

HESnW: History Encounters-Based Spray-and-Wait Routing Protocol for Delay Tolerant Networks

Shunyi Gan*, Jipeng Zhou*, and Kaimin Wei*

Abstract

Mobile nodes can't always connect each other in DTNs (delay tolerant networks). Many DTN routing protocols that favor the “multi-hop forwarding” are proposed to solve these network problems. But they also lead to intolerant delivery cost so that designing a overhead-efficient routing protocol which is able to perform well in delivery ratio with lower delivery cost at the same time is valuable. Therefore, we utilize the small-world property and propose a new delivery metric called multi-probability to design our relay node selection principles that nodes with lower delivery predictability can also be selected to be the relay nodes if one of their history nodes has higher delivery predictability. So, we can find more potential relay nodes to reduce the forwarding overhead of successfully delivered messages through our proposed algorithm called HESnW. We also apply our new messages copies allocation scheme to optimize the routing performance. Comparing to existing routing algorithms, simulation results show that HESnW can reduce the delivery cost while it can also obtain a rather high delivery ratio.

Keywords

Delivery Cost, DTNs, History Node, Multiple Probability, Spray-and-Wait

1. Introduction

Sparse wireless networks that can't always exist the complete road between the source node and the destination node. These networks fall into the general category of delay tolerant networks (DTNs) [1]. Hence, conventional schemes, including MANET routing algorithms such as the AODV [2] and DSR [3], fail to handle frequent disconnection. DTNs [4,5] are a kind of challenged networks in which the latency of end-to-end transmission may be arbitrarily long because of the occasional connections. A bundle layer that consists of the store-carry-forward paradigm [6] and the custody-transfer thought is put forward to solve the above problems. Successful delivery occurs only when one of the infected nodes encounters the destination node.

This paper propose a new forwarding scheme called History Encounter-based Spray-And-Wait Protocol in DTNs (HESnW). To avoid blindly choosing the relay node, our algorithm exploits the history performance of both sender and receiver to design the next hop. In other words, we make comprehensive consideration of the potential ability of both sender and receiver nodes. We know that

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previous work just focus on the delivery possibility of the peer node without noticing the current node's delivery possibility when two nodes encounter each other. So, this is our first time to consider the delivery predictability of both sender and receiver and, to evaluate the performance of our algorithm, we have finished groups of simulation experiments.

Below we will show our contributions and originalities of our work:

- We apply the concept of delivery probability in the whole process of the traditional Spray-and-Wait (SnW) algorithm.
- Inspired by the property of the small-world phenomenon, “high cluster coefficient” feature [7], we choose nodes that one of its history nodes can likely encounter the destination to be relay nodes.
- In our algorithm, we introduce a new delivery metric, called multi-probability. If the current node's delivery possibility is larger than the peer node's delivery possibility, we will consider the multi-probability of the peer node.
- When making the decision of the allocation of messages copies between sender and receiver, we consider the potential ability of both sender and receiver.

The remainder of this paper is organized as follows. In Section 2, we shows some related work on forwarding algorithms and “small-world” based protocols of the mobility wireless network. The idea of HESnW algorithm will be proposed in Section 3. Through the comparison to some DTN routing algorithms, Section 4 displays the performance of HESnW. At last, in Section 5, we make the conclusion for our work and discuss our future work.

2. Related Work

The idea of flooding is extended by Epidemic protocol [8] and whenever a node meets another node, both them exchange messages two nodes don't have in common. Through this method, all messages can finally cover the whole network. Although Epidemic protocol finds the same path as the optimal scheme under no contention [9], it wastes network resources extremely and results in many message drops that will also be shown in our simulation results.

SnW [1] greatly cuts the forwarding cost comparing with Epidemic protocol and performs well in delivery delay. The scheme consists of two parts: the spray phase and the wait phase. In the spray phase, L nodes without message M that firstly encountered by the source node can receive a message copy from the source node. If these L nodes do not include the destination node, the protocol then changes into the wait phase in which these L nodes move around the network with the message copy until one of them reaches the destination node. For binary SnW, a node forwards half the message copies ($L / 2$) to the encounter node.

