2012 9th International Conference on Ubiquitous Intelligence and Computing and 9th International Conference on Autonomic and Trusted Computing

Improving the Estimation of Residual Delay based Forwarding Method in Opportunistic Vehicular Networks

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***Abstract*—To accommodate the dynamic characteristics in opportunistic networks, "carry-and-forward" technique is utilized. In this paradigm, the next hop forwarding relay node is usually decided by inferring future contact opportunities. A practical method is to predict future encounter time using nodes' contact history. But limited by prediction accuracy, this method has only an uncertain effect on improving delay performance. To improve the efficiency of selected relay(s), this paper introduces a new metric used to deicide whether an intermediate node is appropriate to be selected. The metric is based on the estimation of Residual Expected Delay (RED), and combined with a threshold value to guard the fidelity of prediction based relay selection judgement. After then, a single-copy and a multi-copy two-hop forwarding algorithms are proposed. Finally, based on the underlying vehicular opportunistic network extracted from large-scale realistic vehicle trace records, we give an empirical evaluation and analysis of the proposed method. Results show the new metric is efficient in improving delivery ratio with a low delivery cost.**

***Keywords*-opportunistic vehicular networks; relay selection metric; delivery ratio**

I. Introduction

Vehicular Ad-Hoc Network (VANET) is an important component of Intelligent Traffic System (ITS) which provides fundamental communication ability between vehicles. During the past several years, a number of applications have been proposed in VANET. Most of these applications are safety-related, which are mainly time-critical services requiring messages to spread quickly with broadcast or multicast method [1]. While there is another type of non-emergency applications emerging, in which message can tolerant a certain level of latency and can be delivered in an opportunistic way [2]. For example, let's consider the scenario of map data sharing. Cars driving in different blocks may be generate lots of private local map update data such as routes or marks. Suppose someone wants to share a piece of such data with one of his friends. If they have not synchronized future driving schedule, these data should be transferred in an opportunistic way in condition of without backbone support.

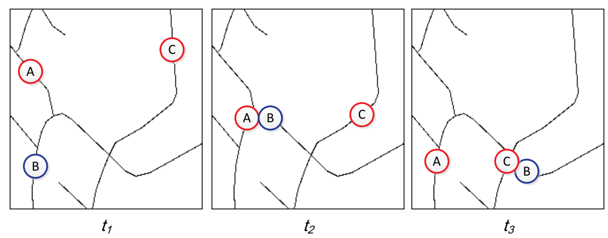


Figure 1: Example of Relay Assisted Data Delivery

Conventionally, carry-and-forward techniques are used in this scenario. Direct Forwarding (DF) is the most basic scheme, in which messages are carried until the source vehicle encounters the destination, and then forwarded to the target directly. To improve the forwarding performance, relays may be involved to assist data exchange. For example in Fig. 1, a simple street map and the positions of vehicles V_A, V_B and V_C at three different moments t_1, t_2 and t_3 are illustrated; assume vehicle V_A wants to send data to V_C. If the sender meets vehicle V_B before V_C, it may request V_B to help carrying and forwarding the data to the recipient V_C, which is mostly likely to meet with V_B earlier than the source sender.

Apparently, the core issue here is how to determine effective relay(s). Many strategies proposed in previous literatures utilize the history information of connection between mobile nodes to get a predicated or estimated metric to make relay selection [3][4][5][6][7]. However, it is impossible to predicate future contact events accurately in practical, which leads to the selected relay has only incidental rather than intentional effect on forwarding performance [8] such as delivery delay. Therefor, to find out nodes which have more higher probability and ability to reduce the delivery latency is an important problem in opportunistic networks.

This paper introduce a relay selection metric named Residual Expected Delay (RED). Based on RED, we introduce a threshold value guarded relay selection scheme to improve the prediction based relay decision fidelity. RED is calculated from local pairwise history contact records between vehicles, and the factor of elapsed time since last contact [9] is taken into consideration. Then, we propose a multiple copies two-hop forwarding algorithm with controlled message copies number. Meanwhile, a first meet relay based single copy forwarding algorithm is also introduced. Finally, we make an empirical evaluation on the proposed relay selection metric and forwarding schemes in an opportunistic vehicular networks extracted from hundreds of realistic taxis drive trace records. Results show that they are effective in improving opportunistic forwarding performance.

