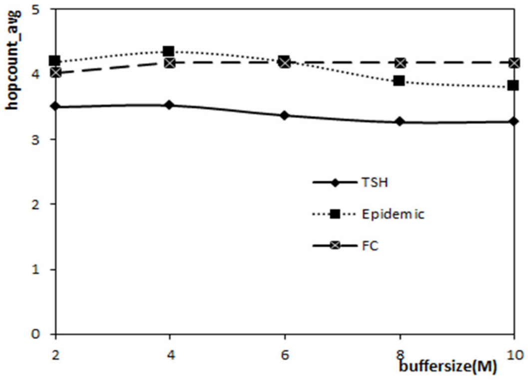
Fig. 4 (d) compares the number of dropped messages for all the four protocols. FirstContact has the fewest dropped messages. Compared to FirstContact, the number of dropped messages of Binary Spray & Wait is slightly higher. Our proposed TSH has an approximately good performance as Spray & Wait. Nevertheless, Epidemic performs



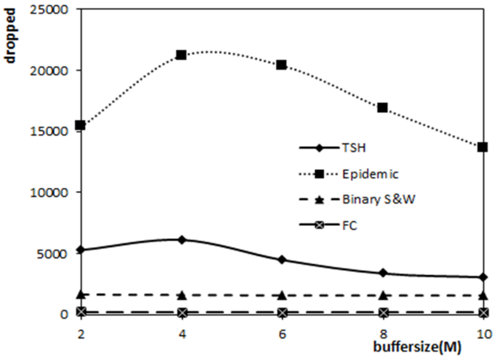
(a) delivery ratio



(b) overhead ratio



(c) average hop count



(d) dropped bundles

Fig. 3. Delivery ratio, overhead ratio, average hop count, dropped bundles VS buffer size in random walk.

worst, for that the blind flooding strategy consumes the buffer resource quickly.

Regarding from all the results shown in Fig. 4, FirstContact and Binary Spray & Wait have good performance only when the message time-to-live value is set to be large enough. When the message time-to-live is short, flooding strategy might be a more suitable choice. TSH employs a time-slice based scheme to combine multi-copy and single-copy strategies which avoid the blind flooding in the network, and consequently have an overall better performance than Epidemic.

3.1.3. Varying the Multi-copy Period in the Time-slice

By controlling the length of the multi-copy period in the time-slice of TSH, we can easily adjust the balance between delivery ratio and the overhead ratio. Fig. 5 evaluates the routing performance by setting the multi-copy period to different lengths. As shown in Fig. 5 (a), when the buffer size is less than 4M, TSH_10 %, TSH_30 % and TSH_50 % has the better performance of delivery than TSH_70% and TSH_90 %. When the buffer size is more than 6M, we have the delivery performance that TSH_10 % < TSH_30 % < TSH_50 % < TSH_70 % < TSH_90 %.

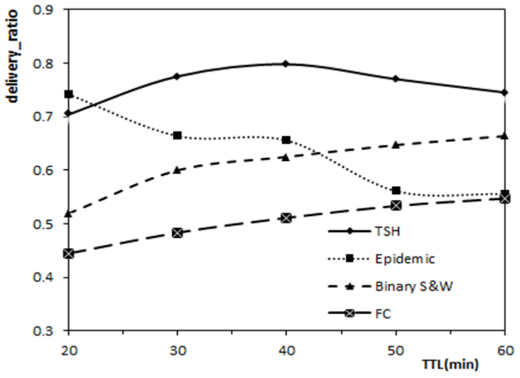
Fig. 5 (b) illustrates the simulation results in overhead ratio performance. We also have the result that TSH_10 % < TSH_30 % < TSH_50 % < TSH_70 % < TSH_90 %. The reason is that the longer multi-copy period we set, the more message replicas will be added to the network, which thus leads to a higher overhead ratio. Regarding the result in Fig. 5, when the network resource is highly constrained, TSH_50 % is the best choice in the network with relatively low node moving speed. When the network resource is relatively sufficient, we can employ TSH_70 % or TSH_90 % respectively to dynamically adjust the balance between the routing performance and the routing cost.

