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Invited paper

VENDNET: VEhicular Named Data NETwork

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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. Thus, NDN can be implemented in Vehicular ad-hoc NETwork (VANET) to meet the particular requirements. Therefore, all of vehicles refer to the real time traffic status by a faster and more efficient network. In this paper, we propose VEhicular Named Data NETwork (VENDNET) 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 shows that the solution with NDN enhances the Quality of Service (QoS) of VANET significantly.

1. Introduction

Vehicular ad-hoc NETwork (VANET) is a technique that uses moving vehicles as wireless nodes in a mobile network, in which each wireless node takes a role as an end-user and wireless router to support wide range communications. Motivated by the increasing demand for efficient and reliable information dissemination and retrieval, the Named Data Networking (NDN) 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 typically hierarchical and human readable. Each NDN node maintains three data structures: Forwarding Information Base (FIB), Pending Interest Table (PIT) and Content Store (CS). Once an NDN node receives a IntPk, it will lookup for a content in the CS. If the appropriate content is found, the DataPk will be sent in response to the 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 upstream towards a potential content source based on the FIB's information. A returned DataPk will be sent downstream and stored in the CS buffer.

Related to the exponent growth of traffic, a skewness characteristic of the popularity of content was found, that is to say, a few popular contents are often queried by the huge number of end-users. The high skewness of popular content makes the Least Recently Used (LRU) and Least Frequently Used (LFU) replacement policies suffer from low efficiency for NDN. In order to fully exhibit the better performance of the NDN compared to traditional network architectures, we suggest to use the popularity prediction mechanism. That is to say, by counting the times of the prefix's appearance in the content, the NDN node maintains a *prefix tree* (PT) for all contents, and quickly finds popular contents in PT [2]. Popular contents are classified and every content is marked with a suitable lifetime. A more popularity level content will be given a longer lifetime. The above prediction-based scheme is dubbed *Prefix-Tree LRU* (PT-LRU). Hence, PT-LRU is a simple approach for NDN nodes to achieve higher hitting rate than LRU and LFU.

Furthermore, an enhanced version of PT-LRU, dubbed *Prefix-Tree Sharing* (PT-Sharing), is taken into account. NDN nodes running PT-LRU are periodic exchange of the most popular prefix information with their neighboring NDN nodes. Therefore, in the PT-Sharing mechanism, NDN nodes can learn and predict about the popularity trend for a near future, posed the PT-Sharing mechanism finds the most popular content more quickly than PT-LRU mechanism. With a simple cooperation between NDN nodes, higher hitting rate and faster convergence speed to final state are achieved. The four schemes LRU, LFU, PT-LRU and PT-Sharing are successfully constructed in the NDN node. The simulation results indicate that PT-LRU and PT-Sharing outperform LRU and LFU with highly effective caching.

In this paper, we propose our solution, *Vehicular Named Data Networking (VENDNET)*, by inheriting the basic principle of the NDN. However, extending the NDN model to the VANET is not straightforward due to a lot of challenges in the vehicle environment such as the limited and intermittent connectivity, and node

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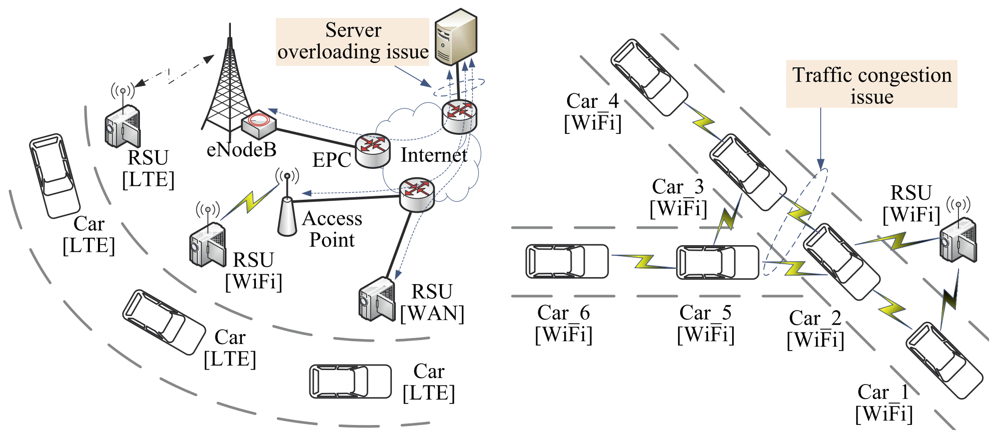


(a) V2I in LTE network. (b) V2R&V2V in WiFi adhoc network.