The structure of the paper is as follows. Section II presents the related works. Section III introduces the RED based relay selection scheme and forwarding algorithm. Section IV gives the evaluation result and analysis. Finally, the conclusion of this paper is made in Section V.

II. Related Works

Opportunistic messages forwarding has attracted many research attentions in the field of Delay Tolerant Networks (DTN). Although the rudimentary strategies of flooding and epidemic [10] are efficient in achieving high delivery ratio and low latency, the fault of resource hungry makes such strategies impracticable. Enhancements to offset this drawback have been introduced in many schemes [3][4][5][8], which intended to control message replicas as well as obtain an acceptable delivery performance.

The key issue is to select and determine relays. Using the knowledge of history contact records between mobile nodes to assist relay decision is a practical method. In some literatures, history contacts are used to calculate a probability metric between nodes [3][4][11][12][13]. Such metric aims to maximize the successful message delivery probability. But it usually has a complex framework to calculate and update the probability value.

In some other works, history contacts are used to estimate the expected delay time for a specific node pair. The node has lower expected delay with destination is to be used as relay. For example, MED [14] and MEED [6] use the mean pairwise inter-contact time (MICT) as expected delay. Minimum Expected Delay (MED) [14] is defined as the average waiting time in the ideal condition that having full knowledge of future contacts time. While MEED [6] is an improvement of MED that uses the observed contact history in a past time sliding window to calculate the MICT as expected delay. Other metrics such as MEMD [7] and CREST [15] take into account the elapsed time since last meeting time to estimate the residual time of next meeting opportunity as expected delay. They estimate the residual meeting time according to the conditional distribution of inter-contact time. The difference is that MEMD uses the statistic distribution method, while CREST makes use of the continual distribution method.

Our work established a renewal process model [16] to estimate residual encounter time based on history contact records, and the elapsed time from the latest meeting is also considered. In particular, we introduce a threshold based method to improve the decision accuracy of relay selection so that improve the delivery ratio of opportunistic forwarding.

III. RED based Forwarding Scheme

In this section, we introduce the Residual Expected Delay (RED) based relay selection scheme and forwarding algorithm. RED is the estimation value of residual meeting time for a pair of mobile nodes, which is calculated based on the history contact records according to the renewal process model.

A. Residual Delay based Relay Selection Condition

Suppose from the time node S injects a message (*Msg*), which is target to the destination node D, to the time S contact with D directly, S will meet a set of nodes in time order, represented by $\Omega = \{R_1, R_2, \cdots, R_m\}$. In order to reduce the delay time of direct forwarding, S may choose one or some nodes from Ω to assist the transmission of *Msg*. Therefore, Ω can be regarded as the potential candidate set of relay. Naturally, the central issue is how to find out an appropriate node from Ω to be utilized as relay.

Generally, the mean pairwise inter-contact time (MICT) indicates the average expected waiting time of a pair of nodes to meet with each other again and reflects the contact frequency between them. For this reason, it is used as a typical relay selection metric [6][14]. However, MICT may not correctly reflect the delivery delay in reality, because it ignores the concrete relay selection environment.

Residual delay is a more promising metric, which refers to the time from a relay decision moment to the time that the message arriving at destination successfully. For simplicity, we only consider the residual delay in case of direct forwarding. Inherently, residual delay can be used as the metric to determine whether a node is proper for relaying a message. An example of residual delay based relay selection decision process is demonstrated in Fig.2, in which the movement trajectories of three node *Source* (*S*), *Relay* (*R*) and *Destination* (*D*) are showed with time line. As showed in the figure, if the message is injected by *S* at moment t_0, when it meets *R* at t_1, it comes to a relay decision moment. The periods from this moment to the time they meet with *D*, i.e. t_2 and t_3, are calculated as *residual delay* of this message respectively for node *S* and *R*. Because the residual delay $t_2 - t_1 < t_3 - t_1$, node *R* is more effective than node *S* to carry the message to the target *D*.