ProPHET is an estimation-based forwarding algorithm that applies encounter possibility [10]. It builds a summary vector to mark messages a node has. It introduces the delivery predictability, a new metric, $P_{(a,b)} \in [0,1]$, which means the possibility that node a meets node b .

To get the delivery predictabilities, three steps should be done. Firstly, once meet a node, the delivery predictability is recalculated according to Eq. (1), and $P_{ini} \in (0, 1]$ refers to an initialization constant.

$$P_{(a,b)} = P_{(a,b)old} + (1 - P_{(a,b)old}) \times P_{ini} \quad (1)$$

Secondly, if two nodes that ever met before don't meet again for long time, the possibility that they encounter again become small, which means the delivery predictability between them ages. Then the delivery predictability is recalculate according to Eq. (2), in which $\gamma \in (0,1)$ refers to the *aging constant*, and K refers to the number of time units that have elapsed since the last time the delivery predictability was aged.

$$P_{(a,b)} = P_{(a,b)old} \times \gamma^K \quad (2)$$

Finally, this metric has transitivity which means if node a often meets node b while node b often meets node c , then node a can often meets node c , just as Eq. (3) refers to. In Eq. (3), β refers to the scaling constant and use to decide the impacts that transitivity makes on the delivery predictability.

$$P_{(a,c)} = P_{(a,c)old} + (1 - P_{(a,c)old}) \times P_{(a,b)} \times P_{(b,c)} \times \beta \quad (3)$$

The pioneering work of Milgram [1] in the 1960's firstly propose the "small-world" theory which expresses the phenomenon that people are actually connected by short of acquaintances. This phenomenon indicates the essential features of social communication network: "short average path length" and "high cluster coefficient", and has been applied in wireless communication network [12-14]. Some other work [15-19] focus on the small world phenomenon of DTNs. Chaintreau et al. [15] propose that the distribution of inter-contact time between human with mobile devices meets a power law distribution. Wei et al. [19] exploits the small world theory to make the selection of relay nodes in DTNs and improved their routing performance in [20].

In our work, the "small-world" theory is applied into the relay node selection based on the traditional SnW and PRoPHET. Meanwhile, extensive simulations have done and proved the efficiency and utility of HESnW.

3. History Encounters-Based Spray-and-Wait Routing Protocol

In this section, we firstly present a new delivery metric in wait phase to quantify the forwarding possibility of nodes by considering the delivery probability of history encounters. After that, we propose our routing protocol called HESnW that introduces an idea about how to choose relay nodes in both spray phase and wait phase and our new copy allocation scheme between sender and receiver.

In order to clearly propose our new delivery metric, we firstly make a brief introduction of the main notations in our routing algorithm:

- $mP_{a,c,b}$: The multiple-probability between node a and node b under the participation of a certain node c that node a ever met before, or mP for short.
- $P_{a,b}$: The meet probability between node a and node b , is updated according to the way of PRoPHET protocol.
- L_a : The number of copies for a certain message that node a owns.
- $thrh$: The threshold of the delivery predictability of selecting a relay node, its initial value is 0.

3.1 New Message Property

In our work, as messages are allowed to transfer to a node with lower delivery predictability as long as it has a multiple probability that is higher than the sender's delivery predictability, it can easily cause the problem that the following relay node's delivery predictability becomes lower and lower. In order to solve this problem, we introduce a new property for messages called transfer threshold, denoted by *thrh*, indicating the threshold of the delivery predictability when selecting a relay node.

We suggest that only when the peer node's delivery predictability or multiple probability (when the peer node's delivery predictability is lower than *thrh* in spray phase) is higher than the value of *thrh* can the sender forward the message to it. The initial value of *thrh* is the source node's delivery predictability. Then each receiver will update it to their delivery predictability if their delivery predictability are high than the previous *thrh*.

