Content-Centric Routing Scheme Combined with Traffic Infrastructure in Urban VANET

Hui Guo,Lanlan Rui, Jiawen Li, Biyao Li, Zhen Xia, Xuesong Qiu
State Key Laboratory of Networking and Switching Technology
Beijing University of Posts and Telecommunications
Beijing 100876, China
E-mail: guohui@bupt.edu.cn, llrui@bupt.edu.cn, 18800101516@163.com, libiyao@bupt.edu.cn, xaly@bupt.edu.cn
xsqiu@bupt.edu.cn

Abstract*—*It is difficult for TCP/ IP to manage the mobile nodes in the dynamic environment of VANET, and the traffic infrastructure in urban can be of great help to VANET routing process, so combining urban VANET with ICN and traffic infrastructure, this paper proposes a new routing scheme-CRTI for urban VANET. Firstly, CRTI gives up broadcasting Interest, it introduces a registration mechanism, every vehicle needs to choose a directly connected RSU or TCC node as its registration node; Secondly, based on the registration nodes, we also design a content node locating process to get the destination content node; Finally, according to the registration nodes and content nodes, CRTI would build a routing path for Interest to request the content, which aims at turning the mobile routings into partial static routings. Simulation results have shown that compared with TCP/IP, CCVN and V-NDN, our scheme is more efficient.

Keywords*— *urban VANET, ICN, traffic infrastructure, registration mechanism

I INTRODUCTION

As the most important part of Intelligent Transportation System (ITS) [1], the research of VANET (Vehicular Ad-hoc Network) [2, 3] has attracted more and more attention, and in this paper, we mainly focus on the main two issues in urban VANET.

- Traditional TCP/IP architecture cannot handle the mobile network well, and in [4], authors summarized the main shortcomings in the following aspects. First, assigning IP addresses to moving nodes is difficult. Second, as technological advances have brought greater-than-ever numbers of computing devices. Third, a node meets an application's request only by selecting a specific node to send data to, which is inefficient and it is easy to result in suboptimal data delivery. Finally, the binding between a mobile node and its current IP address is critical, and with high node mobility, a node suffers from high overhead to keep the binding updated, a loss of connectivity due to outdated binding information, or both.

- In order to get a better service, ITS has set a series of traffic infrastructures in urban environment, such as RSU (Road Side Unit), TCC (Traffic Control Center), and so on. The above infrastructures have a strong ability to collect the traffic information, and as their fixed location we can locate them quickly. However, there are few VANET routing strategies have considered combining with the fixed traffic infrastructures, and most of routing process apply a flooding way, which is easy to result in lots of useless network traffic and data collision, it lowers the network performance badly.

Bearing the first issue, this paper suggests solutions using the named data in mobile networks and gives up the IP architecture.

Different from TCP/IP, information-centric networking (ICN) [5] focuses on whether the Interest packets can be satisfied. It neglects the position of a source node and its destination node. Thus, ICN transforms the network mode from host-centric to content-centric, and it is mainly designed around the following idea: 1) Packets in ICN are divided into two types: Interest and Data, and communication in ICN is driven by data consumers. 2) An on-path [6] caching mechanism reduces network traffic and improves the efficiency of information distribution. 3) Network security can be realized by ensuring that the content is secure. 4) Routing forwarding in ICN is completed by three important structures: CS (content store), PIT (pending interest table), and FIB (forwarding information base).

The CS caches contents that have been forwarded. The PIT records track the mapping between incoming interfaces and pending interest packets that have arrived but have not been served yet. The FIB maps prefixes of content names to one or multiple output interfaces that indicate next hop routers.

When a node receives an Interest, it firstly searches for a content name match in its CS. If the content is found, a Data packet will be sent as a reply; otherwise, it will check whether there is a corresponding entry in PIT. If so, the node will record the interest packet and then drop it or it will forward the packet via FIB. However, if FIB is also missed, the Interest will be dropped. Together, the ICN features remove the address limitation in TCP/IP and make it easy to manage mobile nodes. Content-centric networking [7] (CCN) and named data networking [8] (NDN) are the most prominent interest-based ICN architectures.