Now drawing lessons from the example discussed above, we formally describe the residual delay based relay selection

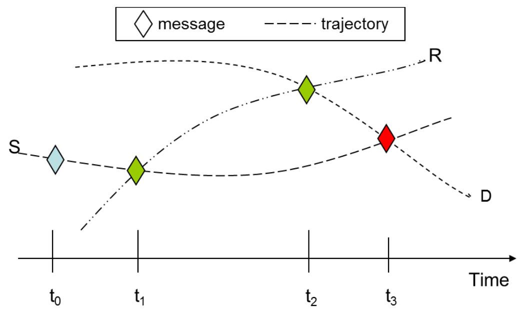


Figure 2: Example of Residual Delay based Relay Decision

strategy as following. Assume the notation $T_{R_{XY}}$ represents the residual delay of a message delivered directly from node X to Y. Nodes in set $\Omega = \{R_1, R_2, \cdots, R_m\}$ are the intermediate nodes that node S meets before the target D. Then, the relay selection judgement is determined by comparing the residual expected delay values of node pairs S-D and R_i-D.

Basic strategy: For $R_i \in \Omega$, if

$$E[T_{R_{SD}}] \geq E[T_{R_{R_iD}}] \tag{1}$$

then R_i is regarded to be fitting for carrying and forwarding *Msg* to D.

To improve the accuracy of decision judgement, we introduce a more strict strategy with threshold to guard the fidelity of comparison result based on estimated expectation values. When the threshold is set to zero, it degrades to the basic strategy.

Threshold based strategy: For $R_i \in \Omega$ and a threshold value T_s, if

$$E[T_{R_{SD}}] - E[T_{R_{R_iD}}] \geq T_s \tag{2}$$

then R_i is regarded to be fitting for carrying and forwarding *Msg* to D.

B. Estimation of Residual Delay

The mean pairwise inter contact time can be considered as a rough estimation of residual delay in an average situation for a node pair. However, because it is prone to be blind with specific circumstances factor which may pretend a determining role in the judgement of relay decision, MICT is not so efficient in making relay decision in opportunistic forwarding.

As a remedy, we take into account the *elapsed time* (ET) form last contact to predict the next future contact time. To make the prediction, each node needs to record a set of encounter time stamps for itself and any other node. And the value of ET can be easily obtained from the latest contact time stamp record and current time.

Assume each node records the last *n+1* meeting time with others. For a pair of nodes, the records are represented by time series $t_1, t_2, \cdots, t_{n+1}$, where t_1 is the most recent record and t_{n+1} is the earliest record. If current time is *t*, then ET is calculated as $T_E = t - t_1$. For simplicity, the contact duration time is not consider when calculating inter contact time. This is reasonable in vehicular ad hoc networks, because the contact duration is usually far more smaller than the contact interval [17][18]. Thus, the last *n* inter contact time series can be calculated as $\Delta_M = \{t_1 - t_2, t_2 - t_3, \cdots, t_n - t_{n+1}\}$. To be described conveniently, we denote the ICT series with $\Delta_M = \{I_i\}$, in which the elements are sorted by ICT value from small to large. Thereby, the residual encounter time for a node pair can be estimated according to Theorem 1.

Theorem 1. Given a series of sorted ICT records of node pair S-D is $\Delta_M = \{I_1, I_2, \cdots, I_n\}$, where $I_1 \leq I_2 \leq \cdots \leq I_n$. If the elapsed time from last meeting between S and D to the relay decision moment is T_E, and $I_k \leq T_E < I_{k+1}$, then the expectation of residual encounter time T_R for S-D can be calculated by

$$E[T_R] = \frac{1}{n-k} \sum_{k+1}^{n} I_i - T_E \tag{3}$$

Proof: We model the contact process as a renewal process [16]. Under this model, the elapsed time corresponds to the *age*, while the residual encounter time corresponds to the *residual lifetime* before the next renewal event. Denoting the time interval from last renewal to the next future renewal as T_0, then the residual lifetime is $T_R = T_0 - T_E$. Thus, the expectation of residual lifetime is $E[T_R] = E[T_0] - E[T_E]$. Since T_E is a constant in current renewal process, consequently,

$$E[T_R] = E[T_0 \mid T_0 > T_E] - T_E$$

According to renewal process theory, renewal interval T_0 and $\Delta_M = \{I_i\}$ are non-negative i.i.d.. Thus we can obtain

