Connected Vehicles using NDN for Intelligent Transportation Systems

Zakaria SABIR and Aouatif AMINE
Boss Team, LGS Laboratory, National School of Applied Sciences
Ibn Tofail University
University Campus P. O. Box 241, Kenitra, Morocco
zakaria.sabir@uit.ac.ma , amine_aouatif@univ-ibntofail.ac.ma

Abstract

Connected vehicle technologies aim to tackle some of the biggest challenges in the surface transportation industry. Connected vehicles feature safety warnings that alert drivers of potentially dangerous conditions - impending collisions, real-time information about traffic conditions and dangerous curves - before the driver is aware of them. The technology is anticipated to reduce unimpaired vehicle crashes by 80 percent. This paper presents the Named Data Networking (NDN) approach that seems to be the best suited to mobile environments, especially for connected vehicle. This work will describe the NDN along with its components, we will include some details of NDN in Vehicular Ad hoc NETwork (VANET) and finally, we will discuss the open issues and future research directions.

Keywords
Connected Vehicle; V2V; V2I; NDN; ICN; CCN; ITS.

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.

The technology of connected vehicle aims to remarkably decrease the number of lives lost each year, by giving to the drivers necessary tools to forecast possible crashes. A connected vehicle can predict, learn and analyze. While increasing the driver’s comfort and safety, it collects information from its neighboring and enhance its performance. For example, it provides passengers with Wi-Fi access and allow them to download software updates and retrieve media content. Thanks to connectivity, the vehicle is now able to put together valuable data that changes the way of driving. It can communicate with its environment and obtain information about obstacles, speed, traffic conditions, location, and acceleration, in order to reduce the accident rate.

The development of new vehicular applications is essential for improving the safety of transportation systems, generally known as Intelligent Transportation Systems (ITS). According to (J.A. Guerrero-Ibáñez et al., 2013), there is no single definition of ITS. Depending on the intention behind the implementation of the ITS, each country has its own definition. In the United States for example, the ITS refers to various technologies that address many of existed transportation problems, and aim to save lives, time and money (ITSA, 2011). Japan describes ITS as a significant solution to deal with transportation systems problems, including traffic congestion, environmental pollution and traffic accidents (ITS, 2010). Finally, Europe represents ITS as a new application used in urban transport by information and communication technologies (ERTICO, 1998).

Connected vehicle system is a component of ITS. It has been proposed as a hopeful technology which uses wireless communication and aims to tackle some of the biggest challenges in the surface transportation, by enabling Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications. Most connected vehicle applications are based on the IP protocol which is designed for point to point connection and that is inadequate for information dissemination. Thus, in this article, we are interested in the Named Data Networking (NDN) approach which focuses on the content rather than the source of the information, and therefore, seems to be the best suitable to mobile environments, as we will explain later.

The rest of this paper is organized as follows: in section 2, we provide a description of NDN along with its components. Section 3, includes details of NDN in connected vehicles. The open issues and future research directions are discussed in section 4. Finally, we conclude this article in section 5.

2. Named Data Networking (NDN)

Named Data Networking is one instance of Information Centric Networking (ICN) which is a more general network research orientation (G. Xylomenos et al., 2013) as can be found in Figure 1 (FIA). It is a new internet architecture that ignore mapping between what (the content) and where (the network location), the focus is just on the content and how to retrieve it. Instead of source and destination address, the named data packets are used (L. Zang et al., 2010). While IP-based routers use IP address headers for packets forwarding, the NDN-based routers use each packet's name prefix to forward packets. Communication using unique content names permits routers to keep track of packet's states, in contrast to the IP routers. The name in an NDN packet can be used for anything; a data chunk in a book or a movie, an end point, a command, etc. (L. Zang et al., 2014).

