Information-Centric Networking for Connected Vehicles: A Survey and Future Perspectives

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Abstract

In the connected vehicle ecosystem, a high volume of information-rich and safety-critical data will be exchanged by road-side units and on-board transceivers to improve the driving and traveling experience. However, poor-quality wireless links and the mobility of vehicles highly challenge data delivery. The IP address-centric model of the current Internet barely works in such extremely dynamic environments and poorly matches the localized nature of the majority of vehicular communications, that typically target specific road areas (e.g., in the proximity of a hazard or a point of interest) regardless the identity/address of the single vehicle passing by. Therefore, a paradigm shift is advocated from the traditional IP-based networking towards the groundbreaking *Information Centric Networking*.

In this paper, we scrutinize the applicability of this paradigm in vehicular environments, by reviewing its core functionalities and the related work. The analysis shows that, thanks to features like named content retrieval, innate multicast support and in-network data caching, Information Centric Networking is positioned to meet the challenging demands of vehicular networks and their evolution. Interoperability with the standard architectures for vehicular applications along with synergies with emerging computing and networking paradigms are debated as future research perspectives.

Index Terms

Information-Centric Networking, Vehicular Ad Hoc Networks, Named Data Networking, Future Internet

I. Introduction

After years of research and standardization efforts, connected vehicle technologies are almost ready to take off [1]. Primarily conceived to improve driving safety and enable crash prevention through the timely and reliable dissemination of hazard/warning messages among vehicles, connected vehicle technologies are expected to satisfy the ever-increasing data appetite of users on wheels entailing *vehicle-to-everything* (V2X) interactions (Figure 1). Vehicles exchange data not only with other vehicles (V2V), the roadside and remote infrastructure (V2R, V2I), but with many other nodes in the vehicle's neighborhood such as the personal communication devices of pedestrians and cyclists, charging stations and smart grids, e.g., for greener transportation.

Overall, vehicular applications require the distribution of *huge amount of data among heterogeneous players* under *poor and intermittent connectivity* in high mobility, harsh signal propagation, and sparse roadside infrastructure conditions. The host-centric IP-based protocols of the current Internet, being designed with the end-to-end connectivity principle in mind, barely work under such settings. As a matter of fact, stakeholders are open to new networked communication solutions that replace or pull alongside IP, e.g., by leveraging in-network data caching and localized replication mechanisms to speed up the retrieval of *spatial-* and *time-dependent* contents, to reduce congestion and counteract the intermittent wireless connectivity.

This is where the Information Centric Networking (ICN) paradigm [2] comes into the picture. ICN originates as a candidate architecture for the future Internet to meet the increasing demand for scalable, reliable and efficient content distribution. It reverses the traditional IP address-centric philosophy into a content-centric one; this means that a user interested in getting a given content directly uses a "name" to retrieve it, without referring to the IP address of the node storing the content.

This innovative approach particularly suits the vehicular ecosystem that natively privileges the information (e.g., trusted road traffic information relevant to a given incident area) rather than the node identity. Furthermore, with in-network data caching, ICN helps in coping with mobility and sporadic connectivity issues.

As a further strength, unlike the IP solution, which resorted to *patches* for enabling not originally conceived features (e.g., user mobility, security), ICN can be shaped to meet the requirements of future Internet scenarios, as identified by the ICN Research Group of the Internet Research Task Force[1].

Early works, i.e., [3], [4], showed the benefits of ICN w.r.t. IP-based solutions in Vehicular Ad hoc NETworks (VANETs) and a booming of related proposals have been registered in the last couple of years. Such premises motivate this paper, whose organization can be summarized as follows:

- we start with an overview of the ICN paradigm and its potentials in vehicular environments;
- we scan the recent literature, which promotes ICN and extends its core functionalities to better fit the peculiarities of vehicular communications;
- we identify challenges and debate perspectives for the ICN deployment in upcoming VANETs.

II. Information-Centric Networking

The ICN paradigm was pioneered by the TRIAD project (http://gregorio.stanford.edu/triad/), which defined a *content layer* implementing name-based routing and caching. In more recent years, different ICN architectures have been designed [2], inspired by the aim to reflect better the increasing use of the Internet for information retrieval and dissemination rather than for supporting conversations between pairs of end nodes, like in the original design. Among them, Content Centric Networking (CCN), originally proposed by Van Jacobson, is under continuous development by research initiatives worldwide, such as the Named Data Networking (NDN) project (http:://named-data.net/).

