A Geographic Opportunistic Forwarding Strategy for Vehicular Named Data Networking

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Abstract. Recent advanced intelligent devices enable vehicles to retrieve information while they are traveling along a road. The store-carry-and-forward paradigm has a better performance than traditional communication due to the tolerance to intermittent connectivity in vehicular networks. Named Data Networking is an alternative to IP-based networks for data retrieval. On account of most vehicular applications taking interest in geographic location related information, this paper propose a Geographical Opportunistic Forwarding Protocol (GOFP) to support geo-tagged name based information retrieval in Vehicle Named Data Networking (V-NDN). The proposed protocol adopts the opportunistic forwarding strategy, and the position of interest and trajectories of vehicles are used in forwarding decision. Then the ONE simulator is extended to support GOFP and simulation results show that GOFP has a better performance when compared to other similar protocols in V-NDN.

Index Terms **—Vehicular networks, Opportunistic forwarding, Named Data Networking, Geographic routing**

1 INTRODUCTION

Recent advanced intelligent devices enable vehicles to retrieve information while travelling. Message transmitting normally follows multi-hop routing that use moving vehicles as intermediate nodes. However, efficient routing is challenged by high mobility of vehicles. To overcome intermittent connectivity, the store-carry-and-forward paradigm of Delay-Tolerant Networks (DTNs) is proposed, in which appropriate relay selection is the key problem. On the other hand, Named Data Networking (NDN)[1] is developed as an effective content-centric model for information retrieval, in which each node maintains three structures: Forwarding Information Base (FIB), Pending Interest Table (PIT) and Content Store (CS), to process Interest Packet (IntPkt) and Data Packet (DatPkt). A node (called consumer) sends out an IntPkt with a name to retrieve desired data. After receiving an IntPkt, nodes check local CS. If desired data is found, this IntPkt is satisfied and a DatPkt containing name and data is generated and is transmitted back along IntPkt's reverse path to consumer. Otherwise IntPkt is added in PIT and is forwarded based on FIB until desired data is found or IntPkt TTL expires. Though DTN and NDN are developed for different purposes, they have some similarities: flexible routing and network packet storage. Thus, they can be combined to improve data delivery.

Most vehicular applications are interested in location related information. Though some studies proposed to encode Position of Interest (POI) into data names to identify data, packet forwarding still adopts broadcasting or location-independent routing in traditional NDN. Since a node would not store data unless it has corresponding pending interest in its PIT[2], IntPkt is hardly to satisfy at any place far from POI and broadcasting IntPkt results in poor performance. Besides, forwarding DatPkt to consumer along IntPkt's reverse paths is impractical in V-NDN because of dynamic topology. As a possible solution to these problems, this paper presents a Geographical Opportunistic Forwarding Protocol (GOFP) for V-NDN. To the best of our knowledge, this work is the first that applies geographic information to routing named data. The store-carry-and-forward paradigm is supported in GOFP, and geographic location of POI and the trajectories of vehicles are used to select better next relay nodes. To evaluate GOFP, the ONE simulator is extended and simulation results show that GOFP has better performance, when compared to similar forwarding strategies in V-NDN.

The rest of the paper is organized as follows. Section II briefly summarizes related work in DTN and NDN. The proposed application scenario is discussed in section III and the design of GOFP is described in section IV. Section V shows simulation results and related analysis and section VI concludes presenting suggestions for future work.

2 RELATED WORK

As most vehicular applications need to disseminate information to specific geographic areas, many geographic routing protocols are available. A position-based greedy forwarding approach and a repair strategy to choose the next hop are proposed in [3]. Distance based routing protocol [4] selects next hop base on in-vehicular distance and connectivity duration. Geographical opportunistic routing [5] and GeoSpray [6] follow the store-carry-and-forward paradigm and minimum estimated time of delivery is used as a utility function to make routing decisions. These protocols are designed for the scenario where the destination is stationary and forward process is one-way, so they do not apply in situation that destination (consumer) is mobile and communication process is a query-reply mode.

