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Packet-Oriented Routing in Delay-Tolerant Vehicular Sensor Networks[*]

XU LI, HONG-YU HUANG, MING-LU LI, WEI SHU[+] AND MIN-YOU WU
Department of Computer Science and Engineering
Shanghai Jiao Tong University
Shanghai, 200240 P.R. China
[+]*Department of Electrical and Computer Engineering*
The University of New Mexico
Albuquerque, 87131 U.S.A.

Currently, vehicular sensor network (VSN) has been paid much attention for monitoring the physical world of urban areas. We have studied VSNs by utilizing about 4000 taxis and 1000 buses equipped with GPS-based mobile sensors in Shanghai to constitute a virtual vehicular sensor network. The communication-connection intermittence makes the routing issue nontrivial when delay-tolerant applications are deployed in VSNs. The existing DTN routing protocols can be categorized as "neighbor-oriented" and how to select a neighbor candidate was always neglected. In this paper, we present a new DTN routing protocol for Delay-Tolerant Vehicular Sensor Networks, Packet-Oriented Routing protocol (POR), which is designed to emphasize neighbor selection based on awareness of packets to be sent and in consideration of probability to complete transferring of these packets. Our results show that POR performs much better than the ordinary Epidemic routing, as well as other popular routing protocols applied in a similar setting.

Keywords: password, authentication, software token, cryptographic camouflage, guessing attack

1. INTRODUCTION

Currently, a new infrastructure for monitoring the physical world is emerging, named Vehicular Sensor Network (VSN) [1, 2], which is a sort of VANET. Usually, it can be effective in urban areas where a high density of vehicles equipped with on board sensors is expected. Unlike sensors in traditional wireless sensor networks, vehicles are typically not affected by strict energy constraints and can be easily equipped with powerful processing units, wireless transmitters and sensing devices. VSN offers a tremendous opportunity for various large scale applications, from traffic surveillance to environmental monitoring, *etc*. Especially, Delay-Tolerant Vehicular Sensor Network (DTVSN) enables transfer of data when vehicles are connected only intermittently. However, the inherent uncertainty resulting from this communication-connection intermittence makes routing in DTVSN a challenging problem [3].

The primary focus of many existing DTN (Delay-Tolerant Networks) routing protocols is to increase the probability of finding a path with limited information. These

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protocols, however, only focus on transferring operation between the two nodes upon an established connection, but not on how to choose a neighbor candidate to connect. These protocols can be categorized as "neighbor-oriented". That is, information about packets is only utilized after the node already determined which neighbor to construct a connection.

In this paper, we present a new DTN routing protocol, Packet-Oriented Routing protocol (POR), to emphasize the packet-aware neighbor selection, that is, how to choose a neighbor to connect will be based on awareness of packets to be sent and in prior consideration of the probability of successful transferring of these packets. POR formulates the DTN routing protocol as a packet-oriented utility-driven resource allocation problem. Different from previous routing protocols, POR takes advantage of information about packets to choose a neighbor for connection with the maximum marginal utility.

We conduct our testing with a real-trace driven simulator, which is called Shanghai Urban Vehicular Sensor Network (SUVSNet). We have utilized about 4000 taxis equipped with GPS-based mobile sensors in Shanghai metropolitan area to constitute a virtual vehicular sensor network, presuming those vehicles could communicate with each other. In our simulations, the packet size is set to large value in order to emulate the large sensing file transferring in DTVSNs. Also, we assume that the buffer size is unlimited on every vehicle node. Our results show that POR performs much better than the ordinary Epidemic routing protocol, as well as other popular routing protocols.

The rest of the paper is organized as follows. Section 2 discusses related work. In section 3, we present the POR protocol in details. The overview of SUVSNet is presented in section 4, followed by the performance evaluations in section 5. Section 6 concludes the paper.

2. RELATED WORK

In recent years, routing strategies in DTN have been well studied [4]. Zhang [5] wrote a survey on existing protocols, in which DTN routing protocols are divided into deterministic and stochastic cases according to the scheduling of the node movement. When the movement of node can be scheduled, a global optimization would help to improve the network performance. Specially, the Minimal Expected Delay (MED) routing in [6], which aims to transfer data according to the minimum expected delay of packets based on a contact summary oracle. As an extension of the work by Jain [6], Jones proposed to use observed information to estimate waiting time for each contact [7]. Their protocol (MEED, Minimal Estimated Expected Delay) obtained performance similar to the schemes with a global knowledge of the network topology. Epidemic routing [8] is an early proposal suitable to stochastic mobility. When two nodes meet, they first exchange their summary vectors and then infect the peer with the packet.

