Vehicular Inter-Networking via Named Data – An OPNET Simulation Study

Dung Ong Mau[1], Yin Zhang[1], Tarik Taleb[2], and Min Chen[1](✉)

[1] School of Computer Science and Technology,
Huazhong University of Science and Technology,
1037 Luoyu Road, Wuhan 430074, China
omdung@gmail.com, {yin.zhang.cn,minchen}@ieee.org

[2] NEC Laboratories Europe, NEC Europe Ltd., Kurfrsten-Anlage 36,
69115 Heidelberg, Germany
talebtarik@ieee.org

Abstract. Named Data Networking (NDN) is proposed for effective content distribution when a large number of end-users demand for popular content at the same time. In this paper, NDN is implemented in Vehicular Ad-hoc NETwork (VANET) to meet its particular requirements, such that all of vehicles refer to the real time traffic status for safe driving. We propose Vehicular Named Data Networking according to three different vehicle communication mechanisms, which are vehicle-to-infrastructure (V2I), a hybrid of vehicle to road side unit (V2R) and vehicle to vehicle (V2V). Furthermore, this paper illustrates the experimental results conducted by OPNET Modeler, and proves that the solution with NDN enhances the Quality of Service (QoS) of VANET significantly.

Keywords: VANET · LTE · NDN · QoS

1 Introduction

Vehicular Ad-hoc NETwork (VANET) is the technique that uses moving vehicles as wireless nodes in a mobile network. And each wireless node takes a role as an end-user and wireless router to create a wide range communication. Motivated by the increasing demand for efficient and reliable information dissemination and retrieval, the Named Data Networking (NDN) architecture presents a simple and effective communication model [1]. In NDN, an interest packet (IntPk) and a data packet (DataPk) are two packet types mainly used to identify a content, which is typical hierarchical and human readable. NDN node maintains three data structures: Forwarding Information Base (FIB), Pending Interest Table (PIT) and Content Store (CS). Once NDN node receives a IntPk, it will lookup for a content in the CS. If the appropriate content is found, the DataPk will be send for a request, otherwise the IntPk will be checked in the PIT. The PIT takes a role to keep track on unsatisfied IntPks. After the PIT creates a new entry for unsatisfied IntPk, which is forwarded to upstream toward to a

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potential content source based on the FIB's information. A returned DataPk will be sent to downstream and stored on the CS buffer. To maximize the probability of sharing and minimize upstream bandwidth demand, the CS should keep all arrived DataPks as long as possible. When the CS is about to get full or receive a new content, it will store the new one according to the replacement policy to leave space for the new content. Least Recently Used (LRU) and Least Frequently Used (LFU) are two dedicated replacement policies in original NDN. In [2], Giulio et al. propose V-NDN, applying the NDN to networking vehicles on the run. However, the design just illustrates NDNs promising potential to providing a unifying architecture, but does not provide more details about its feasibility, performance and practicability.

In this paper, we propose our solution, *Vehicular Named Data Networking*, by inheriting the basic principle of the NDN. However, extending the NDN model to the VANET is not straightforward application due to a lot of challenges in the vehicle environment such as the limited and intermittent connectivity, and the node mobility. The contribution of the paper as follows. We first introduce some meeting challenges in different types of vehicle communication mechanism. Then we discuss and evaluate the benefits brought by the NDN. The two schemes LRU and LFU are successfully constructed in the NDN node. Motivation from the NDN model simulation, the Vehicular Named Data Networking performance is taken into account by clearly comparison the VANET under two scenarios: with typical clients-server connection and with NDN connection.