What's more, to make full use of the traffic infrastructures, in this paper, based on ICN architecture, we propose a new VANET routing scheme, which combines with the Bus, RSU

The work is supported by National Natural Science Foundation of China (61302078, 61372108), 863 Program (2011AA01A102), Funds for Creative Research Groups of China (61121061)

and TCC fully to create some unicast routings, and we name it as CRTI (Content Routing combined with Traffic Infrastructures).

The rest of the paper is organized as follows: Section 2 describes related work regarding VANET working with the ICN design idea and some urban VANET routing schemes. In Section 3, we describe our CRTI scheme in detail. Then, the simulation results in Section 4 demonstrate our strategy's efficiency and superiority. Finally, in Section 5, we conclude our paper and propose future works.

II RELATED WORKS

A. VANET with ICN

In [9], the authors conclude the main shortcomings for mobile network based on IP protocol, and then some researchers have aimed at applying ICN idea to VANET.

In [10], the DMND (Collecting Data from Mobile Using Named Data) model is proposed aiming at building a new architecture that can effectively handle vehicular mobility, intermittent connectivity, and data security. Different from the idea of our CRTI, the authors use a base station to broadcast routing announcements, *Interest* packets, and even PIT entries. Then, it assigns each piece of data a name that can be directly used by the applications, which is different from DONA [11] and PSIRP, [12] whose name data uses cryptographic-based flat identifiers. Then based on [10], the same authors in [13] have realized that the broadcasting method easily results in data collision in the wireless channel. So they have embedded the geo-location information into data names in a V2V (vehicle-to-vehicle) scenario, wherein the NDN layer can explain the name on a higher semantic level, making the forwarding more intelligent. Different from our thinking, it improves its naming mechanism and defines some timer structures to avoid data collision.

Similarly, with the inspiration of NDN architecture, Grassi G and others put forward the concept of V-NDN [14]. In V-NDN, a vehicle node can play four roles: consumer, producer, forwarder, and "data mule." The main idea in V-NDN is as follows. First, it takes full advantage of the nature of wireless broadcast, a vehicle may want to cache all received data regardless of whether it has a matching PIT entry or whether it needs the data for itself. Second, *Data* packets can be carried in moving vehicles even without network connectivity. Furthermore, V-NDN applies a simple greedy forwarding strategy to spread NDN interest packets in all directions. Therefore, the design in V-NDN is exactly the opposite of our idea. It tries its best to take advantage of the broadcast channel to decrease the negative impacts caused by high volatility and intermittent connectivity.

Authors in [15] design a CCVN framework, which relies on the main CCN pillars. Without using a completed broadcast method, CCVN enforces a simple counter-based approach coupled with deferred transmission timers and interest retransmission routines. Firstly, it divides *Interest* packets into *B-Int* and *A-Int* upon different functions. When there is an *Interest*, the requester uses a *B-Int* packet to locate the producers and then chooses a preferable content node to ask for series of data with an *A-Int*. Moreover, *Interest* forwarding is based on a counter; an *Interest* packet would be broadcast only the first time it is received. To ensure transmission reliability, CCVN also designs a timer for each *Interest* to deal with retransmission and prevent data loss. The design idea of CCVN is similar with our CRTI to a certain degree: first we both want to locate the content nodes before the real request process, then CCVN also thinks a broadcast packets is unnecessary; thus, it uses a hop counter as a broadcast limitation.

To examine whether the potential ICN benefits are suitable to a VANET environment, in [16], authors consider two ICN-specific design options: data source selection policies and caching policies. Then some researchers in [17] have analyzed the propagation behavior of *Interest* and *Data* packets in VANETs and proposed the CODIE scheme to control the data flooding/broadcast storm in the naïve V-NDN. The main idea of CODIE is to allow the consumer vehicle to start a hop counter for an *Interest* packet. But when the density of a vehicle is increasing, the hop numbers between two nodes may be greater than before.

B. VANET Routing in Urban Environment

The packets' routing process of VANET can be divided into two phases: carrying phase and forwarding phase, when a node has no idea about how to handle a packet, it would carry it until the packet can be forwarded, thus the network delay is mainly generated at the carrying phase.

In [18], some researchers propose a new data forwarding scheme and construct a new link delay model- Vehicular Carry and Forward Model (VADD). To obtain the minimum transmission delay, they adopt a random traffic flow model in their simulations, and based on the road traffic density, vehicles on different roads would get their different carrying and forwarding priority.