Within all ICN-based Internet architectures, *information becomes the first-class network citizen*: pieces of information are assigned a *name* and are retrieved without explicitly addressing the hosts/servers that generate or own the

[1]E. Davies et al., "Request For Comments: 7476. Information Centric Networking: Baseline Scenarios", Internet Research Task Force (IRTF), March 2015.

information itself. Names uniquely and persistently identify a content (e.g., a movie, a picture, a document, a web page), independently of the location of the producer generating/hosting it, and routers use name-based forwarding rules to retrieve the named content.

This approach has the advantage of securing data instead of the transport channel by embedding authentication and integrity materials in each data packet so to make it *self-consistent*. As such, each content packet can be cached by network nodes that make it available for further requests.

The ICN communication model is *connectionless*, *asynchronous* (i.e., consumers and producers exchange data even if not simultaneously connected), and supports *anycast* data retrieval (i.e., the routers forward the request towards any node holding that content). With ICN, *receiver-driven* data exchange is triggered by the consumer sending a request/subscription for a named content; this bans unsolicited data.

Without loss of generality, in the following, we refer to the NDN architecture to describe the information-centric content retrieval. NDN is based on two packet types, *Interest* and *Data*, which are respectively used by the forwarding plane of NDN nodes in a two-step process: *(i)* consumers send out Interest packets specifying the name of the requested content; *(ii)* Data packets flow back, carrying the named and secured content units, by following the *traces* left by the forwarded Interests in the nodes.

NDN considers *hierarchical* content names[2], which appear as user-friendly Uniform Resource Identifier (URI)-like identifiers with variable length and variable number of components separated by "/". For instance, a picture stored at the UNIRC university server may have the name */unirc/pictures/pictureA.jpg*.

Each NDN node maintains three data structures. A Forwarding Information Base (FIB) routes Interests towards Data through name-based look up. A Pending Interest Table (PIT) keeps state of the forwarded Interest(s) that are not yet satisfied with a returned Data packet. Each crossed node can temporarily cache incoming Data packets in a Content Store (CS) for faster reply to late requests.

In summary, at the Interest reception, a node follows the algorithm in Figure 2: it first looks in its CS to find a content copy; if a matching is not found, it looks in the PIT and, eventually, in the FIB. The example of Interest/Data exchange in Figure 3 refers to a vehicular environment.

III. ICN for Connected Vehicles: Motivations

ICN-based VANETs promise enhancements in the areas of *Application*, *Mobility* and *Security*, as dissected in the following.

Application. Whatever their target, road safety or infotainment, vehicular applications are *information-oriented* in nature: they address a content (e.g., road conditions) and do not mind about the producer identity. Generated data are relevant to a given *location* (e.g., points-of-interest notification), and/or to a given *time interval* (e.g., traffic jam warnings expire in a few hours; parking lots availability lasts a few seconds). Finally, generated data are intended for groups of recipients (e.g., ads of parking lots to approaching vehicles).

[2]In a more general ICN design, also *flat* names are possible, i.e., fixed-length identifiers with no semantic structure.

Through *named data* and routing-by-name, ICN matches the described vehicular applications' pattern better than the current Internet. Content discovery is simpler because ICN does not need name-to-IP address resolution, and does not ask for the producer to be always connected.

In addition, ICN simplifies data retrieval from multiple consumers (e.g., map downloading from a common roadside unit) by aggregating requests for the same named content in the PIT; it is sufficient to keep track of the Interest incoming interfaces for later Data delivery.

Mobility. IP-based host-centric protocols work awkwardly in mobile environments, and functionality patches, such as Mobile IP, are known to add complexity and perform unsatisfactorily in VANETs [3]. In both *highway*, where vehicles move at very high speeds, and *urban* scenarios, with signal propagation typically obstructed by buildings, the quality and duration of V2V and V2R links can be plagued. In such topologies, classic IP networking operations, like address assignment and path maintenance, become difficult to achieve. Consequently, networking solutions alternative or complementary to IP are encouraged also by standardization bodies in the vehicular application/technology domain [1].