In [9], we propose a new Distance-Aware Epidemic Routing (DAER) algorithm, which constitutes of three components, including a bundle priority assignment strategy, a pruning strategy, and a buffer replacement policy. The results showed a considerable performance improvement beyond Epidemic and other DTN routing protocols. In [10], we presented BLER (Bus Line-based Effective Routing), a DTN algorithm specifically designed for BUS networks in city urban areas. BLER considered routing issue by using the knowledge of bus line and bus schedule. In [11], authors introduced DTN routing as a resource allocation problem. Their protocol RAPID optimizes an administrator specified routing metric, where routing is done by packet replication. How packets should be replicated is determined by computing per-packet utilities. Work in [12] proposed PROPHET, a probabilistic protocol for routing in intermittently connected networks which uses history of node encounters and transitivity to enhance performance. MV routing in [13] learns structure in the movement patterns of network participants and uses it to enable informed message passing. In [14] authors define the anycast semantics for DTN based on a new model. A novel metric named EMDDA (Expected Multi-Destination Delay for Anycast) and a corresponding routing algorithm for anycast routing in DTNs are presented. [15] introduced Spray and Wait routing scheme, it sprays a number of copies into the network, and then waits till one of these nodes meets the destination to overcome the resource wasting. In [16] the authors studied the problem of using multiple ferries to deliver data in networks with stationary nodes and designing ferry routes so that average message delay can be minimized. Other coding-based routing protocols can be found in [17, 18].

Besides design of routing protocols for DTN, other researchers also attempted to improve and evaluate the performance of DTN for different scenarios. In [19], authors conducted some field testing of DTN with 30 buses and evaluated their DTN protocol on the simulated topologies. The results showed that it performed well in a variety of DTN environments. Although these works improved the performance of DTN, they did not answer the question about whether the DTN routing protocols are able to perform well in a large-scale network, which has motivated the study in this paper.

In addition, a number of works have studied the vehicular ad hoc networks, which can be found in [20-23]. Other researches focused on proposing suitable routing protocols for vehicular ad hoc networks (VANET). B. Karp and H. T. Kung proposed a location based packet forwarding decision [24]. Although it was not specifically designed for DTN, its location based idea and greedy forwarding decisions have been considered in many works such as [25].

3. POCKET-ORIENTED PROTOCOL

3.1 Network Model

A delay-tolerant vehicular sensor network is modeled as a set of mobile nodes. Two nodes can transfer data packets to each other when they are located within the communication range (CR). During a transfer, the sender replicates packets while retaining a copy. A node can deliver packets to a destination node directly or via intermediate nodes, but packets cannot be fragmented. At each mobile node, the available transfer bandwidth is limited but not the storage space, because we focus on the scenario of vehicular sensor networks. It is practical to assume infinite buffer and energy on every vehicle. Node-meeting is assumed to be short-lived because of the high speed of vehicle.

Formally, a DTVSN consists of a node-meeting schedule and a workload. The node-meeting schedule is a directed multigraph $\boldsymbol{G} = (\boldsymbol{V}, \boldsymbol{E})$, where $\boldsymbol{V}$ and $\boldsymbol{E}$ represent the set of nodes and edges respectively. Each directed edge $\boldsymbol{e}$ between two nodes represents a node-meeting between them, annotated by a tuple $(\boldsymbol{t_e}, \boldsymbol{s_e})$ where $\boldsymbol{t}$ is the time of the meeting and $\boldsymbol{s}$ is the size of the transfer opportunity. The workload is a set of packets $\boldsymbol{P} = \{(\boldsymbol{u_1}, \boldsymbol{v_1}, \boldsymbol{s_1},$

t_1), (u_2, v_2, s_2, t_2), …} where the i^{th} tuple represents the source, destination, size, and time of creation (at the source), respectively, of packet ***i***. In addition, it is assumed that every node can obtain the locations of other nodes at any time from a centralized location service, which is a common assumption in the position-based routing protocols [24-26]. Unlike other general DTN routing protocols, POR is designed for vehicular networks, where the nodes equipped with GPS devices is expected.