In terms of research about NDN, Grassi et. al. [7] applied named data to networking running vehicles and described a prototype implementation of V-NDN. A named data based traffic information dissemination application was developed in [8], which shows that data names can greatly facilitate the dissemination process. But using broadcast to propagate packets potentially leads to poor performance. Furthermore, Kuai et. al. evaluated IntPkt broadcast in [9] and indicated that it incurs to increased loss ratio at high density scenarios in V-NDN. Pesavento et. al. in [10] pointed that most vehicular applications focus on getting POI related information and proposed an approach to map bi-dimensional geographic areas into a uni-dimensional naming scheme to identify geographic areas related data. Yu et.al. in [11] proposed a Neighborhood-Aware Interest Forwarding (NAIF) routing protocol to improve the NDN Forwarding protocol[2]. Instead of indiscriminate flooding, NAIF selects cooperative nodes to forward IntPkt fractions. Lu et. al. [12] presented a social-tie based content retrieval algorithm, where K-mean clustering algorithm is used to structure an hierarchical architecture among nodes, but it needs a process to build the social-ties.

3 CONTEXT AND APPLICATION SCENARIO

We present the relevant application scenario to help explaining this research work motivation. Some vehicular applications require information about specific geographic areas. For instance, the parking application may need to know any available parking spaces around the vehicle's destination in order to direct the driver to the most convenient one. The service platform of parking lots broadcasts information of parking fees, current capacity and estimated available spots in several hours later. The vehicles moving near the parking lots can receive the information. We cannot assume constant connectivity between the vehicles and the service platform because of sparse vehicle density or high vehicles mobility. There are two potential processes in this scenario: (1) Consumer vehicle sends IntPkts with geo-tagged name to request the information about POI; (2) Once IntPkt reaches a vehicle carrying desired data, corresponding DatPkt is generated and is forwarded back to the moving consumer. GOFP is proposed for both these two processes.

4 GOFP PROTOCOL DESIGN

4. 1 Data Naming Scheme and Packets Structure

The application should have a good data naming scheme that lets data providers to describe what they have and consumers to express what they want. Our data naming scheme is proposed as: */application/geo-reference/temporal-field/nonce/*. The field *application* indicates different application-dependent data. The *geo-reference* presents ID of POI, which can be converted to geographic coordinate (x, y) by GPS devices. The *temporal-field* is represented as *start-time/end-time* in IntPkt, and is set as data published time in DatPkt. The start and end time designate the time interval of desired data, e.g. the user may indicate he want the parking information from 10 AM to 11 AM. If all other fields are matched and published time of data is within the time interval of IntPkt, IntPkt is satisfied. The *nonce* is a random number used to distinguish different data providers.

The proposed structures of IntPkt and DatPkt are shown in Fig. 1. To differentiate IntPkt and DatPkt, the "type" field is reserved. The TTL (Time-To-Live) defines live time of packets in seconds and packet is discarded once it expires. The trajectory info indicates the consumer's trajectory till TTL expires. Outdated items will be deleted from the trajectory every time the packet is forwarded. DatPkt has the field content to store data.

Fig. 1. Structure of Interest Packet (IntPkt) and Data Packet (DatPkt)

4. 2 Forwarding Strategies for Interest and Data Packets

Under assumption of equipping vehicles with GPS devices, vehicles can obtain their current position and future trajectory. GOFP is based on the opportunistic forwarding, so the most important issue involves the selection of relay nodes. Since it is possible to obtain desired data from carried nodes, IntPkt is just forwarded to the vicinity of POI to increase satisfied probability, rather than to data provider. Conversely, DatPkts must be delivered to certain moving consumer. Thus, GOFP adopts different forwarding strategies for the IntPkt and DatPkt respectively.

4.2.1 Interest Packets Forwarding

To propagate IntPkt close to POI quickly, wireless channel should be used as much as possible because its transfer speed is faster than moving speed of vehicles. The GPS equipped vehicle knows its own trajectory and can convert place ID in IntPkt name to specific geographic position $(\mathrm{x}_a, \mathrm{y}_a)$. Thus, when carrier vehicle meets a vehicle which is nearer or moves faster toward POI in a future period, the IntPkt will be forwarded to it. The position of vehicle i at time t is denoted by $P_i(\mathrm{t})$ and the time is slotted with customizable interval. The trajectory of the vehicle is defined as Definition 1.

