A Simulation Study of Connected Vehicle Systems Using Named Data Networking

Tao Jiang, Xiaowei Xu, Lu Pu, Yu Hu(✉), and Zhijun Qiu

School of Optical and Electronic Information,
Huazhong University of Science and Technology, Wuhan, China
huyu.cs@gmail.com

Abstract. A Connected vehicle (CV) system is a crossing field of intelligent transportation systems (ITS) and the internet of things (IoT). The IP-based network protocol has been employed in CV systems. Recently, studies have been conducted to explore the adaptation of Named Data Networking (NDN) in certain CV applications, particularly in cloud computing-based applications and services, to enhance the QoS and lower the cost of network infrastructure. In this paper, we propose SimIVC-NDN, an federated simulation platform with the capability of performing a microscopic traffic simulation with both NDN and IP-based networking. Using SimIVC-NDN, we have conducted a quantitative simulation comparison for two CV systems powered by NDN and IP solutions, respectively, for image dissemination, a common cloud computing service. In the experiments we construct a CV system 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, indicating that an NDN-based networking is 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 · High level architect

1 Introduction

Connected vehicle (CV) is a crossing field of intelligent transportation systems (ITS) and internet of things (IoT), which focuses on supporting safety, mobility and environmental applications. Network protocol, affecting both communication delay and the quality of service (QoS) of traffic applications, is an essential component of the CV research. The conventional IP-based network protocol has been a mature and popular means in vehicle communication applications [8].

Recently, researchers in the CV community started to explore the adaptation of Named Data Networking (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, 6, 7]. NDN aims to provide secure content-oriented data transmission [1, 3]. Different from IP-based networking, NDN focuses on "what to send" (the content) instead of "where to send" (the address) [15]. In this new network

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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 [4, 5]. 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 federated 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 a common cloud computing-based application (image dissemination) 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, indicating that an NDN-based networking is a promising alternative to the conventional IP-based one for cloud computing applications of CV systems.

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 Sects. 4 and 5 for a case study comparing using NDN and IP-based networking in a CV application. The paper is concluded in Sect. 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 Introduction to Connected Vehicle

Connected vehicle (CV) focuses on supporting mobility, safety and environmental applications [9]. Mobility applications provide a connected vehicle and infrastructure environment which is designed 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.

The cloud infrastructure is an indispensable component to CV applications. The cloud infrastructure captures real-time data from equipments located either on-board vehicles or within the transportation infrastructure (e.g. the road side stations for collecting and disseminating information). The data are transmitted wirelessly and are utilized by a wide range of multi-modal applications (e.g. application that aims to make better future route planning).

2.2 Introduction to NDN

The layered architectures of IP and NDN are shown in Fig. 1.

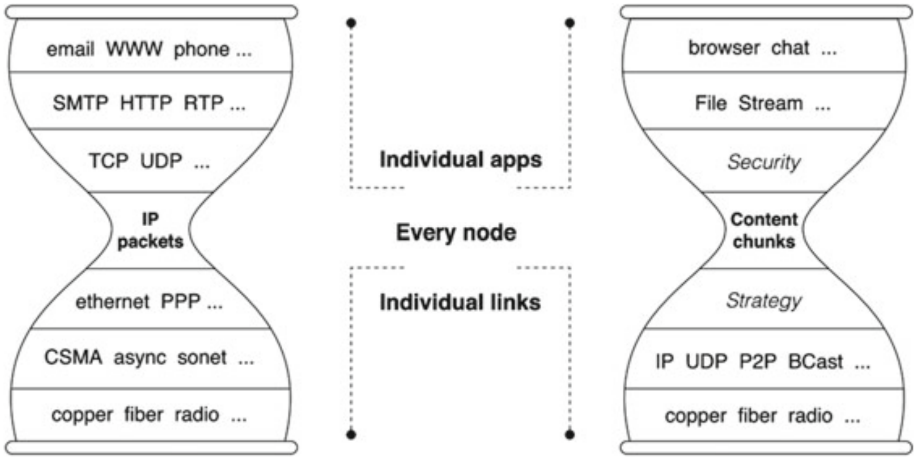

Fig. 1. IP vs. NDN layered architecture overview [1]

Unlike IP (host-to-host communication based on IP addresses), NDN is *content-centric* communication. The IP-based routers utilize IP address headers to forward packets. The NDN-based routers, however, utilize the *name prefix* (which uniquely identify a piece of data) of each packet for packet forwarding.

