Threshold-based Message Copies Control in Delay Tolerant Networks

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Abstract—Delay Tolerant Networks (DTN) generally lack end-to-end connectivity and multiple message copies routing protocols are often used to improve the efficiency that messages are delivered successfully, but network load is increased due to a large number of message copies. A new scheme based on threshold is presented to control message copies efficiently in the networks. A contact counter is added in every node for Epidemic routing scheme and the counter of every node records the number of nodes, which it contacts, with the same copy for a message. If the counter value of a node reaches the threshold which was set, then the node drops message copy. We analysis threshold in theory and derive the lower bound of threshold in delay tolerant networks. According to the lower bound of threshold, we can set a proper threshold in the networks. Using the new scheme message copies reduce obviously and are dropped completely in the end. The successful delivery ratio is no less than Epidemic routing and message copies are controlled efficiently. We show that it is validity in our scheme by comparing with the trends of message copies among different thresholds in two mobility scenes.

Index Terms—Delay Tolerant Networks; Epidemic Routing; Threshold setting; Message copies

I. INTRODUCTION

Delay Tolerant Networks (DTN) [1][2] belong to a particular class of networks where end-to-end multi-hop paths may not exist and communication routes may only be available through time and mobility [3]. Since the nodes can store and forward messages, messages are delivered to destination using of the proper mobility-based routing protocol. Messages are generally forwarded by a store-carry-and-forward routing model and usually experiences long delays. Owing to the nodes’ mobility, the network topology varies frequently. In order to deliver message successfully, most routing protocols adopt multiple copies forwarding schemes such as Epidemic routing [4], Spray and Wait [5], and so on. Epidemic routing [4], a flood based forwarding scheme, can gain high delivery ratio and low delay, however, it can result in too much redundancy and a large number of copies may give rise to large consumption of resources such as buffer, bandwidth and energy. Spray and Wait routing scheme [5] limits the number of message copies forwarded and reduces the network bandwidth and buffer space consumption of Epidemic routing, but the delivery ratio is lower than Epidemic scheme.

Message copies control is a key problem in delay tolerant networks. There are some representative methods to dropping message copies from nodes’ buffers. The simplest method is to use Time-to-Live (TTL) that all nodes of a message drop their copies after a time limit. TTL method is the easiest but lacking flexibility and robustness. The method of anti-packet [6] is generally used that the destination receives a message then releases an anti-packet for the message. When any node receives the anti-packet, it drops its copy of message. However, the excessive anti-packets also increase network congestion seriously before these packets expire and are eliminated. It is challenging to achieve higher delivery ratio and lower delay about Epidemic routing, and at the same time consume the least cost of network resources.

A new threshold-based scheme of message copies control based on epidemic routing is proposed. Every mobile node uses a counter for a message to record the number of contacts which the node meets other nodes carrying the same message copies, and drops the message copy until the value of counter exceeds the given threshold. We can also use the new scheme associating with TTL or anti-packet methods to improve the performance that message is delivered to destination successfully, and message copies are also dropped efficiently. Through analyzing threshold by probability method, we derive the theoretical lower bound of threshold. The lower bound is regarded as a reference value which threshold is chosen according to the characteristic of network.

The rest of the paper is organized as follows. The next section gives the message copies control scheme. Section III gives the experiment and analysis that confirm the validity of the proposed method. Section IV gives the related work. We conclude in Section V.
II. MESSAGE COPIES CONTROL SCHEME

A. Message copies increasing process

The source node $S$ creates a message $M$ which is delivered to destination node $D$. All nodes are mobile in the network. When $S$ meets another node $A$ without the message $M$, it copies $M$ and delivers a copy of $M$ to $A$. In the same manner the M’s copy is transferred between nodes with $M$ and other nodes without $M$. This is the principle of Epidemic routing imitating infectious disease. The contact process of nodes is considered importantly in the network because nodes exchange message each other in the process. The contact process is analyzed under different mobility model in the following.

Proposition 1 [7] Contact rate $\alpha$ for a pair of nodes:

$$\alpha \approx \frac{2\omega d E[V]}{A}$$

where $\omega$ is a constant specific to the mobility model, $d$ is the transmission range, $E[V]$ is the expectation of average relative speed between two nodes, and $A$ is the limited area where the nodes move.