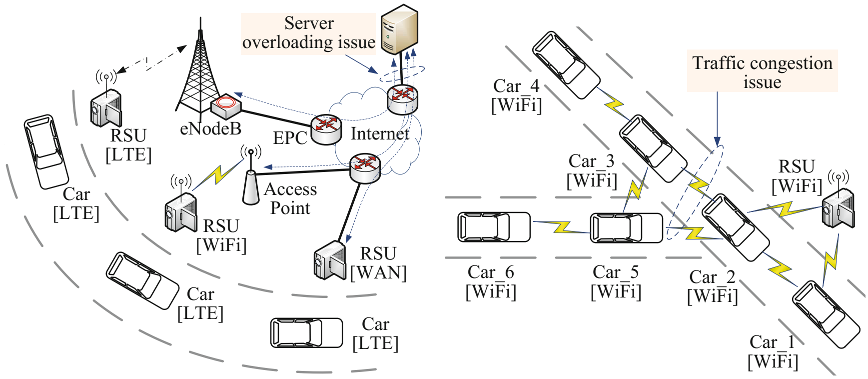
The remainder of this paper is organized as follows. Section 2 provides the VANET background, and reactive routing applied for the NDN. Section 3 illustrates simulation and evaluation results for basic NDN model. Then, Section 4 portrays envisioned Vehicular Named Data Networking architecture of the simulation setup and discusses simulation results. Finally, Section 5 concludes this paper.

2 Background

2.1 VANET: An Overview

In vehicle-to-infrastructure (V2I) network, assistance transmission networks are required, such as 2.5G, 3G, 4G, to centrally manage all the vehicles communication [3]. With handover technique between radio cells, vehicles always keep pace with a server supplied VANET applications. For instance, a serving distance of mobile base stations operated at $900MHz$ carrier frequency is typically from $2km$ in microcell up to $35km$ in macrocell. Therefore, vehicles are least to handover between base stations. For this reason, proactive routing is utilized in V2I network. In this paper, we propose to use the latest cellular network: Long Term Evolution (LTE) [4] for V2I scheme.

Fig. 1(a) shows an example of V2I communication in LTE network. *Road-Side Units (RSUs)* are cameras to capture the road traffic status. An end point connection to RSUs can be LTE, Wireless Fidelity (WiFi) or wide area network (WAN). Vehicle subscribers request and receive an updated road traffic status



(a) V2I in LTE network. (b) V2R&V2V in WiFi adhoc network.

Fig. 1. Two aspects of vehicle communication

from the server through LTE. Because of a large number of RSUs and vehicle subscribers, the server is easy to meet an overloading issue. Moreover, the current mobile networks are centralized management, e.g. in Long Term Evolution (LTE) network, all of Internet mobile traffic are come in and come out via the Evolved Packet Core (EPC) entity, leading to high requirement for a backbone mobile traffic. Especially in traffic jams, a group of nearby vehicles often requires the same information from the server (e.g. traffic status), which poses high redundancy contents in the backbone transmission.

In a hybrid network, vehicle-to-RSU (V2R) and vehicle-to-vehicle (V2V), multi-hop networking and a short range communication are critical. Typically, dedicated short range communication (DSRC) and wireless access in vehicular environments (WAVE) are utilized to directly exchange data between adjacent vehicles. However, with advances in smart-phone and tablet, the huge number of VANET applications are designed and installed on smart-phone by using available WiFi module on the mobile devices. The infrastructure-less network based on vehicles has greater challenges than fixed wireless networks caused by various speeds, traffic patterns, and driving environments. Therefore, reactive routing should be used in V2R&V2V scheme. Fig. 1(b) shows an example of V2R&V2V communication in WiFi ad-hoc network. At the wireless router node (e.g. Car_2) and RSU, they meet a traffic congestion issue when a huge number of vehicle subscribers are nearby RSU and request content at the same time. In this scheme, WiFi route may be the bottleneck of data transmission because all of wireless nodes share the bandwidth for the communication.

Due to the existing issues in VANET, both of V2I and V2R&V2V are proposed to implement with Named Data Networking (NDN) for better network performance (e.g. network traffic offloading, reducing traffic congestion and lower round trip time) than the typical clients-server connection [5].

