Performance of Named Data Networking in Connected Vehicles

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Abstract

Vehicular Networks are likely to be implemented in future vehicles. Their usage can enhance road safety and enable new forms of communications such as Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications. The simulation of this type of network is the most useful method to test new techniques, algorithms, and architectures. This is basically due to the high cost of deploying such systems in real scenarios. Named Data Networking (NDN) is a new architecture that researchers have proposed recently as a promising architecture for future Internet technologies. It is expected to support various applications in vehicular communications and aims to overcome the problem of classically TCP/IP-based architecture concerning mobility, by relying on naming the content rather than using end-to-end node addresses. Indeed, the in-network caching feature in NDN makes this architecture more suitable for vehicular networks. To prove the usefulness of NDN in connected vehicles, we propose a simulation study in an urban network architecture.

Keywords
Connected Vehicles, NDN, V2V, TCP/IP, Road Safety

1. Introduction
In 2013, 5.6 million vehicle crashes and 32,719 deaths have been accounted, according to the National Highway Traffic Safety Administration (NHSTA). Motorists and onboard telematics solutions providers are concerned about automotive safety devices. With great support from the drivers, technological devices and systems related to automotive safety are being evolved: fatigue warning system, night vision assist system, reversing sensor, lane departure warning, … etc.

Manufacturers discussed different conceptions and notions such as Intelligent Transportation Systems (ITS) in order to achieve road safety and comfortable driving. Today, a variety of technologies are already deployed and vehicles can now use navigation systems, connect to the network and run different applications. In addition to the mentioned services, manufacturers and research communities aim to achieve Vehicle to Vehicle (V2V) (Sabir & Amine, 2021a) and Vehicle to Infrastructure communications (V2I) (Sabir et al., 2019) (Sabir & Amine, 2021c) in order to enhance road safety by exchanging alerts and safety messages between vehicles and between vehicles and Road Side Units (RSUs).

Most connected vehicle applications are IP-based network protocol, which influences both quality of service (QoS) and latency. Nevertheless, the IP protocol is designed for host-to-host connection which is low effective for information dissemination. Moreover, IP protocol is unsatisfactory in supporting direct communication in connected vehicles with high mobility and in absence of Road Side Units (RSU). Thus, many researchers begin to test Named Data Networking (NDN), a new Internet architecture, in connected vehicle applications (Sabir & Amine, 2018). This architecture supports the caching of data in the network in order to satisfy future requests, which gives an advantage to NDN in terms of data transfer.

In this paper, we present a simulation study of TCP/IP (Transmission Control Protocol/Internet Protocol), the current Internet model, and NDN, the future Internet architecture, over vehicular networks. We attempt to study the performance of the new architecture compared to the old one. This paper is considered a continuation of our previous work (Sabir & Amine, 2020). The remainder of the paper is organized as follows: Section II presents the limitations of the TCP/IP protocol, Section III introduces vehicular communications over NDN. The performance evaluation and the simulation results are analyzed in Section IV, Section V concludes the paper.

2. Limitations of the TCP/IP Architecture

The TCP/IP model maintains end-to-end connectivity. TCP is responsible for higher-level functions like error detection and segmentation whereas IP is handling datagram routing (Forouzan, 2009). This model specifies the addressing, transmission, receiving of data at the destination, formatting, and routing. Nevertheless, the research community showed that the TCP/IP model has limitations (Izquierdo et al., 2011). Shang et al. (Shang et al., 2016) analyzed some challenges in IoT networking via TCP/IP architecture in different points. They indicated that the design of the TCP/IP protocol stack is not a good fit for the IoT environment, since it faces a lot of issues, in terms of the network layer, transport layer, and application layer. Another difficulty is caching, the model of TCP/IP necessitates that both the client and the server are connected at the same time, which is challenging for IoT applications such as connected vehicles due to the intermittent and dynamic network environment.

