A Comparison Study of Connected Vehicle Systems between Named Data Networking and IP

Xiaowei Xu, Tao Jiang, Lu Pu, Tony Z. Qiu, Yu Hu
School of Optical and Electronic Information, Huazhong University of Science and Technology, China
bryanhu@hust.edu.cn

Abstract

Connected vehicle (CV) system has been a very promising technology to improve transportation safety and efficiency, which is a crossing field of intelligent transportation systems (ITS) and the internet of things (IoT). The popular IP-based network protocol has been employed in most CV applications. However, the host-to-host feature of IP protocol is low-efficient for information dissemination. Further more, IP protocol is limited to support direct communication among vehicles with highly ad hoc connectivity. Recently, the next generation network, Named Data Networking (NDN), has been proposed to be a very promising technology to address the information dissemination problem of IP protocol, particularly in cloud computing-based applications and services. In this paper, SimIVC-NDN, a federated simulation platform with the capability of performing a microscopic traffic simulation with both NDN and IP-based networking is proposed. With SimIVC-NDN, we have conducted a quantitative simulation comparison of two CV systems powered by NDN and IP protocols respectively for image dissemination, a common cloud computing service. In the experiments CV systems are constructed based on a calibrated traffic model of Whitemud Drive at Edmonton, Canada. The simulation results show that the NDN-based CV system lowers the packet delay by two orders of magnitude compared with the IP-based one with low packet loss rate, indicating that a NDN-based networking may be a promising alternative to the conventional IP-based one for cloud computing applications of CV systems.

Keywords: Cloud computing, Named data networking, Connected vehicle, VISSIM, NS-3.

1 Introduction

During recent years, intelligent transportation systems (ITS) have attracted increasingly attention, aiming to improve transportation safety and efficiency with the help of new technologies. Simultaneously, internet of things (IoT) has a great revolution to create a virtual internet-like structure of identifiable objects. The combination of ITS and IoT has brought connected vehicle (CV) into our daily life. CV is a crossing field of intelligent transportation systems (ITS) and internet of things (IoT), which focuses on supporting safety, mobility and environmental applications using wireless communication technology. Network protocol, affecting both communication delay and the quality of service (QoS) of traffic applications, is an essential component of the CV applications. The conventional IP-based network protocol has been a mature and popular means in vehicle communication applications [1].

However, IP protocol is designed for point-to-point connection which is not efficient for information dissemination. And the recent IP protocol has rather limited support for direct communication among vehicles with highly ad hoc connectivity without road side units (RSU, static stations by roads). Furthermore, the traffic information exchanged among vehicles is highly relevant, which is very important for information dissemination in CV applications. Therefore, IP protocol is not very suitable for CV applications.

Recently, researchers in the CV community started to explore the adaptation of NDN in certain CV applications, particularly in cloud computing-based applications and services, to enhance the QoS and lower the cost of network infrastructure [2-5]. NDN aims to provide secure content-oriented data transmission [6-7]. Different from IP-based networking, NDN focuses on “what to send” (the content) instead of “where to send” (the address) [8]. In this new network architecture, a data packet will be cached in the network for future requesters, which makes NDN has great advantage in media data transmission. Studies have shown that NDN has a superior performance compared with the IP-based network in many applications [9-10]. However, to the best of our knowledge, there is no quantitative study on the application of the NDN to CV.

In this paper, we quantitatively exploit the advantage of NDN-based CV. The major contributions of this paper are two-fold. We have proposed a high level architect SimIVC-NDN, an integrated simulation platform with the capability of performing a microscopic traffic simulation with both NDN and IP-based networking. The platform is implemented based on VISSIM, a commercial traffic simulator, and NS-3, a popular academia network simulator. Using SimIVC-NDN, we have performed a quantitative comparison between NDN and IP enabled CV system for

*Corresponding author: Yu Hu; E-mail: bryanhu@hust.edu.cn
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a common cloud computing-based image dissemination application based on a calibrated traffic model of Whitemud Drive at Edmonton, Canada.