2.2 Reactive Routing in NDN

In reactive routing, both a request node and an intermediate nodes do not have a routing table which is known as the FIB entity in NDN mechanism. For a wireless ad-hoc network to setup a reverse path from the server to an end-user, flooding is a fundamental mechanism to implement the multi-hop broadcasting the IntPk in order to build up the reverse path. However, broadcasting scheme causes several issues as follows; i.e., *i)* a burst transmission is generated by broadcasting all of received IntPks. Flooding in many cases, especially in a dense network, introduces significant communication overhead due to redundant re-broadcasting. *ii)* A loop network in routing is occurred when more than two intermediate nodes are within a radio range communication. And *iii)* a data burst of responding traffic is generated because there may exist many reverse paths from the server to the client. To alleviate the well-known broadcast storm problem, all broadcasting methods in VANET utilize position information to identify the next relay node. However, in the real-life scenario, a vehicle does not have knowledge about position information of both neighboring vehicles and RSUs. In order to restrict the number of nodes relaying the broadcasting data without addition requirement information, we suggest to minimize a hop count between the RSU and the target vehicle. The minimum hop count is taken place at intermediate nodes by checking the hop count value embedded in arrived IntPks before broadcasting. Typically, the first arrived packet in a bunch of new IntPk always has a minimum hop count and will be broadcasted. Then, all the same IntPk arrived later should be deleted. Fig. 2 shows the main operations for NDN vehicles.

3 Basic NDN Network Architecture

To evaluate the performance of NDN mechanism, we implemented NDN and conducted simulations using the OPNET Modeler 16.0 [6][7]. There are many simulators for VANET but none of them can provide a complete solution for simulating VANETs [8][9]. Among a number of simulation tools such as Vanet-MobiSim, SUMO, NS2, QualNet, etc., we would like to use OPNET because it supports for a realistic mobile network environment (e.g. 2.5G/3G/4G). In the simulation, NDN is overlayed over the IP layer. Indeed, we integrated the NDN processing modules into all network elements, such as mobile stations (MSs), Evolved Node B (eNodeB), routers, PCs, servers and IP Cloud.

3.1 Network Architecture

With every intention to consider a typical Internet network topology, we assumes the network topology as same as shown in Fig. 3 and we apply our new caching policies in both WAN and LTE network. The simulation LTE network includes three cells with 2000 meters of diameter for the radio coverage in each cell. Each cell has 1 eNodeB, 1 NDN processor node and 25 LTE MSs. And all the MSs