In the Wireless Access in Vehicular Environments (WAVE) stack, the WAVE Short Message Protocol (WSMP), for instance, runs directly over the access layer and supports the single-hop broadcasting of time-sensitive safety data without the need of connection set-up operations. In the ISO/ETSI architecture for an Intelligent Transportation System (ITS) station, at the Networking & Transport layer, besides the IPv6 solution for remote communications, there is room for *geonetworking*, using the geographical position of vehicles for addressing and forwarding purposes, and other, still under definition, networking protocols.

With ICN, the use of named data simplifies mobility support. The *anycasting* and *in-network caching* properties of ICN allow vehicles to retrieve content from the most convenient (typically, the nearest to the consumer) producer/storage point. This reduces data latency and network traffic. Moreover, a *store-carry-and-forward* mechanism can be supported by ICN, through which a vehicle can serve as a link ("data mule") between disconnected areas and enable communications even under intermittent connectivity. This is achieved at low cost, thanks to the practically "unlimited" capabilities of vehicles, which do not have energy, processing or storage constraints.

Security. Due to *ephemeral* nature of vehicular communications, trustworthiness should be based on data instead of the reputation of providing entities.

ICN natively provides *content-based security*, with protection and trust implemented at the packet level rather than at the communication channel level. Therefore, the set-up of a secure connection is no longer required, and the trust in data is decoupled from how/where the data is obtained.

IV. Research solutions and opportunities

Although ICN basic mechanisms can be potentially beneficial to address the peculiarities of VANETs identified in the three above-mentioned areas, adequate extensions must be devised to perfectly fit them, namely: *(i)* ICN namespaces matching *Applications*' scope, which in turn influence the implementation of in-network *Security*; and *(ii)* ICN routing and forwarding strategies, together with in-network caching, effectively managing *Mobility* issues.

In the following, we scan the representative literature solutions by grouping them according to the main investigated ICN mechanism (i.e., Naming and Security, Routing and Forwarding, In-network caching) and identifying the related open issues. Table I summarizes the following discussion.

A. Naming and Security

In the context of VANETs, flexible and expressive naming conventions must be defined to enable applications to retrieve contents locally/remotely available or generated *on demand*. In all cases, content *integrity* and *provenance* must be verified to prevent malicious reporting of fake data and, at the same time, mechanisms are required to protect the user's privacy.

There is a wide consensus on the use of hierarchical naming schemes to effectively match vehicular applications [3], [5]–[8]. Hierarchical names are in fact highly expressive and can be easily aggregated under common prefixes to facilitate routing operations and limit the number of FIB entries.

In [6] the namespace */traffic/geolocation/timestamp/datatype* is proposed to manage a decentralized floating car data application, where the prefix */traffic* identifies the application, the *geolocation* and *timestamp* components represent the geographical and temporal scope of the content, respectively, and the *datatype* indicates the meaning of the content itself, e.g., vehicle speed. The *geolocation* component is used for *scalable scope-based* content retrieval, as also discussed in [7], where nodes aggregate data at different geolocation granularities (district level, street level, etc.).

The organization of the namespace can be based also on different logical hierarchies. In [5], the namespace is organized as */Category/ServiceName/AdditionalInfo/*, where the main prefix identifies an information category according to content popularity and shareability features. Here, the *Category* component (instead of *geolocation*) is used to guide the packets dissemination.

With hierarchical naming, security information (e.g., the publisher signature) is carried in a separate field of the Data packet, thus requiring a Public Key Infrastructure (PKI) for integrity checks. In [3], Data packets collected from vehicles are tagged with their signature and encrypted using the public key of a reference server. The authors assume that manufacturers record public keys of vehicles and store the public key of the server inside the vehicles before release. A different strategy for an efficient naming and security framework is to capitalize the strengths of hierarchical and flat names and create hybrid namespaces [9]. Flat names, in fact, enable the use of self-certifying names, so that integrity checks run without the need for a PKI, while hierarchical names simplify the prefix-based aggregation.

Although these preliminary research works make the best of ICN names to improve packet delivery (e.g., based on the spatial scope), we are still far from a leading naming solution. If, on the one hand, the freedom in the naming design allows researchers to experiment and look for the best performing scheme, on the other hand, the proliferation of different schemes may delay the agreement on common naming conventions and the deployment of large-scale applications. Similarly, some global standardization would be beneficial in the ICN security mechanism, together with an analysis of the possible threats (e.g., Distributed Denial of Service attacks based on Interest flooding), which are still almost uninvestigated in the vehicular environment.

