

# Regional Token Based Routing for DTNs

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**Abstract—** In Delay and Disruption Tolerant Networks (DTNs), there are no stable end-to-end paths because the connectivity of nodes is frequently disrupted by their mobility, power saving or other reasons. Nevertheless nodes can communicate each other by a store-and-forward paradigm if there are end-to-end paths on the union of network snapshots over time. Many previous studies have proposed routing protocols adopting this paradigm. We propose Regional Token Based Routing (RTBR) that reflect mobility patterns of real users. The real networks may consist of several sub networks (called “regions”) and have mobile nodes that move within regions or between regions. RTBR exploits node mobility and region information. It assigns “tokens” for each region to messages and sprays message copies into the regions as many as tokens for each region. Using simulation, we show that RTBR outperforms over 25% better delivery ratio than other flooding based schemes and maintains low overhead.

## I. INTRODUCTION

Recently many kinds of networks such as wireless LANs, sensor networks, and WiMAXs are being deployed. Delay Tolerant Networks [1] have been studied to support integration of heterogeneous networks that have very different features from each other. In sensor networks, nodes may be easily turned off because of their limited battery power. In Vehicular Ad-hoc Networks (VANETs), nodes are mobile and the connectivity of nodes is disrupted by their mobility. The links in wireless networks may be unstable because of wireless channel condition. These make network topology change frequently. So there may not be a complete path from a source to a destination at a given time, or a discovered path is very unstable. In order to support these situations, the concept of Delay and Disruption Tolerant Networks (DTNs) is proposed.

Research areas on DTN are network architecture, routing and forwarding protocols, message store management and etc. Routing where end-to-end connectivity is not guaranteed and one-hop connectivity is dynamically changed, is one of the popular research areas.

Various routing protocols for conventional multi-hop wireless networks such as sensor networks, VANETs and mobile ad-hoc networks (MANETs) have been proposed [3, 4, 5]. Since in the DTN model there may never be a contemporaneous end-to-end path, conventional ad-hoc network routing schemes, such as DSR [3], AODV [4] and Directed Diffusion [5] would fail to communicate from a source to a destination. Reactive schemes will fail to discover a complete path. Proactive schemes could not gather topology update messages, so that routing information may not be correct.

Even though there isn't stable end-to-end path, end-to-end path may exist on the union of network snapshots over time. Nodes can communicate each other by using “store-and-forward” paradigm. Using node's mobility, Messages sent by a source are stored by intermediate nodes and physically carried until intermediate nodes meet a suitable next hop node or a destination to forward the messages. This paradigm is called “store-carry-and-forward”. It can be applied to mobile environments for applications that do not need instant end-to-end interaction.

Routing protocols adopting store-carry-and-forward paradigm are proposed [6, 7, 8]. Epidemic Routing [6] is based on flooding. In Epidemic routing, a node forwards replicated message to every node it encounters. PROPHET [7] is also based on flooding and use encounters of nodes to predict their future suitability to deliver messages to a certain target. Spray and Wait Routing (SNW in this paper) [8] is similar to Epidemic Routing, but it limits the number of replicated messages to reduce overhead caused by replicated messages. The differences between various routing protocols are the amount of information they have available to make forwarding decisions and mobility pattern they assume.

In this paper, we present a novel protocol for routing in DTNs, called Regional Token Based Routing (RTBR). To reflect the mobility patterns of real users, we considered the situation that the entire network consists of sub networks called “regions” and nodes know region information. Fig. 1 shows the example. There are three regions. Some nodes move within a region such as urban buses (small cars in this figure). And the others move from a region to a region such as cross-region buses (buses in this figure). Each region can be sub network in DTNs

RTBR is based on SNW. The basic idea of RTBR is that evenly distributing message to the entire network increases the delivery ratio. In order to distribute replicated messages evenly, we assigned “tokens” for each region to messages and messages can be forwarded as many as tokens for each region. The total number of replicated messages and transmissions per message are bounded by tokens.

We simulated our scheme with Epidemic Routing, PROPHET and SNW. Simulation results show that delivery ratio of RTBR is the highest of all schemes. Some messages which destination was in out of source's region could never be delivered in SNW because of the limited number of message replication. The results also show the overhead of replicated messages of RTBR is the lowest of all schemes and the average latency of RTBR is quite good. The overhead of replicated messages is very large in Epidemic Routing and

PROPHET. PROPHET’s assumption, community model is similar to that of our scheme, but it did not perform better than RTBR.