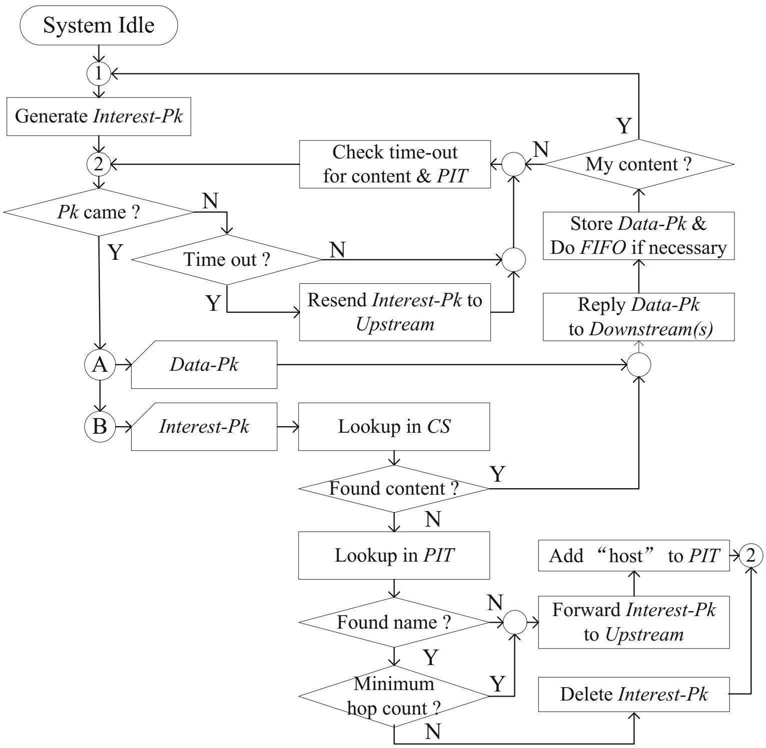


Fig. 2. NDN vehicle flow chart

request video content from the same server following a power function distribution. For example, a *Pareto* distribution: 20 MSs (80% traffic) request popular video contents while the other 5 MSs (20% traffic) request unpopular video items. There are two scenarios in the simulation,they are LRU and LFU, respectively. Hitting rate, coverage time to final state and a percentage of traffic offloading are important metrics to be verified in the simulation results. There are the same configuration and scenarios in WAN network. The simulation parameters we selected to reflect real-world implementations of in-network caching refers to the related work [10][11]. The simulations were run multiple times and the presented results are an average of these runs.

3.2 Performance Evaluation for Basic NDN Model

We first evaluate the performance of different content caching/replacement policies for different cache sizes. Let a relative cache size denote for the percentage of a cache size over a catalog size. In Fig. 4(a), the relative cache size in NDN node is increased by 0.06%, 0.1%, 0.16% and 0.2%. It should be noted that in the simulation, the catalog size(500000 files) is much greater than the cache size

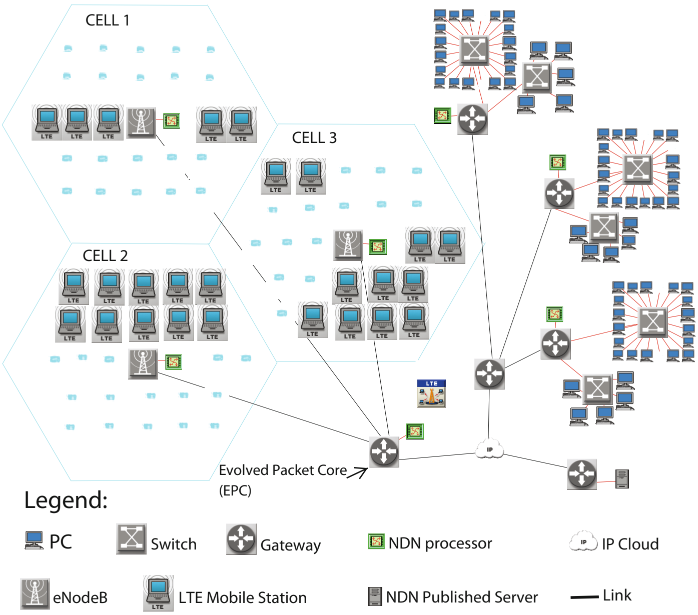
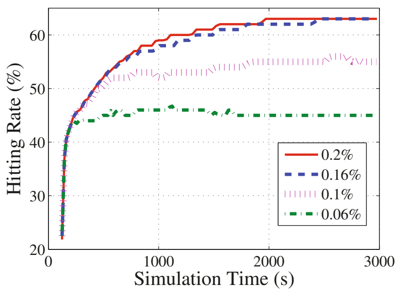


Fig. 3. Envisioned NDN network architecture

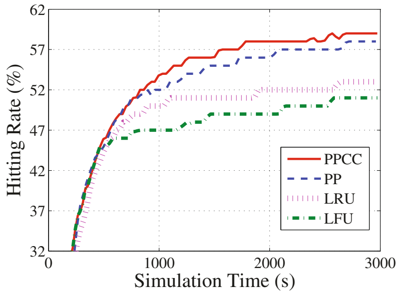
(equal or less than 1000 files). Therefore, the relative cache size is equal to or less than 0.2%.