Note that contact is a process where two nodes enter the signal transmission range each other until to leave.

The expectation $E[V]$ of average relative speed between two nodes is achieved by the follow proposition.

Proposition 2 [8] There are two nodes both moving in a straight line and let their direction of moving be uniformly distributed. If the two nodes are moving with speeds $V_1 = v_1$ and $V_2 = v_2$ respectively, and the speeds are selected uniformly from $[v_{\min}, v_{\max}]$, then the Cumulative Distribution Function of their relative speed is given by

$$P(V \leq v | V_1 = v_1; V_2 = v_2) = \begin{cases} 0 & v \leq |v_1 - v_2| \\ \frac{1}{\pi} \arccos \left( \frac{\sqrt{v_1^2 + v_2^2 - v^2}}{2v_1v_2} \right) & |v_1 - v_2| < v < v_1 + v_2 \\ 1 & v \geq v_1 + v_2 \end{cases}$$

The conditional probability density function follows:

$$f_Y(v | V_1 = v_1; V_2 = v_2) = \begin{cases} \frac{v}{\pi v_1 v_2 \left( \frac{v_1^2 + v_2^2 - v^2}{v_1 v_2} \right)^{3/2}} & |v_1 - v_2| < v < v_1 + v_2 \\ 0 & \text{otherwise} \end{cases}$$

For the random waypoint mobility model, the probability density function of average relative speed is given by

$$f_Y(v) = \frac{1}{\ln^2 \left( \frac{v_{\max}}{v_{\min}} \right)} \int_{\frac{v_{\max}}{v_{\min}}}^{v_{\max}} \int_{\frac{v_{\max}}{v_{\min}}}^{\frac{v_{\max}}{v_{\min}}} f_Y(v_1; v_2 = v_2) dv_1 dv_2$$

$$E[V] = \int_0^{2v_{\max}} f_Y(v) dv$$

The expectation $E[V]$ of average relative speed can be calculated:

$$E[V] = \int_0^{2v_{\max}} f_Y(v) dv$$

The paper adopts the random waypoint mobility model in simulation experiment.

Proposition 3 [9] The average number function of infected nodes $N(t)$:

$$N(t) = \frac{N}{1 + (N - 1)e^{-\alpha N t}}$$

$N$ is the number of nodes in the network.

When $t = 0$, the copies sum of message is 1. It is the initial state that the source generates a message. When $t \to \infty$, the copies sum of a message is $N$. All nodes have the message copies, and it shows that message can be transferred to every node in the network.

Theorem 1 The average number of contacts in a period of time $t$:

$$\Gamma_1 = \frac{1}{2} \alpha N (N - 1)t$$

$N$ is the number of nodes in the network.

Proof: In unit time, all the number of contacts appeared possibly is $\left( \frac{N}{2} \right) = \frac{N(N - 1)}{2}$. According to the contact rate of Proposition 1, the average number of contacts appeared practically is $\frac{1}{2} \alpha N (N - 1)t$. Given a period of time with length $t$, finally we obtain the practical number of contacts in $t$ time. 

In conclusion, there is an approximate linear relationship between the number of contacts $\Gamma_1$ and time $t$.

B. Message copies removing process

In Epidemic routing scheme a large number of message copies are created and transferred in order to deliver message successfully. However, lots of message copies cause excessive redundancy, and results in large consumption of resources seriously, such as buffer, bandwidth and energy. A new method of dropping message copies is proposed in this paper based on threshold of the number of contacts.
As long as a node receives a new message, it constructs a counter for the message. The counter records the number of contacts that two nodes meet with the same message copies. If the value of counter reaches the given threshold, the node deletes the message copy, but it is still regarded as a node which once carried the message, namely if it contacts other nodes with the same message, it no longer receives the message, while other nodes add 1 in the counter until the value of counter reaches the given threshold. The threshold is chosen reasonably reference to the following theorem.

**Theorem 2** The lower bound $Q$ of the threshold of removing message copies is the ceiling of average number that a node contacts another node with the same message copy,

$$Q = \left\lceil \int_0^T \alpha \left( N(t) \right)^2 \left( \left[ N(t) \right] - 1 \right)^2 \frac{dt}{N^2(N-1)} \right\rceil$$

where $T$ is the time that all nodes receive message copies without removing, $\left\lceil \cdot \right\rceil$ is the ceiling function.