3.2 The POR Protocol

In this section we discuss the details of POR. Our approach can be summarized as follows: the mobile nodes try to send their data to the destinations. In other words, each node tries to deliver its packets to a neighboring node, which is the best carrier based on some metrics.

The neighbor selection process selects the neighbor candidate to construct a connection based on awareness of packets to be sent and in prior consideration of the probability of successful transferring of these packets. POR models DTN routing as a packet-oriented utility-driven resource allocation problem. POR gives the definition of neighbor utility, by which the node chooses the neighbor candidate. More precisely, a node first checks which packets it currently carried and where are their destinations. Then POR uses neighbor utility function to calculate which idle neighbor has the maximum marginal utility if the node chooses to construct a connection with this neighbor. After the node decided the neighbor candidate, it begins to construct a connection. Then the following step is similar with RAPID [11]. In our work, we extend DTN routing model as a packet-oriented resource allocation problem, which adds a neighbor selection process based on the knowledge of packets.

Next, we present the definitions of neighbor and packet utilities in POR. In our work, we still consider distance as an important metric to forward packet, which is very popular in position-based routing [25].

For an idle node v_i (That is, v_i is not with connection with other node), the idle neighbors of v_i is denoted as:

$$\wp(v_i) = \{n_1, n_2, \ldots, n_j\}$$

and a set of packets currently carried by v_i is denoted as:

$$\aleph(v_i) = \{p_1, p_2, \ldots, p_k\}.$$

Initially, the utility of neighbor n_j (denoted as $\boldsymbol{U}_j^{nb}$) is 0 because n_j still do not help v_i to forward data. Then we give the definition of utility function of neighbor n_j if v_i chooses n_j to construct a connection:

$$\boldsymbol{U}_j^{nb} = (\sum\Psi(p_{k'}))/S(\aleph'(v_i)),$$

where $p_{k'}$ is a packet that the distance of its destination and n_j is nearer than the distance of its destination and v_i. $\Psi(p_{k'})$ is the distance of n_j and the destination of $p_{k'}$. $\aleph'(v_i)$ is the set of such $p_{k'}$, thus $\aleph'(v_i) \subseteq \aleph(v_i)$. $S(\aleph'(v_i))$ is the size of $\aleph'(v_i)$ in bytes.

In fact, now the marginal utility of neighbor n_j is:

$$\delta \boldsymbol{U}_j^{nb} = \boldsymbol{U}_j^{nb} - 0 = \Psi(p_{k'}))/S(\aleph'(v_i)).$$

Then we select the neighbor as neighbor candidate which has the *maximum* marginal utility $\delta \boldsymbol{U}_j^{nb}$ if v_i chooses this neighbor to construct a connection. For a given packet, whether it could reach its destination and its expected delay will contribute to the performance metrics of the whole network, such as delivery ratio and average delay. Thus, the definition of $\delta \boldsymbol{U}_j^{nb}$ holds a criterion that the packets, whose destinations are farther than other packets, should have higher priority to be transferred. Then, $\delta \boldsymbol{U}_j^{nb}$ attempts to choose the neighbor, which can reduce the expected delay and increase the probability of successful delivering for packets as much as possible.

After v_i decided n_j as the neighbor candidate, we give the definition of utility function of packet $p_{k'}$:

$$\boldsymbol{U}_{k'}{}^{pk} = \Psi(p_{k'})//s(p_{k'}),$$

where $s(p_{k'})$ is the size of $p_{k'}$. $\delta \boldsymbol{U}_{k'}{}^{pk}$ is the marginal utility if v_i transfer $p_{k'}$ to n_j. Then v_i begins to replicate packets in decreasing order of $\delta \boldsymbol{U}_{k'}{}^{pk}$ to n_j, and vice versa.