Fig. 1. Two aspects of vehicle communication.

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 prediction-based schemes for the NDN. Motivation from the NDN model simulation, the VENDNET performance is taken into account by clearly comparing 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 VENDNET network 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 supplying VANET applications. For instance, a serving distance of mobile base stations operated at 900 MHz carrier frequency is typically from 2 km in microcell up to 35 km in macrocell. Therefore, vehicles are mobility and the handover between base stations is inevitable. 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 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 LTE network, all of Internet mobile traffic are coming in and coming 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 [5]. Typically, dedicated short range communication (DSRC) and wireless access in vehicular environments (WAVE) are utilized to provide wireless communication 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 close to 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.

With the development of VANET, the effective transmission of media content, e.g., image, audio and video, is the basis of media communications in VANET, such as social communications and video sharing. In [6] Vinel et al. introduce novel vehicular applications that are based on video transmission and targeted at improving road safety, efficiency and public security. In [7], Luan et al. propose an integrity-oriented inter-vehicle content transmissions. However, it is difficult to improve the media transmission via traditional network architecture.

Due to the existing issues in VANET, both of V2I and V2R&V2V are proposed to implement with NDN for better network performance (e.g. offloading network traffic, reducing traffic congestion and lowering round trip time) than the typical clients–server connection [8].

2.2. Reactive routing in NDN

In reactive routing, both a request node and an intermediate node 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

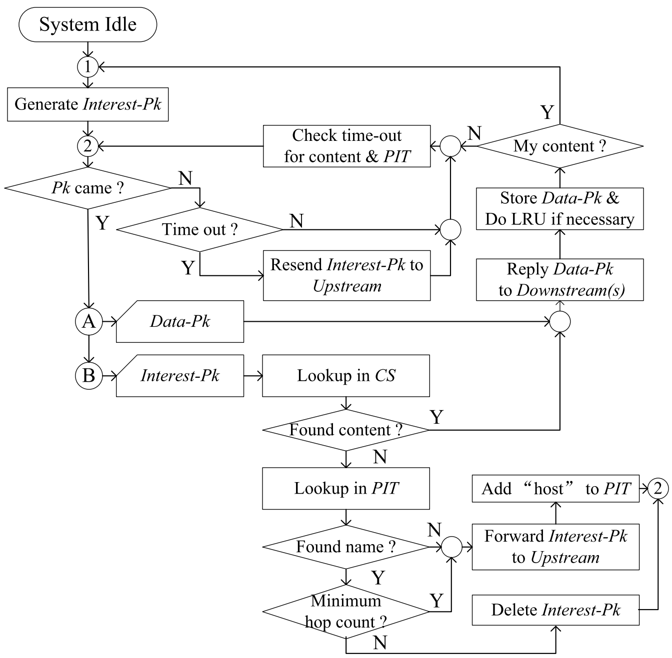


Fig. 2. NDN vehicle flow chart.