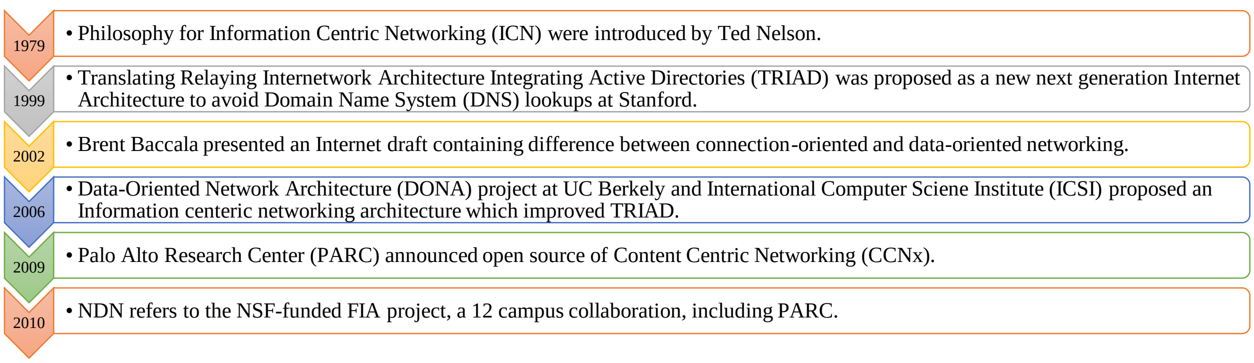

Figure 1. NDN timeline

The main design principles of NDN are founded on the Internet. Major IP services like inter-domain routing policies and Domain Name Service (DNS) can be directly used in NDN. With little modifications, OSPF and BGP which are routing protocols in IP architecture, can be adjusted to NDN. Figure 2 depicts the layered hourglass architectures of NDN and IP (V. Jacobson et al., 2009). As shown in the figure, Internet and NDN share the same layered hourglass architecture with some practical variations between equivalent layers. The main blocks of NDN are the named content chunks, whereas the base unit of communication in IP is an end-to-end channel which connects two endpoints recognized by IP addresses.

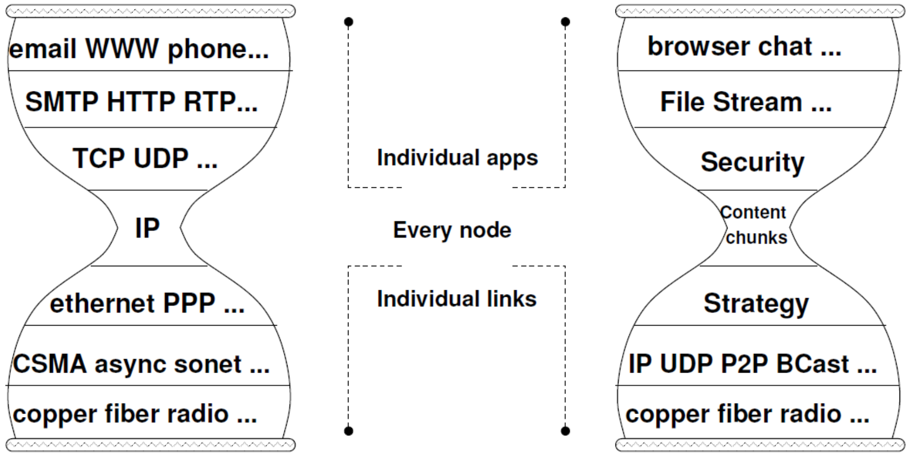

Figure 2. IP and NDN hourglass architectures

From Figure 2, it can be seen that editing the OSI communication model by adding new functionalities and modifying the existent ones is difficult. In the NDN model, two new layers are added: Strategy layer that is used in the forwarding plane which is responsible of forwarding decision and which include also all functions of Internet's transport layer. And security layer, which is responsible of securing each content, rather than securing the whole transmission medium.