**Proof:** The average number of all contact at time $t$ is from Proposition 1, $\Gamma_1 = \frac{1}{2} \alpha N(N-1) t$.

The message copies $M$ takes the ceiling of $N(t)$ from Proposition 3, $M = \left\lceil N(t) \right\rceil$.

The contact probability of two nodes with the same message at time $t$ is

$$P(t) = \frac{M}{2} = \frac{M(M-1)}{N(N-1)}$$

The average contact number of two nodes with the same message at time $t$ is

$$\Gamma_2 = \Gamma_1 \times P(t) = \frac{1}{2} \alpha M(M-1)t$$

The average contact number of all nodes with the same message at a period of time with length $T$ is

$$E_T = \int_0^T \Gamma_2 \times P(t) dt = \frac{1}{2} \alpha M(M-1) \frac{M(M-1)}{N(N-1)} \int_0^T dt$$

The average contact number of every node with the same message at a period of time when all nodes achieve the same message is $\frac{2E_T}{N}$.

The lower bound $Q$ of threshold of removing message copies is stated in the above theorem. $\square$

According to simulation condition of Section III, we calculate the lower bounds of threshold in two scenes from Theorem 2. In the fast scene the lower bound of threshold is 3, and in the slow scene the lower bound of threshold is 4. The lower bound offers a useful reference for threshold selection, and is discussed in the next section.

Message copies forwarding and dropping algorithm is showed in Fig. 1. The counter value of every node is $-1,0,1,2,\ldots,H-1$ respectively, and $H$ is a threshold $(H \geq Q)$ that is given with network requirement according to the lower bound in Theorem 2. For message $M$, $counter = 0$ means that the node does not have $M$; $counter = 1$ means that the node receives $M$ for the first time, and if the node is the source, message $M$ is created by the node and $counter = -1$ too; $counter = l(l \leq i \leq H-1)$ means that the node with $counter = i-1$ meets other nodes with $counter \neq 0$ and the counter adds 1 namely $counter = i$; $counter = -1$ means that the contact counter reaches $H$, and the node deletes message copy. Nodes with $counter = -1$ will not receive the message, and when the node with the message meets them, the counter must add 1, but the counters of them remain -1.

![Figure 1. Message copies forwarding and dropping algorithm flow chart](image)

In Fig. 1, node x and node y record the number of counters denoted by $C_x$ and $C_y$. According to the value of counter, the node chooses to whether forwarding message or dropping.

A message is created by source node. If the message delivering and the copies dropping completely are viewed as a whole process, we can discover that it is favorable for successful delivery to the destination by using of our method. A lot of message copies exist in the network during the earlier period, because the value of counter of
every node needs accumulation. During the later period message copies tend to be deleted, because the value of counter has been accumulated to a larger value which is closed to $H$. The principle of our method is completely satisfied with the requirement of message delivery.

III. SIMULATION RESULTS

A. Simulation setup

In this section we evaluate the threshold-based method of message copies dropping about the time of delivering successfully and the time of dropping completely. 20 mobile nodes perform independent Random Waypoint mobility model, and adopt 2.4GHz communication channel. Simulation tool is OMNet++3.2 [10]. Two scenes are given.

**Scene 1** (fast scene) $1000m \times 1000m$, signal range radius: $r = 30m$, speed: $v \in [20m/s, 50m/s]$, interval time: $t \in [3s, 8s]$.

**Scene 2** (slow scene) $500m \times 500m$, signal range radius: $r = 10m$, speed: $v \in [1m/s, 8m/s]$, interval time: $t \in [0s, 8s]$.

We assume that a pair of nodes can finish all transmission of required messages in communication range during a contact process. The time which nodes exchange message each other is neglected, because it is far below the node mobility time and message delay.

B. Performance analysis

![Figure 2. Comparison between simulation and theory in two mobility scenes](image)

In simulation, a node, which is selected as a source at random, creates a message and delivers its copies to destination node. We compare message copies between theory model and simulation in Fig. 2. The increasing trend of message copies in simulation is similar to the theory model in two scenes, and furthermore, the fit of the model in scene 1 is higher than scene 2, because the relative speed in scene 1 is quicker.