3.2. Simulation in Random Waypoint Model

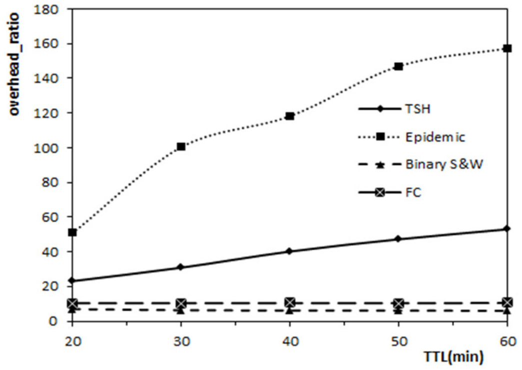
Table 2 shows the simulation settings of random waypoint model. We compare the four protocols, FirstContact, Epidemic, PRoPHET and our proposed TSH.

3.2.1. Varying the Buffer Size

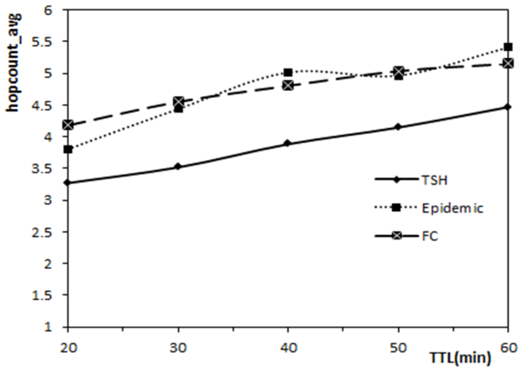
Fig. 6 shows the influence of the buffer size on the performance of the four routing protocols. As shown in Fig. 6 (a), the delivery of TSH is much higher than PRoPHET and FirstContact. When the buffer size is less than 8M, the delivery ratio of TSH is higher than Epidemic. This shows the evident advantage of the controlled flooding strategy of TSH



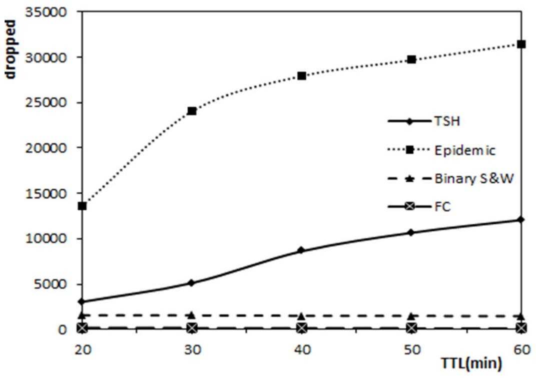
(a) delivery ratio



(b) overhead ratio

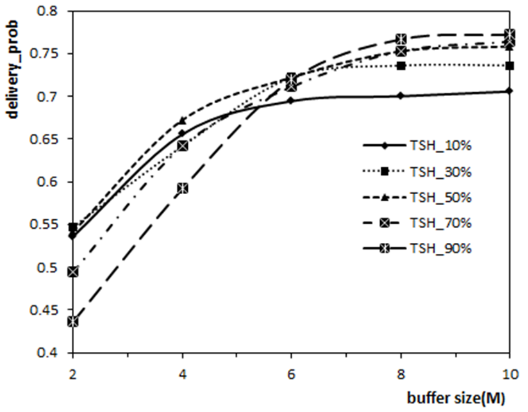


(c) average hop count

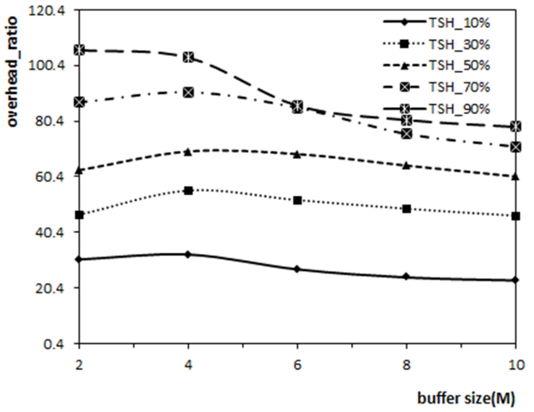


(d) dropped bundles

Fig. 4. Delivery ratio, overhead ratio, average hop count, dropped bundles VS message time-to-live in random walk.



(a) delivery ratio



(b) overhead ratio

Fig. 5. Different TSH in random walk.