3.2 New Delivery Metric

Just as stated above, you can transfer messages through "your friend's friends". How to decide which one of "your friend's friends" can be the candidate? Here we propose a new delivery metric called multiple probability, calculated according to Eq. (4), where *S* refers to the current node, *D* refers to the destination and *H* is the history node that *S* ever met; $P_{S,H}$ is the delivery predictability (the same as PRoPHET, calculated according to the above Eqs. (1)-(3)) from node *S* to node *D*; $P_{H,D}$ is the delivery predictability from node *H* to node *D*; $mP_{S,H,D}$ is the new delivery metric we present, it means the multiple delivery predictability from node *S* to node *D*.

$$mP_{S,H,D} = P_{S,H} * P_{H,D} \quad (4)$$

3.3 HESnW Routing Protocol

3.3.1 Message allocation scheme

As we all know, in spray phase, the traditional SnW protocol allocates one message copy to the relay node while binary SnW protocol allocates half the message copies. As for PRoPHET routing protocol, one copy can be gained for the relay node. In our proposed routing protocol, we present a new allocation scheme that, in spray phase, the number of the message copies the relay node can gain is based on the multiple probability of both the sender and the receiver if the delivery predictability of relay node is less than that of the current node. If the delivery predictability of the relay node is higher than that of the current node, then the message copies are proportionally allocated according to their probability. In wait phase, just like the PRoPHET routing protocol, it only forwards one message copy to the node with higher delivery probability than its own *thrh*.

3.3.2 Spray phase and wait phase

Conventional SnW routing blindly chooses relay nodes in the spray phase and only transfer message to the destination node in the wait phase, while PRoPHET routing only chooses the node that with a

higher delivery predictability, which can easily ignore the potential node whose “friends” may reach the destination node with a large probability. We propose a new algorithm for both spray phase and wait phase in the combination of PROPHET and the feature observed in the “small-world” phenomenon. Next, we present our routing algorithm.

• **Spray phase**

When $L > 1$, we divide it into two cases: $P_{A,D} \leq P_{B,D}$ and $P_{A,D} > P_{B,D}$. Fig. 1 shows the idea that our algorithm expresses.

At $T = t_0$, source node A creates L copies for message m whose initial thr_h value is 0 and node A updates thr_h to its delivery predictability, i.e., $thr_h_A = 0.6$.

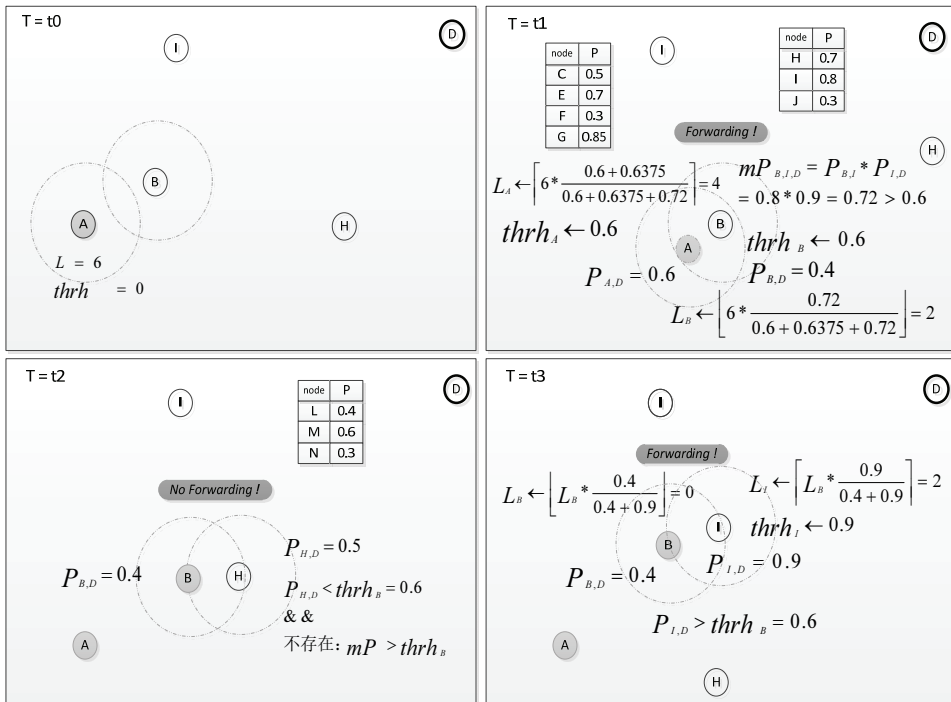


Fig. 1. Spray phase example.