NDN communication is consumer-driven. Data consumer sends out request (named *Interest* under NDN terminology) with specific name prefix for desired content (named *Data*), where the name prefix of the Interest packet and that of the Data packet are identical. Due to the content-centric (instead of host-centric) nature, NDN can run over any physically connected network [1]; 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 request, 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 request is immediately satisfied.

The detailed description of NDN can be found in [1, 2].

3 Simulation Architecture

As to the connected vehicle simulation, depending on the needed simulation resolution of both vehicular driving behaviors and networking protocols, it is desired to develop a state-of-the-art simulator capable of performing both fine-grained microscopic traffic simulation and network simulation. We thus propose a simulation platform that integrates VISSIM and NS-3 which stems from our previous work [10].

The architecture of our simulation platform is shown in Fig. 2. We created a simulation control layer (SimCL), which aims to: (a) handle synchronization between traffic simulator VISSIM and network simulator NS-3 (currently our implementation is through the file level synchronization); (b) transfer traffic information from VISSIM to NS-3 and; (c) send back network information (not implemented yet) for further traffic guidance and management.

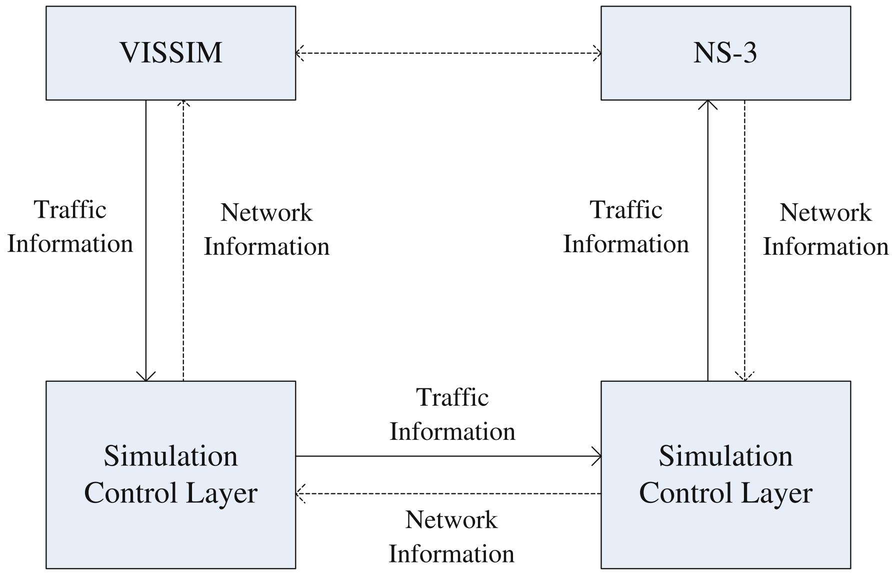

Fig. 2. SimIVC-NDN architecture overview

The new system has two main benefits [10]: (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 either corresponding field, the coupling simulation approach (instead of implementing both the traffic and network simulator alone [13]) is more realistic and trustable. 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 Sect. 4.

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

Based on SimIVC-NDN described in the previous section, we propose an image disseminating application scenario to conduct a comparison between NDN and conventional IP-based networking under the connected vehicle communication environment.

4.1 Application Overview

As shown in Fig. 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 (Vehicle to Infrastructure) is involved; that is to say, 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 request (with the request interval *VehInt*) for the latest image from certain camera.