Table 2. Simulation settings of RandomWaypoint.

Parameter	Default value	Range
Area size	1000 m x 1000 m	-
Number of nodes	20	-
Size of time slice	100 s	-
Transmit radius	100 m	-
Message size	500 K	-
Message interval	40 s	-
Transmit speed	250 Kbps	-
Moving speed	0.5-1.5 (m/s)	-
Node buffer size	20 M	2~10 M
Time-To-Live (TTL)	20 min	20-60 min
Simulation time	4 hours	-

outperforms others when the node mobility is relatively high. When the buffer size is larger than 8M, the delivery ratio of Epidemic is the highest. PRoPHET has an acceptable delivery ratio, of which the delivery ratio increases more slowly than that of Epidemic.

Fig. 6 (b) evaluates the overhead ratio of each protocol. The overhead ratio of Epidemic is the highest and is much higher than any other protocols. TSH performs slightly better than FirstContact, which indicates that TSH can control the overhead ratio under a very low level. When the buffer size is less than 4M, the overhead ratio of PRoPHET is always higher than FirstContact. Nevertheless, when the buffer size is set to be more than 4M, PRoPHET has the best performance in overhead ratio among all the four protocols.

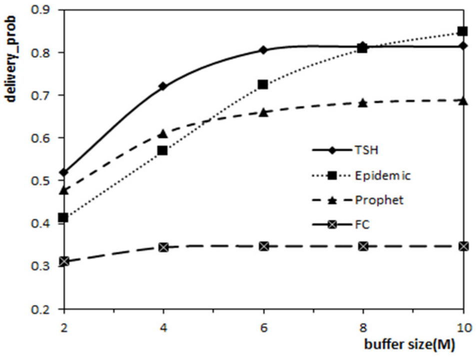
As shown in Fig. 6 (c), the average hop count of FirstContact is the highest, since that it forwards the message blindly to the first encountered node without an optimal object. Epidemic performs better than FirstContact but still has a relatively high average hop count value. PRoPHET performs the best among all the four protocols, for that it employs a considerable next-hop choice in each forward operation. The performance of TSH is approximate to that of PRoPHET. However, it is much easier to implement since it only relies on the position information of one-hop neighbor(s).

Fig. 6 (d) shows the result of dropped messages. We can see from it that the number of dropped messages of Epidemic is much higher than the others due to its uncontrolled flooding strategy. The performance is approximate between PRoPHET and TSH and either of them is much lower than Epidemic. This is because both of them have the optimal object when choosing the next-hop relay. FirstContact has the fewest dropped messages, while it also has an unacceptable low delivery ratio.

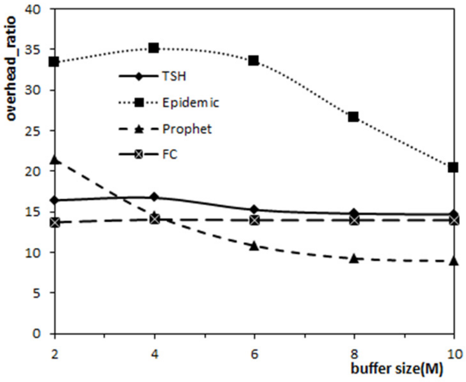
3.2.2. Varying the Message Time-to-live

Fig. 7 shows the result of varying the message time-to-live. As shown in Fig. 7(a), the delivery ratio of TSH is obviously higher than FirstContact and PRoPHET. When the message time-to-live is set to be more than 25 minutes, TSH has the better performance than Epidemic. This result verifies that TSH has the evident advantage in improve the performance of delivery. When the message time-to-live is less than 20 minutes, Epidemic achieves the highest delivery ratio among all the protocols. Thus we know that the number of message copies can be controlled by adjusting the message time-to-live value. When the message time-to-live is set to be less than 30 minutes, the delivery performance of PRoPHET is worse than Epidemic. Nevertheless, when we set the message time-to-live to be larger than 30 minutes, though the delivery ratio of PRoPHET keeps decreasing, it is always higher than Epidemic.