B. Routing and Forwarding

ICN routing schemes for VANETs can be broadly classified in *proactive*, when periodic advertisements from the content providers are needed to keep fresh routing information in the FIB of intermediate nodes; and *reactive*, when the advertisements are not sent in advance and the retrieval is based on Interests flooding.

Flooding-based discovery particularly suits the VANET scenario. It has the advantage of quickly finding the nearest data copy and does not require periodical FIB updates, which can be a heavy (useless) task due to the environment dynamicity and the short-lived contents. However, if not properly controlled, flooding may cause network congestion and broadcast storm over the wireless medium. This is why literature solutions improve the forwarding plane with the following strategies:

- *Collision avoidance and packet suppression.* These mechanisms consist in randomizing both Interest and Data sending times and aborting transmission when detecting that another node has already transmitted the same packet, e.g., in [4], [10]–[12].
- *Selective flooding.* Some works use selective criteria to limit the flooding of the requests due to reactive forwarding. In [5], the route to popular non shareable/non-cacheable data is proactively stored in the FIBs, while other types of content are searched on demand. In [12], vehicles exchange encounter information; the Interest is only flooded when the producer location is unknown, and only until a relay finds a matching location information; when this happens, the Interest is forwarded by geo-routing. A simpler distance-based scheme is deployed in [10], where only the first Interest is flooded to discover the reachable content producer(s) and, then, subsequent Interests advertise the selected producer identifier and the distance to it, so that intermediate nodes forward a request only if they are closer to the provider than the previous sender.

In devising such strategies, the research community mainly benefitted from the lessons learnt in the past literature for routing in VANETs. But further efforts would be required to account for the unique features of ICN, e.g., the availability of multiple providers caching the content, the need to maintain low the PIT and FIB sizes and so limit the look-up delay.

Surveyed solutions are essential in wireless networks with distributed (uncoordinated) access to the medium (e.g., IEEE 802.11p) to reduce the loss rate and the congestion. However, today's vehicular networks are moving towards the use of multiple access technologies [1]. By taking advantage of the ICN *layer-2 agnosticism*, a node with multiple radio interfaces can select the most convenient one at a given time, based on measured performances on each of them (e.g., throughput, round-trip time) or collected network information (e.g., density and topology). For instance, in [8], the cellular network is proposed to carry the NDN signalling, while short-range communications are exploited for content distribution. Further enhancements are required to link the design of smart and dynamic selection of the outgoing interface for Interests/Data with the definition of rules for prioritized data transmission (e.g., safety data should have priority w.r.t. non-safety data).

C. In-network caching

Content caching and replacement policies studied for VANETs, such as pre-fetching and cooperative caching, can be applied or extended to the ICN context. The caching decision may involve contents that vehicles have not requested but that they overhear over the wireless medium. Although the vanilla ICN assumes that only solicited Data can be cached, it could be useful for a vehicle to store and forward overheard unsolicited contents (e.g., alarms generated by a vehicle in trouble). Many works like [6], [8], [9], [11], [12] extend the ICN Data processing in VANETs in this sense.

In addition, there is still room for caching policies that make the best of hierarchical names exposing the *temporal/spatial* scope of the vehicular contents, as preliminary discussed in [6]. Caching contents out of their spatial scope (e.g., accident warnings beyond the relevance area) as well as caching outdated contents (e.g., traffic jam advertisements of the day before) could be useless. Through ICN naming, vehicles/RSUs can identify the content scope and cache only contents within a specific spatial/temporal range.

So far, however, the benefits of temporal and spatial properties of ICN names in the caching decision have not been clearly supported with quantitative results. We encourage the research community in investigating this promising aspect.

V. A LOOK INTO THE FUTURE

It is our convincement that, in the path towards a wider acceptance and a large-scale deployment of ICN-based VANETs, further crucial issues need to be addressed, in addition to the enhancements of the ICN mechanisms *per se*, undertaken so far in the literature. First, interoperability of ICN with existing and underway connected vehicle standards, technologies, and message sets should be pursued. Then, synergies of ICN with the emerging trend of network softwarization should be explored to support the upcoming V2X landscape with the variety of its applications. The latter ones, still under definition, are not necessarily related to the ITS arena, for instance, environment monitoring, emergency and disaster management [13], and go beyond data distribution, hence challenging the capabilities of ICN as originally conceived.