In Fig. 4(a), the simulation results show that high hitting rates can be achieved with high cache sizes for all the simulated policies. In this figure, it is obvious that the increment of the hitting rate is not linear to the cache volume. Moreover, it also indicates that when the relative size is equal to 0.16%, the cache can handle most requests for popular contents. However, increasing to 0.2% the performance degrades, because of the tradeoff between cache volume (cost) and performance. Hence, there is consequently need to retrieve a suitable cache size.

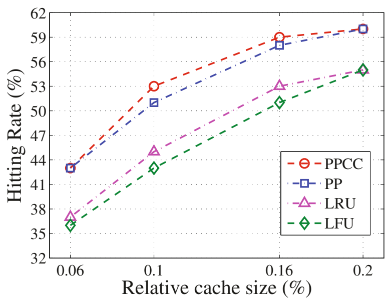
In Fig. 4(b), it illustrates the LRU and LFU performance comparison when the relative cache size is set to 0.16%. The figure shows that LRU is just slightly higher than LFU. In Fig. 4(c), it illustrates the further comparison LRU and LFU for different relative cache sizes. Fig. 4(d) shows amount of traffic responding by the server under LRU and LFU schemes and relative cache size 0.1%. With higher hitting rate, lower requested traffic is fetched to the server, then higher percentage of traffic offloading is achieved. Because LRU and LFU have quite similar hitting rate, their capable of traffic offloading are similar too.



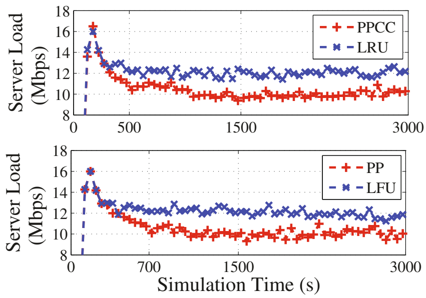
(a) Performance of LRU for varying relative cache sizes.



(b) LRU and LFU with relative cache size 0.16%.



(c) Final state of LRU and LFU.



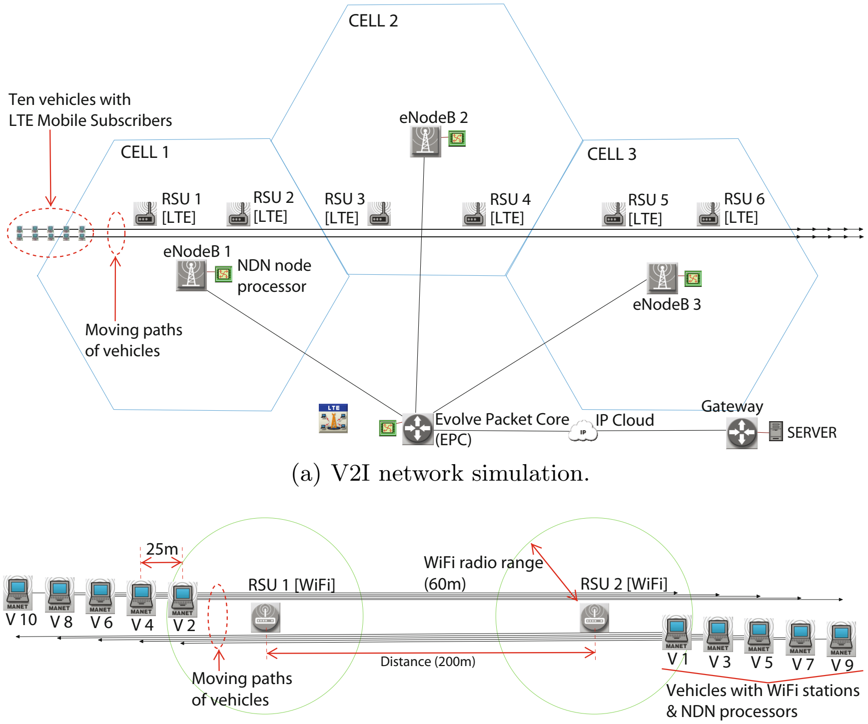
(d) Server load with relative cache size 0.1%.