2.1 NDN Architecture

The architecture in NDN is receiver-driven. It employs two types of packets: Interest and Data, as presented in Figure 3 (V. Jacobson et al., 2013-2015). A data consumer who desires a content chunk starts the transaction by sending to the network an Interest packet, which contain the name of the desired piece of data. Nodes on the network will replay with Data packets. To achieve this, NDN routers propagate the reachability information of content names in a way like the current Internet propagates the reachability information of IP-prefixes (M. Zang et al., 2015). Once a node that possesses the requested data receives the Interest, it will respond with a Data packet which contains a couple of content and name, in combination with a signature by the producer's key. To get back to the consumer, the Data packet pursues in reverse the path taken by the interest.

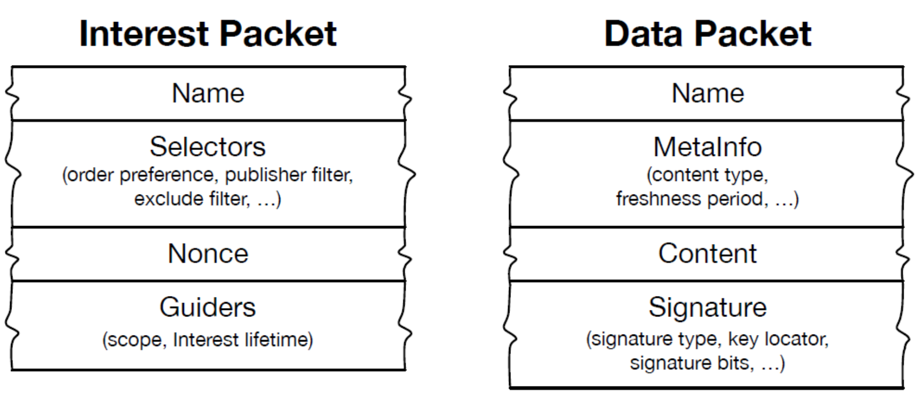

Figure 3. Structure of Interest and Data packets in NDN

The main components of an Interest packet are **Content Name** and **Nonce**. Interest packets are individually recognized thanks to this couple. The first one indicates the name of the desired data. The other one is a random number generated by the consumer in order to discriminate between various consumers asking for the same content. None is also used to destroy looping Interests. **Selectors** and **Guiders** are secondary constituents are added to the principle ones in order to determine the conduct of the Interest packet. Selector is utilized to determine and select the Data that correspond best to the Interest. As for guiders, they are used to specify the lifetime of the Interest packet and how far it can travel.

The Data packet contains four fields, starting with the Name and ending with the Signature. **Name** present a succession of name components in a hierarchical way. **MetaInfo** is an element that contains further information about finalblokid, freshness period, content type, etc. This information is useful for specification of the final block in the fragments chain, replacement in content store, and identification of actual data. As for **Content**, it represents the requested data. This content will be bound to the producer with the help of the **Signature**, which gives further information about the publisher. The verification and the trust of the producer allows to trust every Data packet signed by that producer. Consequently, packets coming from a router's cache, can be determined as confident depending on their signatures. Thus, NDN aims to secure every single Data packet by singing it, rather than securing the channel between two nodes.

In NDN, each node includes three key data structures, as can be found in Figure 4 (M. Amadeo et al., 2017): A Forwarding Information Base (FIB), a Pending Interest Table (PIT) and a Content Store (CS):

- The **FIB** stores forwarding information such as next hop(s) and content prefix, which is used to guide Interest towards the content sources. NDN and IP have similar FIB, with a difference in the prefixes. The first one has name prefixes whereas the other one has IP address prefixes.
- The **PIT** is a cache table for Interest packet, designed to record disseminated Interests that are not yet satisfied, so the packets can correctly return back with Data to the original requesting consumers. Each entry of the PIT records the incoming interface of the interest, the name, and the outgoing interface the Interest has been forwarded to.
- The **CS** is used by an NDN router to temporary cache a copy of Data packet, recently forwarded in order to serve future requests and maximize the probability of sharing.