Initial design ideas and hints presented in the following are summarized in Table II.

Interoperability with reference VANET architectures. We believe that synergies among ICN and ITS standards will provide advantages and accelerate the development in both domains. Although the scientific literature has almost neglected this aspect, it is worth discussing if and how ICN operations can be viewed as components of legacy reference vehicular architectures. The work in [4] was pioneer in proposing to deploy ICN as a replacement (or a complement) of TCP/IP on top of the access layer in the WAVE stack of a vehicular node. Here, we refine our first intuition as illustrated in Figure 4(a), where we propose to locate ICN in the WAVE stack so to encompass also some security operations of IEEE 1609.2 at the networking layer.

In the ISO/ETSI stack for an ITS station, we suggest considering ICN to span the Networking & Transport layer (representing OSI layers 3 and 4), the Facilities layer (representing OSI layers 5, 6, and 7; supporting, for instance, message handling and publish-subscribe mechanisms) and the Security layer, as illustrated in Figure 4(b). For a full

ICN integration, proper interfaces should be clearly defined between the ICN block and existing layers to facilitate interactions without task duplication in different modules.

A means to favour the integration of ICN in the reference architecture could be in our opinion to use standard cooperative awareness messages (i.e., CAM in the ETSI architecture, a.k.a. BSM in the WAVE architecture), regularly transmitted by all vehicles, to support ICN routing and forwarding operations, and help to build neighborhood tables without additional overhead.

Co-existence with the IP-based core network. It is quite intuitive that ICN deployment in isolated vehicular network segments could be easier than the replacement of IP in the core network. Indeed, ICN-enabled on-board units could be easily mounted in newly sold cars, and RSUs could be equipped with ICN functions on top of layer 2 (e.g., IEEE 802.11p), hence easily allowing V2V and V2R ICN-based local communications, as preliminarily experimented in [14]. This would facilitate wider ICN penetration with incremental graceful upgrades.

Issues may emerge when vehicles generate/request data for/to remote players, reachable via RSUs connected to the Internet or through a cellular interface.

The first case can be addressed from an application-level perspective: we think that similarities between the ICN hierarchical names and the URIs of resources remotely provided/accessed with a RESTful architecture can facilitate such a co-existence. For instance, an RSU interfacing ICN vehicular islands and the rest of the Internet could act as a proxy and properly translate URIs-into-ICN names and vice versa.

The second case of delivery of ICN messages over the cellular interface may raise different concerns. If the advantages in making Internet routers ICN-capable are well-known since the dawn of the ICN paradigm, the benefits of letting nodes of the mobile backhaul and core networks understand the semantics of ICN packets and, possibly, perform ICN operations (e.g., caching) deserve investigation. Findings in such domain are expected to give insights into the performance of ICN also in multi-interface vehicular nodes and to facilitate remote communications.

Quality of Service (QoS) support. The delivery requirements of vehicular applications, like short latency and high reliability, have not been considered so far as an input to ICN operations. ICN mainly works as a *best-effort* framework. However, the growing data traffic and strict demands for some future applications (e.g., autonomous driving) pave the way to extend ICN towards QoS support. For instance, Software-Defined Networking (SDN) techniques, recently proposed for VANETs [1], can improve QoS provisioning. With logically centralized network intelligence and state at a controller node, SDN could help to make better decisions based on the combined information from multiple sources, not just individual perception from each node. For instance, SDN-aided ICN forwarding can dynamically decide at which time what type of traffic will use which radio interface (e.g., LTE, 802.11p) and configure the forwarding rules (e.g., by injecting the FIBs) for a given type of traffic (e.g., surveillance data in emergency scenarios) according to its name.

Vehicular cloud computing. Vehicles are getting smarter objects, able to share their processing, storage, and sensing resources to support advanced services (e.g., data fusion and processing from different sensors for autonomous driving), by acting as a *local cloud*. In [15], the concept of *vehicular cloud networking* is initially proposed, where such clouds are set-up and maintained with the help of ICN. Indeed, through the flexibility of ICN naming, vehicles could request resources by names in a manner that is *agnostic of the physical location* and of the configuration of the system/node that provides them. However, the implications and open questions of ICN-based vehicular clouds are still manifold, since ICN should evolve from a framework delivering contents to a system orchestrating heterogeneous and complex tasks. This means that the semantics of ICN packets, the forwarding and caching fabric should be re-thought.