Fig. 4. LRU and LFU performance comparison

4 Simulation and Results

4.1 Network Simulation

Motivation from the NDN model simulation, we enhance Vehicular Named Data Networking simulation with two scenarios: V2I network and V2R&V2V network. V2I network simulation is illustrated in Fig. 5(a). There are three cells in LTE network, and each cell includes an eNodeB connected with NDN node. The eNodeB provides a radio communication within 2000 meters range while NDN node is added component to implement NDN protocol. Two RSUs that are implemented in each LTE cell, generate content with $64Kbps$ rate and transmit content to a server over LTE network. Data from different RSUs are distinguished by RSU identification (RSU_ID) and current geometric location. The server stores all received data from RSUs, and send the corresponding content to vehicles and NDN nodes. There are ten vehicles equipped with LTE mobile station. While vehicles are moving with $20km/h$ speed, they continuously send IntPks attached with their current geometric location (e.g. five seconds every IntPk), which is used to determine an appropriate content on the server/NDN node.



(a) V2I network simulation.

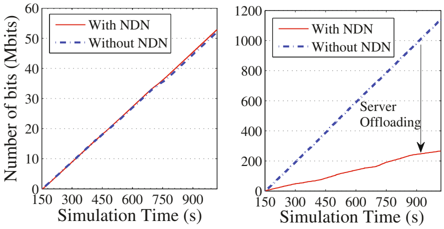
(b) V2R&V2V network simulation.

Fig. 5. VANDNET simulation

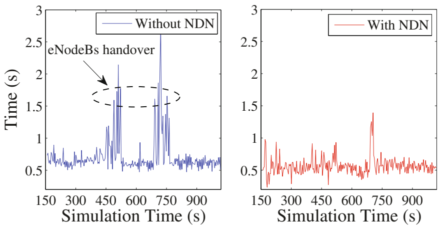
Fig. 5(b) demonstrates V2R&V2V network. There are two RSUs placed 200 meters apart. Ten vehicles divided into two groups moved slowly on two direction with $5km/h$ speed. Both RSUs and vehicles are equipped with WiFi card operated under IEEE802.11g standard and within 60 meters radio range. When the two flows of vehicles meet together, a traffic explosion caused by IntPks and DataPks happens. This scenario is useful to compare network performance between with and without NDN application. It should be noted that the typical speed of vehicles is about $40 - 80km/h$. However, we would like to determine the responding of the Vehicular Named Data Networking model in some of the worst situations, i.e., *i)* a group of vehicles move very slowly at handover areas in LTE/WiFi, and *ii)* a long time of the traffic explosion caused by IntPks and DataPks.

4.2 Simulation Results

Fig. 6(a) shows the vehicles would receive similar data results with or without NDN, but the data sent by the server is different. Without caching, all requests are fetched to the server which poses high redundancy content replied by the

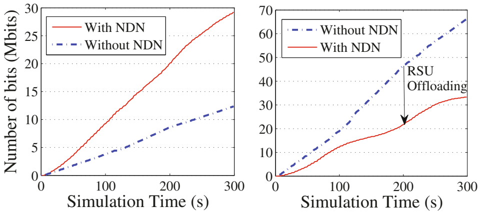


(a) Total bits received by vehicles and sent by server.

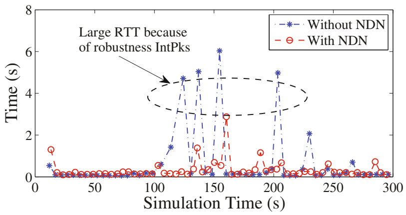


(b) Average RTT at vehicles.

Fig. 6. V2I simulation results



(a) Total bits received by vehicles and sent by RSU.



(b) Average RTT at vehicles.