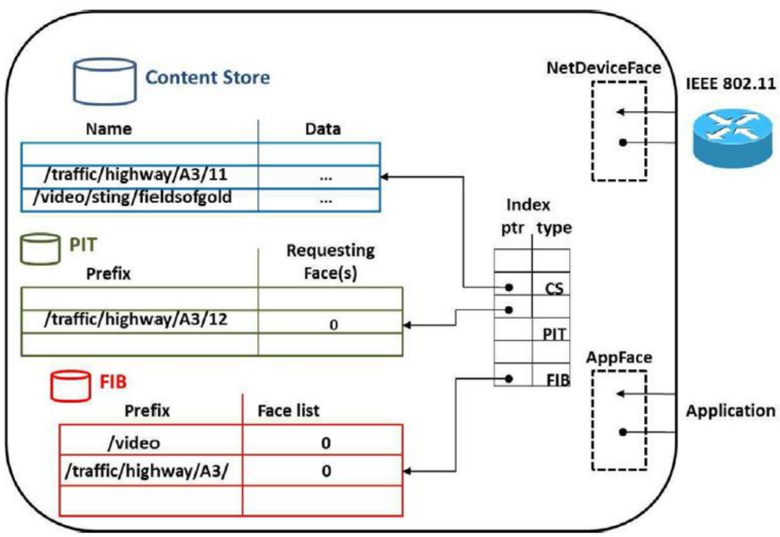

Figure 4. NDN node structure

2.2 Interest and Data processing in NDN

In NDN, the lookup and forwarding process is less complicated in comparison with IP (S. Hassan et al., 2016). Whenever an NDN node receives an Interest, it makes its forwarding decision based on the following algorithm, illustrated in Figure 5 (V. Jacobson et al., 2011-2013): First, it looks up in his CS for an entry linked to the requested content, if a match exists, the node sends the Data to the same interface of the processed Interest (M. Amadeo et al., 2014). Otherwise, it inquires its PIT by checking the entries. If the entry already exists, so it means that another consumer had already asked for the same content, and therefore, his Interest was forwarded earlier. So, the router edits the present PIT entry by adding this new Interest (Z. A. Jaffri et al., 2013). If the name does not exist in the PIT, then the Interest is passed to the FIB which performs a longest prefix match. Once the corresponding FIB entry is identified, the Interest packet is forwarded to the appropriate next-hop(s). A new PIT entry is then created with its incoming interface. Differently, the Interest is diffused to all outgoing interfaces or deleted, depending on the forwarding policy (D. Saxena et al., 2016).

When a Data packet reaches an NDN router, its name is used to query the PIT. If some more entries for the same Data packet are founded in the PIT, then the packet is cached in the CS and sent to all the requesting faces (the interfaces from where each Interest was received). Finally, the entry is deleted from the PIT when it is fulfilled. In another condition, if a match is not found in the PIT, then the Data packet is an unwanted one and is consequently dropped.