Another idea for VANET routing scheme is based on the vehicle trajectory. For example, TSF [19] is an algorithm based on the vehicular movement journey, to decrease the network delay, it chooses an optimal RSU as destination node, then calculating the expected delivery delay (EDD) upon the nodes' trajectory. Every node in TSF would like to share their calculated EDD with others, and the one who has a least EDD value would be the next hop. What's more, in [20], the authors came up with a routing scheme that is based on the Statistics of the vehicle movement trajectory, different with TSF, it focuses on the information delivery between vehicles and RSU, but TSF pays attention to the information delivery among RSUs. Paper [21] shows a data delivery scheme based on the shared trajectory information for V2V communication. It apply a prediction scheme, and to make the network predictable, vehicles need to share their trajectories all the time. However, in a real world, people do not want to reveal their travel information to others in most cases.

The concept of using the public traffic for data delivery process has been proposed in [22], authors design a BusNET architecture, which tries to take advantage of the public traffic to improve the communication among vehicular nodes. Similar to the idea of [22], paper [23] introduces a dual VANET architecture, bus nodes construct the backbone network for the data transmission, and routing nodes have been divided into two tiers: the one is composed of regular vehicular nodes, and bus nodes lie in the other tier. On the basis of the nodes' speed, direction and location, the above architecture can estimate the link connection time roughly, the authors also design a registration method for regular nodes, then through registering the bus node with a longest connection time, a vehicular nodes can transfer its data delivery mission to its registration node.

In [24], the authors make buses as the data mule to complete the collection and dissemination process of information. Buses move along the predetermined route, at the same time, they do not only collects the information of the surrounding vehicles, but also delivery their carried information to them, which enlarges the coverage area of messages. Moreover, researchers in [25] design a mathematic metric-Expected Min-Max Delay (EMMD) to select some bus nodes as relay nodes, on the basis of the schedule of the buss nodes, they compute the maximum and minimum dealy for each potential routing path, and finally the path with the least maximum delay would be applied.

III CRTI DESIGNING

A. Designing Principles

In the urban environment, in order to collect and control the traffic flow, ITS has set a series of fixed traffic infrastructures such as RSU, TCC. Through our study, we have found that there are some VANET routing schemes based on the bus schedule and trajectory prediction, but few strategy has considered to take advantage of RSU and TCC, which has a wide transmission range and strong ability to collect the traffic information. Therefore, in this paper, we have designed a new urban VANET roting scheme- CRTI (Content Routing combined with Traffic Infrastructures), whose work mechanism is not only based on ICN architecture, but also combined with the function of RSU and TCC.

Firstly, the routing nodes in CRTI can be divided into 4 types: regular vehicular nodes, bus nodes, RSU nodes and TCC nodes. Our design is on the basis of the following hypothesises:

- All of the vehicles, buses, and RSU nodes are equipped with DSRC devices, GPS and digital maps to help with getting the real-time traffic information.
- Vehicular nodes know the time table and trajectory of each bus, and they also master the location of each RSU and TCC nodes.

Secondly, we introduce a registration mechanism in CRTI, every vehicle needs to choose a directly connected RSU or TCC node as its registration node.We design the registration process under the following considerations. By using the registration node, CRTI can locate the destination nodes quickly. Moreover, as the buses' movement is predictable and the transmission range of RSU is much larger than the vehicles, using the registration nodes to complete the data delivery can be more efficient. However, there are some issues need to be considered for the registration process. Such as, when there are multiple bus and RSU nodes around a vehicle, how should it to choose an optimal registration node? Or, what are the metrics for the selecting process? If there is no bus or RSU node around a vehicle, what should it do?

In ICN design, the Data packets return along with the Interest packets' reverse request paths, so the key design of CRTI is the request process of Interest packet.

B. CRTI Designing

1) Choosing Registration Nodes

In the proposed CRTI scheme, each vehicle node needs to sign up for a nearby Bus or RSU as its registration node. However, if a vehicle node receives bacon messages from multiple neighboring Bus or RSU nodes, how should the registration node be chosen? And how to determine the connection loss between vehicle nodes and their registered nodes?

When a vehicle node receives the bacon message from a Bus or RSU, the Bus or RSU node would be considered as a candidate for the registration node and added to a candidate set, when the vehicle node has a link failure with its registered Bus or RSU node lost contact, it would need to re-register a Bus or RSU node from the candidate set.