At $T = t_1$, node A meets node B during its movement. They exchange and update the delivery probability for all their nodes (hereafter referred to routines). As we can see, the delivery probability between node A and D , denoted by $P_{A,D}$, is higher than $P_{B,D}$, so we switch to comparing the multiple delivery probability of B . As the history list (list that records nodes ever met before and the corresponding meet probability) shown in Fig. 1, we calculate the mP of node B according to Eq. (4). As long as we find one history node M that satisfies $mP_{B,M,D} = P_{B,M} \times P_{M,D} > thr_h_A$, we can forward the message m to B . To calculate the copies node B can be allocated, L_B , we should also calculate the mP of node A . In this case, $P_{B,D} < thr_h_A$, then we allocate the copies according to Eqs. (5) and (6), where S, R, D , and H , respectively represent sender, receiver, destination and history node of sender or receiver.

$$L_S = \left[L^* \frac{P_{S,D} + \sum_{\forall H, mP_{S,H,D} > thrh} mP_{S,H,D}}{P_{S,D} + \sum_{\forall H, mP_{S,H,D} > thrh} mP_{S,H,D} + \sum_{\forall H, mP_{R,H,D} > thrh} mP_{R,H,D}} \right] \quad (5)$$

$$L_R = \left[L^* \frac{\sum_{\forall H, mP_{R,H,D} > thrh} mP_{R,H,D}}{P_{S,D} + \sum_{\forall H, mP_{S,H,D} > thrh} mP_{S,H,D} + \sum_{\forall H, mP_{R,H,D} > thrh} mP_{R,H,D}} \right] = L - L_S \quad (6)$$

At $T = t2$, node B meets node H and operates like the work mentioned above. In this case, $P_{H,D} < thrh_B$ and there is no history node of node H that satisfies $mP_{H,M,D} = P_{H,M} \times P_{M,D} > thrh_B$. So node B doesn't forward message to H .

At $T = t3$, node B encounters node I and $P_{I,D} > thrh_B$. Then, on this occasion, node I can be selected to be the relay node and the allocation of messages between node B and I is according to Eqs. (7) and (8).

$$L_S = \left[L^* \frac{P_{S,D}}{P_{S,D} + P_{R,D}} \right] \quad (7)$$

$$L_R = \left[L^* \frac{P_{R,D}}{P_{S,D} + P_{R,D}} \right] = L - L_S \quad (8)$$

All nodes that satisfy $L > 1$ go through these steps until $L = 1$.

Algorithm 1 Spray phase procedure on S when it meets R

- 1: **for** message m carried by S **do**
 - 2: **if** S is the source of message m **then**
 - 3: $thrh_S \leftarrow P_{S,D}$
 - 4: **end if**
 - 5: **if** $R == D$ **then**
 - 6: forward m to R
 - 7: remove message m from S 's local buffer
 - 8: **else if** $P_{R,D} \geq thrh_S$ **then**
 - 9: forward m to R
 - 10: $L_R \leftarrow \lfloor L \cdot \frac{P_{R,D}}{P_{S,D} + P_{R,D}} \rfloor$
 - 11: $thrh_R \leftarrow P_{R,D}$
 - 12: **else if** $P_{R,D} < thrh_S$ **then**
 - 13: **if** $\exists H, mP_{R,H,D} > thrh_S$ **then**
 - 14: forward m to R
 - 15: $L_R \leftarrow \lfloor L \cdot \frac{\sum_{\forall H, mP_{R,H,D} > thrh_S} mP_{R,H,D}}{P_{S,D} + \sum_{\forall H, mP_{S,H,D} > thrh_S} mP_{S,H,D} + \sum_{\forall H, mP_{R,H,D} > thrh_S} mP_{R,H,D}} \rfloor$
 - 16: $thrh_R \leftarrow P_{R,D}$
 - 17: **end if**
 - 18: **end if**
 - 19: **end for**
 - 20: update the value of $P_{S,R}$ according to Eq.(1)
-