In summarize, for idle node v_i, it first checks idle neighboring nodes ($\wp(v_i)$). Then the node v_i launches neighbor selection process to decide which neighbor to connect by its local knowledge (with the maximum $\delta \boldsymbol{U}_j^{nb}$). We admit that the final neighbor candidate may not be the best choice because of incomplete local knowledge of node v_i. For example, the packet $p_{k'}$ contributes to calculating marginal utility of n_j while $p_{k'}$ is not necessary to be transferred from v_i to n_j if n_j already carried $p_{k'}$. Thus, POR aims to choose neighbor candidate with approximate optimization. The reason is that if a node uses global information to determine the highest utility neighbor by exchanging information with all neighboring nodes, it seems to require connection setups, which implies considerable overhead and degrades the advantage of neighbor selection process. Next, if node v_i found a neighbor candidate, these two nodes begin to construct a connection and the statuses of them are changed from idle to busy. After establishing a connection, node v_i first exchanges metadata with this neighbor. The metadata often includes some useful knowledge, such as the acknowledgements of delivered packets, which only take a fraction of bandwidth compared with the large-size packet. Metadata enables efficient routing and helps remove copies of packets that are already delivered, increasing the overall performance of POR. Then, POR replicates the packets $p_{k'}$ in decreasing order of marginal utility $\delta \boldsymbol{U}_{k'}{}^{pk}$ to neighbor candidate n_j. Node v_i is referred as *active* node because it initiates a neighbor selection process. It could terminate the connection when it completes transfer of packets. Neighbor node n_j, is referred as *reactive* node in this connection, which only transfers the packets to v_i in decreasing order of marginal utility after v_i constructed a connection with it. The outline of POR is shown in Fig. 1.

In our work, we assume that the transmitter equipped on vehicles only has one interface, which means the node cannot monitor other channels during ongoing transmission. Thus, the rationale of POR is that the node continues a connection until the peer is gone or they are out of packets for each other. Actually, if we assume that a node can sense the changes of neighboring nodes by monitoring multiple channels simultaneously, the node could utilize other new available neighboring nodes. That is, we can explore when to recalculate the best neighbor in real-time. For example: nodes *B* and *C* arrive, node *A* to

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Protocol: POR($v_i$)
Input: the idle node $v_i$
1.  $\wp(v_i)$ = getIdleNeighbors($v_i$);
2.  $n_j$ = getNbrWithMaxMarginalUtility ($v_i$, $\wp(v_i)$);
3.  exchangeMetadata($v_i$, $n_j$);
4.  initialize a packet list pks;
5.  for each $p_k$ in node $v_i$ and not in $n_j$ do
6.      if $p_k$ is destined to $n_j$ then
7.          send $p_k$ to $n_j$;
8.      else
9.          $\delta\mathbf{U}_k^{pk}$ = calcMarginalUtilityOfPkt ($p_k$);
10.         addPktToListOrderByDesc(pks, $p_k$, $\delta\mathbf{U}_k^{pk}$);
11. for each $p_k$ in node pks do
12.     replicate $p_k$ and send to $n_j$
13. $n_j$ do the same operations as $v_i$ (from step 4 to 12)
14. End transfer when $v_i$ complete all packets it needs to
    transfer or out of commutation range.
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Fig. 1. The packet-oriented routing protocol (POR).

connect to *C*. Then *D* arrives, whether *A* should proactively break the ongoing connection with *C* and launch a new connection with *D* if currently *D* has highest marginal utility? However, we found that in vehicular networks scenario, the time duration of a connection is often limited because of the high speed of vehicles and dynamic topology change. Frequent connection breakings and setups may incur considerable overhead. Thus, whether or not the node should proactively break the ongoing transmission for peering optimization needs more study, which is a part of our future work.

4. OVERVIEW OF SUVSNET

Currently, over 4,000 taxis in Shanghai equipped with GPS devices, report their locations in real time, as shown in Fig. 2 (a). We map these data onto a digital map to obtain their real traces and to construct a virtual vehicular sensor network, named as Shanghai Urban Vehicular Sensor Network (SUVSNet), as shown in Fig. 2 (b). In our work, we mainly focus on the inner loop area of Shanghai city because it is the downtown area with high density of taxis.

The number of taxis in inner loop is about 1,000. The size is 102km^2, with the average density being about 10 taxis/km^2. For the network topology and connectivity, with the communication range of 250m, the taxis are scattered into many disconnected partitions. The more details about SUVSNet, please refer to [9] in details.

5. PERFORMANCE EVALUATION

The primary goals of DTN routing protocol is to maximize the delivery rate of offered packets and to minimize the latency between source and destination. With variation

(a) (b)

Fig. 2. (a) GPS-based sensor deployed on the dash board of a taxi; (b) Visualization of SUVSnet (The surrounded area depicts the inner-loop area, every dot represents a taxi).