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 [9,10]. There are many simulators for VANET but none of them can provide a complete solution for simulating VANETs [11,12]. Among a number of simulation tools such as VanetMobiSim, 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 in 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 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 as follows. The first scenario considers three kinds of replacement policies which are stand-alone, such as LRU at eNodeB_1 (cell-1), LFU at eNodeB_2 (cell-2), and PT-LRU at eNodeB_3 (cell-3). The second scenario considers a co-operative caching between cells. We set up PT-Sharing for all three cells. Hitting rate, coverage time to final state and a percentage of offloading traffic are important metrics to be verified in the simulation results. There are the same configuration and scenarios in

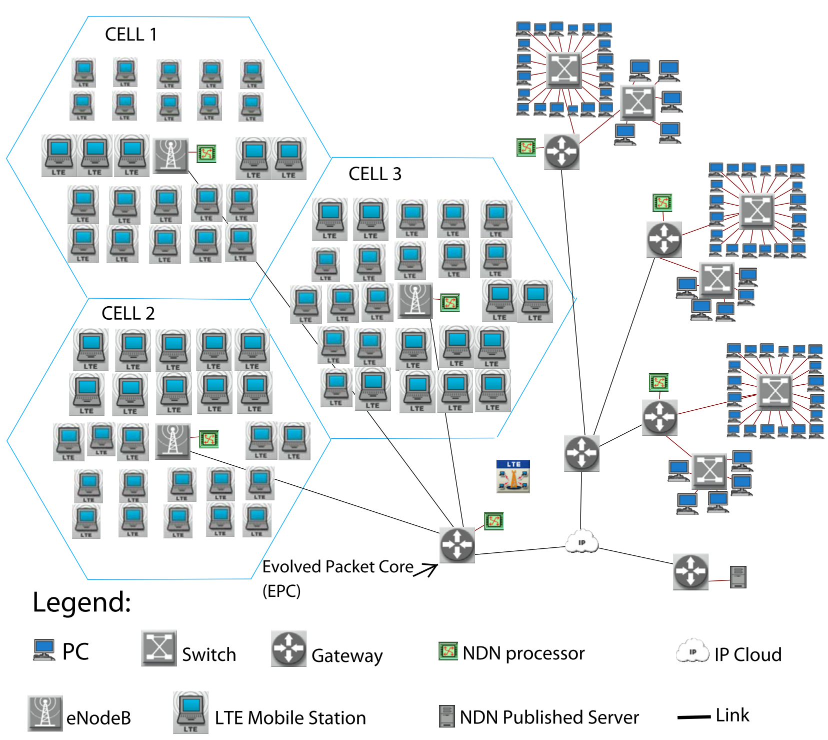
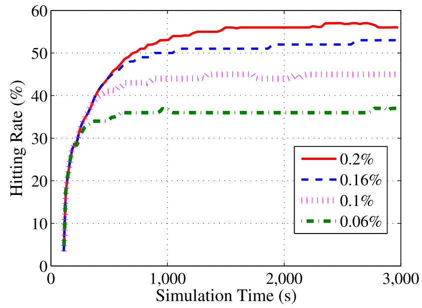
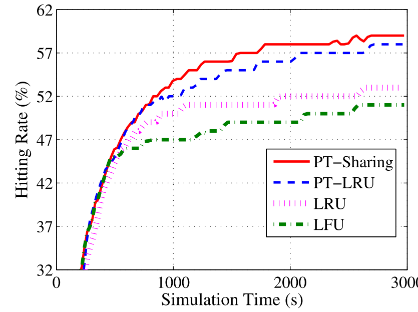


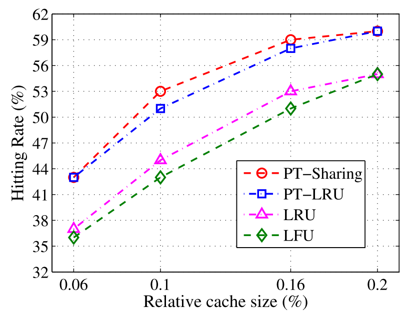
Fig. 3. Envisioned NDN network architecture.



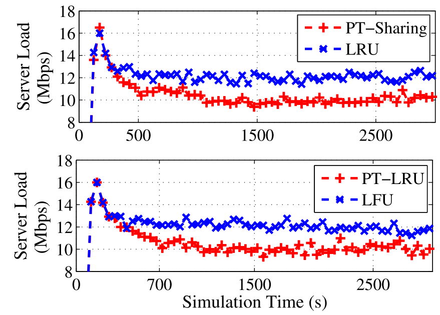
(a) Performance of LRU for varying relative cache sizes.



