An SDN hybrid architecture for vehicular networks: Application to Intelligent Transport System

("abstract of regular paper")

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I. INTRODUCTION

The evolution of cars technology deals with assisting the driver on the road. Cars are more and more equipped with sensors in order to cope with several driving tasks as automatic switching of the lights or wipers, warning the driver if he goes out of his driving lane, front and backward detectors for urgent breaking or backward driving assistance, park assist, etc. Going further, the next generation of cars will be connected and organized in networks for sharing information that will be first transmitted and processed in the cloud facilities of car manufacturers or suppliers. Such a system is called an Intelligent Transport System (ITS) and is aimed at using information and communication technologies of transport infrastructures to improve safety, reliability, efficiency and quality for all travels by car [1].

In this context, Continental Digital Service France (CDSF) and LAAS-CNRS started the eHorizon project (2017-2021) for addressing the research and technological issues of such ITS. This paper then deals with presenting the global communication architecture for the ITS, as well as its requirements in terms of communications, including reliability and QoS parameters. It is especially required for this system to be highly flexible to adapt to any situation and use case, and to provide very low latency. For this purpose, the ITS system relies on two new and original concepts in the context of ITS, namely the use of Software Defined Networks (SDN) and fog computing concepts. These concepts are detailed in the paper, and their benefits are evaluated on some very representative scenarios.

II. THE GLOBAL COMMUNICATION ARCHITECTURE OF AN INTELLIGENT TRANSPORT SYSTEM

In this section, we describe the global communication architecture of an ITS. We first present the components of this architecture and their interactions, the technologies and standards used. Then, we discuss the different communication challenges that arise in such system.

A. Main Components

The global architecture consists of three main parts as shown in Fig.1: The vehicle, the network infrastructure managed by an Internet Service Provider (ISP), and the cloud platform controlled by an ITS service provider:

- **Vehicle:** A vehicle is equipped with a set of sensors and systems (GPS, Radar, Lidar, Advanced Driver-Assistance System (ADAS) camera, etc.) enabling it to collect several information about its environment (position, speed, neighboring vehicles, temperature, etc.). Depending on its location, it can be reached, as shown in Figure 1, only by a Road Side Unit (RSU) (vehicle A), or only by a Base Station (vehicle B), or both (vehicle C), or it may be out of any network coverage (vehicle D). A vehicle can be equipped with several interfaces allowing it to interact with the various components of the system: (1) a 3/4G interface enabling it to benefit from different functionalities offered by the cellular network (Internet access, communication with other parts of the system (Vehicles, Cloud, etc.)), (2) a Dedicated Short Range Communication (DSRC) Interface enabling it to communicate with the RSU entities as well as other vehicles equipped with the same interface, and (3) a Bluetooth Interface allowing it to communicate with the connected objects that surround it, as well as with the different User Equipments (UE) handled by the pedestrians, as illustrated in Figure 1. A vehicle acts not only as an end node, but also as a router to transmit information to other vehicles.

- **Road Side Unit:** A RSU entity represents one of the dedicated components for an ITS system. It may be implemented in a base station, or in a dedicated stationary entity installed along the road. It is mainly equipped with a DSRC interface, with which, it can communicate with any component equipped with the same interface (vehicle, RSU, etc.). Its communication range depends on the environment and the technology used. For example an RSU entity that supports the DSRC standard can have a communication range of 300 m in urban environnements, and a communication range up to 1km in rural environnements. The Road Side Units may be interconnected via a wired or wireless medium, and they can not only provide a local service but also a cloud service and/or Internet access to the different vehicles.

- **Cellular Network:** The cellular network represents one of the main technologies that may support the different vehicular communications. It has a very high network capacity enabling it to support applications requiring high throughput/bandwidth demands. Moreover, it is characterized by a wider communication range, which allows a base station to maintain connectivity with a network node (vehicle) as long as possible,