Definition 1 (Manifestation of Vehicle's Trajectory) The trajectory of vehicle i is a sequence of positions in a given time span $[\mathrm{t}_a, \mathrm{t}_b]$, denoted by

$$T_i = <(t_a, P_i(t_a)), (t_{a+1}, \mathrm{P}_i(t_{a+1})), \ldots.(t_{a+k}, \mathrm{P}_i(t_{a+k})), \ldots(t_b, \mathrm{P}_i(t_b))>$$

Each vehicle can calculate the nearest distance to $(\mathrm{x}_a, \mathrm{y}_a)$ on its trajectory in time period $(CurrentTime \le t \le CurrentTime + \delta)$, where δ is the defined time interval.

The Euclidean distance of two points $(\mathrm{x}_1, \mathrm{y}_1)$ and $(\mathrm{x}_2, \mathrm{y}_2)$ is calculated by formula (1).

$$d_{i,j} = d((\mathrm{x}_1, \mathrm{y}_1), (\mathrm{x}_2, \mathrm{y}_2)) = \sqrt{(\mathrm{x}_1 - \mathrm{x}_2)^2 + (\mathrm{y}_1 - \mathrm{y}_2)^2} \qquad (1)$$

Definition 2 (Near Degree to POI): The near degree of vehicle i to POI is defined as the shortest distance of its trajectory to POI in a given interval δ. It is indicated as formula (2):

$$d_{\min}(\mathrm{i,poi}) = \min d_{pi,\mathrm{POI}}(\mathrm{t}) \quad \mathrm{t} \in [CurrentTime \le t \le CurrentTime + \delta] \qquad (2)$$

The Near Degree of vehicle i to POI is calculated as shown in Fig. 2. If the $d_{\min}(\mathrm{i,poi})$ is smaller than communication range, vehicle i can get data from POI server directly.

The better relay vehicle is the one can potentially satisfy IntPkt earlier, which means a vehicle is chosen as next relay node if either it holds desired data in their CS or it will move closer to POI. In GOFP, vehicles announce the cached data name digest to their neighbors. If there is a neighbor that holds the desired data, the carrier will forward IntPkt to it. Otherwise, $d_{\min}(\mathrm{i}, \mathrm{poi})$ is the metric to select the vehicle that meets the second condition. When δ is set a proper value, e.g. it is enough to let two contacted vehicle passing each other's current position using current speed, $d_{\min}(\mathrm{i}, \mathrm{poi})$ is able to reflect if vehicle *i* is moving closer to POI in future period. The smaller $d_{\min}$ the vehicle has, the closer it is to POI. If no vehicle meets these two conditions, current vehicle continues to carry IntPkt. The pseudo-code in Fig.3 presents that vehicle *i* forwards IntPkt process. The forwarding list indicates subsequent relay node for each IntPkt. If there is desired data in neighbor *j*'s CS or vehicle *j* has smallest near degree $d_{\min}(\mathrm{i}, \mathrm{poi})$ for IntPkt pi, an item (pi, *j*) will be added into forwarding list. Finally, all IntPkts are transferred based on this forwarding list.

```
Input : Positon of POI; Trajectory of vehicle i; interval δ
Output: The near degree dmin (i, poi)
dmin(i, poi) = dpi,POI(CurrentTime);
if (dmin(i, poi) <Communicaiton Range) return;
for(each CurrentTime< t<CurrentTime+ δ ) {
  if(dpi,POI(t)<dmin(i, poi))  dmin(i, poi) = dpi,POI(t);
  if (dmin(i, poi) <Communicaiton Range) return;
}
```

Fig. 2. Calculating the Near Degree to POI (pseudo-code)

```
Input :IntPkt bundles, neighbor vehicles set
Output: forward list
check and remove satisfied IntPkt();
for (each IntPkt pi in bundles buffer){
   get poi of IntPkt; read dmin(i, poi);
   for( each neighbor vehicle j){
      if( CS of j contains pi's desired named data) insert (pi,j) to forwarding list;
      else if (dmin(j, poi) is minimal dmin to POI) insert or update (pi,j) in forward list;
   }
}
transfer IntPkts according by forwarding list
```

Fig. 3. IntPkt Forwarding Process (pseudo-code)

4.2.2 Data Packets Forwarding

The better relay nodes would route DatPkt from the vehicle where IntPkt is satisfied, nearer or quicker to the moving consumer, which means that any vehicle that either goes closer to, or travels faster near, consumer should be the next carrier. Two conditions are considered: (1) The proximity of the trajectories of candidate node and target consumer before DatPkt expires; (2) The instant time when these two vehicles would travel closest. Unlike IntPkt forwarding, in DatPkt forwarding we consider the nearest distance between the trajectories of candidate vehicle and consumer vehicle before DatPkt expires. The consumer's trajectory in IntPkt appends in "trajectory info" field of DatPkt when DatPkt is generated.