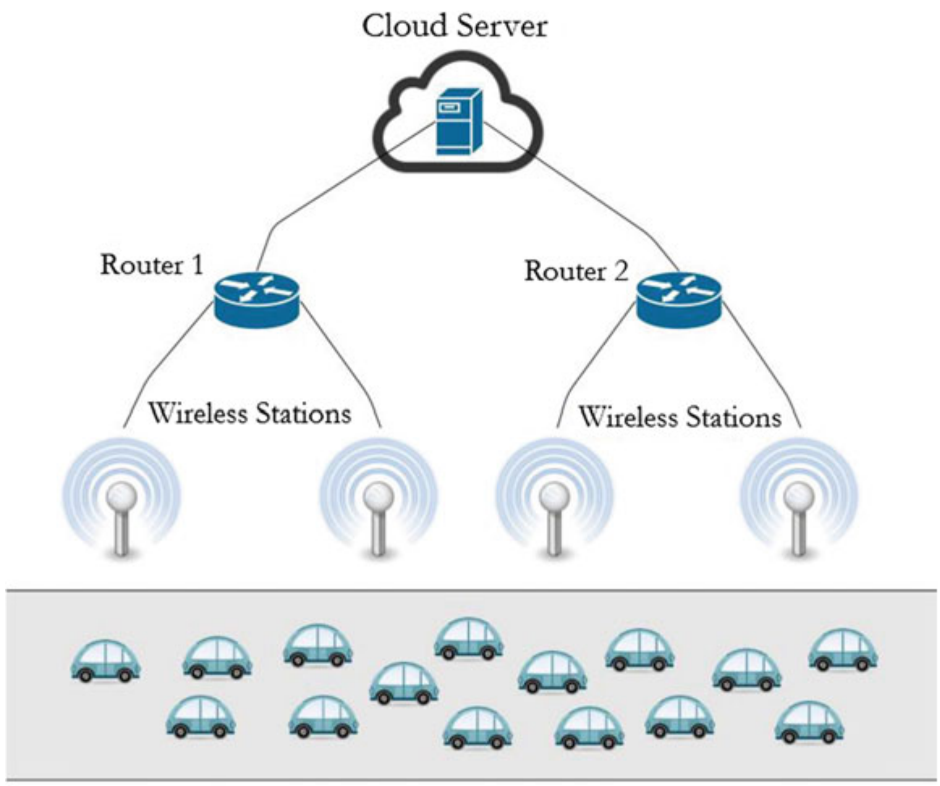

Fig. 3. Image dissemination application scenario

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 rules. For cases with IP, the station will forward the request according to the routing table. For cases with NDN, the station will forward the request according to the CS, PIT and FIT which we have described in Sect. 2.2. For example, 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, the router is equipped only with wired networking interfaces. 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

After an overview of our proposed cloud-based image dissemination application scenario, the simulation setup details will be described in this section.

(a) Simulation Methodology
The simulation network topology corresponding to our application scenario is presented in Fig. 4. As shown in the figure, the bandwidth of either *Backbone 1* or *Backbone 2* is 1000 Mbps, while the bandwidth of either four *branches* is 100 Mbps. We assume that all wired connections' transmission delay is 1 ms.

The VISSIM simulates the *wireless* communication between stations and vehicles; and it will generate a file (that will be explained in detail later) 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.