The remainder of this paper includes the follows. Section 2 introduces the basic concepts of CV and NDN. Section 3 describes the architecture of the proposed federated simulation platform SimIVC-NDN, which is used in Sections 4 and 5 for a case study comparing using NDN and IP-based networking in a CV application. The paper is concluded in Section 6. To the best of our knowledge, this is the first work that quantitatively studies the effectiveness of adopting NDN in the CV for cloud computing-based applications.

2 Background

2.1 Connected Vehicle

ITS supports advanced applications, aiming to provide plenty of innovative services to make more efficient traffic operation and management. And at the same time, drivers can be better informed and make more coordinated and safer decisions in the transport networks.

Recently, among the proposed technologies, CV, which includes vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-mobile device (V2D) communications, has been a very promising technology for ITS. In CV environment, all the vehicles are equipped with wireless devices, and they can communicate with other vehicles, mobile devices and RSUs, sharing traffic information and forming an information-rich CV environment. With the traffic information, drivers will have a much better driving experience. They can adjust the driving speed dynamically with the traffic information and change their route plans, saving travel time and fuels. And the city managers can make much better management with the mass information.

CV focuses on supporting mobility, safety and environmental applications [11]. Mobility applications make use of the mass traffic information for drivers to facilitate better mobility. Safety applications are designed to reduce or eliminate crashes. Environmental applications both generate and capture environmentally relevant real-time transportation information and create actionable feedback to facilitate green transportation decisions.

Usually, the cloud infrastructure is an indispensible component to CV environment. The cloud infrastructure captures real-time data from devices located either on vehicles or within RSUs. The data are transmitted wirelessly and are utilized by a wide range of multi-modal applications.

2.2 NDN

As the IP-based internet has developed into a global network, a grand ocean of information has been formed, bringing an evolution of our life. Applications of the IP-based internet have been changing rapidly, which are formed in terms of what information they need rather than where it is located. The shortcomings of the IP protocol appear which make the IP-based internet lack of security, mobility, reliability and flexibility for today's applications.

Currently, NDN has been proposed to address the above problems. Unlike IP, whose communication pattern is host-to-host based on IP addresses, NDN is content-centric communication. The IP-based routers utilize IP address headers to forward packets, while the NDN-based routers, however, utilize the name prefix (which uniquely identify a piece of data) of each packet for packet forwarding. The layered architectures of IP and NDN are shown in Figure 1.

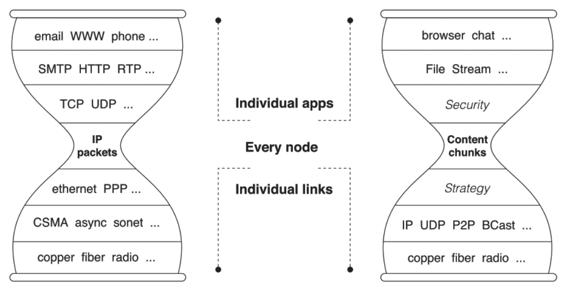


Figure 1 IP vs. NDN Layered Architecture Overview [6]

NDN communication is consumer-driven. Data consumers send out *interest* requests with specific name prefix for desired content, where the names prefix of the *interest* packet and that of the data packet are identical. Due to the content-centric nature, NDN can run over any physically connected network [6]; e.g., a network with only MAC addresses (which can uniquely identify a physical device) can also run NDN protocol directly regardless of IP addresses.

NDN-based router consists of three logical elements, Forwarding Information Base (FIB), Pending Interest Table (PIT), and Content Store (CS). FIB is the routing table based on name prefix instead of IP address. PIT is designed to keep the Interest packets that have not yet been responded within a certain period of time. CS is related to the caching mechanism of NDN; when a data packet is sent back to the data consumer who sent out the *interest* packet, the intermediate nodes along the path will cache the data packet in their CS. With caching mechanism, when an *interest* request is received by a node, the node will first check its CS; if a copy of the desired data (within a certain range of living time) is found, the copy is sent back and the *interest* request is immediately satisfied.