By using the message copies control scheme based on Epidemic routing. We record the time of delivering and the time of dropping all message copies.

In Fig. 3, we show that the minimum epidemic time and the time of dropping message copies completely with different thresholds in fast scene. The percents are the delivery ratio with different thresholds. When threshold is greater than 3, the delivery delay becomes low. If regardless of redundancy, the greater threshold is better. But the resources is limited, the message copies are deleted the sooner the better.

![Figure 3. Minimum epidemic time and dropping copies completely with different thresholds in fast scene](image)

In Fig. 4, we show that the minimum epidemic time and the time of dropping message copies completely with different thresholds in slow scene. 

![Figure 4. Minimum epidemic time and dropping copies completely with different thresholds in slow scene](image)

In Fig. 5 and Fig. 6, the number of contacts is regarded as X-axis, because there is an approximate linear relationship between the number of contacts and time in Theorem 1. Message transferring take place during the contact process of a pair of nodes. It is pretty
straightforward to take the number of contacts as X-axis of Fig. 5 and Fig. 6.

When the threshold $H = 0$, it is the epidemic routing without dropping scheme. Message increasing process is similar to the mathematical model of Proposition 3.

In Fig. 5 and Fig. 6 we evaluate the variation of message copies with different thresholds separately in scene 1 and scene 2.

The cases $H = 2, 3, 4, 5, 6$ show that the amount of removed message copies decrease slowly with increase of thresholds, but the success ratio of delivery goes up. If threshold is set too small, then message copies are deleted quickly and message may not be delivered to destination, such as the cases $H = 2$ of scene 1 in Fig. 3 and $H = 2$ and 3 of scene 2 in Fig. 4. Furthermore, some exceptions may be appeared with the small thresholds, such as the cases $H = 3$ in Fig. 3 and in Fig. 5. The removing time of the case $H = 3$ exceeds that of the case $H = 6$. The reason is that nodes with message copy delete the message prematurely if threshold is too small, and the number of required transferring messages is too low, the delay of deliver increases so much. We find that the threshold is chosen at least as 3 in scene 1 and 4 in scene 2 according to Theorem 5, and is similar to simulation experiment.

When choosing a threshold we generally consider that the time which all nodes receive message copies and the time which all nodes remove message copies completely consume as little as possible simultaneously.

We find that the case $H = 4$ is suitable for the scene 1, and scene 2 too. In scene 1, if the low delay of message is a top priority, we can choose $H = 6$ that the case is the same as the one with no threshold. If the network load and storage are considered as a priority, we can choose $H = 4$ that message copies are deleted quickly. In scene 2, $H = 4, 5, 6$ can be selected to a priority of delay because the time of delivering is uniform in three cases. $H = 4$ can be selected suitably with the least time of removing message.

C. Enhancement to TTL method and anti-packet method

The scheme proposed in this paper is essentially different from the existing schemes of TTL and anti-packet. Moreover, it overcomes the disadvantages that the two schemes is used in delay tolerant network environment, and can improve performance associating with TTL and anti-packet methods.

The TTL method is the simplest and is used most commonly that each message is stamped with a creation time and all carriers of message remove message copies after a certain time limit. It is relatively easy to implement and possibly easier to analyze. However, the main drawbacks are that the TTL method may remove message before it is delivered and the TTL value must be carefully chosen based on assumptions about the network. Especially in delay tolerant network environment, the method lacks flexibility and robustness because there are usually longer delays.

With our method we can set a larger TTL in order to avoiding to remove copies early, at the same time message copies in the network are controlled efficiently.

In Fig. 7 and Fig. 8, we evaluate the delivery ratio and number of message copies with different TTL in the fast mobility scene.

In Fig. 7 and Fig. 8, we evaluate the delivery ratio and number of message copies with different TTL in the fast mobility scene.
mobility scene, and show that the delivery ratio in the case $H = 3$ is basically the same as the case of no threshold in Fig. 7, but the redundancy of copies is significantly decreased in Fig. 8.

The case $H = 3$ is closed to the lower bound by Theorem 2 in the fast mobility scene, and the following case $H = 4$ is analogous in the slow mobility scene.