CRTI estimates the packet transmission delay based on distance and traffic density, and uses it as a metric to judge the connection interruption. Since each vehicle node knows its own route and speed, it can predict its location at any time. When the predicted transmission delay between two nodes is greater than a given threshold T, the connection between the two is considered to be interrupted.

Because the data can be carried or forwarded by a node, the packet transmission delay consists of two parts: carrying and forwarding, the following definitions are used to calculate the packet transmission delay:

- L_{ij} : The road length from intersection i to intersection j
- L_f and L_c : The distance of forwarding and carrying phase separately;
- d_{ij}: The packet transmission delay from intersection i to intersection j
- v_{ij}: The average speed of the vehicle on the road r_{ij}

If the communication range of vehicle R is less than L_{ij}, we need to divide the L_{ij} into several intersection parts, and for a road section, the transmission delay can be expressed as:

$$\begin{cases} d_{i,j} = \alpha \times \frac{L_f}{R} + \frac{L_c}{v_{i,j}} \\ L_f = P[F] \times L_{i,j} \\ L_c = L_{i,j} - L_f - R \end{cases} \tag{1}$$

Where α is a constant to adjust the transmission delay, $P[F]$ represents the probability when the packets are in the forwarding phase, if the distance between vehicles follow the exponential distribution, $\rho_{i,j}$ is the traffic density from the road intersection i to road intersection j, then there are:

$$P[F] = 1 - e^{-R\times\rho_{i,j}} \quad (2)$$

The total packet transmission delay is:

$$\mathrm{D} = \sum_{\substack{m\le x\le n-1\\ m+1\le y\le n}} d_{x,y} \quad (3)$$

However, considering that the transmission distance between vehicles is greater than the road length $L_{i,j}$, the transmission delay is no longer calculated based on each road segment. Using distance L (AB) to represent the distance between the vehicle node A and its registration node B. The distance between them is the sum of the distances of all road segments on the transmission path. Figure 1 gives an example.

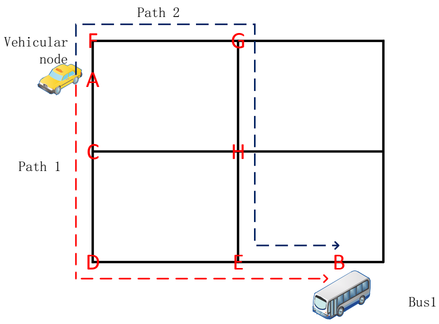

Fig 1. Distance between vehicular node and registration node

And we can get:

$$\mathrm{L1(AB) = L(AC) + L(CD) + L(DE) + L(EB)} \quad (4)$$

$$\mathrm{L2(AB) = L(AF) + L(FG) + L(GH) + L(HE)} \\ \mathrm{+L(EB)} \quad (5)$$

Thus the transmission delay from A to B can be expressed as:

$$\begin{cases} D(AB) = \alpha \times \frac{L_f}{R} + \frac{L_c}{v_{A,B}} \\ L_f = P[F] \times L_{A,B} \\ L_c = L_{A,B} - L_f - R \end{cases} \quad (6)$$

Since there may be multiple possible packet transmission paths, CRTI would pick one of the paths with the least delay, and if there are n possible paths, then:

$$\mathrm{EstimatedDeliveryDelay} = \min\{D_1, D_2, D_3, \dots, D_n\} \quad (7)$$

In order to identify when a vehicle losts contact with its candidate nodes, CRTI would check the connection between the node and its candidate Bus or RSU nodes at each intersection. In addition, a Bus or RSU node at an intersection is considered lost contact, but at other intersection and it is in the connection state, which means the lost time is very short, so removing the candidate nodes is not reasonable in the above case. Therefore, CRTI sets a threshold N_t as the maximum tolerated time for connection loss, if the connection loss time is more than N_t, then the Bus or RSU node would be removed from the candidate set.