Definition 3 (Trajectory Nearest Distance $d_{\min}(\mathrm{i}, \mathrm{c})$ to moving consumer): The vehicle *i*'s trajectory nearest distance to the consumer *c* before TTL of DatPkt TTL_{DatPkt} is defined as:

$$d_{\min}(\mathrm{i,c}) = \min d_{pi,\mathrm{pc}}(\mathrm{t}) = \min \sqrt{(\mathrm{x_{pi}}(t) - \mathrm{x_{pc}}(t))^2 + (y_{\mathrm{pi}}(t) - y_{\mathrm{pc}}(t))^2} \quad t \in [CurrentTime, TTL_{DatPkt}] \quad (3)$$

Definition 4 (Nearest Time $t_{near}(\mathrm{i,c})$): The nearest time $t_{near}(\mathrm{i,c})$ is defined as the earliest time when vehicle i and consumer c reach nearest distance $d_{\min}(\mathrm{i,c})$ apart.

$d_{\min}(\mathrm{i,c})$ and $t_{\mathrm{near}}(\mathrm{i,c})$ are calculated in the same way as $d_{\min}(\mathrm{i}, POI)$, the only difference is that the consumer's trajectory is obtained from DatPkt fields, rather than data name. They serve as metrics to determine next relay node of DatPkt and a comprehensive metric is defined as Definition 5.

Definition 5 (Comprehensive Nearest Metric $dt_{\min}(\mathrm{i,c})$): The comprehensive nearest metric $dt_{\min}(\mathrm{i,c})$ combines the nearest distance and nearest time. It is represented as formula (4).

$$dt_{\min}(\mathrm{i,c}) = k\frac{d_{\min}(\mathrm{i,c})}{D(\mathrm{n}_{sat},\mathrm{c})} + (1-\mathrm{k})\frac{t_{near}(\mathrm{i,c})}{TTL_{DatPkt}} \quad (4)$$

where $\mathrm{D}(\mathrm{n}_{sat},\mathrm{c})$ is the constant distance between consumer and the DatPkt provider vehicle when DatPkt is generated. *k* is the impact ratio of $d_{\min}(\mathrm{i,c})$ and $t_{\mathrm{near}}(\mathrm{i,c})$. Similar to IntPkt forwarding process, if contacting a vehicle with smaller $dt_{\min}(\mathrm{k,c})$ for a DatPkt, vehicle *i* forward this DatPkt to it, else vehicle *i* continues to be the carrier.

4.3 Receiving Process for Interest and Data Packets

The pseudo-code of processing an incoming IntPkt is shown in Fig. 4. Whenever an IntPkt is received, the node checks local CS. On name matching, the IntPkt is satisfied and corresponding DatPkt is generated. In case of local CS not containing desired data, unsatisfied interest is stored in PIT. Only one entry is created in PIT for the same data name. If there is no entry for this name, a new entry is created and consumer information from IntPkt is stored in request hosts list that stores all hosts requesting the same data. Otherwise, consumer information is appended or updated in the existing PIT entry of this name.

After receiving a DatPkt, the node check local PIT for corresponding interest. If current node is subscriber, the interest is satisfied and the data from DatPkt is stored in repository. If there is a PIT entry for this data, this PIT entry is deleted and the data is stored in local CS, then DatPkt is sent to each requested hosts respectively. Otherwise, DatPkt is discarded.

```
Input :incoming IntPkt received
Output:
get request name and consumer information from IntPkt and check local CS;
if(Local CS contains desired data){
   generate DatPkt containing the rest of TTL and Trajectory info from IntPkt;
   remove the IntPkt and add DatPkt into bundles buffer; }
else if (local PIT contains the name){
     if(consumer is not in request host list) insert consumer into Request Host List;
     else update consumer in Request Host List with new TTL and trajectory info; }
else { create new interest entry for name in PIT;
        add consumer into Request Host List of new entry; }
}
```

Fig. 4. IntPkt Receiving Process (pseudo-code)