Big data. A tremendous amount of data is expected to be generated, delivered, processed and stored in the upcoming vehicular landscape. ICN already provides some mechanisms to reduce the traffic volume, by avoiding request and data packets duplication. Moreover, although not initially conceived to perform in-network data processing operations, ICN could be extended to provide data manipulation *on the fly* (e.g., *filtering* useless data, *aggregating* redundant data) with the advantage to increase data retrieval scalability and to reduce the network resources usage. Such idea is pioneered by the Named Function Networking (NFN) project (http://www.named-function.net/). NFN allows consumers to express by name also *functions* to be applied over contents, e.g., a consumer could request a zipped video file in a specific format (mp4) with the name */name/of/video|/codec/mpeg4|/util/compress/zip*. A major challenge of this approach is the design of naming schemes able to identify both functions and data.

Business models. Another crucial aspect to investigate for ICN success in upcoming VANETs will be the definition of incentive mechanisms to motivate car owners to release their on-vehicle resources by caching, processing, and forwarding data they may not be interested in. A possible approach is to reward vehicles either with monetary incentives or with other services in return, like free parking, access to manufacturer/traffic tips. The values of incentives can be determined according to the level of participation (e.g., the volume of forwarded/cached data), the quality of provided resources (e.g., the Quality of Information may decrease according to the temporal/spatial scope). Overall, agreements and business models are strongly needed between involved stakeholders, e.g., individual drivers, road traffic authorities, content providers, Telco operators.

VI. CONCLUSIONS

In this paper, we have discussed the potential of the ICN paradigm as a networking solution for connected vehicles. The analysis shows that the native design principles of ICN well match the main distinctive features of VANETs and the targeted wide set of vehicular applications. The literature on ICN for VANETs - still at its infancy, due to the age of the ICN topic - designing adaptations and customizations of the baseline ICN architecture to better fit the vehicular environment has been surveyed.

ICN holds several promises for future VANETs evolution but some challenges still lie ahead to let this paradigm be deployed on a large-scale, co-exist with being and upcoming connected vehicles technologies and standards. In the overall balance, the pros weigh more than the cons and encourage the research community to put efforts in this timely and increasingly relevant topic.

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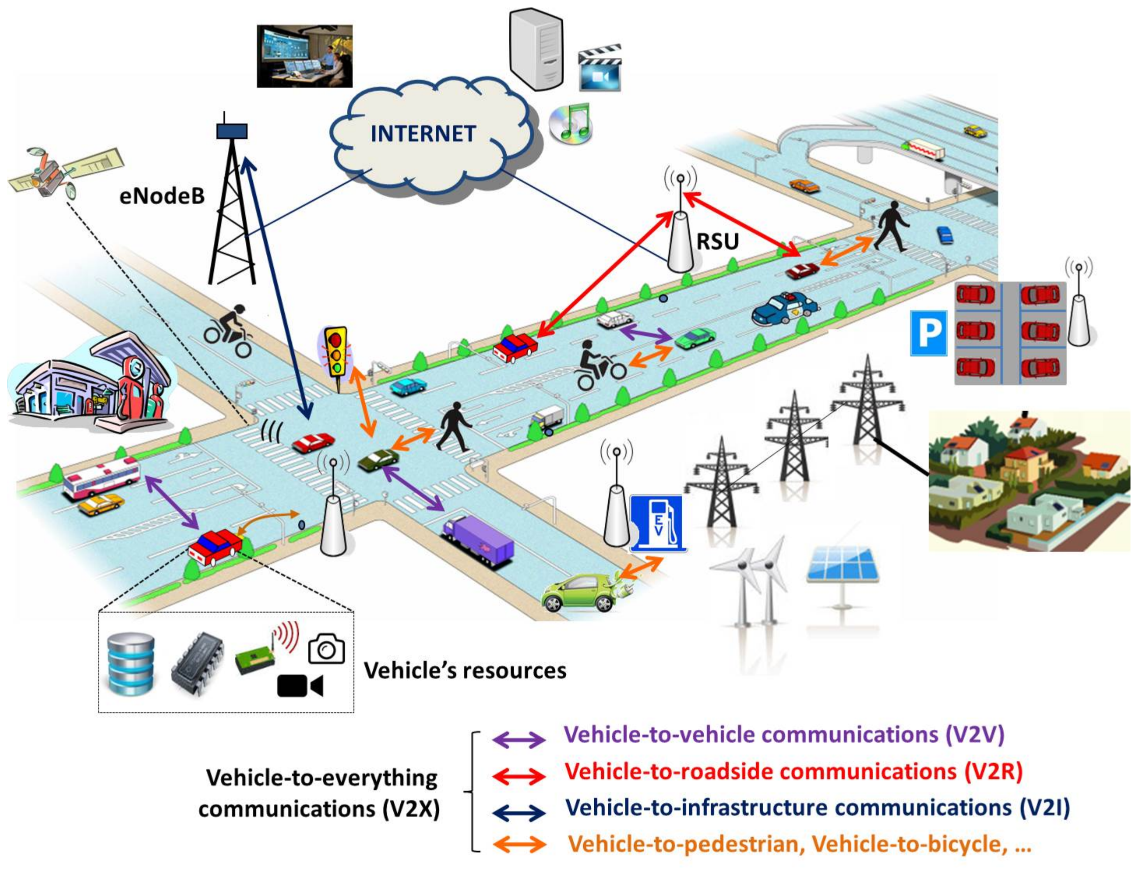