3 Simulation Architecture

As to the connected vehicle simulation, the needed simulation resolution of both vehicular driving behaviors and networking protocols is a big concerning. And it is very important to develop a state-of-the-art simulator capable of performing both fine-grained microscopic traffic simulation and network simulation for applications. We thus propose SimIVC-NDN, a simulation platform that federates VISSIM and NS-3 which stems from our previous work [12].

The architecture of the proposed simulation platform is shown in Figure 2, in which the solid lines represent what have already been implemented while the dashed lines not. We created a simulation control layer (SimCL), which aims to: (a) handle synchronization between the traffic simulator VISSIM and the network simulator NS-3; (b) transfer traffic information from VISSIM to NS-3 and; (c) send back network information (not implemented yet) for further traffic guidance and management.

VISSIM is responsible for the traffic simulation, including vehicular mobility, traffic signals, etc. VISSIM sends and receives traffic information to and from the VISSIM control interface to simulate traffic changes due to driving behavior, traffic infrastructure, etc. OMNeT++ is responsible for the network simulation involved mainly with data transmission. OMNeT++ will provide network information to the OMNeT++ control interface and get position update and network control data from it.

The new system has two main benefits: (1) by using both traffic and network simulators, it provides more insights into both traffic and network simulation process; (2) because VISSIM and NS-3 are both the state-of-the-art simulation tools in both corresponding field, the coupling simulation approach is more realistic and trustable than implementing both the traffic and network simulator alone [13]. Currently, our simulation platform of coupling VISSIM and NS-3 is a unidirectional coupling, i.e., the SimCL only conveys information from VISSIM to NS-3. The implementation details are described in Section 4.

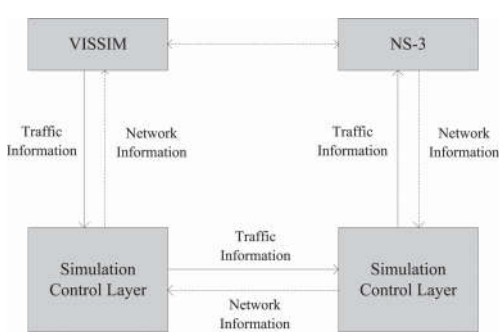


Figure 2 SimIVC-NDN Architecture Overview

4 Case Study: A Comparison of NDN and IP in an Image Disseminating Application

Based on SimIVC-NDN described in the previous section, an image disseminating application scenario is proposed to conduct a comparison between NDN and conventional IP-based networking under the CV environment.

4.1 Application Overview

As shown in Figure 3, the cloud server, routers, wireless stations and moving vehicles are all implemented with either IP or NDN protocol stack. Each vehicle is equipped with a Wi-Fi or cellular device for wireless communication. In our scenario, only V2I is involved, which means vehicles can only communicate with road side stations, and cannot communicate with each other directly. To facilitate drivers' future route planning, the cloud server stores the images captured from cameras equipped at road intersections or highway entrances. The latest images stored in the server are updated with an interval of *UpdateInt*. Each vehicle periodically broadcasts *interest* request (with the *interest* request interval *VehInt*) for the latest image from certain camera.

The station is equipped with both wireless and wired interfaces. On receiving a request from some vehicle, it will handle the request according to either IP or NDN protocol. For cases with IP, the station will forward the request according to the routing table. For cases with NDN, the station will forward the *interest* request according to the CS, PIT and FIT which we have described in Section 2.2. If CS has a copy of the requested image data, the request is immediately satisfied. The router operates in almost the same way as the station. The only difference is that the router is equipped only with wired networking interfaces.