$$E[T_R] = E[I_i \mid I_i > T_E] - T_E$$

Because $I_k \leq T_E < I_{k+1}$, we have

$$E[I_i \mid I_i > T_E] = \frac{1}{n-k} \sum_{k+1}^{n} I_i$$

Therefore

$$E[T_R] = \frac{1}{n-k} \sum_{k+1}^{n} I_i - T_E$$

■

Note, when the elapsed time T_E is lower than the minimum value in $\Delta_M = \{I_i\}$, i.e. $T_E < I_1$, the residual delay estimated according to Eq. 3 degrade to the mean inter contact time. While if T_E is equal to or greater than the maximum value in $\Delta_M = \{I_i\}$, i.e. $T_E \geq I_n$, Eq. 3 is invalid to estimate the residual delay. To remedy this condition, we also use the mean inter contact time as the estimation of residual delay. This is because, for a general renewal process, the residual lifetime satisfies $E[T_R] = (1 + m(T_E))E[I_i] - T_E$, where $m(T_E)$ is the expectation value of renewal event number before time T_E. Apparently, $m(T_E)$ can be calculated as $m(T_E) = \frac{T_E}{E[I_i]}$. Thus, we have

$$\begin{aligned} E[T_R] &= (1 + m(T_E))E[I_i] - T_E \\ &= (1 + \frac{T_E}{E[I_i]})E[I_i] - T_E \\ &= E[I_i] \end{aligned}$$

Therefore, Eq. 3 is improved to be as the following

$$E[T_R] = \begin{cases} \frac{1}{n-k}\sum_{i=k+1}^{n} I_i - T_E & I_k \le T_E < I_{k+1} \\ \frac{1}{n}\sum_{1}^{n} I_i & I_n \le T_E \end{cases} \quad (4)$$

C. RED based Forwarding Scheme

Based on RED metric, we design a multi-copy two hop forwarding algorithm, which is a variant of "Spray-and-Wait" [19], and thus called *RED-SW*. Similar to Spray-and-Wait, RED-SW algorithm operates in two phases. First, in *Spraying* phase, the source determines a certain number of nodes (for example ℓ) that are going to get a copy of the message. In the second step of *Waiting* phase, the nodes that have got a copy of the message deliver it directly to the destination when they gets within communication range.

The procedure of RED-SW forwarding algorithm is described in Algorithm 1. Since the contact opportunities emerge asynchronously, it is hard to determine whether the future arrived nodes is more optional than current encountered one. Therefor, to avoid missing relay opportunities, the algorithm employs the classical first meet relay scheme [14] to select the first ℓ met nodes satisfying the selection condition of Eq. 2 as relays in the *Spraying* phase. RED-SW uses the per-contact relay decision scheme [6], in which the sender makes a relay selection judgement at each time when it meets with a potential relay node, until the replica number of a message is up to the limitation ℓ, or until the destination node D arrives. The judgement metrics $E[T_{R_{SD}}]$ and $E[T_{R_{RD}}]$ are estimated according to Eq. 4. In the *Waiting* phase, any node carrying a copy of the message as well as the source node will forward it directly when they meet with the destination D. In this step, the direct forwarding path is retained. This will guarantee the message can be delivered to destination by source node directly if there is no satisfying intermediate node found. So a message has a maximum of $\ell + 1$ copies in the network.

On the other hand, to investigate RED based relay selection strategy in single copy condition, we also design a first meet relay based single copy two-hop forwarding algorithm, which is named as *RED-FMR*. In the single copy scheme, only one relay node is needed, and there exists only one replication of message in the network, i.e., different from RED-SW, if the sender forwards a message to the next hop node, it will discard its own replica.

In the RED based per-contact decision forwarding algorithms, very little control information need to be exchanged when making relay selection decision. The decision process just involves the information of destination node and the corresponding residual delay expectation values of node pairs S-D and R_i-D. Besides, since the estimation of RED metric only needs local contact records, the control and state update overhead is relatively trivial.