Researchers of FIA (Future Internet Architecture) (*NSF Future Internet Architecture Project*, n.d.) considered fundamental limitations of the TCP/IP model with regard to transmission, storage, processing/handling of data, and control. Transmission of data, which refers to the exchange of data, suffers from problems of security, since it is not built in the architecture, but only given by different extensions. Storage, which refers to disks, buffers, caches, memory, etc., experiences due to attacks and breakdowns problems such as availability of information while transferring, storage management and retrieval, loss of storage encrypted data, and integrity. The processing/handling of data, which refers to forwarders, computers, CPUs, etc., faces difficulties as well. Hosts are unable to run appropriate actions and failures are not easily identified. In control and supporting mobility, which refers to analysis, observation, and decision, there is a lack of congestion control, as current schemes are based on collaboration between the network and end systems which causes more expenses.

3. Vehicular Communications over NDN

Named Data Networking (NDN) is a well-known Information-Centric Networking (ICN) instance that has been proposed as a promising future Internet architecture. It presents a new communication concept based on content-centric (Jacobson et al., 2009). NDN uses two new types of packets which are “Interest packet” and “Data packet” (Hassan et al., 2016). They are forwarded to the network based on their name prefix instead of IP addresses (E. Zhang et al., 2010) (Jacobson et al., 2012; L. Zhang et al., 2011). Hence, it focuses on “what to send” rather than “where to send”.

In order to process the packets, each node includes three key data structures: A Forwarding Information Base (FIB) which stores forwarding information such as next hops and content prefix used to guide Interest towards the content sources. A Pending Interest Table (PIT) which is designed to record disseminated Interests that are not yet satisfied, so the packets can correctly return back with Data to the original requesting consumers. And a Content Store (CS) which is used by an NDN router to temporarily cache a copy of the Data packet, recently forwarded in order to serve future requests and maximize the probability of sharing.

Several researchers proposed to bring NDN to connected vehicles due to various technical issues that are faced when attempting to enable vehicular data exchanges over TCP/IP. Figure 1 (Sabir & Amine, 2021b) depicts an example of NDN-based VANET architecture.

In this example, Consumer 1 asks for the content “/parking/ Mimosas/P3”. Given that the Forwarder has already cashed the requested content, it directly replies to Consumer 1 without forwarding its Interest packet to the original Producer. The Interest for content “/traffic/highway/A5/20” by Consumer 3 is instead forwarded to the Producer. If, in the meanwhile, Consumer 3 receives an Interest for the same content from Consumer 2; the request is aggregated in the PIT, and the Interest is not forwarded again. When the Data packet arrives at the Forwarder, it is forwarded to Consumer 3, which forwards it in its turn to Consumer 2 by following the PIT entries. Applying NDN to vehicular environment brings various benefits such as:

- **In-network caching:** thanks to this NDN feature, the data availability is improved and consumers’ requests are satisfied even when original content publishers are no longer available. As vehicles have considerable space for storage and elevated processing capacity, they can smoothly support exhaustive computations and easily cache a significant quantity of data.

- **Mobility and Routing:** vehicular communications over NDN don't have to seek new addresses while moving, thanks to adopting routing based on content names which improve vehicle mobility. Additionally, the implementation of adaptive forwarding logic allows vehicles to take advantage of various interfaces naturally at the same time. Therefore, a vehicle can switch to another interface if the used one is defective or operates insufficiently.
- **In-Data Security:** in NDN, security is no longer specified by the classic methods that secure the transmission support itself. Given that any vehicle in the network can cache content, the security attributes of the content have to be decoupled from its location. For that reason, security must be built in the Data packet itself by binding the content name to the data. However, various types of network attacks still exist in NDN.