4.4 Validity of Messages

The validity of message is also one of the important issues for GOFP. Firstly, a retention period is set for the data stored in CS. Its value is application-depended and indicates the freshness of data. After retention period has elapsed, the data is useless and will be deleted from CS. Secondly, IntPkt and DatPkt all contain TTL field: TTL of IntPkt is assigned by consumer to represent the expected latest time to obtain desired data and TTL of DatPkt is set as the rest of TTL of corresponding IntPkt. The node monitors the validity of each carried packets and discards the packet once its TTL expires. Consumer will resend the interest if it never receives desired data until TTL expires. Finally, each node maintains delivered packets information it knew. The node will delete any packet that is stored in its bundles buffer and is announced as delivered by neighbor nodes.

5 PERFORMANCE EVALUATION

To evaluate the performance of GOFP, we extended the Opportunistic Networking Environment (ONE) [13] simulator to support the proposed forwarding strategy and compared GOFP with two algorithms: (1) FirstContact [14], an opportunistic routing algorithm in which carrier vehicle forwards packets to the first contact vehicle. Like in GOFP, current carrier removes these packets after forwarding; (2) P-Random [14], another opportunistic routing protocol, which randomly decides whether or not to forward packets to other node by a certain probability and only one copy of every packet is retained in the network. In simulations, the probability is set to 0.2. The metrics used to evaluate GOFP for different vehicle densities include the hops of Interest Packet, the hops of Data Packet, the satisfied delay of Interest Packet and the delivery delay of Data Packet.

1. Simulation Scenario

The deployment scenario of simulation was the map of Helsinki city, Finland. There are four groups of vehicles: a stationary data provider with zero velocity at POI, two groups of cars with different velocity whose numbers are varied to construct different traffic density and a tram group with one tram node. The main simulation parameters are listed in Table 1.

Table 1. The Main Simulation Parameters

Parameter	Value
Simulation time:	21600 sec
Deployment field:	4500m × 3400m
Transmission Range:	Cars: 50m; Trams: 200m
Transmission rate:	Simple Interface: 250k; High Speed Interface: 10M
Node Speed (m/s):	The first group of cars: 2.2 - 8.34;
	The second group of cars: 2.7 - 13.9; Trams: 10 - 30
Traffic density:	40, 60, 80,100, 120
NDN Parameter:	Interest TTL: 180 min; Trajectory interval: 10 sec;
	Given period δ : 360 sec; Weight factor k: 0.0, 0.5, 1.0

For different traffic densities, the simulation was run 25 times with different movement random seeds. A vehicle was selected randomly as the consumer in each simulation and only a single IntPkt was generated at a preset time. Results are always presented with 90% confidence interval. Our goal is to just evaluate forwarding performance, thus the packet size is small and message drops are not considered.

2. Experimental Results

Fig. 5(a) presents the average number of hops of IntPkt resulting in different algorithms. The value of k has no effect on IntPkt forwarding in GOFP. GOFP outperforms two other algorithms to make the average hops of IntPkt holding steady under 20 nodes, which decreased respectively up to 85.8% and 69.8% over FirstContact and P-Random algorithms whenever vehicles density is low or high. FirstContact and P-Random algorithms all show a larger number of hops which increases as vehicles number increases. This is mainly because that it has more chance to contact and transmit IntPkt to other vehicles in high density situation. GOFP choose relay vehicle with optimal forwarding metric, thus, the vehicles density does not influence the average hops of IntPkt. Fig. 5(b) plots the average hops of DatPkt of different algorithms in varying vehicle destinies. With different values of *k*, GOPFs still have lower hops than FirstContact and P-Random. Though selecting next carrier vehicle at random, P-Random shows better performance than FirstContact that constantly attempts to forward the packets to first neighbors within its communication range.

Due to variation of *k*, GOFP presents different values for the average hops of DatPkt. When *k* equals 0, the nearest time metric is only considered to select next relay node; when *k* equals 1, only the nearest distance metric is considered; when *k* is 0.5, both nearest time and nearest distance are take into account. Fig. 5(b) shows that smaller hops are required when the nearest distance is used in next carrier selection (as *k=0.5* or *k=1*), while for *k=1*, hops are higher. This is caused by the fact that the vehicle with nearest trajectory distance may carry DatPkt closer to consumer and potentially reduce the forwarding frequency.