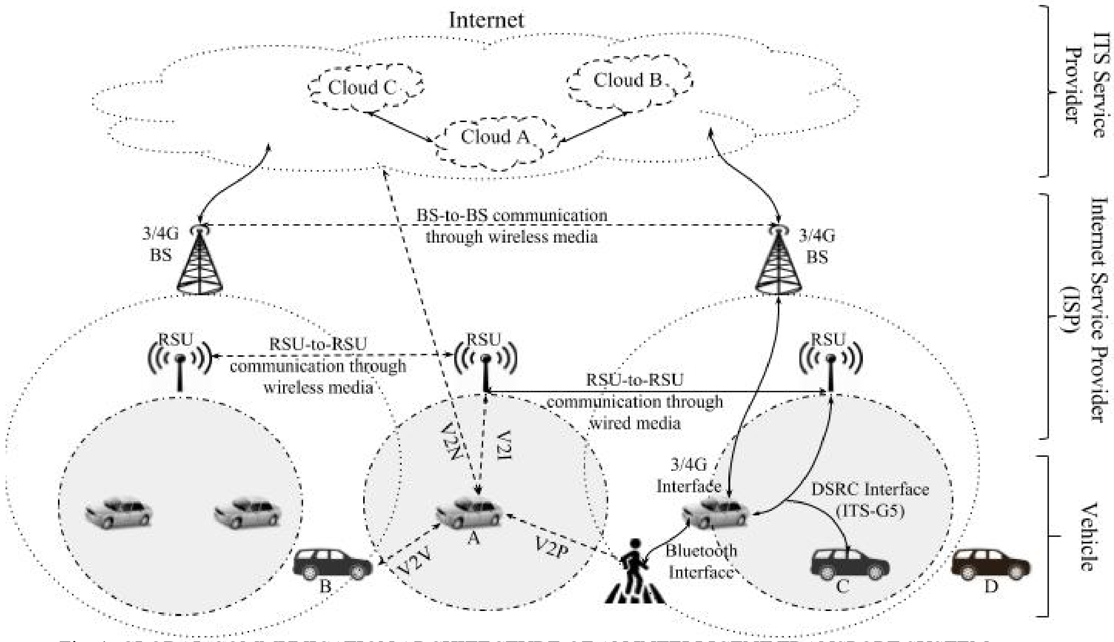

Fig. 1. GLOBAL COMMUNICATION ARCHITECTURE OF AN INTELLIGENT TRANSPORT SYSTEM

thereby limiting handover operations. In addition, It offers Multicast/ Broadcast transmission services (MBMS/eMBMS) and D2D communication technology, which can be used extensively in an ITS system.

- **Cloud/Fog computing:** The cloud computing is the intelligent part of the system. It has a high storage and processing capabilities to massively collect data, and process them to provide customized ITS services to different vehicles, whereas Fog computing represents a distributed data-center whose computing devices are closer to the end users in order to provide real-time services that require a very low latency.

B. Communication Types

A vehicle can interact with its environment through various types of communication, as presented in Figure 1, and specified in [2]:

- **V2V** (Vehicle-to-Vehicle): A type of communication, in which both communicating parties are UEs (vehicles) using V2V applications.

- **V2P** (Vehicle-to-Pedestrian): A type of communication, in which both communicating parties are UEs (vehicle, pedestrian) using V2P applications.

- **V2I** (Vehicle-to-Infrastructure): A type of communication, in which one part is a UE (vehicle) and the other part is an RSU entity, both using V2I applications.

- **V2N** (Vehicle-to-Network): A type of communication, in which one part is a UE (vehicle) and the other part is a serving entity, both using V2N applications.

C. Communication Challenges

The density and the speed of the vehicles are the major factors affecting the quality of the vehicular communications. In high density networks, vehicles must efficiently share available network resources in order to avoid congestion problems, which is a challenging task. Besides, the high speed of the vehicles complicates the maintenance of the communication between the nodes. This situation becomes more complicated when the vehicles move in opposite directions. Table I shows the variation of the speed and the density of vehicles per environment (urban, suburban and highway) as described in [3]. It is noticed that when the density of the vehicles decreases, the speed of the vehicles and the range of communication increase.

Scenario	Vehicle density (vehicles/km2)	Relative Velocity (Km/h)	Communication range (m)
Urban	1000-3000	0-100	50-100
Suburban	500-1000	0-200	100-200
Highway	100-500	0-500	200-1000

TABLE I. CHARACTERISTICS OF THE DIFFERENT ENVIRONMENTS

III. SERVICES AND THEIR REQUIREMENTS

In this section, we present some ITS services and their network requirements. We then discuss some communication technologies that may support these requirements.

ITS services can be classified into safety and non-safety services as specified in [4]:

- **Safety Services:** The main objective of these services is to improve the road safety by minimizing the number of accidents and reducing the possibilities of life loss. They require a very low latency and high reliability. Some safety services and their network traffic models are presented in Table III.

- **Non Safety Services:** The main objective of these services is to improve the traffic efficiency (avoid traffic jams, optimize transport times and gas consumption, etc.) and to provide to the vehicle's users some services (infotainment, Internet access, etc.) that enhance their experience. These services have no stringent demands on latency and reliability compared to safety services. Some non safety services and their network traffic models are presented in Table III.