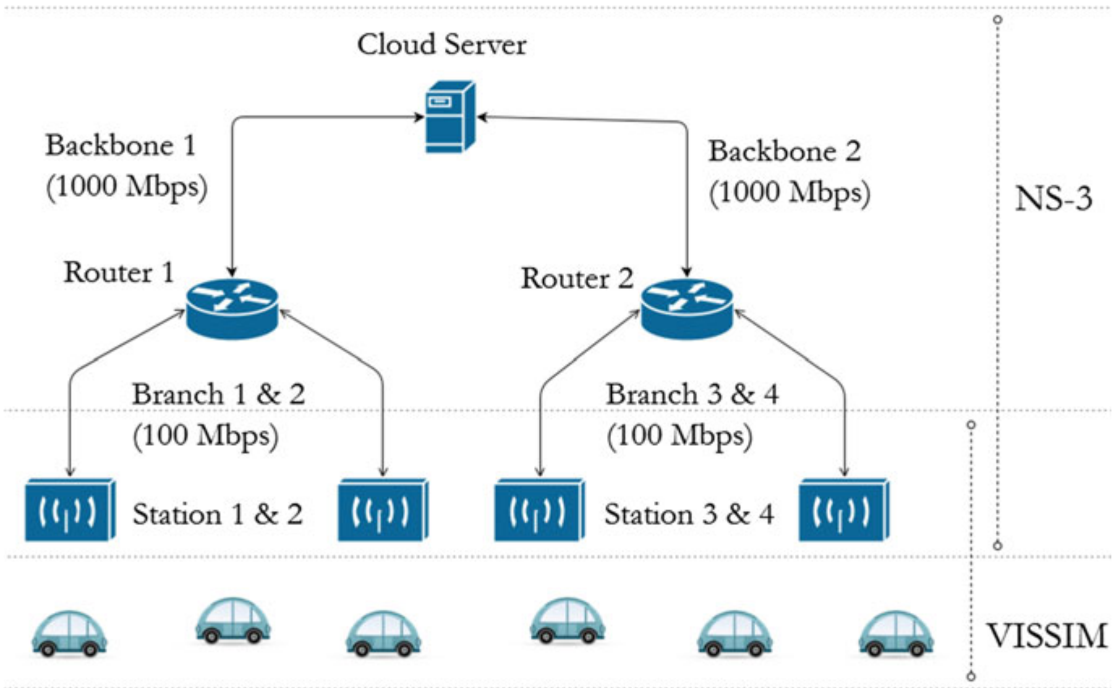

Fig. 4. Simulation network topology

(b) 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 [11, 12]. Within the road model, four stations are located with an interval of approximately 500 m, as shown in Fig. 5.

We utilize the Car2X functionality of VISSIM [16] to simulate the wireless communication processes between vehicles and stations, with the assumption that the communication range of each vehicle is 250 m (only within this range, a vehicle can wirelessly communicate with the nearest station).

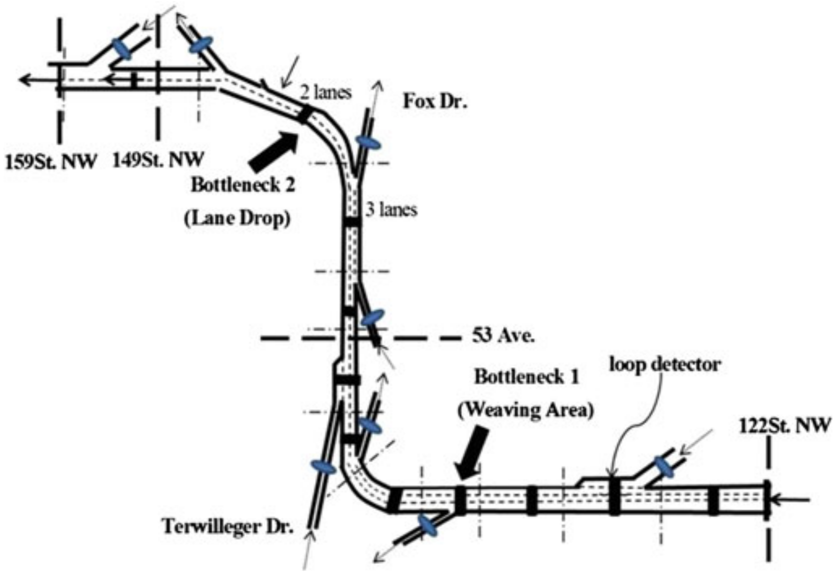

Fig. 5. Whitemud Drive road model, modeled and calibrated with VISSIM

The vehicles periodically send requests for desired image data during the simulation. The interval between each request (i.e. the *VehInt*) is designed to be 1 s, 2 s, 4 s, 8 s, and 16 s in different experiments. On receiving a request from some vehicle, the station records the current timestamp (i.e. the simulation time step) 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 we can obtain the communication frequency between vehicles and each station; also, the NS-3 simulation can synchronize with the VISSIM simulation by utilizing the timestamps in the table.

The runtime of the simulation is 600 s.

(c) 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) 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 rules. For cases with IP, the simulation is based on the IP protocol stack implemented by NS-3 [14]. For cases with NDN, the simulation is based on the NDN protocol stack implemented by Lixia Zhang [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 the possibility is 1. Secondly, as to the name prefix under NDN-based network, if the image updating interval *UpdateInt* is 2 s, 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"* (the meaning has been explained in Sect. 4.1).

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 experiments.