Algorithm 1 displays the pseudo-code of the spray phase. In spray phase, if the encounter node's delivery probability is higher or equal to the current node's *thr_h*, then forward message copies to the peer and they can obtain the messages copies in proportion to their respective delivery probability. Otherwise, we will compare the multi-probability of the encounter node with the current node's *thr_h* and forward messages to the encounter node only if one of its multi-probability is higher than *thr_h* and allocate the copies according to Eqs. (5) and (6).

In all the situations mentioned above, a node will update the value of *thr_h* to their delivery probability if their delivery probability is higher than the present *thr_h*.

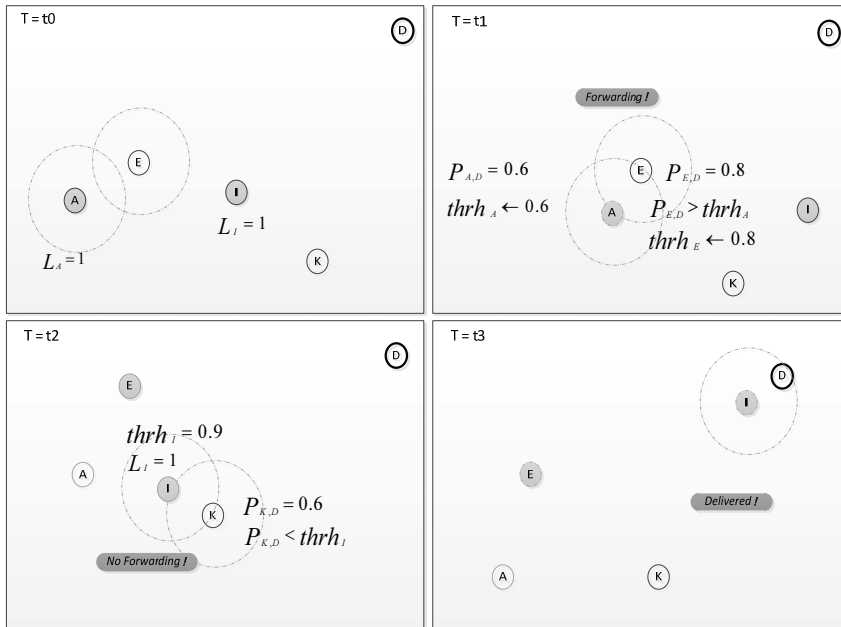


Fig. 2. Wait phase example.

• **Wait phase**

When $L=1$, after the spray phase, a node move on to the wait phase just as Fig. 2 shows.

At $T = t_0$, for node A and I, as their value of L is 1, they both stay in the wait phase.

At $T = t_1$, node A meets E and they finish the routines. Node A forwards the message to node E as $P_{E,D} > thr_{h,A}$. Node E updates *thr_h* to its delivery probability, i.e., $thr_{h,E} = 0.8$.

At $T = t_2$, node I meets K and then they finish the routines. However, node K can't receive the message from node K, as $P_{K,D} < thr_{h,I}$.

At $T = t_3$, node I encounters node D, the destination node for the message, and the message is successfully delivered.

All nodes that satisfy $L = 1$ go through these steps until the message is successfully delivered or it's expired.

Algorithm 2 shows the pseudo-code of the wait phase. During wait phase, if a node S encounters node R with higher delivery probability, then it will forward the message copy to R. At the same time, the encounter node will update the value of *thr_h* to its own delivery probability. Until a node with a message reaches a destination can the delivery be successful.