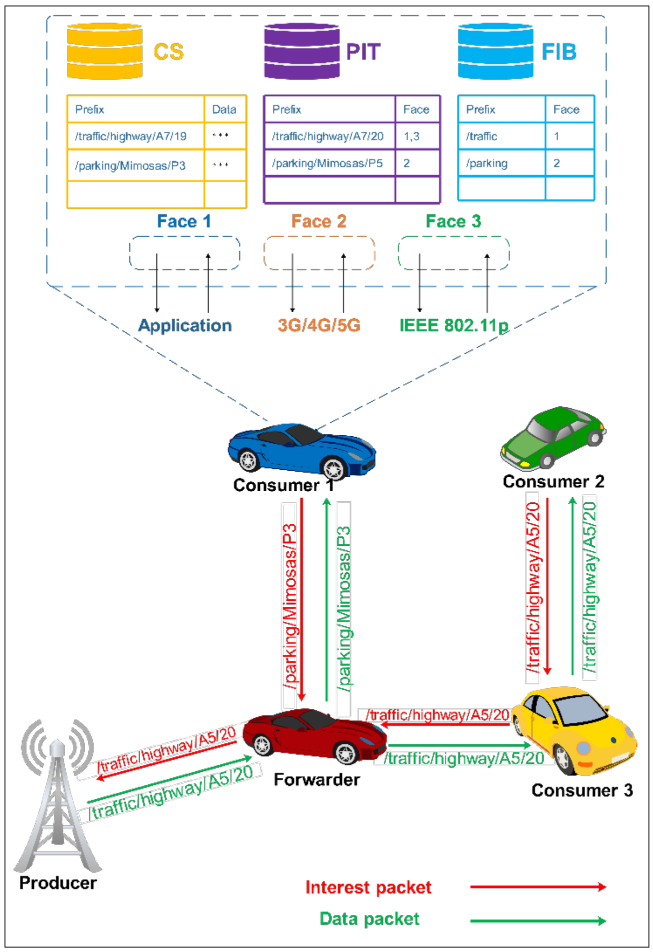

Figure 1. Example of connected vehicles using NDN

4. Performance Evaluation

In this section, we will evaluate the performance of connected vehicles based on the two models: TCP/IP (current Internet architecture) and NDN (future Internet architecture). We will first present a brief comparative study then we will expose and discuss the simulation results.

Named data networking is based on content-centric, it deploys name prefixes instead of IP addresses and it manages three tables: the CS, the PIT, and the FIB, while the TCP/IP model is based on a host-to-host communication pattern and uses IP addresses for source and destination nodes. It manages only the FIB table, thus, in-network caching of solicited data is supported in NDN while it is not in the TCP/IP. NDN routers use nonce with packet name to avoid loops, whereas TCP/IP routers rely on routing protocols. Since the packets are not recorded in the routing table, TCP/IP cannot monitor data rendering, while NDN can do it thanks to the PIT state and calculation of Round-Trip Time (RTT). Routing protocols are also used in TCP/IP to control failures in packet forwarding, which may generate extra charges in the network. In NDN, this is done through examining interfaces regularly. To provide security, a secure medium is used between hosts on the current Internet, while NDN includes security in the architecture, as every Data packet is signed by the original provider.

In order to complete this comparative study, we propose to simulate a scenario of vehicular networks using TCP/IP and NDN. Thus, we used ndnSIM (Afanasyev et al., 2012), an ns3-based NDN simulator (Nsnam, n.d., p. 3). The simulation consists of 66 vehicles moving in a residential area of Kenitra city. The cars' mobility is generated using SUMO (Krajzewicz et al., 2012) and OpenStreetMap (*OpenStreetMap*, n.d.). Simulation has been done on Intel Core i5 CPU at 2.4 GHz, with 8 GB DDR3 RAM. The overall simulation time is 30 s that includes the communication between 66 vehicles: 12 producers and others are consumers and data mules. The consumers are requesting contents with a rate of 10 Interest/s. Simulation parameters are summarized in Table 1.

Table 1. Simulation parameters

Parameters	Values
Protocol Stack	TCP/IP vs NDN
Network Simulator	ns-3 & ndnSIM
Traffic Simulator	SUMO
Simulation Scenario	Urban
Number of vehicles	66
Simulation Time	30 s
Speed	20 m/s
Mac Type	IEEE802.11p
Interest rate	10 /s
Data Payload Size	1200 bytes
CS Cache Method	LRU
CS Max Size	1000
Forwarding strategy	Best Route

Figure 2 shows the average throughput in both NDN and TCP/IP. From this comparison, it is clear that the throughput in NDN is much higher than in the TCP/IP. In the first one, the throughput starts at a low value and increases as time moves forward, in contrary to the second one where the throughput is higher in the beginning and decreases by the end.