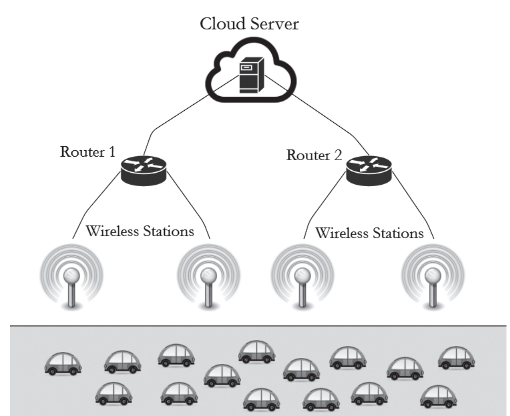


Figure 3 Image Dissemination Application Scenario

When the request reaches the top level layer (i.e., the cloud server in our topology), the cloud server will response the request with the desired image data if it exists.

Here we make an assumption of the name prefixes regarding cases of NDN. The name prefix has a form like "/root/traffic/image/LuoyuRoad/GuanshanAve/20130522/1028/30," which means that the image is taken from the camera at the intersection of Luoyu road and Guanshan avenue at the time of May 22th 2013, 10:28:30.

4.2 Simulation Setup

The simulation setup details will be described in this section.

4.2.1 Simulation Methodology

The simulation network topology corresponding to the application scenario is presented in Figure 4. As shown in the figure, the bandwidth of both Backbone 1 and Backbone 2 are 1,000 Mbps, while the bandwidths of all four branches are 100 Mbps. We assume that all wired connections' transmission delay is 1ms.

The VISSIM simulates the wireless communication between stations and vehicles; and it will generate a file indicating the communication frequency between vehicles and stations. With the file generated by VISSIM, NS-3 simulates the wired communication processes among the cloud server, routers and stations.

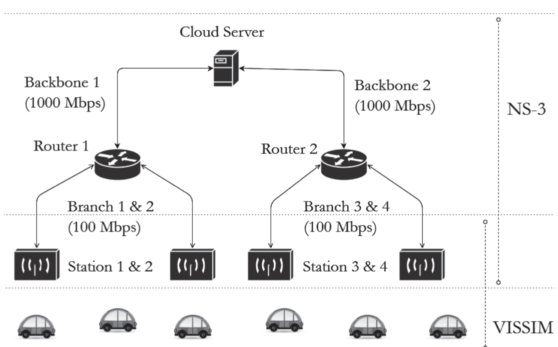


Figure 4 Simulation Network Topology

4.2.2 VISSIM Simulation

As to the traffic simulation part, we adopt a calibrated road network model of Whitemud Drive, the main east-west freeway in southern Edmonton, Canada. The road network model has been carefully calibrated with VISSIM according to the feedback of realistic traffic data [14-15]. Within the road model, four stations are located with an interval of approximately 500 meters, as shown in Figure 5.

The Car2X module of VISSIM [16] is utilized to simulate the wireless communication processes between

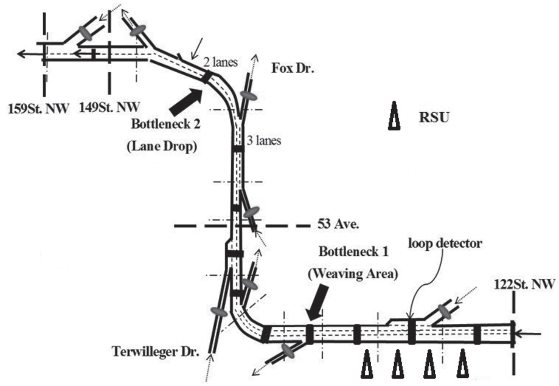


Figure 5 Whitemud Drive Road Model

vehicles and stations, and assumptions are made that the communication range of each vehicle is 250 meters, which means that only within this range, a vehicle can wirelessly communicate with the station.