Model 1	periodic, broadcast, maximum latency=100ms, minimum frequency=10 Hz, high reliability requirements
Model 2	non-periodic, unicast, maximum latency=100ms, minimum frequency=10 Hz, high reliability requirements
Model 3	periodic, broadcast, maximum latency=500ms, minimum frequency=2 Hz, low reliability requirements
Model 4	non-periodic, unicast, maximum latency=500ms, minimum frequency=2 Hz, low reliability requirements

TABLE II. NETWORK TRAFFIC MODELS

ITS Services	Use Case	Usage	M1	M2	M3	M4
Safety Services	Co-operative forward collision warning	Avoid longitudinal collision	√	√		
	Emergency vehicle warning	Reduce emergency vehicle's intervention time	√			
	Wrong way driving warning	Limit as much as possible frontal collisions	√			
Non Safety Services	Traffic information and recommended itinerary	Traffic information and regulation			√	
	Automatic access control/ parking access	Facilitate vehicle access to controlled areas			√	√
	Remote diagnosis and just in time repair notification	Reduce the risk of vehicle failure			√	√

TABLE III. ITS SERVICES AND THEIR NETWORK TRAFFIC MODELS

The network traffic models are derived from a requirement analysis of these services as specified in [4]. A traffic is defined by a behavior (periodic or non-periodic), a transmission mode (unicast, broadcast), a maximum latency, a minimum frequency for the periodic messages, and a level of transmission reliability. Other elements can be considered such as the required security mechanisms. Table II presents the identified network traffic models. Table III summarizes the models that characterize the traffic generated by each service.

Two main technologies are considered to support these requirements, DSRC and cellular technologies (LTE), However, these technologies have some limitations, making them unable to efficiently support these services. The short range communication of DSRC entities (e.g. RSU) limits their ability to offer the services that require continuous data dissemination along the road (e.g. data streaming, online gaming, Internet access), especially when the vehicles move at high speed. In addition, the CSMA/CA technique used by the DSRC standards to avoid collision introduces a significant access delay to the channel, which causes scalability problems especially in dense environments. On the other hand, cellular technologies are not suitable to support V2V communications which require a very low latency, due to the centralized architecture of cellular networks. The studies in [5] and [6] show that the performance of each technology drops once the speed and the density increase. Consequently, A new architecture with new mechanisms is required to efficiently support these new services.

IV. AN SDN HYBRID ARCHITECTURE

In this section, we describe the proposed SDN architecture. We first present the SDN concept, then the advantages of applying it to the global architecture of an ITS system. A use case is presented to show the benefits of our approach.

A. *Software Defined Network*

SDN is an emerging network paradigm which advocates the idea of taking control plane functions out of network forwarding devices and relocating them on remote external computing machines called SDN controllers. The network intelligence and state are logically centralized [7]. The SDN controller communicates with the different network nodes using a southbound interface protocol, i.e. the widely used OpenFlow standard [8], while applications explicit their requirements to the SDN controller using Northbound Interface (API), as presented in Figure 2. In this architecture, the network nodes forward packets according to the rules installed on network devices by the SDN controller in a proactive or reactive manner.

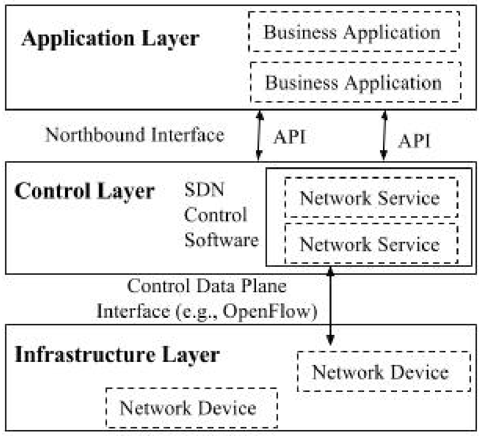

Fig. 2. SOFTWARE DEFINED NETWORK ARCHITECTURE [7]