Algorithm 2 Wait phase procedure on S when it meets R

```

1: for message  $m$  carried by  $S$  do
2:   if  $R == D$  then
3:     forward  $m$  to  $R$ 
4:     remove message  $m$  from  $S$ 's local buffer
5:   else if  $P_{R,D} > thrh_S$  then
6:     forward  $m$  to  $R$ 
7:     remove message  $m$  from  $S$ 's local buffer
8:      $thrh_R \leftarrow P_{R,D}$ 
9:   end if
10: end for
11: update the value of  $P_{S,R}$  according to Eq.(1)

```

4. Performance Evaluation

4.1 Simulation Setup

To evaluate the performance of our proposed routing algorithm, we implement it in the simulator ONE (opportunistic network environment simulator). The ONE simulator was developed by Helsinki University and provides a map of the Helsinki area [21] which is a city that covers an area of $4,500 \text{ m} \times 3,400 \text{ m}$ and there are 150 mobile nodes, including city roads, cars and pedestrians.

The simulation parameters are listed in Table 1.

Table 1. Simulation parameters

Parameter	Value
Routing protocol	Proposed \ SnW \ ProPHET \ Epidemic
Simulation area	4,500 m×3,400 m
Simulation time	12h = 43,200s
Buffer policy	FIFO
Mobility models for pedestrians	Shortest path map based movement model
Mobility models for cars and trains	Map route movement
Buffer sizes ranges	[1M,18M]
Time-to-live (TTL) ranges	[2min,12h]
Nodes	50
Speed ranges (km/h)	Pedestrians: [0.5,1.5] Cars: [10,80] Trains: [10,80]

Below we show the performance metrics that our simulation tests bases on.

- Delivery ratio. The ratio between the number of messages that are successfully delivered within their TTL to the total number of messages created.
- Delivery overhead. The average number of forwarding used for the successfully delivered messages.

4.2 On the Effect of Message TTL

Fig. 3(a) shows the performance results on the delivery ratio of four protocols as a function of *TTL*. As we can see, HESnW outperforms both SnW routing protocol and P_{RO}PHET routing protocol. But before the *TTL* equals to 30m, Epidemic's delivery ratio is higher than all the other routing protocols. We attribute the result to two factors.

First, Epidemic routing spreads all the messages to the whole network, so that it can reach a high delivery ratio. But as the *TTL* increasing, it goes down and finally stays at a fixed value. This is because it doesn't consider the buffer space and the delivery ratio for Epidemic routing turns into the performance bottleneck while *TTL* is large enough. From Fig. 3(a), it can also infer that the number of messages dropped for epidemic routing becomes high fast and remains at the same value.

Second, HESnW will not ignore the potential nodes that with lower delivery probability but may likely deliver the message to the destination through its history nodes. Finally, our routing protocol adopts a new message allocation scheme that can optimize the delivery performance. Just as the advantages of our routing protocol mentioned above, from Fig. 3(b) for delivery overhead, HESnW outperforms all the other routing protocols all the time.

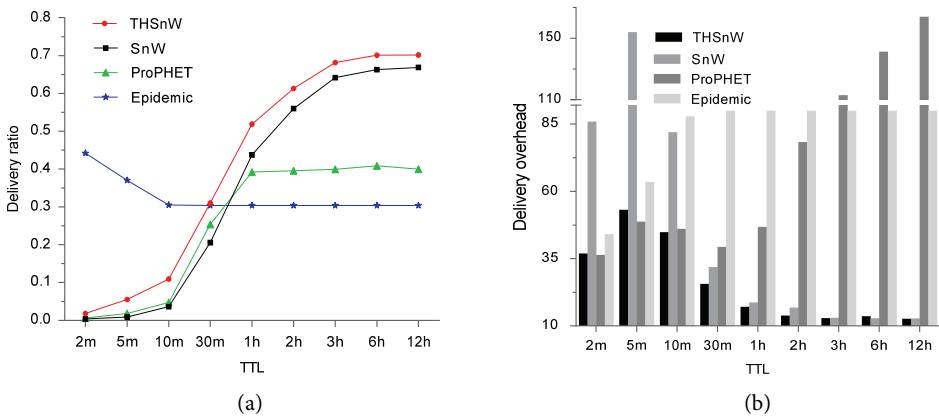


Fig. 3. Performance evaluation results under different *TTL*: (a) delivery ratio and (b) delivery overhead.