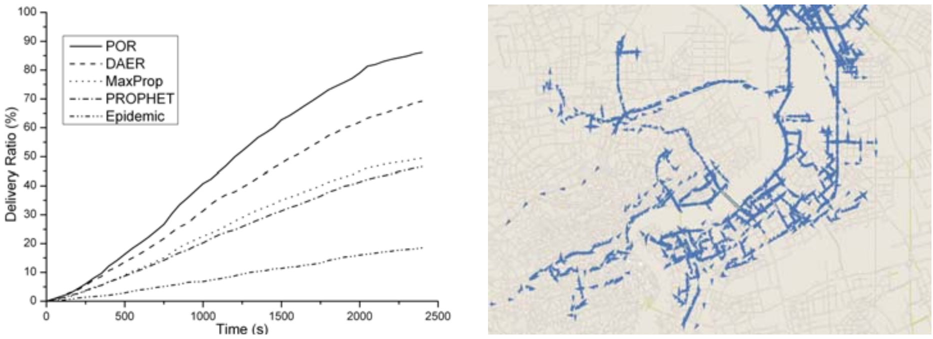
of load, communication range, and packet size, our protocol delivered more packets with lower latency than other protocols.

5.1 Experimental Setup

We have implemented a stand alone simulator using C++ to evaluate the routing scheme presented in this paper. This simulator only implements the transport and network layers and it makes simple assumptions regarding lower layers. The input is the real traces of the vehicles and the configuration of the parameters, such as the choice of the routing protocol, communication range, buffer size, *etc*. The output is the data statistics about the metrics. In our work, we mainly focus on two performance evaluation metrics: the delivery ratio and the average delay. The delivery ratio is the ratio of the total number of packets successful delivered to the total number of generated packets. The delivery ratio reflects the how often the method successfully delivers each packet to its destination. The average delay is the average delay of all the packets delivered to the destination. The delay of a delivered packet is calculated by subtracting the delivery time by the packet generation time. Our evaluations are based on this real-trace driven simulator. We compare POR to other four routing protocols: Epidemic [8], MaxProp [19], PROPHET [12] and DAER [9]. Table 1 lists some properties of SUVSNet and the default parameters used for all the experiments in our simulation. The selection of the values of the experimental parameters is based on field testing in Shanghai urban area, such as average speed of taxi, bandwidth, *etc*. We set the communication range at 200m because we predict some real technology will support this requirement soon. Meantime, the packet size is assumed constant for simplicity in our testing. Each data point is averaged over 30 runs. In our simulations, the packet size is set to large value in order to emulate the large file transferring in vehicular sensor networks. Typical application includes transfer large multimedia files between vehicles, such as images of accidents, traffic status on the road, and so on. All packets are sent at the beginning of the simulation. In addition, as mentioned above, we also assumed that every node can obtain the locations of other nodes at any time from a centralized location service, which is similar with other position-based routing protocols. Thus, the overhead for calculating the location and distance between neighbor nodes of corresponding destinations can be neglected.

Table 1. Experiment parameters.

Simulation Area	102km^2
Simulation Time Duration	2400s
Number of Taxi	845-1171
Average Speed of Taxi	25.6km/hc
Communication Range (CR)	200m
Packet Size	256KB
Total Traffic Load in Network	1500 pks
Buffer Size	unlimited
Bandwidth	1 Mbps



(a) (b)

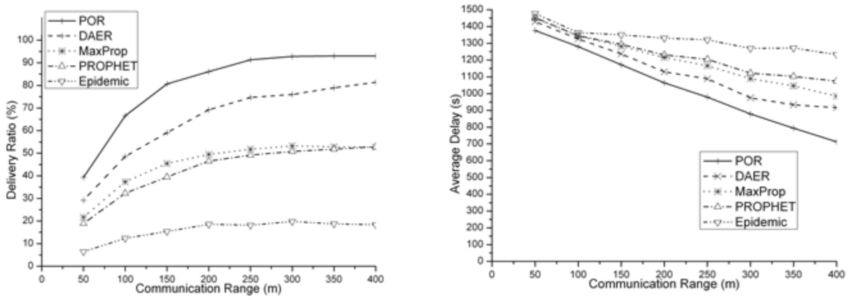
Fig. 3. (a) Cumulative distribution function (CDF) of the delivery ratio of five protocols; (b) The trace of a taxi in a whole day.