The vehicles periodically send requests for desired image data during the simulation. The interval between adjacent *interest* requests, *VehInt* is designed to be 1 s, 2 s, 4 s, 8 s, and 16 s in different experiments. Once receiving a request from some vehicle, the station records simulation time steps as current timestamps in a request-time table, which will then be exported to a file utilized by NS-3.The request-time table records every request's timestamp during the simulation, thus the communication frequency between vehicles and each station can be obtained; also, the NS-3 simulation can synchronize with the VISSIM simulation by utilizing the timestamps in the table.

The runtime of the simulation is 6,000 seconds.

4.2.3 NS-3 Simulation

As to the network simulation part, NS-3 utilizes the request-time table generated by VISSIM to keep synchronized with the vehicles' requests. We implement an application within the stations which will handle the request packets according to either IP or NDN protocol sent from "virtual vehicles" according to the timestamp recorded in the request-time table. Also, on receiving the request packets, the routers and the cloud server will handle them according to either IP or NDN protocol. For cases with IP, the simulation is based on the IP protocol stack implemented by NS-3 [17]. For cases with NDN, the simulation is based on the NDN protocol stack implemented by Zhang et al. [2].

We make several assumptions here. Firstly, as the vehicles on the same section of road have a rather high possibility to request for the image captured from the same intersection or highway entrance etc., we assume that all the vehicles send requests for the image data of the same place, which means the possibility is 100%. Secondly, as to the name prefix under NDN-based network, if the image updating interval UpdateInt is 2 seconds, for example, the name prefix of either *interest* packet or data packet would be like "{...}/1028/30," "{...}/1028/32," "{...}/1028/34," and so on; and the "{...}" part is "/root/traffic/image/LuoyuRoad/GuanshanAve/20130522."

All the parameters used in NS-3 simulation are summarized in Table 1. As shown in Table 1, the size of each image data is designed to be 40 KB or 80 KB in different experiment.

The measurements of evaluation of the simulation are delay, packet loss rate and throughput. It is toted that the delay in the simulation is calculated from when the station send the request to when the station receives the desired data.

Table 1 NS-3 simulation parameter

Parameter	Type/Value
Protocol stack	NDN vs. IP
UpdateInt = *VehInt*	1 s, 2 s, 4 s, 8 s, 16 s
Request package size	[20 B, 40 B], uniform distribution
Image size	40 KB, 80 KB
Chunk data size	1 KB

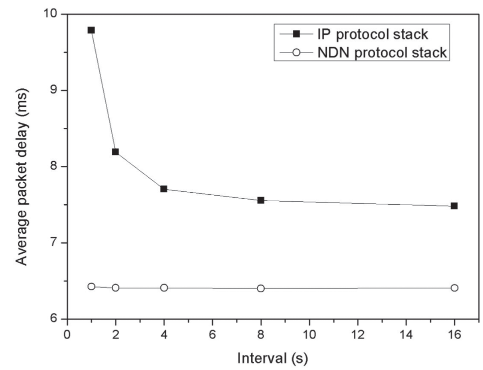
5 Simulation Results and Analysis

The results of the simulation are shown above. Figure 6(a) and (b) show the average delay between request packet and response packet, each for 40 KB and 80 KB image data size. Figure 7 shows average packet loss rate with different intervals and packet size under NDN and IP protocol stacks. Figure 8(a) and (b) shows the average throughputs considering the four branches and two backbones (as shown in Figure 4), each for 40KB and 80KB image data size. The horizontal axis "interval" indicates the equaled updated interval (*UpdateInt*) and the request interval (*VehInt*).

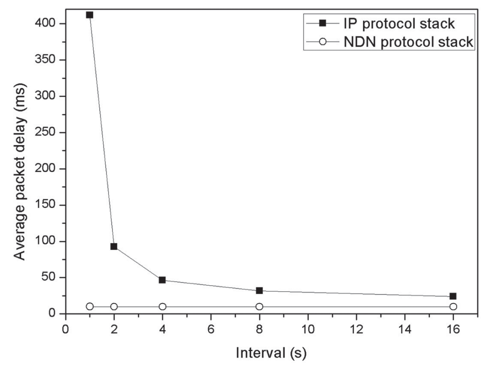
As shown in Figure 6, under IP circumstance, when *VehInt* decreases, the delay increases exponentially; while under NDN, when the interval decreases, the delay almost stays the same.