Algorithm 1 RED-SW Forwarding Algorithm

```
Require: the source node S and destination node D;
         S meets R_1, R_2, ..., R_n in time sequence;
         the replicas limitation ℓ; the threshold value T_S;
         the message carrier node set C; the counter k.
Initial: k = 0; C = ∅
Phase I:
for R in R_1, R_2, ..., R_n do
    if R is D then
        S --msg--> D
        exit;
    else if E[T_{R_SD}] - E[T_{R_RD}] ≥ T_S and k < ℓ then
        S --msg--> R; C = C ∪ {R}; k = k + 1
        if k == ℓ then
            break;
        end if
    end if
end for
Phase II:
for msg carrier R in C ∪ {S} do
    while R meets with node X do
        if X is D then
            R --msg--> D
            exit;
        end if
    end while
end for
```

IV. Evaluation and Analysis

In this section, we present the evaluation of the RED based relay selection and forwarding scheme. The simulation are carried out with Cabspotting [20][21] taxi traces based opportunistic vehicular network which includes 536 vehicles. These taxis operate in San Francisco city Bay area with a core driving coverage of about 13×11 km^2. The configuration of simulation environment is displayed in Table I.

We randomly generate a test set containing 8000 pairs of source-destination (S-D) combination. And to avoid the delivery time of S-D sessions being beyond the record time range in the trace dataset, the messages sending requests are randomly injected by node S within the first three days

Table I: Simulation Configuration

Node number	536
Main coverage area	$13 \times 11\ km^2$
Node density	3.8 vehicles per km^2
Record duration	25 *days*
Communication range	100 m
Contact number	7,855,840
Contact node pairs	279,374
Average contact number for each pair	28.1

of the records. In the simulation, the two hop opportunistic forwarding paradigm is investigated. Performance of RED based scheme is compared with the mean inter-contact time (MICT) based scheme [14][6] mentioned above.

A. Relay Efficiency in Different Threshold Value

First, let's investigate the efficiency of relays selected by different schemes and with different threshold values. We use a statistical method to study the relay efficiency and explore the insight towards the uncertain characteristic of opportunistic forwarding. The main purpose of using relay is to enhance delivery ratio and reduce delivery delay. Therefor, to measure the efficiency of relays, we define two metrics: *Effective Relay Ratio (ERR)* and *Delay Reduced Ratio (DRR)*. They are introduced in the following.

Assume after the source node S injects a message sending request targeting to destination D, it will meet a series of other intermediate nodes before meeting with D. Suppose the source node attempts to find if there is any appropriate intermediate node R that can help delivering the message to arrive at D earlier. If we denote the direct forwarding delay of S-D session by T_{DF}, and denote the relay assisted delivery delay by T_{SRD}, then an *Effective Relay* is define as such an intermediate node that satisfies $T_{SRD} < T_{DF}$. On the other hand, we call those intermediate nodes satisfying relay selection condition in Eq. 2 as *Qualified Nodes*, which are the candidates may be selected as relays in the opportunistic forwarding process. Then, relay efficiency matrics ERR and DRR are defined as follows.

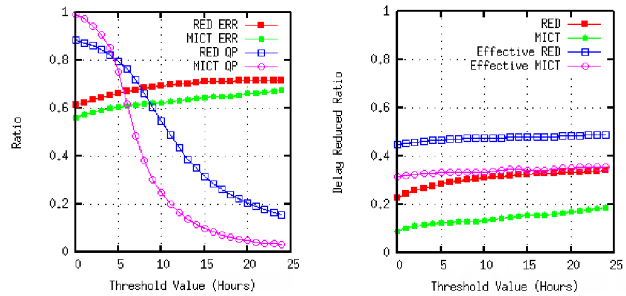
- *Effective Relay Ratio* (α): The ratio of effective relay number to the qualified node number for an S-D session. Formally,

$$\alpha = \frac{N_{effective\ relay}}{N_{qualified\ node}}$$

- *Delay Reduced Ratio* (β): DRR is measured with the delivery time saved by using a relay compared to the delay of direct forwarding. Formally,

$$\beta = \frac{T_{DF} - T_{SRD}}{T_{DF}}$$

According to the law of large numbers in statistics, we can regard that for a random chosen relay, ERR reflects the probability that it will make the delivery delay reduced,



(a) ERR and QP (b) DRR

Figure 3: Relay Efficiency in Different Threshold Values

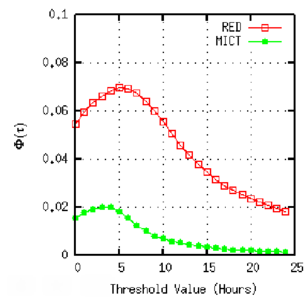


Figure 4: Efficiency Function

while DRR reflects the ability of how many delivery delay can be reduced by the relay.