Table 1 NS-3 simulation parameter

Parameter	Type/Value
Protocol stack	NDN vs. IP
UpdateInt	1 s, 2 s, 4 s, 8 s, 16 s
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 our simulation are shown below. Figure 6(a, b) shows the average delay between request packet and response packet, each for 40 KB and 80 KB image data size. Figure 6(c, d) shows the average throughputs considering the four branches and two backbones (as shown in Fig. 4), each for 40 KB and 80 KB image data size. The horizontal axis "interval" indicates the request interval (i.e. *VehInt*).

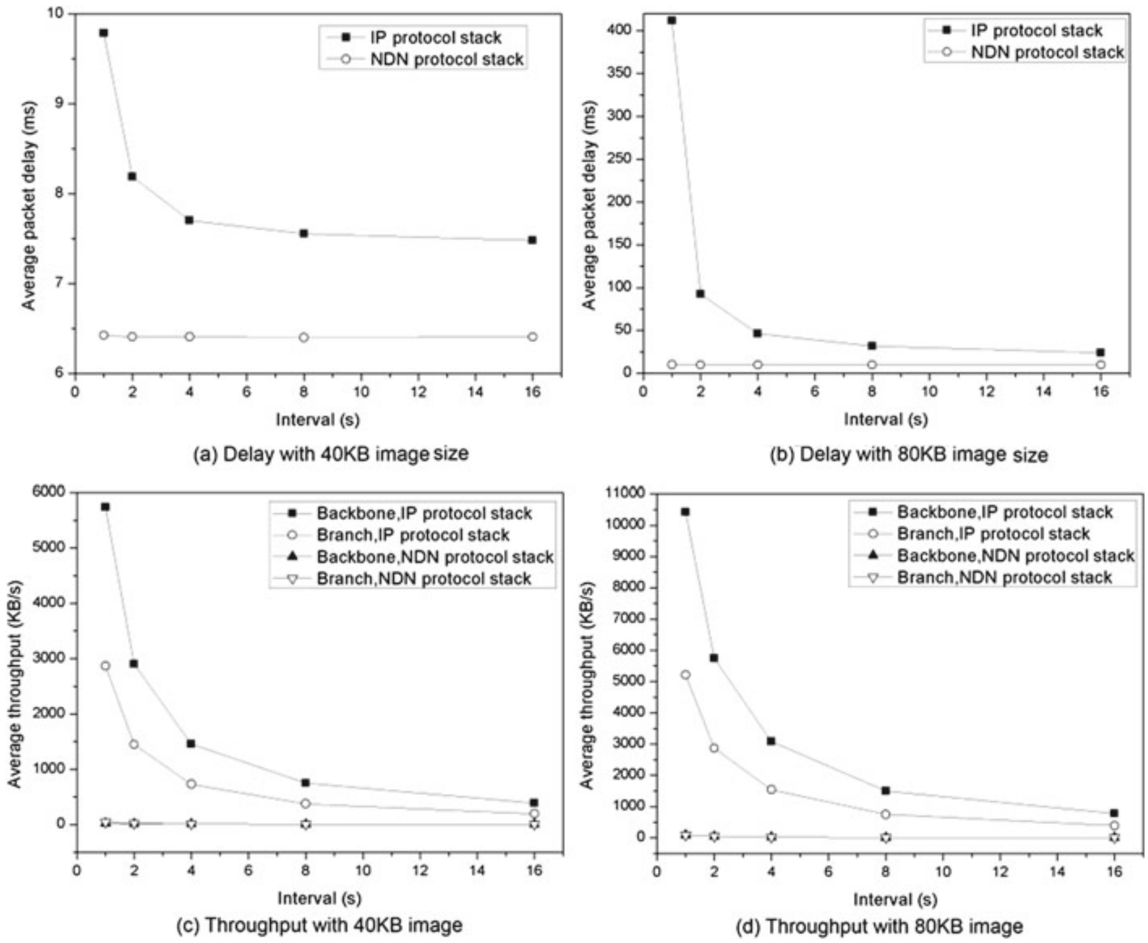

Fig. 6. Simulation results of our application scenario

As to average delay, under IP circumstance, when *VehInt* decreases, the delay increases exponentially; while under NDN, when the interval decreases, the delay almost stays the same. As to average throughput, similar phenomena can be observed. 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.

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, 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 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, an 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, indicating that an NDN-based networking is 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.

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