5.2 Protocol Comparisons

In Fig. 3 (a), we plot the Cumulative Distribution Function (CDF) of the delivery delays, using the default parameters listed in Table 1. As shown in Fig. 3 (a), POR outperforms other four routing protocols in our simulation. Nearly 94% packets reached their destinations before the deadline (2400s). Meantime, half of the packets are delivered within 1200s in POR. Compared with POR, the second best routing protocol, DAER, only has the delivery ratio of 70%, which is 25% less than POR in the same simulation environment. The MaxProp and PROPHET are worse than POR and DAER. The underlying reason is that both of them are sort of "probabilistic-based" routing protocols, and they assume that the nodes have no knowledge about network. For example, MaxProp is a general DTN routing scheme without using the locations of taxis. Our work, however, aims to provide a DTN routing special for vehicular networks, where it is reasonable to assume location information can be utilized. Thus, the transferring of data in MaxProp and PROPHET is mainly based on the delivery likelihood of the packets, which is estimated by historical meeting information between nodes. POR in our work has more knowledge to utilize than MaxProp and PROPHET, *i.e.*, the real-time locations of nodes. In fact, POR can be regarded as "location-based" DTN routing protocol. Based on awareness of node locations and dynamic topology of the network, nodes in POR can proactively forward packets to their destinations. Compared with probabilistic-based knowledge in MaxProp and PROPHET, real-time and accurate information about network in POR has more advantages to delivery data, which inevitably leads to best performance of POR.

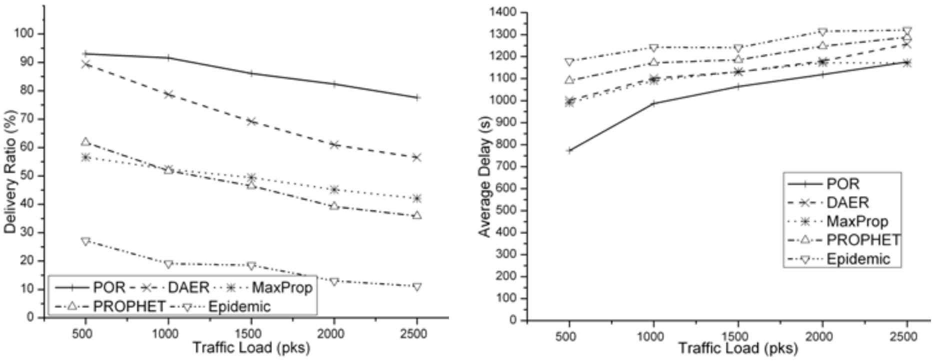
Meantime, work in [12] proposed a new mobility model, named "community model", that each node has one home community which it is more likely to visit than other place. They studied PROPHET based on such synthetic mobility model. In our work, we analyzed the real traces of taxis and found that it is difficult to define home community for a vehicle. As shown in Fig. 3 (b), we track a taxi and draw its trace of whole day on the map of Shanghai. We found that taxi drivers always drive in fixed regions of the city. For example, the taxi in Fig. 3 (b) likes to run in Pudong region of Shanghai (The whole Shanghai city is divided into two parts by Huangpu River, named "Pudong" and "Puxi" regions, respectively), the reason is that Shanghai has a land area covering 6,340 square kilometers, taxi drivers always work in fixed regions, which is already very large. By analyzing whole day trace of the taxi in Pudong region in Fig. 3 (b), we cannot define a home community for this taxi because the realistic trace is throughout the region. Thus, based on the realistic mobility model, the probabilistic-based routing protocols cannot perform as well as in the community model proposed in [12]. Also, researchers studied MaxProp based on a testbed with 30 buses. Due to fixed bus routes and schedule, a probabilistic meeting schedule can form, which is also different from our work, that the taxis do not have the fixed routes and schedules as buses.