Another important factor impacting the efficiency of relay from a whole view is the percentage of the S-D sessions that can find at least one relay node according to the relay selection scheme, i.e., there is at least one qualified node for each of those S-D sessions. For simplicity, it is referred as *Qualified Percentage (QP)*, and mathematically noted by p. If QP is too low, the corresponding relay selection method will be couldn't find satisfied intermediate node to be used as relay for many S-D sessions. Consequently, the relay selection scheme will be inefficient in exploiting the benefit of relay diversity. Mathematically

$$p = \frac{N_{sessions\ with\ relay}}{N_{total\ sessions}}$$

Now, we look at the efficiency of relays selected by RED and MICT based schemes with different threshold values. As showed in Fig. 3, we investigated the threshold values varying from 0 to 24 hours. Fig. 3(a) illustrates the average effective relay ratio and qualified percentage of RED and MICT based relay selection schemes respectively. First, it is obvious that the ERR of RED based schemes is better than MICT, which means RED possesses a more accurate judgement result in relay selection decision. This result suggests that the RED metric taking into account elapsed time is effective in relay selection. Furthermore, for RED based schemes, the ERR grows moderately with threshold value, which indicates a threshold can improve the confidence of relay selection. However, ERR grows up to a limitation of about 70% when the threshold value increases to 15 hours. That is to say, the maximum average effective relay ratio we can get is about 70%, even in higher threshold value. While in the same time, Fig. 3(a) also shows that QP declines fast with the threshold value, which means the higher the threshold is, the more S-D sessions will be couldn't find relay nodes. Such a situation suggests increasing threshold value bring not only benefit but also drawback. Therefor, there should exist a tradeoff between the threshold value and relay efficiency.

Fig. 3(b) illustrates the average delay reduced ratio in different threshold values. Two conditions are displayed: (1) the average DRR of all qualified nodes based on RED and MICT schemes; (2) the average DRR of effective relays in their qualified nodes. The figure shows, DRRs has a mildly increment with threshold value. Besides, in both conditions, RED based scheme has better DRRs than MICT. And the superiority keeps in about 10% all the time.

To investigate the tradeoff between threshold value and relay efficiency, we establish a framework considering the factors introduced above jointly, and construct an Efficiency Function $\Phi(\tau)$ to measure the efficiency of relay selection schemes. The factors involved are:

- τ : threshold value
- α : average effective relay ratio
- β_Q : average DRR of qualified nodes
- β_E : average DRR of effective nodes in qualified
- p : qualified percentage of S-D sessions

Then, the efficiency function is defined as

$$\Phi(\tau) = \alpha \cdot \beta_Q \cdot \beta_E \cdot p$$

Fig. 4 exhibits the efficiency function values with different threshold. Apparently, the efficiency function value of RED based scheme is greater than MICT in corresponding threshold values. This reflects RED based scheme is more effective than MICT in reducing delivery delay. Specifically, for RED based relay selection scheme, when the threshold is set to 5 or 6 hours, its efficiency function gets the maximum value. Thus we can infer that the best tradeoff threshold value is near to 5 or 6. While for MICT scheme, it can be easily found the best tradeoff threshold is near to 3 or 4. In the following part, those finds are examined in a single copy and multiple copies forwarding schemes.