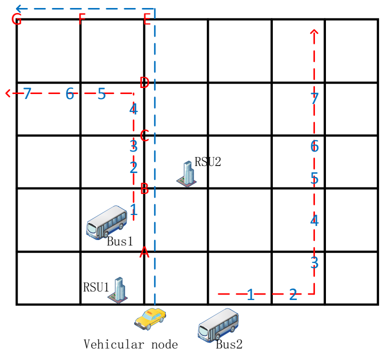

Fig 2. Choosing a Registration Node

Figure 2 shows an example where a vehicle node has four candidate registration nodes: Bus1, Bus2, RSU1, and RSU2. The blue line represents the vehicular route, and the red line represents the Buses's route. When the vehicular node reaches the junction A, the Bus1 arrives at its own point 1 (blue digital point). When the vehicular node moves to the junction B, the Bus1 arrives at its own point 2. At the intersection C, the transmission delay between the vehicular node and Bus2 is greater than the threshold T and the connection would not recover at later, which means their connection lost time would be greater than the maximum tolerance time of N_t, so Bus2 would be deleted from the candidate set. Similarly, RSU1 would be removed from the candidate set, and eventually the vehicle would select Bus1 as the registration node.

2） Locating the Content Nodes

After the nodes have registration nodes, the requester would want to locate the content nodes.

Each Bus or RSU node would maintain a registration table to record the vehicular nodes who has registered them, and the information in the registration table would be reported to the TCC nodes periodically. TCC nodes would also have a location table to store the information collected from the above reporting process. Table 1 shows an example about the location table in TCC1.

To decrease the workload of TCC nodes, CRTI sets the Bus or RSU nodes report their registration information to TCC periodically. However, if the reported information is not fresh, which means the registration information of some vehicular nodes have changed, then in order to deliver the Interest to the correct content nodes, CRTI sets that the old registration nodes would follow the vehicular node who have registered another Bus or RSU node. Table 2 has shown an example about the registration table of Bus1, the null entries represent the registration node is the local node, if a vehicular node has registered a new Bus or RSU node, it needs to inform the precious registered node to follow the vehicular node until the registration table update.

TABLE 1 LOCATION TABLE OF TCC1

Bus or RSU ID	***Vehicular ID***
Bus1	Vehicle1
	Vehicle2
	Vehicle4
Bus2	Vehicle3
RSU1	Vehicle5

TABLE 2 REGISTRATION TABLE OF BUS1

Vehicular ID	***Registration nodes ID***
Vehicle 1	Null
Vehicle 2	Null
Vehicle 3	Bus 2

In addition, each TCC node maintains a content table to record the CS entries of its surrounding nodes. Each node (vehicle, Bus or RSU) would periodically send a content announcement message to the TCC node within its transmission range. Moreover, TCC periodically updates its content table based on the received announcement message, taking the content table in TCC1 (Table 3) as an example.

TABLE 3 CONTENT TABLE OF TCC1

Content ID	***Content storage node ID***
ccnx/district1/name1	Vehicle 1
	Bus 1
ccnx/district1/name2	Vehicle 2
ccnx/raod1/name1	RSU 3

What's more, in order to reduce the unnecessary repeated content locating process, CRTI adds a provider ID to the Interest packet, and the node would also check the provider ID domain during the request process.

When an Interest arrives at a node N1, according to the ICN design, the N1 node would search its CS, PIT and FIB orderly, if anyone of the above three data structures hits, the Interest request process ends. However, if CS, PIT and FIB all miss, the N1 node would check whether the provider ID of the Interest is null, if it is not mull, then there is no need to have a content locating process; otherwise, the N1 first needs to locate the destination node and then write the provider ID domain. With different types of request nodes, the content node locating process can be divided into two cases:

- If N1 is a vehicular node, it needs to send a CQReq (Content Query Request) message to its registration node R1, and the message contains the N1 node ID and the requested content ID; then R1 would send the CQReq to the TCC node T1, which is in its transmission range; next, T1 would search its content table, if a corresponding table is found in content table, T1 would construct a CQRep (Content Query Reply) message to R1, the CQRep message contains the content ID and the corresponding ID of the content node N2; finally, R1 would send CQRep to N1. But, if the content table of T1 misses, T1 would request for other TCC nodes, when there is a CQRep returns, T1 would send it to R1, and then it arrives at N1. Otherwise, each CQReq message has a lifetime, when the message is timeout, the request node will think the Interest can not be satisfied.
- If N1 is a Bus or RSU node, the locating process are the sub-process of the above design. N1 would send a CQReq message to the TCC node T2 within its transmission range, T2 would query its content table, if it finds the corresponding table, it then constructs a CQRep message to N1, and N1 completes the content node locating process. If the content table in T2 does not have a record for CQReq, then T2 continues to make requests to other TCC nodes.