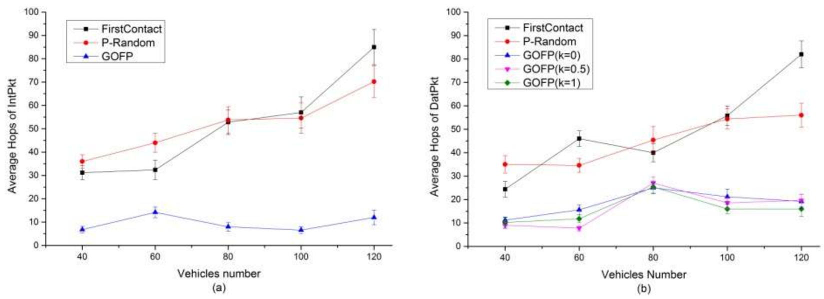

Fig. 5. Average Number of Hops of IntPkt and DatPkt in Different Algorithms

Figure 6(a) presents the average satisfied delay of IntPkt, taken as the difference between the instant in time when IntPkt is generated and the instant in time when IntPkt is satisfied by a vehicle holding desired data. GOFP exhibits a 74%-89.1% delay improvement over the FirstContact and P-Random algorithms under different vehicles density. This verifies the effectiveness that the trajectory distance to POI can indicate if the vehicle is moving towards to POI in next period of time. The average success delivery delay of DatPkt is presented in Fig. 6(b), which describes the difference from the time instant when the consumer sends out interest to the time instant when it receives desired data. FirstContact and P-Random present unstable performance, as their delivery delay depends much on specific situations, which means that they only have better performance when the consumer is in a relatively near area. As one can see, average delivery delay of GOFP is significantly lower, no matter how many vehicles are on the road. Though only little differences between GOFPs with various value of k, it still can be seen in Fig. 7(a) that the delay is a little lower if the shortest time is used in next carrier selection (as *k=0* or *k=0.5*). This is mainly due to the vehicle with shortest time being able to forward packets faster near to the consumer.

Fig. 7(b) shows how GOFP performs under different values of k in the transmission delay which is the difference between the time instant when DatPkt being sent to the network and the time instant when the consumer receives it. It is obvious that the higher the vehicles density is, the less delay the GOFPs exhibit. Besides, when *k* equals 0 or 1, only shortest time or nearest distance is taken into account to select next carrier vehicle separately, which is incomplete and has unstable performance, while GOFP with k=0.5 is better and presents satisfactory performance.

These simulation results show that GOFP has a better performance than those other two similar routing strategies, both in terms of lowering the average hops and delay.

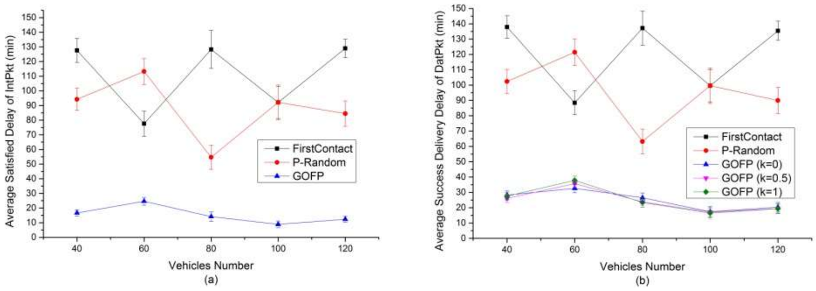

Fig. 6. Average Satisfied Delay of IntPkt and Delivery Delay of DatPkt (GOPF vs others)

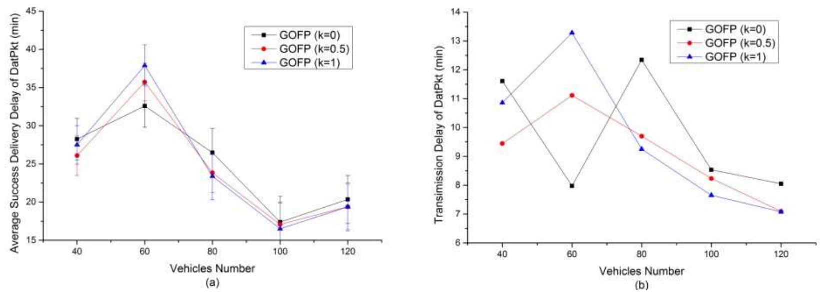

Fig. 7. Average Success Delivery Delay and Transimission Delay of DatPkt in GOFP 6. CONCLUSIONS

This paper proposed GOFP, a new Geographic Opportunistic Forwarding strategy for Vehicle Named Data Networking. Through using geographic position of POI and vehicles trajectories, the different forwarding strategies are provided for IntPkt and DatPkt, respectively, in GOFP. The ONE simulator is extended to evaluate GOFP and the simulation results show that GOFP has better performance and outperforms other two similar algorithms.