B. Single Copy

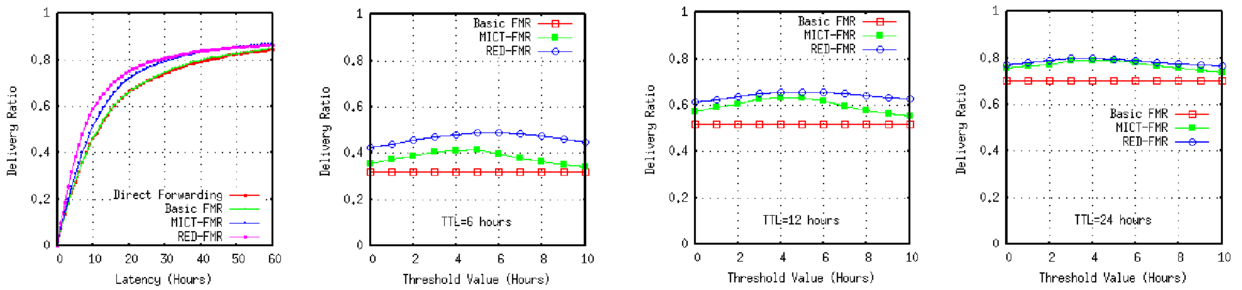
To evaluate the effectiveness of RED metric and the impact of relay selection judgement threshold on relay efficiency, we compare the delivery ratio of RED-FMR with the basic first meet relay [14] and MICT based first meet relay forwarding algorithms [6]. The Basic FMR uses the first intermediate node met by source as relay without judgement, while MICT-FMR selects the first met node satisfying Eq. 2, in which the mean inter-contact time values are used as the estimation of residual delay.

Fig. 5(a) exhibits the cumulative distribution of end-to-end delay for them in which threshold value is not considered. It shows the delivery ratio of RED-FMR is obvious better than others when the latency is lower than 40 hours, especially within the range of 20 hours. For example, when the latency is 10 hours, the delivery ratio of RED-FMR is 59.1%, while MICT-FMR, Basic FMR and direct forwarding are 51.7%, 46.5% and 46.3% respectively. Fig. 5(b), (c) and (d) illustrate the effect of threshold value τ on the delivery ratio of three FMR based single copy schemes. The message Time-To-Live (TTL) is set to 6, 12 and 24 hours respectively. In each plot, threshold values vary from 0 to 10 hours. Since the Basic FMR is determined without judgement, its delivery ratio is not affected by threshold. For MICT-FMR and RED-FMR, it can be seen the highest delivery ratios are mainly appeared at threshold of 4, 5 or 6 hours, which are nearly the best tradeoff threshold values concluded from the efficiency function introduced above. Besides, the effect of threshold is more obvious in lower TTL. For example in Fig. 5(b), when TTL is set to 6 hours, the delivery ratio of RED-FMR is 42.5% with 0 hours threshold and 49.1% with 6 hours. Although the difference becomes weaker when TTL increases, the superiority of RED-FMR over MICT-FMR also can be found in case of TTL=24 hours. Based on these results, we can learn that despite the advantage shrinks with TTL increasing, RED-FMR mainly outperforms than MICT-FMR, and taking into account an appropriate threshold in relay selection judgement enables the nodes to make more effective forwarding decisions in an opportunistic network.

C. Multiple Copies

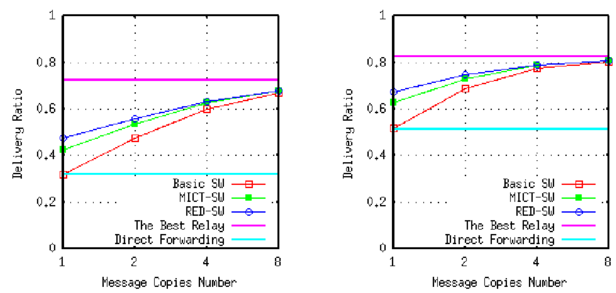
The delivery ratios of multi-copy forwarding algorithms RED-SW are compared with MICT-SW and the basic *Spraying-and-Waiting* algorithm. Similar to the single copy schemes, RED-SW and MICT-SW are different in their relay decision metric. In the evaluation, we investigate the situation without considering relay judgement threshold first. Fig. 6 shows the delivery ratios when TTL is set to 6 an 12 hours. The line labeled with "The Best Relay" represents the performance of best effort two-hop forwarding scheme, in which all the intermediate nodes met by S before D are endowed with a copy of message in the *Spaying* phase, and thus gets the optimal two-hop forwarding latency.

From Fig. 6(a) and (b), we can see when the copies number doubles from 1 to 8, the delivery ratio of all three SW schemes fast approach the boundary of best relay. On the one hand, such a phenomenon demonstrates increasing copies is effective for improving the delivery ratio of opportunistic forwarding. On the other hand, we find from the figure that the marginal benefit brought by increasing message copies dropped rapidly when the copies number is greater than 4.