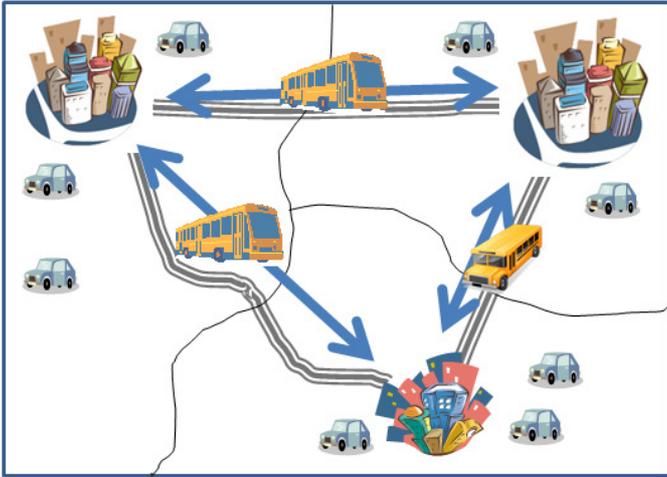


Fig. 1 The example of the network that consists of 3 regions. There are nodes that move within region (small cars) or move between regions (buses)

The remainder of this paper is structured as follows: in Section II, we review related work on routing in DTNs. We introduce our proposed routing scheme, Regional Token Based Routing in Section III. Then, in Section IV, we show the simulation setup and results. Finally we summarize the paper and discuss about future work in Section V.

## II. RELATED WORK

Vahdat and Becker proposed a routing protocol called Epidemic Routing [6]. It is one of the first schemes proposed to deliver messages in the network such as DTNs. It is based on the concept of flooding. Basically node stores messages even if there isn’t currently an available path to the destination. Each node maintains a list of all messages it carries. The list is called a *summary vector*. Whenever a node meets another node, they exchange summary vectors. After exchange, the node can know messages it doesn’t have. Then the node requests the messages from the other node. In this way, messages can be spread to all nodes in an epidemic manner like disease spread.

The hop count field in messages and the available buffer size can restrict the usage of network resource. The hop count field in messages is similar to the TTL field in IP packets. This field limits the maximum number of hops a message can be sent. Messages that are forwarded more than a hop count will be dropped. Buffer overflow can be occurred at nodes. Then some messages carried by nodes will be dropped or the nodes which buffer is full can not receive new messages. If the hop count and available buffer size are sufficiently large, all messages will deliver to the entire network.

Epidemic routing can find the optimal path from a source to a destination. But it uses a network resource very wastefully because each message spreads not only to a destination but

also to nodes which are not destinations. If the hop count is unlimited, all nodes in a network may receive all messages.

Lindgren et al. presented Probabilistic Routing Protocol using History of Encounters and Transitivity (PROPHET) [7]. The basic operation of PROPHET is similar to that of Epidemic Routing. PROPHET uses “community model” that is similar to the network model we considered. PROPHET uses information about the previous contacts and transitivity. It uses the information to predict which node is better to deliver the message to the destination. In order to use this information, the authors established probabilistic metric called *delivery predictability*. This means how likely it is that this node will be able to deliver a message to that destination. When two nodes meet, they exchange summary vectors. Summary vectors in PROPHET contain the delivery predictability information. After exchange, the node uses this information to update its delivery predictability and decide which messages to request from the other node. If the delivery predictability of the destination of the message is higher at the other node, the message is transferred to the other node. Compared with Epidemic Routing, unnecessary message delivery can be reduced in this way. But according to our simulation results, the overhead of this scheme is also large and the messages delivery is suffered from the overhead.

Spyropoulos et al. proposed Spray and Wait routing scheme [8]. SNW limits the maximum number of each message in the network. The initial value of the maximum number of message is called  $L$ . This scheme consists of the two phases. In spray phase, every message generated at a source is spread. But only  $L$  message copies for each message can be spread. The source node spreads messages to the network by forwarding message copies to nodes it encounters similarly to Epidemic Routing. The nodes receiving a copy are called *relays*. So  $L$  distinct relays exist in the network. If the destination is not found during spray phase, the phase is turned to wait phase. In wait phase,  $L$  nodes have only one message copy and perform direct transmission until they meet the destination of the message.

One of the issues of SNW is how many copies are handed over to another node. There are two simple proposals in [8]. When two nodes meet, only one message can be forwarded to another node (“Source SNW”) or half of messages the node has can be forwarded to another node (“Binary SNW”). When all nodes move in an independent and identically-distributed manner, the optimal number of handed-over copies is half of messages at source or relay. Compared with Epidemic Routing, this scheme can dramatically reduce the overhead. But in the situation we considered, the messages which destinations are out of the region of the source node might be never delivered to the destinations. It may occur when many message copies are spread in the region of the source node.