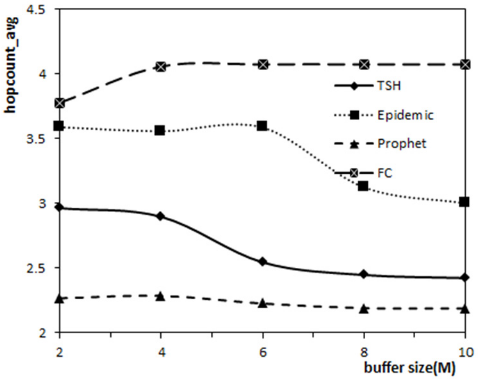
Fig. 7(b) shows the result of overhead ratio. Epidemic has the worst performance. Besides, the overhead ratio increases very quickly, which shows again that Epidemic is only suitable in the network with a very short time-to-live value. Both TSH and PRoPHET employ corresponding schemes so as to achieve the controlled flooding strategy, so that they have relatively approximate results. The overhead ratio of FirstContact is always under a low level. However it is hard to be adopted due to its unacceptable delivery ratio.



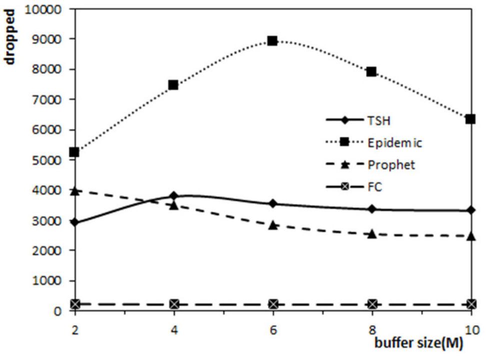
(a) delivery ratio



(b) overhead ratio



(c) average hop count



(d) dropped bundles

Fig. 6. Delivery ratio, overhead ratio, average hop count, dropped bundles VS buffer size in random waypoint.

As shown in Fig. 7(c), the average hop count of FirstContact is highest and increases quickly along with the message time-to-live. The average hop count values of the other three protocols are much lower than FirstContact. The performance of our proposed TSH is slightly worse than PRoPHET but better than Epidemic, which indicates that the relay choosing algorithm of TSH is relatively efficient.

Fig. 7 (d) shows the result of dropped messages. The performance of Epidemic is much worse than other protocols, which verifies again that the uncontrolled flooding strategy leads to the quick consumption of the network resource. The single-copy routing protocol FirstContact has the fewest dropped messages, thus wasting the least resource in the network. When the message time-to-live is less than 30 minutes, the number of dropped messages of PRoPHET is slightly lower than TSH. While when the message time-to-live is larger than 40 minutes, PRoPHET performs better than TSH. Both TSH and PRoPHET employ relatively effective strategies to reduce the redundancy in some sense, thus enhancing the availability of the network resource.

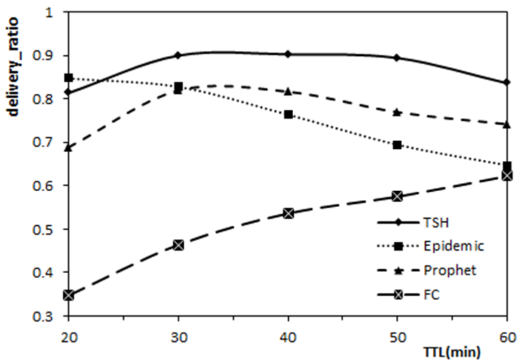
4. Varying the Multi-copy Period in the Time-slice

Fig. 8 shows the simulation result of different TSH protocols with the multi-copy period ratio of 10 %, 30 %, 50 %, 70 % and 90 %. As shown in Fig. 8 (a), when the buffer size is less than 3M, the performance of TSH_10 %, TSH_30 % and TSH_50 % is higher than TSH_70 % and TSH_90 %. When the buffer size is less than 6M, the delivery ratio of TSH_10 %, TSH_30 %, TSH_50 % and TSH_70 % is higher than TSH_90 %. Moreover, when the buffer size is larger than 6M, the performance of both TSH_70 % and TSH_90 % is better than the other three. These results show that we should lower the multi-copy period under 50 % when the buffer resource is constrained. Otherwise we can increase the ratio of the multi-copy period so as to sufficiently utilize the network resource to achieve a higher delivery ratio.