Fig. 7. V2R&V2V simulation results

server. With caching, eNodeBs use available content to directly reply for IntPks from vehicles, and make the request bit rate received by the server to be reduced significantly. Fig. 6(b) shows the different results of round trip time (RTT) at vehicles with or without NDN schemes. A trajectory of ten vehicles are setup to move together and handover between eNodeBs around the 450^{th} and the 750^{th} second. At the roaming moment, vehicles are failed to received content, then they resent IntPks again to the server/NDN node. In the scheme with NDN, eNodeBs only need one content from server to reply all vehicles, while in the scheme without NDN, the server needs to send the same multiple copy of content to all vehicles.

Fig. 7(a) shows the different results between total bits sent by the RSUs and total bits received by the vehicle, which are caused by the following three reasons; i.e., *i)* with NDN mechanism, a minimum of IntPk is forwarded to the RSU, then a minimum of DataPk is sent out by RSU while with a typical clients-server connection, the RSU needs to reply all IntPks from vehicles. *ii)* With NDN mechanism, the IntPk can be intermediately satisfied by multiple one hop neighbor vehicles, while without NDN, the IntPk is only replied by the server. And *iii)* regarding to the bottleneck of WiFi link, all stations share the same physical channel. So that, the RSU and intermediate wireless nodes follows a *first in first serve* (FIFS) policy to serve for all stations. Fig. 7(b) presents an average RTT at vehicles. From the 100^{th} to the 200^{th} second, the traffic explosion is happened, and with NDN mechanism assistant, the RTT stability at vehicles is better than clients-server mechanism.

5 Conclusion

In this paper, we introduced the NDN with two original replacement policies that assist to off-load the traffic of the IP backbone as well as the server. Furthermore, we implement the Vehicular Named Data Networking model with two novel networks: V2I and V2R&V2V, respectively. The performance of the NDN model and the Vehicular Named Data Networking model were evaluated using computer simulations. With the obtained results, it is proved that NDN mechanism can improve the performance of the network significantly. In the future work, the Vehicular Named Data Networking model should be evaluated under various scenarios with a huge number of vehicles, mobility patterns and the prototype.

References

1. Jacobson, V., Smetters, D., Thornton, J., Plass, M., Briggs, N., Braynard, R.: Networking named content. Communication of the ACM **55**(1), 117–124 (2012)
2. Grassi, G., Pesavento, D., Wang, L., et al.: ACM HotMobile 2013 poster: vehicular inter-networking via named data. ACM SIGMOBILE Mobile Computing and Communications Review **17**(3), 23–24 (2013)
3. Yu, Y., Punihaole, T., Gerla, M., Sanadidi, M.Y.: Content Routing In the Vehicle Cloud. Military Communication **2012**, 1–6 (2012)
4. Zheng, K., Liu, F., Xiang, W., Xin, X.: Dynamic downlink aggregation carrier scheduling scheme for wireless networks. IET Communications **8**(1), 114–123 (2014)
5. TalebiFard, P., Leung, V.C.M.: A Content-Centric Perspective to Crowd-sensing in Vehicular Networking. In: Journal of Systems Architecture, 59(10) (2013).
6. OPNET Modeler. Available: www.opnet.com.
7. Chen, M.: OPNET Network Simulation, Press of Tsinghua University, ISBN 7-302-08232-4 (2004)
8. Martinez, F.J., Toh, C.K., Cano, J., Calafate, C.T., Manzoni, P.: A survey and comparative study of simulators for vehicular ad hoc networks (VANETs). Wireless Communications and Mobile Computing **11**(7), 813–828 (2011)
9. NS-3 based Named Data Networking (NDN) simulator. Available: http://ndnsim.net/index.html
10. Li, J., Wu, H., Liu, B., Lu, J., Wang, Y., Wang, X., Zhang, Y., Dong, L.: Popularity-driven Coordinated Caching in Named Data Networking. In: ACM/IEEE symposium on Architectures for networking and communications systems (ANCS), pp. 15–26 (Oct. 2012)
11. Rossi, D., Rossini, G.: Caching performance of content centric networks under multi-path routing (and more). Telecom ParisTech, Technical report, Paris, France (2011)