## III. REGIONAL TOKEN BASED ROUTING

We introduce a novel routing scheme called Regional Token Based Routing (RTBR). This scheme can improve delivery ratio and obtain low message overhead in the network that partitioned into several sub networks. We call

each sub network “region”. For example, regions are similar to cities or towns in real world. Some nodes move within a region such as urban buses and people who don’t leave their town in daily life. And the others move from a region to a region such as cross-region buses and trains. The previous schemes don’t consider such a network. In SNW, it is possible that only a few message copies are delivered to other regions and some message copies are never delivered to other regions.

The basic idea of RTBR is that evenly distributing message copies to the entire network increases the delivery ratio. We suggest RTBR that is based on SNW. In order to distribute message copies to the entire network evenly, we introduce a “token” that corresponds to  $L$  in SNW. RTBR uses token instead of  $L$  when making a decision of forwarding messages.

We classify nodes into two types, “intra-region node” and “inter-region node”. The former is the node that moves within a region and the latter is the node that moves between regions. We assume every node knows the follows:

- The identifier of region in which the node is located
- The identifier of destination region of the node
- Whether it moves within a region or between regions
- The number of regions in the network

RTBR exploits this region information to assign tokens to messages and to decide how many tokens will be handed over.

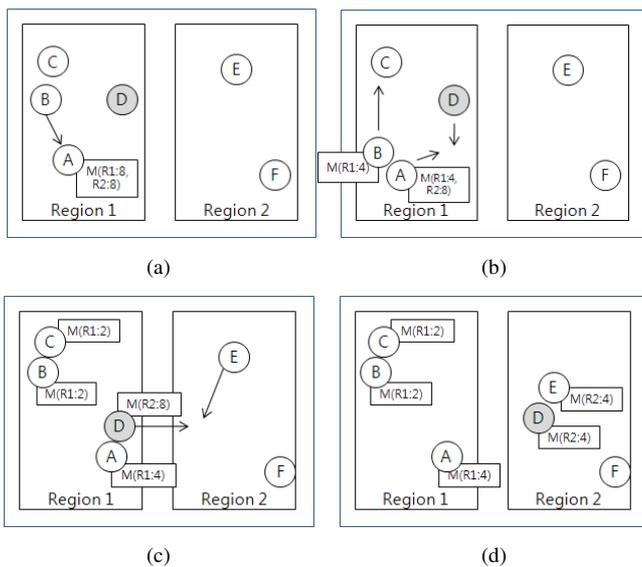


Fig. 2 Regional Token Based Routing. A message with tokens is passed from node A to other nodes. White circle is an intra-region node, Gray circle is and inter-region node and square is a message with tokens for each region.

#### A. Token Assignment

In order to deliver a message to the destination, at least one copy of the message has to get into the region in which the destination is located. To do so,  $L/N$  tokens are assigned for each region.  $L$  is the number of initial copies same as  $L$  in SNW.  $N$  is the number of regions in the network. Fig. 2 illustrates how RTBR relays messages across regions. Fig. 2 (a) shows that node A has a messages originated by itself. The

tokens assigned to the message are 8 for each region, Region 1 and Region 2. In this figure, initial value of  $L$  is 16.

The maximum number of copies of each message is  $L$  in the entire network and  $L/N$  in each region respectively. Assigned tokens for a region are used to spread message copies in that region.

#### B. Message Delivery within a Region

The operation of spreading messages within a region follows that of SNW. It is the issue to decide how many copies are handed over. In this paper, we followed Binary SNW and the sender node gives half of tokens to the receiver.

When any intra-region node A that has  $n > 1$  message copies and meets another intra-region node B with no copies, A hands over  $\lfloor n/2 \rfloor$  tokens to B and keeps  $\lceil n/2 \rceil$  for itself.

If  $n$  is 1, it switches to direct transmission.  $n$  is the number of tokens assigned for intra-region node’s region. That is, tokens for a region are consumed within that region. So the number of tokens for the other regions is not changed.

Fig. 2 (b) shows the situation after nodes A and B meet. A sends a message with 4 tokens to B. After that, node A has 4 tokens for Region 1 and 8 tokens for Region 2. B has 4 tokens for Region 1 where it is located.

#### C. Message Delivery between Regions

Inter-region nodes are responsible for message delivery between regions. When an intra-region node meets an inter-region node, the intra-region node forwards messages which the inter-region node doesn’t have, to the inter-region node. With the messages, the intra-region node hands over all tokens that are assigned for the destination region of the inter-region node.