(b) Multiple replacement policies with relative cache size 0.16%.



(c) Final state of multiple replacement policies.



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

Fig. 4. Replacement policies performance comparison.

WAN network. The simulation parameters we selected to reflect real-world implementations of in-network caching refers to the related work [13,14]. The simulations were run multiple times and the presented results are an average of these runs.

3.2. Performance evaluation for basic NDN model

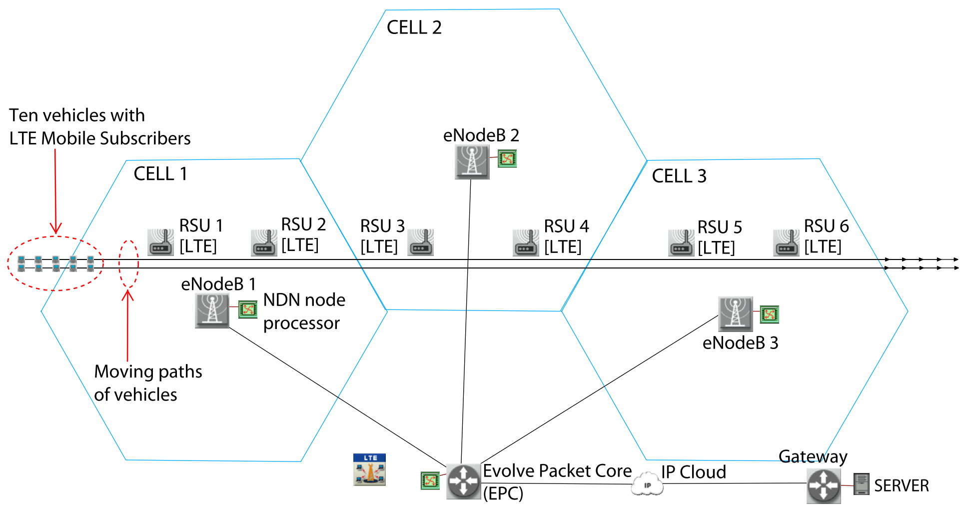
We first evaluate the performance of different content caching/replacement policies for different cache sizes. Assume a relative cache size presents the percentage of a cache size over a catalog size. In Fig. 4(a), the relative cache size in NDN node is increased by 0.06%, 0.1%, 0.16% and 0.2%. It should be noted that in the simulation, the catalog size (500 000 files) is much greater than the cache size (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 constant need to retrieve a suitable cache size.

In Fig. 4(b), it illustrates the performance comparison with the four schemes when the relative cache size is set to 0.16%. The figure shows that PT-Sharing outperforms all the other schemes, followed by PT-LRU, LRU and LFU, respectively. In Fig. 4(c), it illustrates the further comparison with the four schemes for different relative cache sizes. The hitting rates of PT-Sharing and PT-LRU is always higher than the conventional LRU and LFU schemes in all situations. Fig. 4(d) shows amount of traffic responding by the server under various caching schemes and relative cache size 0.1%. With higher hitting ratio, lower requested traffic is fetched to the server, then higher percent offloading traffic achieve. PT-Sharing and PT-LRU help the server to offload total traffic more quickly and deeply than LRU or LFU. PT-Sharing is faster coverage to final state than PP as shown in Fig. 4(d), PT-Sharing helps the server quickly reduce to about 10 Mbps at the 500th second while the 700th second for PT-LRU.

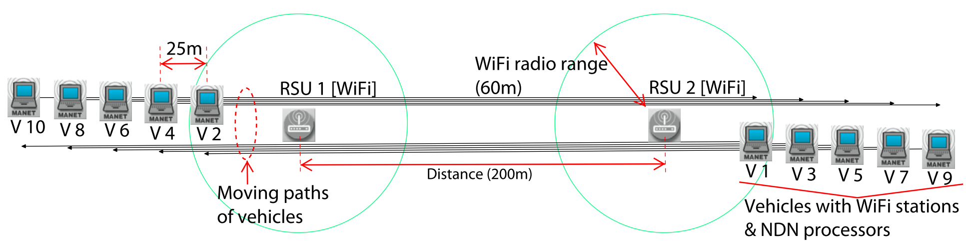
4. VENDNET simulation and results

Motivation from the NDN model simulation, we enhance VENDNET 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 64 Kbps 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 20 km/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.