In Fig. 9 and Fig. 10, we evaluate the delivery ratio and number of message copies with different TTL in the slow mobility scene, and show that the delivery ratio in the case $H = 4$ is basically the same as the case $H = 0$ in Fig. 9, but the redundancy of copies is significantly decreased in Fig. 10.

The anti-packet method is also commonly used, and is often called the vaccine. The idea is that when a message is delivered successfully, the destination releases a piece of meta-data called an anti-packet for the message. The node which receives the anti-packet removes its copy of message. The anti-packets spread in an epidemic manner. The main drawbacks of the method are that excessive anti-packets seriously increase network congestion and extra overhead, and at the same time it is problem how the expiration of anti-packet is set up. With our method, the anti-packs are removed reasonably similar to message copies, avoiding above problems easily.

IV. RELATED WORK

A lot of research interests focus on developing new approaches for routing in delay tolerant networks environment. These routing schemes generally use the store-carry-and-forward approach, where intermediate nodes keep message until contact other nodes to set up new links in the path to the destination.

Jain et al. [11] proposes a framework to formulate the DTN routing by a directed multi-graph, where more than one edge may exist between a pair of nodes, because more than one physical connections or different network link may exist and can be used at different time intervals. The scheme requires the information of all nodes are known in the network. Data mule scheme [12] is suggested that a few mobile nodes perform random walks to gather messages, buffer them and forward them to access point. Message ferrying approach [13] is proposed that the ferries choose a path to connect nodes to exchange packets.

Single-copy routing schemes use only one copy per message and significantly reduce the resource requirements, but suffers from large delay and low delivery ratios [14]. Multi-copy routing schemes have a high probability of delivery and lower delays at the cost of buffer space and more message transfers [15].
Epidemic routing [4] is proposed that when nodes contact, they exchange messages each other and messages will be propagated to the destination. It is based on flooding delivery and consumes plenty of buffer spaces. Spray and wait routing scheme [5] is suggested that a fixed number of copies of each message are sprayed the number of copies are controlled. PROPHET [16] is a probabilistic protocol for routing in intermittently connected networks that is more sophisticated, using history of node contacts and transitivity to enhance performance. MaxProp [17] is based on prioritizing both the schedule of packets transmitted to other peers and the schedule of packets to be dropped in disruption tolerant networks.

Simple counting scheme [18] is proposed to limit the fraction of nodes that carry a copy of message, and it uses two thresholds on transferring and dropping messages, which results in high latency. SMART routing protocol [19] utilizes the travel companions of the destinations to increase the delivery opportunities while limiting message overhead to a bounded. A message source injects a fixed number of message copies into the network to forward the message to a companion of the destination.

(p; q)-Epidemic Routing [20] includes many different forms such as conventional epidemic routing, two-hop forwarding and probabilistic forwarding with the different values of (p; q), and anti-packet is used in the recovery scheme. Storage routing scheme [21] employs nearby nodes with available storage to store data. When congestion occurs, storage routing is invoked to put a set of messages for migration and a set of neighbors as targets for migrated messages. When congestion subsides, the scheme is invoked to retrieve messages that have been previously migrated.

Most researches of DTN routing schemes concentrate on the quantity of message copies forwarded and delivery manner, however, less literatures are appeared about the dropping schemes of message copies forwarded except for the TTL method and the anti-packet method. In the paper, we give a new threshold-based method different from TTL and anti-packet methods. By analysis and experiment, the proposed method is very effective and reasonable.

V. CONCLUSION

A new threshold-based scheme of message copies control is presented based on epidemic routing. We can not use the common dropping methods such as TTL and anti-packet in delay tolerant networks. Of course we also use the proposed method to enhance TTL method and anti-packet method.

Every mobile node sets up a counter for a message, and records the number of contacts that nodes meet each other with the same message copy. We utilize probability tool to analyze threshold and achieve the lower bound in favor of proper choice of the threshold. By comparing the value of the counter with the threshold installed, nodes decide whether the copies are reserved or removed.

We evaluate the transmission process of message copies and dropping process of the message and its copies in two scenes, at the same time, we compare the variation of message copies in different thresholds. According to simulation result, installing proper threshold can ensure delivering message successfully, and message copies are also deleted at the soonest to decrease the consumption of resources. Message copies are controlled efficiently in delay tolerant networks.

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