3） Building Routing Paths

When N1 successfully locates the destination node N2, it writes the provider ID domain in Interest, and then constructs a request path from the request node to the destination content node.

According to different types of source node and destination node, CRTI has divided the communication into the following three types: V2V, V2I and I2V. And here we take the V2V as an example.

When N1 and N2 are both vehicular nodes (V2V), at first, N1 sends a location request message (LReq) to its registration node R1, and there are the ID information of N1 and N2 in LReq message, then R1 sends LReq to the TCC node T1 within its transmission range, after receiving LReq T1 would query its location table to find the the registration node R2 of N2, if the location table hits, T1 would reply a location reply message(LRep) to R1, and then R1 tells N1. However, if the location table of T1 misses, T1 would send the LReq to other TCC nodes.

After getting the LRep, the original Interest packet would be transmitted from N1 to R1, then R1 would send the Interest to R2 through a series of other traffic infrastructure nodes, finally R2 would give the Interest to N2. During each of the above Interest packet transmission process, each node writes its PIT and FIB to ensure the Data packet can be successfully returned.

Finally, N2 constructs a corresponding Data package and returns it to the N1 based on the PIT record.

IV SIMULATION RESULTS ANALYSIS

A. Transmission Efficiency

As shown in Figure 3, 4, and 5, slots on the black lines indicate a transmission efficiency equal to that of our scheme. We can see TCP/IP has the worst results, CCVN is slightly better than V-NDN. We think it is because TCP/IP takes too much time to find the destination, whereas the other three schemes do not care where the hosts are, and our CRTI avoids broadcasting and selects optimal outgoing interfaces in FIB.

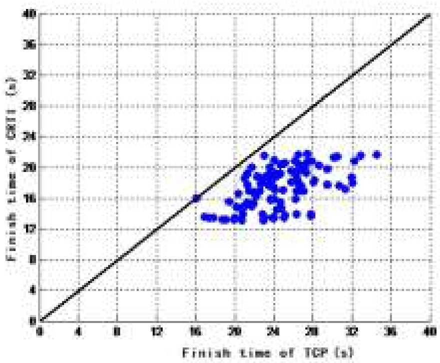

Fig 3. Transmission efficiency comparison with TCP

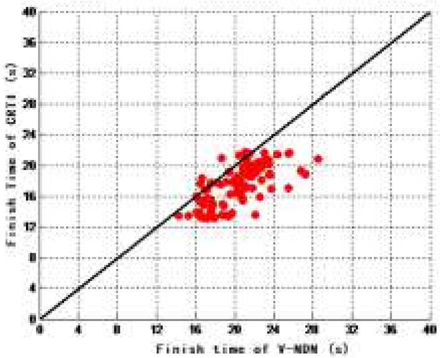

Fig 4. Transmission efficiency comparison with V-NDN

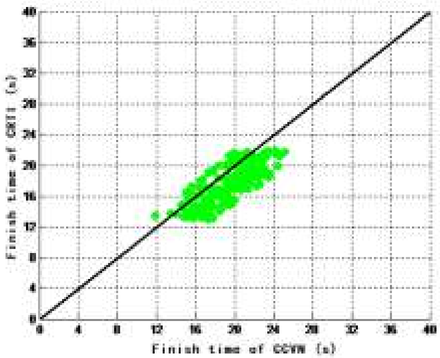

Fig 5. Transmission efficiency comparison with CCVN

B. Response Time

$$ART_i = \frac{\sum_{j=1}^{i} Time_j}{i} \qquad (8)$$

ART_i(Average Response Time) is the average response time within the first i seconds. $Time_j$ is the response time at the j_{th}s.

As shown in Figure 6, our CRTI performs better than the other schemes. CCVN has a closer result with our CRTI: before 60 s, CRTI is better on the average response time. However, after 60 s, we can see the results of V-NDN, CCVN and CRTI reach a steady and similar state. We think it is because of the content caching in ICN, after the network initialization is complete, no matter which scheme (V-NDN, CCVN or CRTI) the nodes are configured, the nearest content caching can respond to the Interests immediately. But In the real VANETs environment, the network topology and nodes' parameters change frequently, the information in CS, PIT and FIB would need to be updated continually, and the result in Figure 6 exactly shows that our CRTI outperforms than others especially in the network initialization process.