When it comes to average packet loss rate, Figure 7 indicates that the average packet loss rate of IP protocol is much higher than NDN protocol both with different intervals and image sizes.

It can be easily concluded from Figure 8 that the throughput of NDN protocol is much lower than IP protocol. Under IP circumstance, when *VehInt* decreases, the throughput of branches and backbones increase exponentially, and the average throughput for backbones is approximately 2 times than that for branches; while under NDN, when the interval decreases, the average throughput almost stays zero.



(a)



(b)

Figure 6 Average Packet Delay with Different Intervals and Packet Size under (a) NDN Protocol Stacks and (b) IP Protocol Stacks

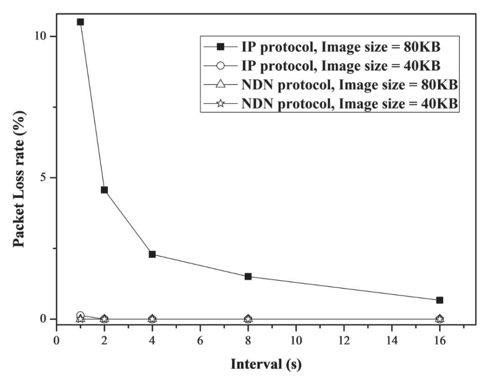
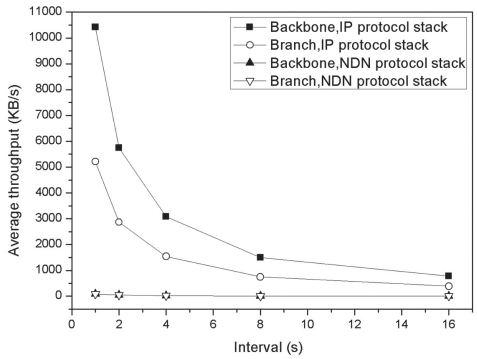
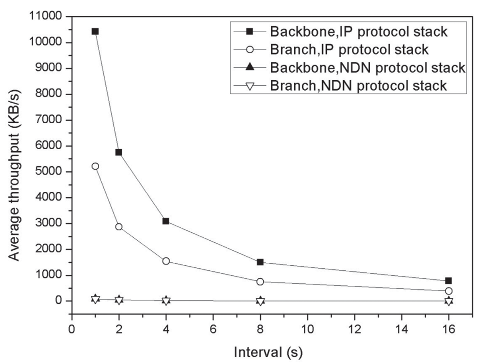


Figure 7 Average Packet Loss Rate with Different Intervals and Packet Size under NDN and IP Protocol Stacks

The difference may be caused by a variety of factors. First, the caching mechanism of NDN makes immediate response of request possible. In our simulation scenario, to IP-based networking, the stations will definitely forward requests to higher level routers; to NDN-based networking,



(a)



(b)

Figure 8 Throughput of Backbones and Branches with Different Intervals and Packet Size under (a) NDN Protocol Stacks and (b) IP Protocol Stacks

however, if a station has a copy of the desired data within its CS, the request would be immediately satisfied and with no need to travel a long distance to the cloud server, thus decreases the overall load of branches and backbones, and also reduces the delay and packet loss rate of image dissemination packets. Second, we have only utilized the raw IP networking functionality instead of taking advantages of other more advanced application protocols such as P2P or introducing more complex IP networking infrastructure such as CDN (Content Delivery Network); out of this factor, we may not fully exploit the potential of IP; though we also only use the raw NDN networking functionality.