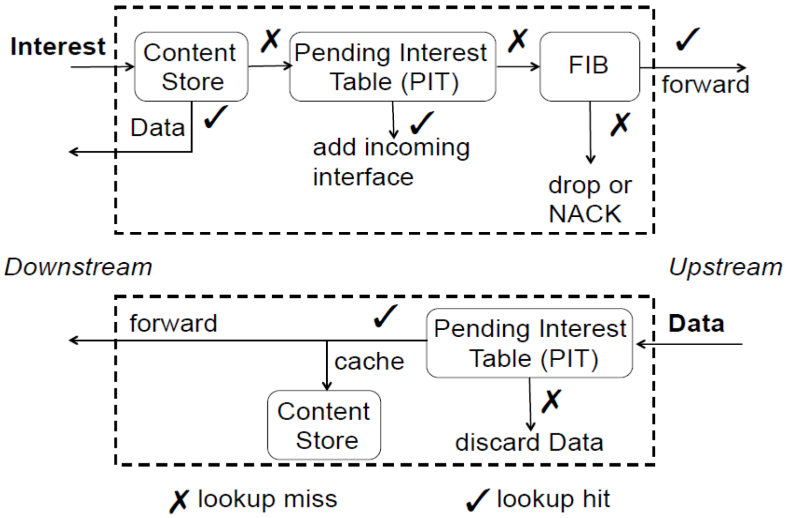

Figure 5. Forwarding process in NDN

3. NDN in Connected Vehicles

3.1 Motivations

Unlike the current host-centric Internet architecture, that insufficiently responds to the high mobility of the vehicular environment, the NDN paradigm naturally fits variety features and requirements of Connected Vehicles (M. Amadeo et al., 2016; P. TalebiFard et al., 2015):

- **Dynamic Network:** The current Internet based on IP perform unsatisfactorily in vehicular environments. Classic IP networking operations such as path maintenance and address assignment get hard to realize. With NDN, the mobility support becomes simplified through features like *in-network caching* and *anycasting*, which facilitate to the consumers the content retrieval from the nearest producer. This helps in reducing network traffic and data latency. In addition, despite the sporadic connectivity, the *store and forward* technique allows a vehicle to carry data between disjointed areas, and thus enable communications.
- **Security:** Communication in vehicular environments has short-lived nature. Therefore, data should be reliable, rather than the channel. This is achieved in NDN, since security is *built-in*, i.e. protection is implemented at the packet instead of the channel, and the secured connection is not needed any more.
- **Vehicular Applications:** The nature of vehicular applications is information-oriented, since they do not care about the source of the information, they only address the content (like road condition). The Data is also related to a specific time interval (like traffic jam warnings) and a specific location (like points of interest). The NDN corresponds better to this description than the current Internet. It is simpler to fetch content because there is no need to address resolution nor permanent connection of the producer.

3.2 Vehicular communications via Named Data

As aforementioned, each NDN node maintains three data structures: CS, FIB and PIT, and follows the algorithm described in Figure 5. In vehicle communications, the nodes are replaced by vehicles, as represented by (M. Amadeo et al., 2016) in Figure 6.