As future work, the interval of vehicles' trajectory will be evaluated and the trams with fixed route, in-line with the findings in [15], will be also considered in message delivery, in order to reduce the amounts of trajectory information in packets.

Acknowledgments

This work is supported in part by the Fundamental Research Funds of Jilin University, No. 450060491509 and partially supported by FCT - Fundação para a Ciência e Tecnologia Portugal in the scope of the project: UID/CEC/00319/2013.

REFERENCES

[1] Ahlgren B, Dannewitz C, Imbrenda C, et al. "A survey of information-centric networking"[J]. Communications Magazine, IEEE, 2012, 50(7): 26-36.

[2] Jacobson V, Smetters D K, Thornton J D, et al. "Networking named content"[C], Proceedings of the 5th Int. Conf. Emerging Networking Experiments and Technologies. ACM, 2009: 1-12.

[3] Karp B and Kung H T. "GPSR: Greedy perimeter stateless routing for wireless networks"[C], Proceedings of the 6th Int. Conf. Mobile Computing and Networking. ACM, 2000:243-254.

[4] Ramakrishna M, "DBR: Distance Based Routing Protocol"[J], International Journal of Information and Electronics Engineering, 2012 Vol.2(2): 228-232

[5] Leontiadis I, Mascolo C. "GeOpps: geographical opportunistic routing for vehicular networks"[C], IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks 2007, Espoo, Finland, June 18–21, 2007: 1–6.

[6] Soares V N G J, Rodrigues J J P C, Farahmand F. "GeoSpray: A geographic routing protocol for vehicular delay-tolerant networks"[J], Information Fusion, Vol. 15, Jan. 2014, pp. 102 – 113

[7] Grassi G, Pesavento D, Pau G, et al. "VANET via Named Data Networking"[C], 2014 IEEE INFOCOM Workshops on Name-Oriented Mobility, 2014:410-415.

[8] Wang L, Afanasyev A, Kuntz R, et al. Zhang. "Rapid traffic information dissemination using named data"[C]. 1st ACM Work. on Emerging Name-Oriented Mobile Networking Design - Architecture, Algorithms, and Applications. ACM 2012: 7–12.

[9] Kuai M, Hong X, Flores R R, "Evaluating Interest Broadcast in Vehicular Named Data Networking"[C], Research and Educational Experiment Workshop,2014 Third GENI. IEEE,2014:77-78.

[10] Pesavento D, Grassi G, Palazzi C E, et al. "A Naming Scheme to Represent Geographic Areas in NDN"[C], Wireless Days (WD), 2013 IFIP. IEEE,2013:1-3.

[11] Yu Y T, Dilmaghani R B, Calo S, et al. "Interest propagation in named data MANETs"[C], Int. Conf. Comput. Netw. Commun. IEEE, 2013: 1118–1122.

[12] Lu Y, Li X, Yu Y T, et al. "Information-Centric Delay-Tolerant Mobile Ad-Hoc Networks"[C], INFOCOM 2014, WKSHPS, 2014 IEEE Conference on. IEEE,2014:428-433.

[13] Keränen A, Ott J, Kärkkäinen T. "The ONE simulator for DTN protocol evaluation"[C], Proceedings of the 2nd Int. Conf. on simulation tools and techniques. ICST (Institute Computer Sciences, Social-Informatics and Telecommunications Engineering), 2009: 55.

[14] Jain S, Fall K, Patra R. "Routing in a delay tolerant network"[C], Proceedings of the Conference on Applications, Technologies, Architectures, and Protocols for Computer Communications. ACM, 2004: 145–157.

[15] Hadiwardoyo S, Santos A. "Deploying Public Surface Transit to Forward Messages in DTN"[C], 11th Int. Wireless Commun. Mobile Computing Conf., Dubrovnick, Croatia, Aug 24-27, 2015.