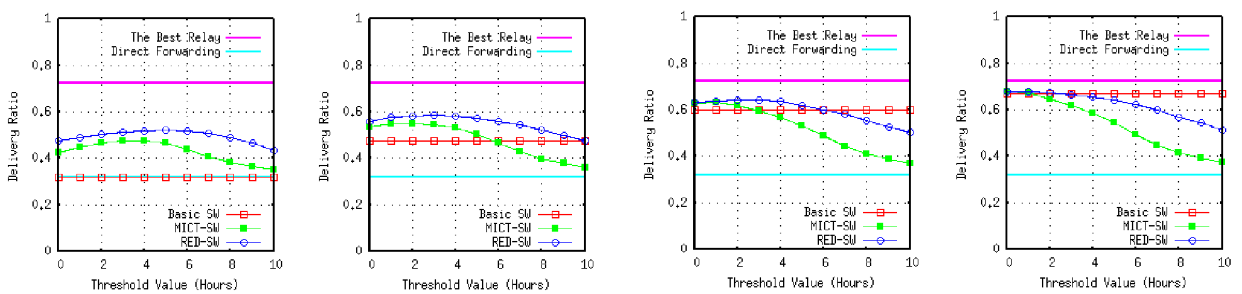
(a) threshold $\tau = 0$ (b) TTL=6 (c) TTL=12 (d) TTL=24

Figure 5: Delivery Ratio of First Meet Relay based Single Copy Scheme with Threshold



(a) TTL=6 (b) TTL=12

Figure 6: Delivery Ratio of Multi-Copy Schemes (threshold $\tau = 0$)



(a) copies limitation $\ell = 1$ (b) copies limitation $\ell = 2$ (c) copies limitation $\ell = 4$ (d) copies limitation $\ell = 8$

Figure 7: Delivery Ratio of Multi-Copy Scheme with Different Threshold (TTL=6 Hours)

Consequently, we can learn that using a limited number of message copies such as 8 could get an approximate optimal delivery ratio of two-hop forwarding scheme.

Fig. 7 shows the delivery ratio of multi-copy forwarding schemes with different relay judgement threshold when message TTL is set to 6 hours. Apparently, when the copies limitation ℓ doubly increased from 1 to 8, the effect of relay judgement threshold becomes weaker and weaker for both MICT-SW and RED-SW, and the optimal tradeoff threshold value decreases with the growth of copies limitation. At the same time, the performance of RED-SW and MICT-SW is continually closing to the basic *Spraying-and-Waiting* algorithm. As showed in Fig. 7(a) and (b), delivery ratio has obvious increment with threshold value until the optimal tradeoff threshold, and drops quickly after then. Meanwhile, the optimal tradeoff threshold decreases from 6 hours to 3 hours for RED-SW, and from 4 hours to 2 hours for MICT-SW. While as showed in Fig. 7(d) where ℓ increased to 8, using relay judgement threshold almost can't produce benefit. These results suggest the judgement threshold makes effect in lower copy number condition, in which to improve the decision accuracy is important. On the contrary, in cases of higher copies limitation, the aggressiveness of relays in cutting down transmission latency is a more determinative factor affecting forwarding delay. Because the threshold based relay selection condition is more conservative and strict, there are some effective relay opportunities are censored out. Therefor, they are not so effective for a higher multiple copies limitation forwarding schemes.

V. Conclusions

In this paper, we introduced a new relay selection metric called residual expected delay which is calculated from local contact records distributively and thus has a low overhead and suitable for opportunistic forwarding scheme in large-scale opportunistic vehicular network. Moreover, to enhance the relay selection judgement accuracy, we introduce a threshold based relay selection condition. Based on realistic vehicle trace records, we ran simulations to evaluate the proposed method and demonstrated the superiority of RED based two-hop forwarding scheme over the mean inter contact time based algorithms. Investigation on the impact of relay selection judgement threshold suggests it can improve delivery ratio when forwarding message copies limitation is low, and the empirical optimal tradeoff threshold value is given out according to a simple analysis framework.

Acknowledgment

This research is partially supported by the National Science Foundation of China under Grant No. 61070211 and No. 61003304; Hunan Provincial Natural Science Foundation of China under grants No. 09JJ4034; and Singapore-MIT IDC IDD61000102 Grant.

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