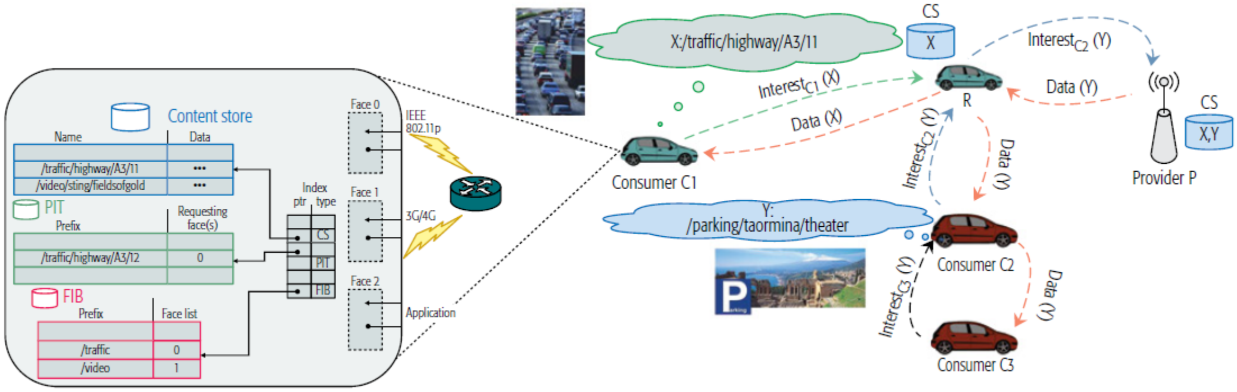

Figure 6. Overview of vehicular communications via NDN

3.2.1 Naming and security

Naming is a basic operation in content-centric applications. Some name structure conventions are already defined in NDN, but other options can be personalized depending on the applications. In vehicular communications, researchers have proposed several naming schemes. Wang et al. (J. Wang et al., 2012) proposed a name structure for the dissemination of the information in a traffic. It defines the geolocation, the time and the data type: */traffic/geolocation/timestamp/datatype*. YT et al. proposed this hierarchy: */Category/ServiceName/AdditionalInfo/* (Y. YT et al., 2013), which identified the type of data, the service provided by nodes, and some other information. Wang et al. (J. Wang et al., 2010) presented a secure application which allows the verification of data authenticity and integrity. Using the public key of a reference database server, the Data packets coming from vehicles are signed and encrypted. Creating hybrid namespaces from flat and hierarchical names, is another strategy for an effective naming and security framework (W. Quan et al, 2014). The prefix-based aggregation is simplified with hierarchical names, whereas self-certifying in flat names allows checking integrity without using a PKI.

3.2.2 Routing and forwarding

NDN routing plans for connected vehicles can be categorized as *proactive* and *reactive*. In the first category, nodes need regular advertisements from the producers, in order to preserve their FIBs updated. In the second category, data retrieval is based on Interest flooding, and the advertisements are not sent (M. Amadeo et al., 2016). Nevertheless, flooding must be controlled, otherwise, it may lead to broadcast storm and network congestion. Thus, improving the forwarding plane attract the attention of researchers, and some solutions have been proposed. *Collision Avoidance* is one of these solutions. It has the principle of canceling packet transmission if another transmission of the same packet has already begun. A collision avoidance timer is used in (Y. YT et al., 2013). This timer is calculated by taking into consideration the distance to the previous node. Therefore, priority of transmission is given to farther nodes. In (M. Amadeo et al., 2013), priority is given to Data transmissions through the use of a timer different than the one used for Interest transmissions. This can help to avoid collision. Authors in (L. Wang et al. 2012) also set a random timer for cars that receive an Interest at the same moment, so they can broadcast Data packets at different instants. Another solution is *Selective Flooding*. A selective criterion is used in some works, to restrict Interests flooding. In (M. Amadeo et al., 2013), an Interest is flooded first to locate the producer. After that, the other Interests send advertisements to the chosen producer. Thus, the distance to it is known, and therefore requests are forwarded by the intermediate nodes only if they are closer to the producer than the previous sender. In (Y. YT et al. 2013), Interests are not flooded without prior knowledge of provider's location. Then the geo-routing is used to forward an Interest.

3.2.3 In-Network Caching

As explained above, whenever an NDN node receives a Data packet, it stores it in his CS, so it can serve future requests. However, vehicles may cache data that they caught in the medium but have not solicited. Despite the fact that NDN consists of caching only requested Data, storing and forwarding unrequested contents could be advantageous (e.g., alerts of a vehicle calling for help). Some works discussed the vehicular contents in relation with the time and the scope. In (J. Wang et al., 2012), authors considered useless the fact of caching contents such as obsolete information (like traffic jam advertisements of one day before) and data out of the spatial scope (like alerts of an accident out of the selected zone).

4. Open Issues

Despite the achieved efforts so far, a variety of open issues and research challenges still remain:

- **Naming Resolution and Naming Schemes:** this is the most important challenge in NDN, since all functionalities are based on this feature (M. Amadeo et al., 2014). Routing is performed based on naming and may need a name resolution, which cannot be achieved with the current Domain Name System (DNS). Thus, a new resolution system is needed for vehicular communications via NDN. As for naming schemes, different ones have been proposed (e.g., human-readable, hash-based, flat, attribute-based, hierarchical and hybrid) but still don't know exactly the best one for vehicular communications.
- **CS, PIT and FIB:** NDN routers keep track of receiving Data packets, by caching them in their CS. However, CS memory space needs management strategies to efficiently and timely make available content to the consumers. PIT and FIB also need management since they receive any packet transmitted via any interface. Therefore, a lot of entries are passed by PIT and FIB structures and need rapid and effective searching strategies.
- **Routing:** Routing strategies are in charge of forwarding Interest and Data between consumers and producers. Thus, efficient routing schemes are required to have a good Quality of Service (QoS) in high speed topologies like vehicular environments.
- **Security:** Communication in vehicular networks is performed through wireless medium, and the wireless security framework needs management to face attacks, such as Interest flooding and cache poisoning. The definition and the development of signature schemes and key management methodology still an open challenge.