In Fig. 2 (c), intra-region A transferred a message with 8 tokens for Region 2 to inter-region node D. Inter-region node with messages moves to its destination region. While it is moving in its destination region, it can encounter an intra-region node moving in the region. Inter-region node forwards not only messages that it gathered from other regions but also tokens assigned for the regions. In Fig. 2 (d), when inter-region node D meet intra-region node E in Region 2, D sends the message it carried with 4 tokens for Region 2 to E. The intra-region node receiving them performs “message delivery within a region”. Then we can easily imagine that  $L/N$  message copies will spread within the region.

## IV. SIMULATION SETUP AND RESULTS

To evaluate and compare the performance of different routing, we used The Opportunistic Network Environment (The ONE) Simulator developed at Helsinki University of Technology [9]. The routing protocols we have simulated are as follows: (1) Epidemic Routing (“epi”), (2) PROPHET (“pro”), (3) Binary SNW (“snw”) and (4) RTBR (“rtb”). We will use the shorter names in the parentheses to refer to each routing scheme in simulation result graphs..

In our simulation, the entire area size is  $4300 \times 3400$  m<sup>2</sup> in common. Table I presents the characteristics of nodes used in simulation. We assume that inter-region nodes are faster and

have more memory. The networking characteristics of intra-area node are similar to the feature of Bluetooth and inter-region node's networking characteristics are similar to the feature of a low power use of 802.11b WLAN [9]. Total 2,000 messages were created for 500s and were spread for 18 hours in each simulation. They were uniformly distributed to all nodes. Message sizes were uniformly distributed between 1 KB and 100 KB. In Epidemic Routing and PROPHET, we set a hop count infinite. Messages could never be dropped by their hop counts, but only be dropped by buffer overflows. We set buffer management policy to drop old messages in the buffer if the buffer is full. Other parameters for PROPHET [7] was set as  $P_{init}=0.75$ ,  $\beta=0.25$ ,  $\gamma=0.98$  and 30 s per time unit.

TABLE I  
THE CHARACTERISTICS OF NODES

	Intra-region node	Inter-region node
Node speed	Random speeds of 0.5-10m/s with pause times of 0-60s	Random speeds of 30-60km/h with pause times of 0-60s
Transmission range	10m	30m
Transmission speed	2Mbps	4Mbps
Buffer size	10MB	2GB
Movement model	Random way point model within regions	Random way point model between regions

We evaluated each routing protocol in respects of three facts.

Delivery ratio

$$\bullet \quad = \frac{(\# \text{ of delivered messages to the destination})}{(\# \text{ of all created messages})}$$

Overhead ratio

$$\bullet \quad = \frac{(\# \text{ of relayed messages}) - (\# \text{ of delivered messages})}{(\# \text{ of all created messages})}$$

Average latency

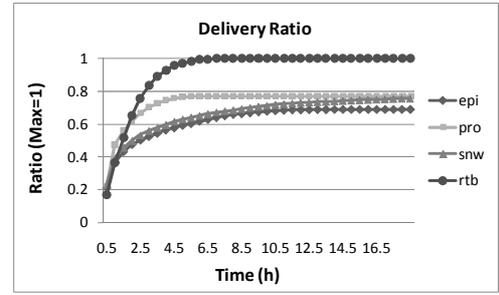
$$\bullet \quad = \frac{(\text{total latency of delivered messages to the destination})}{(\# \text{ of delivered messages})}$$

We used three different scenarios to evaluate the protocols. We simulated each scenario several times with different random values. The parameters changed for each scenario are as follows:

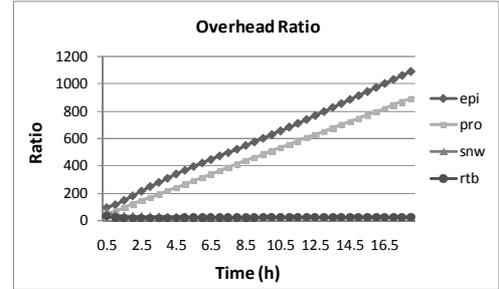
- The number of regions
- The ratio of nodes which move between regions
- The number of nodes

#### A. Simulation Results

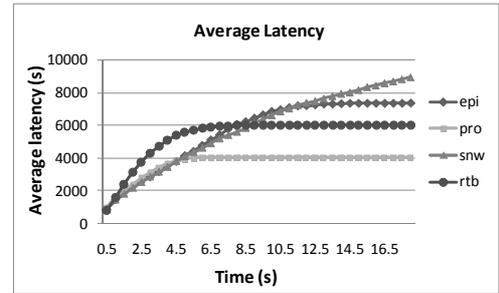
Fig. 3 shows the results when there are 4 regions and 400 nodes with 10% inter-region nodes. The value of L for SNW and RTBR is 16. Total average delivery ratios of schemes are in Fig. 3 (a). RTBR achieved the perfect delivery. All messages were arrived at the destinations of the messages. Because the buffer size of intra-region nodes was small, many messages were dropped in Epidemic Routing and PROPHET.