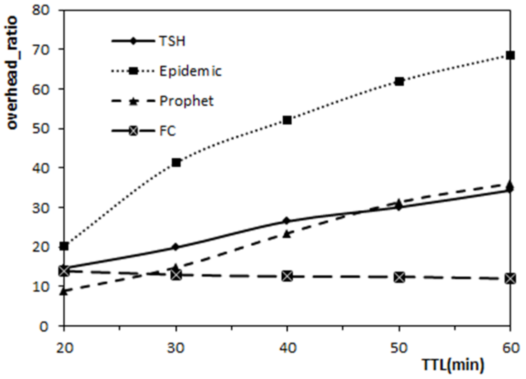
In Fig. 8 (b) we evaluate the result of the overhead ratio among TSH protocols with different settings. The result shows that we have TSH_10 % < TSH_30 % < TSH_50 % < TSH_70 % < TSH_90 %, which intuitively correspond to what we know that extra replicas increase the overhead ratio in the network.

4. Conclusions

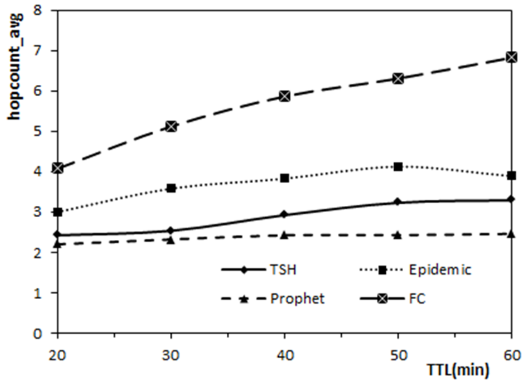
In this paper, we proposed a time-slice based routing protocol TSH for DTNs. TSH only relies on one-hop neighbor(s)'s location information to make the routing decision. The starting point of the time-slice concept is that we intend to combine multi-copy



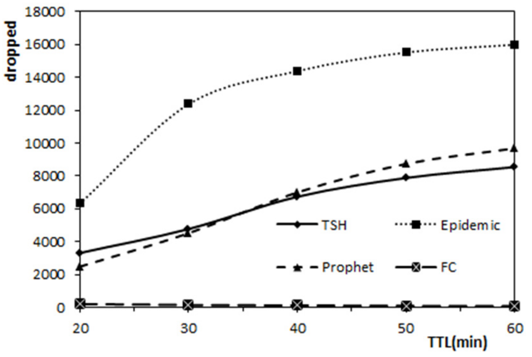
(a) delivery ratio



(b) overhead ratio

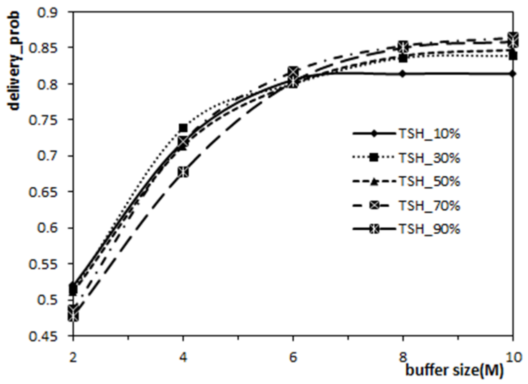


(c) average hop count

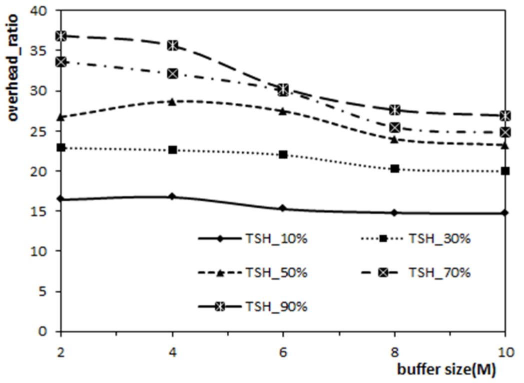


(d) dropped bundles

Fig. 7. Delivery ratio, overhead ratio, average hop count, dropped bundles VS message time-to-live in random waypoint.



(a) delivery ratio



(b) overhead ratio

Fig. 8. Different TSH in random waypoint.

and single-copy strategies to achieve a good balance in routing performance and the cost. When choosing the next hop, we take both direction and distance into consideration. The simulation result shows that TSH achieves overall better performance than others. When the network resource is not sufficient, TSH outperforms Epidemic and is more scalable than the other protocols.

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