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 5 km/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

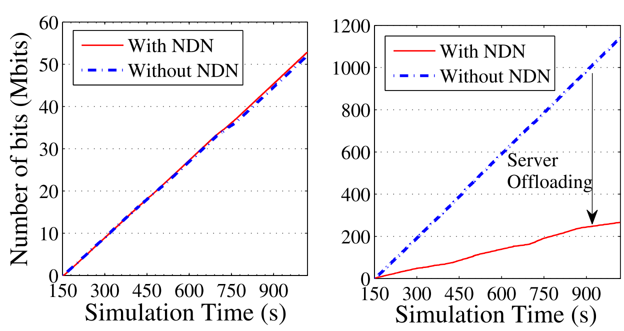


(a) V2I network simulation.

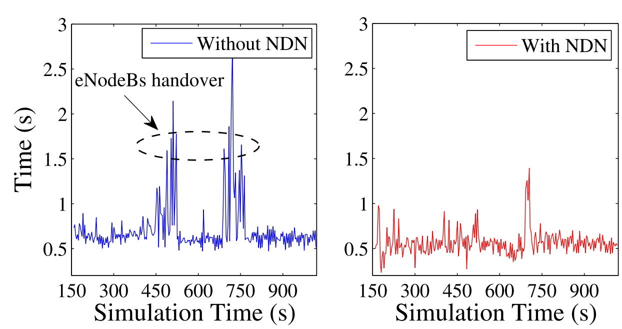


(b) V2R&V2V network simulation.

Fig. 5. VANDNET simulation.

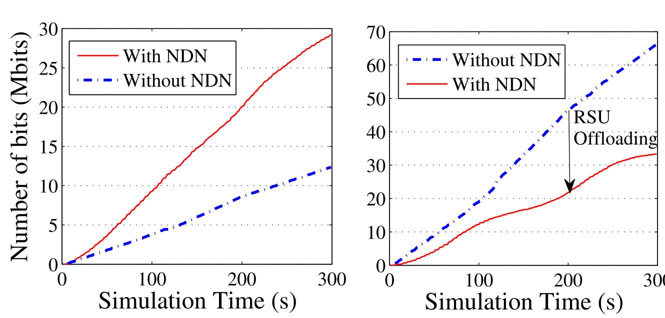


(a) Total bits received by vehicles and sent by server.

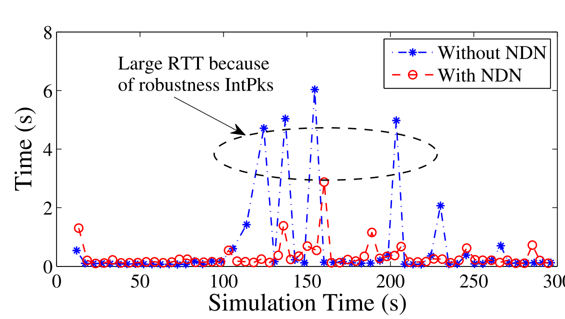


(b) Average RTT at vehicles.

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.

be noted that the typical speed of vehicles is about 40–80 km/h. However, we would like to determine the responding of the VENDNET model in some 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.

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 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 450th and the 750th 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 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; e.i., *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 100th to the 200th 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 have introduced two variants of a new cache decision and replacement policy for NDN that take into account of content popularity. Furthermore, we have implemented the VENDNET model in two networks scenario: V2I and V2R&V2V. The performance of the proposed policy and the VENDNET model have been evaluated using OPNET simulations. The obtained results show that NDN mechanism can improve the performance of the network significantly. In the future work, the VANDNET model should be evaluated under various scenarios with a huge number of vehicles, and mobility patterns, and by using prototypes. Moreover, we will focus on the implementation of VANDNET in practical.

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