6 Conclusion

In this paper SimIVC-NDN, a federated simulation platform with the capability of performing a microscopic traffic simulation with both NDN and IP-based networking, is proposed. Using SimIVC-NDN, we have conducted a quantitative comparison for two CV systems powered by NDN and IP solutions, respectively, for image dissemination, a common cloud computing-based service. The simulation results show that the NDN-based CV system lowers the packet delay by two orders of magnitude compared with the IP-based one with lower packet loss rate, indicating that an NDN-based networking may be a promising alternative to the conventional IP-based one for cloud computing-based applications of CV systems. In our future work, a bi-directional coupling simulation platform will be proposed, and the wireless protocol components of NS-3 will be utilized to obtain a simulation result with higher precision. And more CV applications will be implemented with NDN protocol stack.

Acknowledgements

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References

[1] Sajjad Akbar Mohammad, Asim Rasheed and Amir Qayyum, *VANET Architectures and Protocol Stacks: A Survey*, *Proc. of the 3rd International Conference on Communication Technologies for Vehicles*, Oberpfaffenhofen, Germany, March, 2011, pp.95-105.

[2] Lixia Zhang, Deborah Estrin, Jeffrey Burke, Van Jacobson, James D. Thornton, Diana K. Smetters, et al., *Named data networking (NDN) project*, October, 2010. NDN Technical Report NDN-0001.

[3] Kun Ding, Yun Liu, Hsin-Hung Cho, Han-Chieh Chao and Timothy K. Shih, *Cooperative Detection and Protection for Interest Flooding Attacks in Named Data Networking*, *International Journal of Communication Systems*, 2014, doi:10.1002/dac.2883.

[4] Giulio Grassi, Davide Pesavento, Lucas Wang, Giovanni Pau, Rama Vuyyuru, Ryuji Wakikawa and Lixia Zhang, *Vehicular Inter-networking via Named Data*, *ACM SIGMOBILE Mobile Computing and Communications Review*, Vol.17, No.3, 2013, pp.23-24.

[5] L. Wang, R. Wakikawa, R. Kuntz, R. Vuyyuru and L. Zhang, *Data Naming in Vehicle-to-Vehicle Communications*, *Proc. of IEEE Conference Computer Communications Workshops*, Orlando, FL, March, 2012, pp.328-333.

[6] Van Jacobson, Diana K. Smetters, James D. Thornton, Michael F. Plass, Nicholas H. Briggs and Rebecca L. Braynard, *Networking*

Named Content, *Proc. of 5th ACM International Conference on Emerging Networking Experiments And Technologies*, Rome, Italy, December, 2009, doi:10.1145/1658939.1658941.

[7] J. Pan, S. Paul and R. Jain, *A Survey of the Research on Future Internet Architectures*, *IEEE Journal of Communications Magazine*, Vol.49, No.7, 2011, pp.26-36.

[8] Burt Kaliski, *Driving to a Content-Centric Internet: Van Jacobson Speech*, 2012, http://blogs.verisigninc.com/blog/entry/driving_to_a_content_centric

[9] Zhenkai Zhu, Sen Wang, Xu Yang, Van Jacobson and Lixia Zhang, *ACT: Audio Conference Tool over Named Data Networking*, *Proc. of ACM SIGCOMM Workshop on Information-Centric Networking*, Toronto, Canada, August, 2011, pp.68-73.

[10] Zhenkai Zhu, Chaoyi Bian, Alexander Afanasyev, Van Jacobson and Lixia Zhang, *Chronos: Serverless multi-user chat over NDN*, October, 2012. NDN Technical Report NDN-0008.

[11] U.S. Department of Transportation, *Connected Vehicle Research*, http://www.its.dot.gov/connected_vehicle/connected_vehicle.htm

[12] Xiaowei Xu, Tao Jiang, Pengfei Li, Tony Qiu and Yu Hu, *A High-Level Architecture SimIVC for Simulating the Traffic Network*, *Proc. of 2nd International Conference on Transportation Information and Safety*, Wuhan, China, June/July, 2013, pp.40-48.