Figs. 4 (a) and (b) show the delivery rate and average delay, respectively, of each protocol as offered communication range in the system increases from 50m to 400m. With increase of communication range, we can see an increase in delivery ratio for all protocols. Especially, POR performs much better than DAER when the communication range becomes larger. This phenomenon can be explained that when the communication range is set with a small value, a node has a few of neighbors to choose. Under this situation, POR performs similar behavior as DAER, as a consequence. When the communication range is set with a larger value, more neighbors can be chosen to connect. As a result, POR performs much better than DAER with the large communication range. In addition, MaxProp and PROPHET also perform better as the communication range increases. The reason is that with a large communication range, the probability of meetings between any two nodes becomes higher, which leads to higher delivery likelihood.



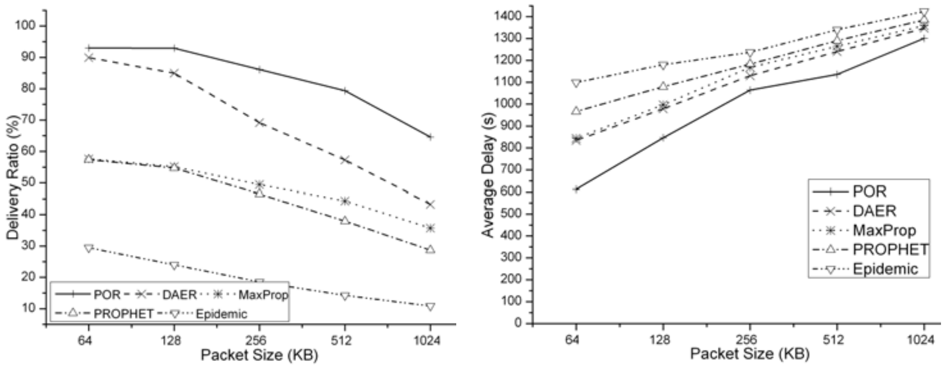
(a) (b)

Fig. 4. (a) Delivery ratio with different communication range; (b) Average delay with different communication range.



(a) (b)

Fig. 5. (a) Delivery ratio with different traffic load; (b) Average delay with different traffic load.



(a) (b)

Fig. 6. (a) Delivery ratio with different packet size; (b) Average delay with different packet size.

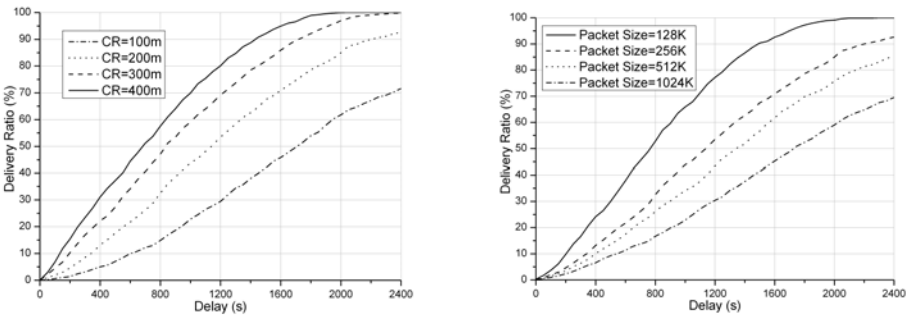
Figs. 5 (a) and (b) show the delivery ratio and average delay, respectively, of each protocol as traffic load in the system increases from 500 packets to 2500 packets. With this increase in traffic load, we can see a drop in delivery rate for all protocols. However, for all scenarios, POR delivers more packets and maintains smallest latency. Figs. 6 (a) and (b) show the delivery ratio and average delay, respectively, of each protocol as the size of the packets increases from 64KB to 1024KB. Increasing packet size models different applications. It is difficult for peers to make use of all transfer opportunities when transferring larger packet, because some of connections are too short in time duration. Here again we see that POR is able to perform better than other protocols.

In addition, it can be seen that Epidemic protocol provides worst performance in all simulations. Ideally, Epidemic routing should performs best when the bandwidth and the buffer size are unlimited. In our work, we also assume unlimited storage on every vehicle, which leads to redundant copies of packets in the network. The bandwidth, however, is still a limited resource (1 Mbps). For a given network transmission capacity, there are more contentions for limited bandwidth between packets. Especially, many copies of packets are transferred unnecessarily, which leads to ineffective usage of limited bandwidth. As a result, Epidemic performs worst in all simulations.