Fig. 1. The connected vehicles landscape: from V2V to V2X.

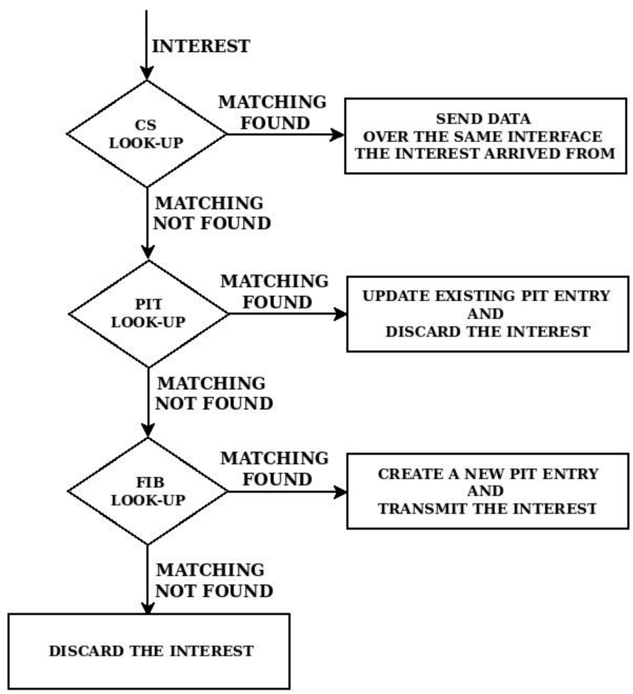


Fig. 2. NDN Interest processing at an intermediate node.

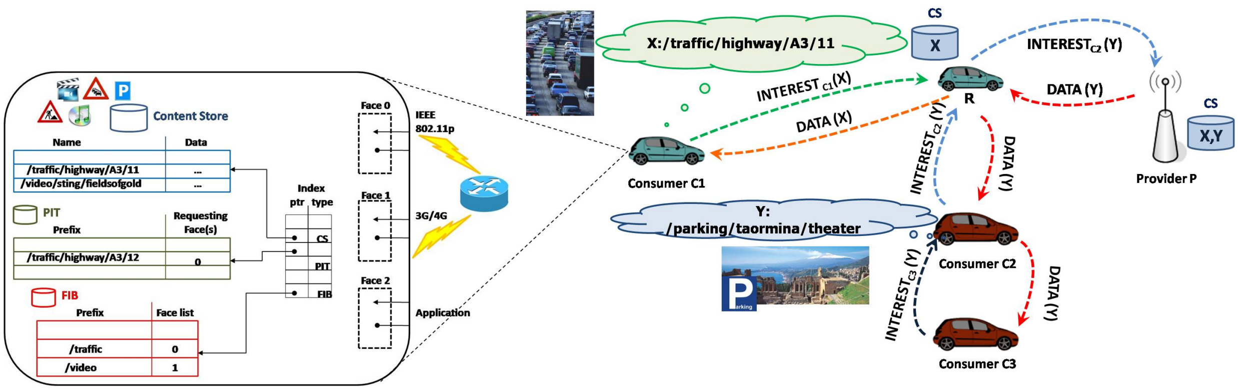
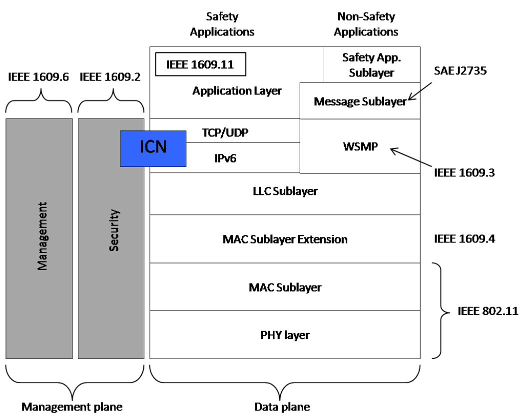