We summarized the discussed issues in Figure 7.

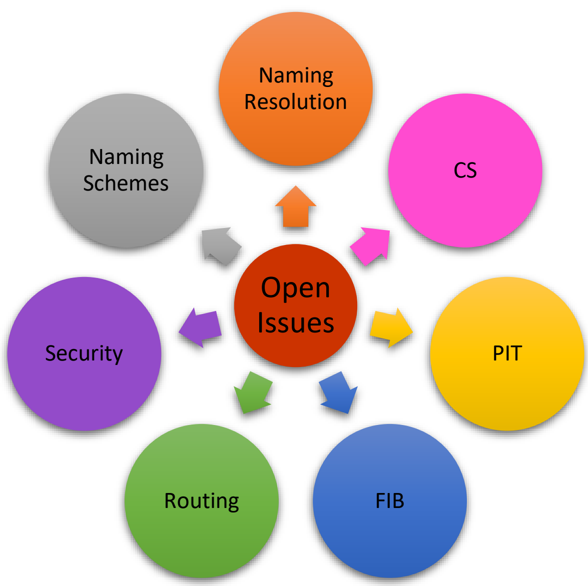

Figure 7. Remaining challenges in connected vehicles via NDN

5. Conclusion

In this paper, we have presented an overview of the research field *NDN for Connected Vehicles*. The overview introduced the Named Data Networking approach along with its details, as well as the use of this architecture in connected vehicles. From the research that has been carried out, we highlighted the open issues in vehicular communications over NDN. The discussed challenges include naming, routing, node structures management and finally security. Our future works will address these challenges, in order to enable vehicular communications and enhance road safety.

Acknowledgements

This research work is supported by the "SafeRoad: Multi-plateform for Road Safety (MRS)" Project under Contract No: 24/2017.