[13] Ta-Yin Hu, Tsai-Yun Liao, Li-Wen Chen, Yung-Kuei Huang and Min-Ling Chiang, *Dynamic Simulation-Assignment Model (DynaTAIWAN) under Mixed Traffic Flows for ITS Applications*, *Proc. of Transportation Research Board 86th Annual Meeting*, Washington, DC, January, 2007, No.07-1616.

[14] Tony Z. Qiu, *Online simulation of networked vehicle based active traffic management for freeway operation*, 2012. University of Alberta Final Report.

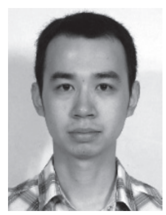
[15] Md. Ahsanul Karim and Tony Z. Qiu, *Study on Calibration and Validation of Fundamental Diagram for Urban Arterials*, *Proc. of Transportation Research Board 91st Annual Meeting*, Washington, DC, January, 2012, No.12-0637.

[16] Yinhai Wang, Yunteng Lao, Cathy Liu and Guangning Xu, *Simulation-Based testbed development for analyzing toll impacts on freeway travel*, June, 2012. Final Report TNW 2012-16.

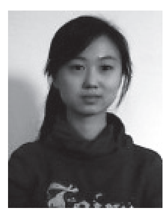
[17] *NS-3 Internet Models*, http://www.nsnam.org/

Biographies

Xiaowei Xu received BS and MS degrees in electronic science and technology from Huazhong University of Science and Technology, Wuhan, China, in 2011 and 2013, respectively. He is currently working toward a PhD degree in electronic engineering at the School of Optimal and Electronic Information, Huazhong University of Science and Technology, Wuhan, China. His research interests include intelligent transportation systems, connected vehicles, and embedded computing. Xu is the recipient of the award for Outstanding Graduate Thesis from Hubei Province, China.



Tao Jiang received BS degree in Communication Engineering from Wuhan University, China, in 2009. He is currently working towards a PhD degree in Electronic Engineering at Huazhong University of Science and Technology, China. His research interests include intelligent transportation system, connected vehicles, wireless sensor network, and embedded computing.



Lu Pu received BS degree in electronic science and technology from Huazhong University of Science and Technology, Wuhan, China, in 2012. She is currently working towards a MS degree in Electronic Engineering at Huazhong University of Science and Technology, China. Her research interests include intelligent transportation system, connected vehicles, wireless sensor network, and embedded computing.

Tony Z. Qiu received the BS degree in Control Science and Engineering in 2001 and the MS in Intelligent Transportation System in 2003, both from Tsinghua University, Beijing, P.R.China. He received the PhD degree in the Department of Civil and Environmental Engineering at University of Wisconsin Madison in 2007. From 2008 ~ 2009, he worked as Post-Doctoral Researcher in California Partners for Advanced Transit and Highways (PATH) at University of California Berkeley. Currently he is working as an Assistant Professor in the department of Civil and Environmental Engineering of University of Alberta, Edmonton, Canada. Dr. Qiu's research interest includes: intelligent transportation system, traffic modeling and simulation, traffic operation and control, traffic state estimation and prediction, and safety analysis for urban and freeway.

Yu Hu received BEng and MEng degrees from the Computer Science and Technology Department, Tsinghua University, Beijing, China, in 2002 and 2005, respectively, and a PhD degree from the Department of Electrical Engineering, University of California, Los Angeles (UCLA), in 2009. From 2010 to 2012, he was an assistant professor in the Department of Electrical and Computer Engineering, University of Alberta, Edmonton, Canada. Since 2012, he has been a professor at the School of Optimal and Electronic Information, Huazhong University of Science and Technology, Wuhan, China. His research interests include intelligent transportation systems, connected vehicles, embedded computing, and general aspects of field-programmable gate arrays (FPGAs). Dr. Hu is the recipient of the Outstanding Graduate Student Award from Tsinghua University in 2005, and he is the corecipient of the Best Contribution Award at the International Workshop of Logic and Synthesis 2008. His work has been nominated for the Best Paper Award multiple times at the International Conference on Computer-Aided Design and Design Automation Conference.