Fig. 3. Example of Interest/Data exchange: vehicle R, caching data */traffic/highway/A3/11* (shortened as *X*), directly replies to consumer C1 without forwarding its Interest to the original provider P. The Interest for content */parking/taormina/theater* (shortened as *Y*) by C2 is instead forwarded to P. If, in the meanwhile, C2 receives an Interest for content *Y* from C3, the request is aggregated in the PIT and the Interest is not forwarded again. When Data *Y* arrives to R, by following the PIT entries, it is forwarded to C2, which forwards on its turn to C3.

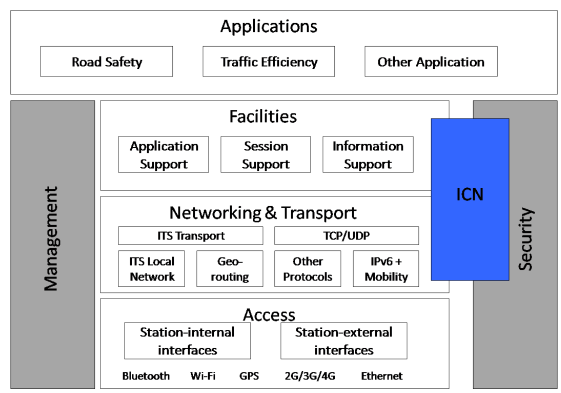
TABLE I

SUMMARY OF THE ICN-VANETS RELEVANT LITERATURE.

ICN mechanisms	Main proposed solutions	Open challenges
Naming and in-network security	Hierarchical schemes [3], [5], [6], [7], [8] Hybrid flat/hierarchical schemes [9] PKI-based integrity checks [3] Self-certifying flat names [9]	- Agreements on common naming and security mechanisms - Analysis of security threats
Routing and forwarding	Collision avoidance and suppression [4], [11] Selective flooding techniques [5], [10], [12]	- Mechanisms to avoid FIB/PIT explosion - Packet prioritization rules - Smart/dynamic outgoing interface selection
In network-caching	Caching of unsolicited contents [6], [8], [9], [11], [12]	- Smart spatial/temporal scope-based caching techniques



(a) ICN functions in the WAVE Architecture (IEEE Std. 1609.0).



(b) ICN functions in the ITS-Station Architecture (ETSI EN 302 665/ISO 21217).

Fig. 4. Reference vehicular architectures and ICN.

TABLE II

FUTURE RESEARCH PERSPECTIVES FOR ICN.

Challenges	Expected Contributions	Potential Benefits
Interoperability and coexistence	• Interworking schemes with existing ITS architectures, protocols, and messages • Co-existence solutions with the IP-based core network through proxy functionalities at the edge • Enabling ICN functions (e.g., caching) in nodes of the mobile backhaul and core networks	• Easier and wider ICN penetration • Improved performance for existing ITS standards and technologies
QoS support	• SDN-based centrally-controlled name-based forwarding rules • SDN-based wise radio interface selection schemes	• Improved QoS for the end-user • Better and flexible resource utilization • Adaptability to dynamic resources and topology changes
Vehicular cloud computing	• Naming schemes addressing cloud resources • Revised forwarding/caching strategies • Simple and effective cloud set-up and maintenance operations	• Support for resource-intensive and co-operative apps (e.g., autonomous driving) • Provisioning of value-added services
Big data	• Support for in-network processing operations (e.g., filtering, aggregation) • Novel naming schemes addressing in-network operations	• Reduced network load • Higher scalability
Business models	• Incentives schemes • Assessment of the participation value	• Large-scale participation in content retrieval/cloud services • Novel business opportunities for involved players

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