(a) Total delivery ratio



(b) Relative overhead per delivered message



(c) Average latency

Fig. 3 Simulation result with time

So delivery ratios of those routing schemes could not reach 1. It can be easily understood by seeing overhead ratio, Fig. 3 (b). Fig. 3 (b) shows that there were many message copies in the network and overhead ratio were increasing as time goes by in Epidemic Routing and PROPHET while SNW and RTBR maintained very low overhead ratio regularly. The difference of the total delivery ratios is caused by difference of delivery ratio of messages between regions. Fig. 3 (c) shows the result of the average latency. RTBR is not the best, but the average latency of RTBR is lower than that of Epidemic Routing and SNW. With these results, we can see that our scheme performed better message delivery between regions than the others with fairly good latency, when there are several regions in the network.

Fig. 4, 5 and 6 show the results when three parameters are changed. Each graph is drawn with the results at 18 hour in simulation time.

Fig. 4 shows a simulation result when the number of regions is changed from 2 to 6. The delivery ratios of all

schemes except for RTBR decreased when the number of regions increased. The more regions are there, the more difficult messages are delivered to other regions.

We simulated with 5, 10, 15 and 20% inter-region nodes in the network. If the number of inter-region nodes increases, messages can be more easily delivered to other regions. The result show that the delivery ratios of all schemes increased in Fig. 5 as we expected. SNW was the worst if there were few inter-region nodes in the network. But it was much better than Epidemic Routing and PROPHET if inter-region nodes increased. In RTBR, messages were delivered faster with same delivery ratio. Because of space limitations, we omit the result of latency in this paper.

In the case that the number of nodes in the network changed, the simulation result is presented in Fig. 6. Because Epidemic Routing and PROPHET can spread rapidly if nodes are dense, their performance increased. However, in SNW some intra-region nodes sent messages to other intra-region nodes more easily before they meet inter-region nodes. So many messages couldn't be delivered to other regions. Fig. 6 shows that result. In RTBR, all messages were delivered to their destinations although the average latency increased.

## V. CONCLUSIONS

Our goal is that design a new routing protocol that performs with high delivery ratio and low overhead when the network consists of several sub networks called regions in DTNs. In this paper, we have proposed Regional Token Based Routing. RTBR exploits region information and provides very efficient routing by assigning tokens for each region to messages and spraying as many copies as assigned tokens for the region into the regions. Compared with other flooding based schemes such as Epidemic Routing, PROPHET and SNW, RTBR outperforms all of them in respects of delivery ratio, overhead ratio and average latency. As our simulation, only RTBR delivered whole messages to their destinations. And RTBR maintained overhead very low alike SNW.

RTBR can be improved by adjusting the number of initial tokens and detecting other regions when nodes don't know that there are how many regions in the network. These works are in progress.

## ACKNOWLEDGMENT

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Fig. 4 Delivery ratio with 2, 4 and 6 regions

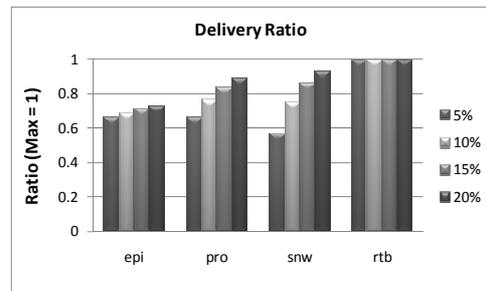


Fig. 5 Delivery ratio with 5, 10, 15 and 20% inter-region nodes

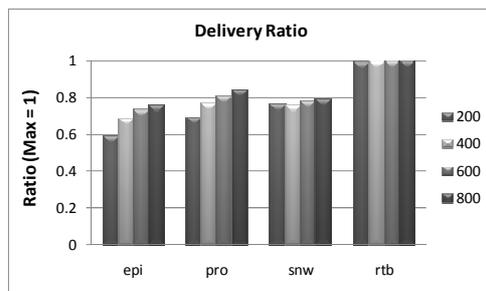


Fig. 6 Delivery ratio with 200, 400, 600, and 800 nodes in the network

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