When it comes to average packet delay, Figure 3 shows how long it takes for a vehicle to obtain the desired content. It indicates that the average packet delay of TCP/IP is much higher than NDN. The latter lowers the delay to almost 0 µs while the former increases as time moves forward. The difference may be caused by a variety of factors such as the caching mechanism of NDN which makes the immediate response of request possible. If a vehicle has a copy of the desired data within its CS, the request (i.e., interest packet) would be immediately satisfied and with no need to travel a long distance to the server (i.e., original producer), which reduces the delay.

Figure 4 and Figure 5 exhibit the total sent and received packets in NDN and TCP/IP respectively. We can clearly analyze that almost all the sent packets in NDN are successfully delivered to their requesters (i.e., consumers) from the beginning to the end of the simulation. While in TCP/IP, the packets are successfully distributed to their requesters only in the beginning and started to be lost as time moves forward.

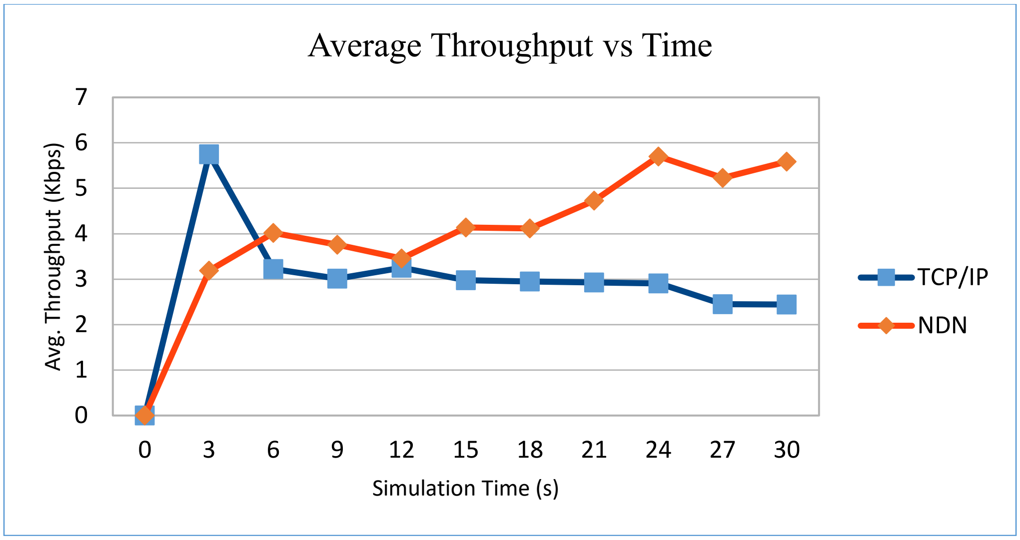

Figure 2. Average throughput vs time

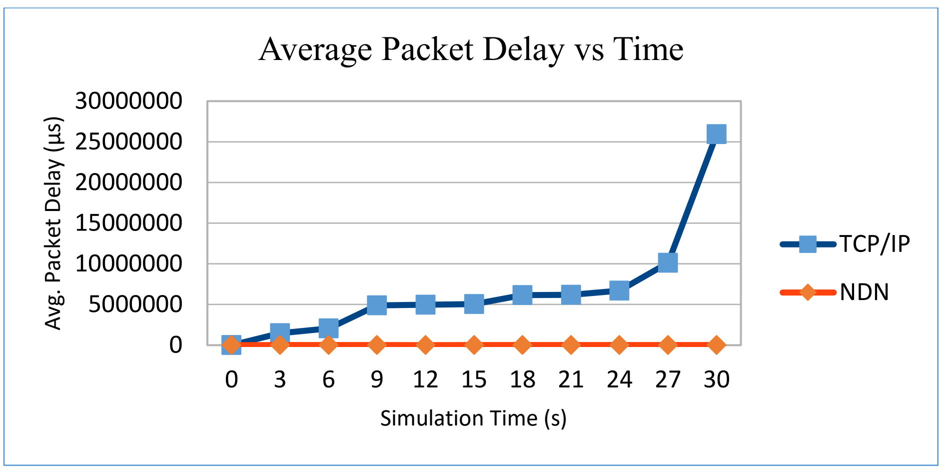

Figure 3. Average packet delay vs time

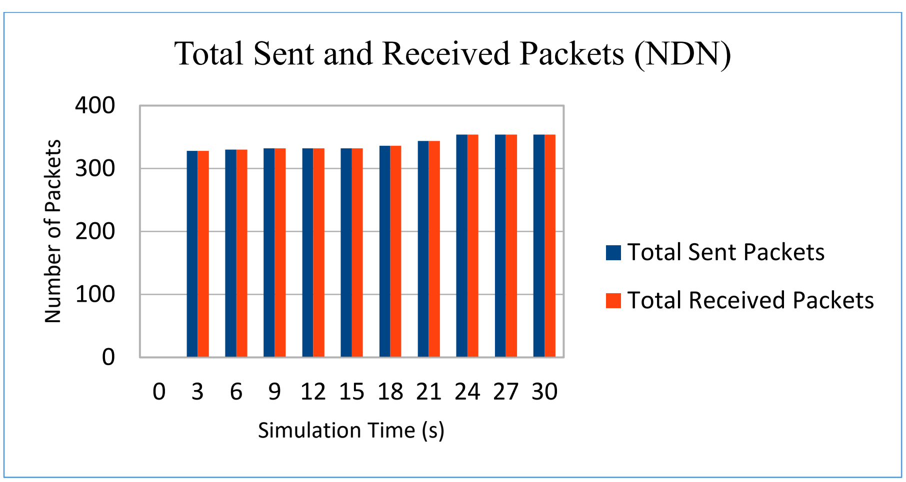

Figure 4. Total sent and received packets in NDN

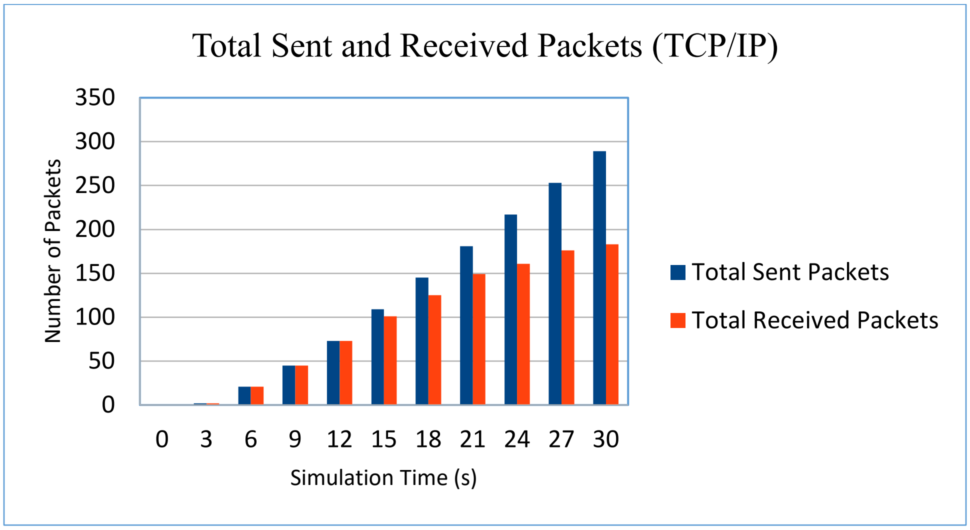

Figure 5. Total sent and received packets in TCP/IP

5. Conclusion

In this paper, we presented a performance analysis through a simulation with both NDN and TCP/IP-based vehicular networks. Using the ndnSIM and ns-3 simulators, we have conducted a comparison of connected vehicle systems powered by NDN and TCP/IP solutions. The simulation results show that the NDN-based vehicular communication system lowers the packet delay and raises the throughput compared with the TCP/IP-based one. It is also worth saying from the sent and received packets graphs that the data drop rate is null in NDN compared to the TCP/IP. We can conclude by stating that NDN-based networking is a promising alternative to the conventional IP-based one for vehicular communications, and it can be implemented in the near future to make the transportation system intelligent and accident-free. In our future work, we will propose a new method to enhance security in vehicular networks over NDN.

Acknowledgments

This research work is supported by the “SafeRoad: Multiplatform for Road Safety (MRS)” Project under contract No: 24/2017, financed by the Ministry of Equipment, Transport, Logistics and Water (METLE), and the National Center for Scientific and Technical Research (CNRST).

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Biographies

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