References

J.A. Guerrero-Ibáñez et al., "Vehicular Ad-hoc Networks (VANETs): Architecture, Protocols and Applications", Computer Communications and Networks, Springer-Verlag London, 2013.
ITSA, ITSA—Intelligent Transportation Society of America. http://www.itsa.org, 2011.
ITS Japan, ITS Japan. http://www.its-jp.org/english/, 2010.
ERTICO, Intelligent city transport: a guidebook to intelligent transport system. Brusells: ITS ERTICO. ITS CITY Pionners Consortium, 1998.
G. Xylomenos et al., "A survey of information-centric networking research", IEEE Communications Surveys Tutorials, 2013.
Future Internet Architecture [Online]. Available: www.netsfia.net/.
L. Zhang et al., "Named Data Networking (NDN) Project", Report, 2010.
L. Zhang et al., "Named Data Networking", ACM SIGCOMM Computer Communication Re-view, Volume 44, Number 3, 2014.
V. Jacobson et al., "Networking named content", In CoNEXT, 2009.
V. Jacobson et al., "Named Data Networking (NDN) Project", Report, 2013-2014.
V. Jacobson et al., "Named Data Networking Next Phase (NDN-NP) Project", Annual Report, 2014-2015.
M. Zhang et al., "A Survey of Caching Mechanisms in Information-Centric Networking", IEEE COMMUNICATION SURVEYS & TUTORIALS, VOL. 17, NO. 3, THIRD QUARTER, 2015.
M. Amadeo et al., "A novel hybrid forwarding strategy for content delivery in wireless information-centric networks", Computer Communications 109, 104–116, 2017
S. Hassan et al., "A Taxonomy of Information-Centric Networking Architectures based on Data Routing and Name Resolution Approaches", Journal of Telecommunication, Electronic and Computer Engineering, Vol. 8 No. 10, 2016.
M. Amadeo et al., "Content-centric wireless networking: A survey", Computer Networks 72, 1–13, 2014.
Z. A. Jaffri et al., "Named Data Networking (NDN), New Approach to Future Internet Architecture Design: A Survey", International Journal of Informatics & Communication Technology (IJ-ICT) Vol.2, No.3, pp. 155~165, 2013.
D. Saxena et al., "Named Data Networking: A survey", Computer Science Review, http://dx.doi.org/10.1016/j.cosrev.2016.01.001, 2016.
V. Jacobson et al., "Named Data Networking (NDN) Project", Annual Report, 2011-2012.
V. Jacobson et al., "Named Data Networking (NDN) Project", Annual Report, 2012-2013.
M. Amadeo et al., "Information-Centric Networking for Connected Vehicles: A Survey and Future Perspectives", IEEE Communications Magazine, 2016.
[P. TalebiFard et al., "Information-Centric Networking for VANETs", Springer International Publishing Switzerland, 2015.
J. Wang et al., "Data naming in vehicle-to-vehicle communications" In: IEEE INFOCOM'12 workshop on emerging design choices in nameoriented networking, pp. 328–33, 2012.
Y. YT et al., "Scalable VANET content routing using hierarchical bloom filters" In: Wireless communications and mobile computing conference (IWCMC). IEEE, New York, pp 1629–1634, 2013.
J. Wang et al., "DMND: collecting data from mobiles using named data" In: IEEE Vehicular Networking Conference (VNC), 2010.
Y. YT et al., "Scalable opportunistic VANET content routing with encounter information", In: International conference on network protocols (ICNP), pp 1–6, 2013.
M. Amadeo et al., "Enhancing Content-Centric Networking for Vehicular Environments," Computer Networks, vol. 57, no. 16, pp. 3222–34, 2013.
L. Wang et al., "Rapid Traffic Information Dissemination Using Named Data," Proc. 1st ACM Wksp. Emerging Name-Oriented Mobile Networking Design-Architecture, Algorithms, and Applications, pp. 7–12, 2012.
W. Quan et al., "Social Cooperation for Information-Centric Multimedia Streaming in Highway Vs," 2014 IEEE 15th WoWMoM, pp. 1–6, 2014.

M. Amadeo, "Forwarding Strategies in Named Data Wireless Ad hoc Networks: Design and Evaluation.", Journal of Network and Computer Applications, 2014.

Biographies

Zakaria SABIR is a Ph.D. student of computer engineering at National School of Applied Sciences (ENSA), Kenitra, Ibn Tofail University. He received his Master's degree in Information Systems Security from the ENSA of Kenitra, and he is currently completing his researches on field of Connected Vehicles and Intelligent Transportation Systems with the BOSS team in the LGS Laboratory, ENSA of Kenitra, Morocco.

Aouatif AMINE is an associate professor at National School of Applied Sciences (ENSA), Kenitra, Ibn Tofail University. She received her Master's degree (DESA) in Computer Sciences and Telecommunications Engineering from the Faculty of Sciences, Mohammed V Agdal University, Rabat, Morocco, in 2004. She remained at Computer Sciences and earned a PhD degree in 2009 for a dissertation titled "Feature Extraction and Selection for Dimensionality Reduction in Pattern Recognition and their Application in Face Recognition". Her research interests include but are not limited to dimensionality reduction, feature selection applied to face detection and recognition and driver hypo-vigilance. She joined the ENSA of Kenitra, Morocco, in 2010 as an assistant professor. Since November 2010, Aouatif AMINE has been a Vice-Chair of IEEE Signal Processing Society, Morocco Chapter. Since April 2015, she is the BOSS team header in the LGS Laboratory, ENSA, Kenitra, Morocco.