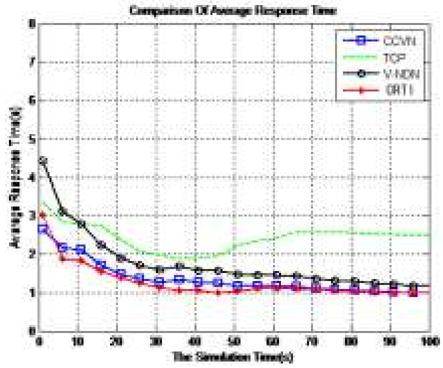

Fig 6. Comparison of average response time

C. Network Traffic

We compare the instantaneous network traffic in our simulation. As shown in Figure 7, at the start stage, we can see the results are close, but with time increases, the curves begin to fluctuate, the volatility of the V-NDN is the biggest and at 49s its instantaneous flow is close to 1100 kbps. With time goes by, our CRTI has a more significant decline compared to V-NDN and CCVN. From the overall performance, CRTI achieves a lowest traffic successfully among all the schems.

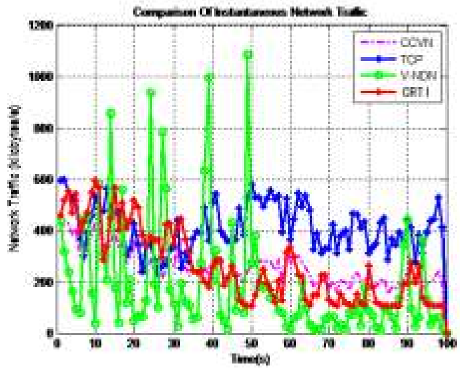

Fig 7. The Comparison of Instantaneous Network Traffic

V CONCLUSION

In this paper, we adopt a new ICN architecture to deal with the mobile VANET, which neglects the drawbacks of TCP/IP. Moreover, based on the urban environment, CRTI combines with the traffic infrastructure to change the mobile routings into partial static routings. Through simulation, we have proved the efficiency of our design.

REFERENCES

[1] Lister M, Christie B, Lowrance C (2011) Educating tomorrows transport professionals-ITS standards. In: 18th World Congress on Intelligent Transport Systems and ITS America Annual Meeting, pp. 6036-6043. https://itswc.confex.com/itswc/WC2011/webprogram/Paper1781.html

[2] Cunha F, Villas L, Boukerche A (2016) Data communication in VANETs: Protocols, application and challenges. Ad hoc Networks 44: 90-103. doi: 10.1016/j.adhoc.2016.02.017

[3] Sahoo PK, Chiang MJ, Wu SL (2014) SVANET: A Smart Vehicular *Ad Hoc* Network for Efficient Data Transmission with Wireless Sensors. Sensors 14: 22230-22260. doi: 10.3390/s141222230

[4] Meisel M.; Pappas V.; Zhang L.X. Ad hoc networking via named data, In fifth ACM international workshop on Mobility in the evolving internet architecture, pp 3-8. doi: 10.1145/1859983.1859986

[5] Jun L.; Zhen C. Xi S. The research of ICN architecture and technology. Netinfo Security, 4:75-80. doi: 10.3969/j.issn.1671-1122.2012.04.021

[6] Arifuzzaman M.; Yu K. P.; Quang N. N.; Sato T. Locating the Content in the Locality: ICN Caching and Routing Strategy Revisited. In 2015 European Conference on Networks and Communications, pp 423-428. doi: 10.1109/EuCNC.2015.7194111

[7] CCNx | PARC's implementation of content-centric networking. http://www.ccnx.org/

[8] Named Data Networking - A Future Internet Architecture. http://named-data.net

[9] Meisel M.; Pappas V.; Zhang L.X. Ad hoc networking via named data, In fifth ACM international workshop on Mobility in the evolving internet architecture, pp 3-8. doi: 10.1145/1859983.1859986

[10] Wang JZ, Ryuji W, Zhang LX (2010) DMND: Collecting data from mobiles using Named Data. In: 2010 IEEE Vehicular Networking Conference, pp 49-56. doi: 10.1109/VNC.2010.5698270