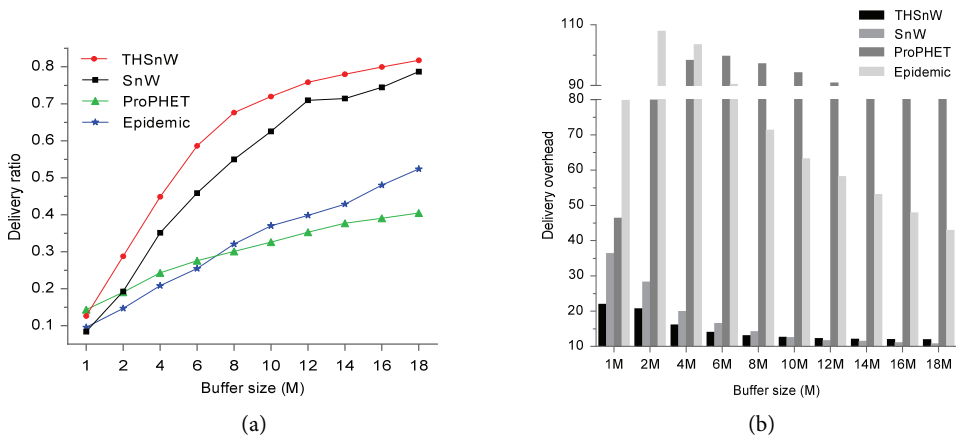


Fig. 4. Performance evaluation results under different buffer size: (a) delivery ratio and (b) delivery overhead.

4.3 On the Effect of Relay Buffer Size

The second group simulation experiment that we do is to test the effect of buffer size in terms of delivery ratio and delivery overhead. From Fig. 4, it is clear to see that, comparing with other routing algorithm, HESnW stays more steady in front of the effect of relay buffer size and it has the lowest delivery overhead and the least number of dropped messages among all the routing protocol. Its advantage can root from the following reason. SnW selects the relay nodes once it encounters other nodes while PRoPHET only selects nodes that have higher delivery predictability. Therefore, the central nodes that many messages flow to would lead to overflow and discard messages. Just as the discard, the average forwarding overhead increases. On the other hand, epidemic routing forwards all the messages to the nodes that it meets and it will easily lead to overflow. However, HESnW adopts the “high cluster coefficient” feature of the “small-world” theory, so that it can avoid this problem.

5. Conclusions

In this paper, we make use of “high cluster coefficient” feature of the “small-world” properties to propose an overhead-efficient routing algorithm that combines SnW with PRoPHET. To avoid the blindness of selecting forwarding nodes in the spray phase of SnW, we add the delivery probability from PRoPHET above it. But PRoPHET just selects the node that with a larger possibility to meet the destination, which may likely ignore potential nodes that may transfer the message to the destination through their “friends” (history nodes they ever met before) whose delivery probability are higher. Just as the “high cluster coefficient” feature found in the “small-world” theory, there exists a large possibility that people make friends with their friends’ friends. So, in our routing algorithm, we use the transitivity between “friends” and their “friends” to transfer messages and, when we calculate the delivery probability for one node, its history nodes’ delivery probability will be taken into consideration, we call it multiple probability. We adopt a new delivery metric to evaluate the forwarding possibility for a node to its destination, so that we will not ignore the potential nodes. Moreover, to optimize the performance, we propose a new scheme of messages allocation. Simulation results have proved that our proposed scheme achieves much lower delivery cost while the delivery ratio also outperforms both SnW and PRoPHET.

Our future work is in progress and try to add buffer management above the routing protocol to deeply improve the delivery ratio.

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