5.3 Examining Impacts of Different Parameters on POR

We expect that the improvement of POR over DAER will increase as communication range increases since POR has more options to select neighbor candidate. Fig. 4 (a) has confirmed our expectation. In order to predict the performance when the communication range can be large enough to cover most of the nodes in the network, we investigate the performance of POR with different communication ranges. It can be seen from Fig. 7 (a) that a large communication range will increase the delivery ratio as expected. Especially, there is a considerable improvement of delivery ratio when the communication range was changed from 100m to 200m. When the communication range becomes larger than 200m, improvement has not been extended further because with communication range of 300 meters, most of nodes in the network can gather together to a small number of partitions.

Fig. 7 (b) shows the impacts of different packets sizes on POR. As we predicted, larger packet size results in lower delivery ratio. When the packet size becomes smaller than 512 KB, most of packets can reach the deadline with the default bandwidth of 1Mbps. When the size is set to 1024 KB, however, there is a considerable drop of delivery ratio, only about 70% packets can reach their destinations. Meantime, we found that the average delay also becomes larger as the packet size increases. As mentioned before, it is more difficult to transfer a larger packet. For a given packet, even a large fraction of packet has been transferred, the link could break suddenly which leads to completely failure of this transferring operation. In other words, this opportunity between two nodes has been wasted.



(a) (b)

Fig. 7. (a) Impacts of different communication range on POR; (b) Impacts of different packet size on POR.

6. CONCLUSION

We present a new DTN routing protocol for Delay-Tolerant Vehicular Sensor Networks (**DTVSN**s), Packet-Oriented Routing protocol (**POR**) , which is designed to complete transferring operation by considering the knowledge of packets during neighbor selection process. POR protocol can support delay-tolerant application in vehicular sensor networks effectively. By comparison, the existing DTN routing protocols lose the opportunity to select a neighbor candidate, which are categorized as neighbor-oriented routing. We carried out our testing on a real-trace driven simulator, which utilizes about 4,000 taxis equipped with GPS-based mobile sensors in Shanghai city. In our simulations, we configure the parameters to emulate the large sensing file transferring in DTVSNs. Our results show that POR performs much better than the ordinary Epidemic and other popular routing protocols.

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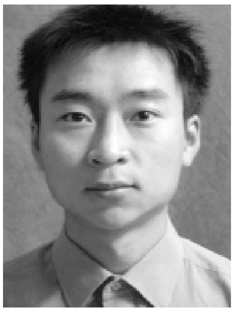
Xu Li (李旭) received the M.S. degree in Computer Science from Shanghai University, Shanghai, China, in 2006. He is currently working toward the Ph.D. degree with the Department of Computer Science and Engineering, Shanghai Jiao Tong University. His research interests include wireless sensor networks, intelligent transportation systems, and grid computing.



Hong-Yu Huang (黃宏宇) received the B.S. and M.S. degrees in Computer Science from Chongqing University, Chongqing, China, in 2002 and 2005, respectively. He is currently working toward the Ph.D. degree with the Department of Computer Science and Engineering, Shanghai Jiao Tong University, Shanghai, China. His research interests include wireless networks and intelligent transportation systems.

Ming-Lu Li (李明祿) received the degree from the School of Electronic Technology, University of Information Engineering, Zhengzhou, China, in 1985 and the Ph.D. degree in Computer Software from Shanghai Jiao Tong University (SJTU), Shanghai, China, in 1996. He is a Full Professor and the Vice Chair of the Department of Computer Science and Engineering, SJTU. His current research interests include grid computing and sensor networks.

Wei Shu (舒葦) received the Ph.D. degree from the University of Illinois at Urbana-Champaign. She is currently an Associate Professor with the Department of Electrical and Computer Engineering, University of New Mexico, Albuquerque. Her current research interests include resource management, multimedia networking, distributed systems, wireless networks, and sensor networks.

Min-You Wu (伍民友) received the M.S. degree from the Graduate School of Academia Sinica, Beijing, China, and the Ph.D. degree from Santa Clara University, Santa Clara, CA. He is an IBM Chair Professor with the Department of Computer Science and Engineering, Shanghai Jiao Tong University, Shanghai, China. He is also a Research Professor with the University of New Mexico, Albuquerque. His research interests include grid computing, wireless networks, sensor networks, overlay networks and multimedia networking.