[11] Koponen T.; Chawla M.; Chun B.-G.; Ermolinskiy A.; Kim K. H.; Shenke S.; Stoica I. A Data-Oriented (and Beyond) Network Architecture. In Proceeding of SIGCOMM 07, 2007.8.27-2007.8.31; pp 182-192. doi: 10.1145/1282380.1282402

[12] Fotiou N.; Polyzos G. C.; Trossen D. Illustrating a Publish-Subscribe Internet Architecture. Telecommunication System, 51(4): 233-245. doi: 10.1007/s11235-011-9432-5

[13] Lucas W.; Romain K.; Alexander A.; Rama V.; Ryuji W.; Zhang L. X. Rapid traffic information dissemination using named data. In Proceedings of the 1st ACM workshop on Emerging Name-Oriented Mobile Networking Design - Architecture, Algorithms, and Applications, June 2012 NoM '12

[14] Grassi G, Pesavento D, Pau G, Rama V, Ryuji W, Zhang LX (2014) VANET via Named Data Networking. In: 2014 IEEE Conference on Computer Communication Workshops, pp 410-415. doi: 10.1109/INFCOMW.2014.6849267

[15] Amadeo M, Campolo C, Molonaro A (2013) Enhancing Content-Centric Networking for Vehicular Environments. Computer Networks 57(16): 3222-3234. doi: 10.1016/j.comnet.2013.07.005

[16] Yu Y. T.; Gerla M. Information-centric VANETs: A study of content routing design alternatives, In Proceeding of 2016 International Conference on Computing, Networking and Communications (ICNC), 2016.2.15-2016.2.18; pp 1-5. DOI: 10.1109/ICCNC.2016.7440705

[17] Syed H. A.; Safdar H. B.; Muhammad A. Y.; Donkyun K.; Houbing S.; Jaime L. CODIE: Controlled Data and Interest Evaluation in Vehicular Named Data Networks. IEEE Transactionson Vehicular Technology, 65(6): J. Zhao and G. Cao, "VADD: Vehicle-assisted data delivery in vehicular

[18] ad hoc networks," *IEEE Trans. Veh. Technol.*, vol. 57, no. 3, pp. 1910–1922, May 2008.3954-3963. doi: 10.1109/TVT.2016.2558650

[19] J. Jeong, S. Guo, Y. Gu, T. He, and D. H. C. Du, "TSF: Trajectory-based statistical forwarding for infrastructure-to-vehicle data delivery in vehicular networks," in *Proc. IEEE Int. Conf. Distributed Computing Systems*, 2010, pp. 557–566.

[20] J. Jeong, S. Guo, Y. Gu, T. He, and D. H. C. Du, "Trajectory-based data forwarding for light-traffic vehicular ad hoc networks," *IEEE Trans.Parallel Distrib. Syst.*, vol. 22, pp. 743–757, May 2011.

[21] F. Xu, S. Guo, J. Jeong, Y. Gu, Q. Cao, M. Liu, and T. He, "Utilizing shared vehicle trajectories for data forwarding in vehicular networks," in *Proc. IEEE INFOCOM*, Apr. 2011, pp. 441–445.

[22] K.-J. Wong, B. S. Lee, B. C. Seet, G. Liu, and L. Zhu, "BUSNet: Model and usage of regular traffic patterns in mobile ad hoc networks for inter-vehicular communications," in *Proc. Patterns Mobile Ad Hoc Networks Inter Vehicular Communications*, 2003.

[23] J. Luo, X. Gu, T. Zhao, and W. Yan, "MI-VANET: A new mobile infrastructure based VANET architecture for urban environment," in *Proc. IEEE Vehicular Technology Conf. Fall*, Sept. 2010, pp. 1–5.

[24] T. Kitani, T. Shinkawa, N. Shibata, K. Yasumoto, M. Ito, and T. Higashino, "Efficient VANET-based traffic information sharing using buses on regular routes," in *Proc. IEEE Vehicular Technology Conf. Spring*, 2008, pp. 3031–3036.

[25] C. Li, L. Zhijun, and J. Shouxu, "An efficient routing protocol in a busbased vehicular ad hoc network," in *Proc. Int. Conf. Pervasive Computing Signal Processing Applications*, 2010, pp. 70–73.

[26] VanetMobiSim. http://vanet.eurecom.fr/.