B. *Benefits of Our Approach*

In our approach, we apply SDN to the global architecture of an ITS, including, not only the ad hoc network as proposed in [9], but also the RSU and cellular networks. This approach responds to the limitations of current architectures, by opening the road to the development of novel network control algorithms that take advantage of: (1) a vision of the state of all three above cited communication networks; (2) the ability to jointly control these networks; and (3) the knowledge of the environment in which vehicles evolve, which is derived from the data present in the cloud. For example, vehicles status information (position, direction, speed) can be used to predict the number of vehicles that will be present in a given region at a given time, allowing the estimation of the potential network load of a routing node (BS/RSU). Moreover, the dynamic nature of vehicular networks requires an adaptable network, SDN brings this flexibility to dynamically program the network according to network conditions. The SDN controller, which is a new component, is added to the architecture, as illustrated in Figure 3. Typically, We consider three controllers: one to manage the cellular network, another to manage the RSU-based network and a last one to coordinate between the different controllers. The main controller builds a global view of the communication infrastructure using the information sent by the controller of each network coupled with the data present in the cloud. It sends to each controller the global rules which describe the general behavior of the network, while the BS and RSU controllers define the specific rules to be installed in each network device. The communication between the SDN controllers is done using a specific interface known as East-West Interface e.g. AMQP, while the communication between the SDN controllers and the cloud is performed through specific APIs.

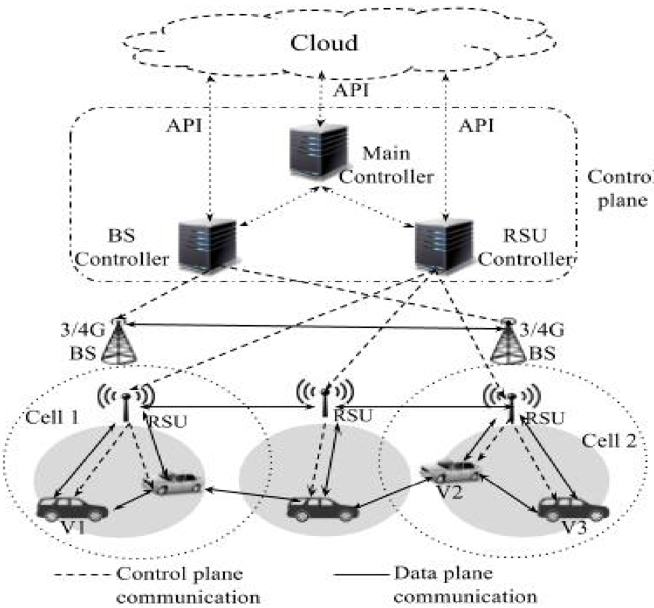

Fig. 3. THE PROPOSED SDN ARCHITECTURE

Among the opportunities brought by this architecture:

- **QoS aware routing with potential environmental inputs in a multi homed context:** The SDN controller provides the best routing path according to the services requirements through efficient routing algorithms that are aware of the QoS requirements of each ITS services and the environment in which vehicles evolve, and which take advantage of the presence of several networks.

- **Mobility Management:** The global vision of the network allows the SDN controller to provide a better coordination of handover operations, moreover, the collected data present in the cloud allows it to predict the mobility of surrounding vehicles in order to anticipate some control operations.

- **Enhanced QoS Management:** The QoS management can be improved thanks to the fine grained as well as on-line programming capabilities offered by SDN. Efficient and dynamic QoS support can be achieved. Joint control algorithms (routing, topology control, etc.) can be developed to that end.

- **Network Load Balancing and flow splitting**.

C. *Use Cases*

In order to study the benefits of our approach, we consider the safety use case presented in table III: "Emergency vehicle warning" which allows an active emergency vehicle to indicate its presence in order to reduce its intervention time. This service requires a very high latency and reliability as illustrated in table III. We consider that the emergency vehicle V1 is equipped only with an LTE interface, and it moves from cell 1 to cell 2, while vehicles V2 and V3 are equipped with DSRC and LTE interfaces as presented in Figure 3. We also suppose that there are sufficient cellular network resources in cell 1, while cell 2 is overloaded. Consequently, the emergency vehicle can't communicate when it arrives to the cell 2.

Our approach can address this type of problems, through the global vision of the SDN controller and the coordination between the RSU and cellular networks. The SDN controller may request from V2 and V3 vehicles to switch to the RSU network in order to release the cellular network resources to the emergency vehicle V1. The SDN controller can anticipate this action through the mobility prediction of emergency vehicle V1 using the data present in the cloud.

V. CONCLUSION AND FUTURE WORK

With the aim to improve the quality of service offered by vehicular networks, this paper aims at presenting a new architecture based on the SDN paradigm combining the RSU and the cellular networks in order to efficiently support the QoS requirements of the envisioned ITS services, combined with the data collected in the cloud, we argue that novel network control algorithms can be devised to improve the efficiency and QoS capabilities of vehicular networks.

We are now working on the development and evaluation of new network control functions (routing, QoS aware resource allocation, etc.) algorithms which take benefit of the proposed architecture.

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