Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 110 (2017) 320–327

Procedia Computer Science

www.elsevier.com/locate/procedia

The 12th International Conference on Future Networks and Communications (FNC-2017)

A New Approach on Communications Architectures for Intelligent Transportation Systems

Susana Sousa, Alexandre Santos, António Costa, Bruno Dias, Bruno Ribeiro, Fábio Gonçalves, Joaquim Macedo, Maria João Nicolau, Óscar Gama

[a]Algoritmi Center, Department of Informatics, University of Minho, Portugal

Abstract

A Vehicular Adhoc Network (VANET) is a generic communications conceptualization that can be applied to Intelligent Transportation Systems (ITS) and its main goal is to allow exchange of information between moving vehicles, fixed infrastructures, pedestrians with personal devices, and all other electronic devices able to connect to a VANET environment. Information exchange between different stakeholders brings a relevant potential to the development of applications to help users in different areas such as traffic safety and efficiency, infotainment and personal comfort. However, due to the expected heterogeneity (different processing power and storage capabilities, communications technologies and mobility patterns) and large scale on the number of devices involved, application interoperability in VANET contexts can be a challenging problem. Non-agnostic standard communications architectures for ITS systems have some deploying limitations and lack important specific implementation details. This paper presents an agnostic VANET architecture (it permits the use of several communication technologies in an open and modular framework), which is an adaption of present standards approach, to be deployed on ITS systems as a mean to overcome their main limitations.

Peer-review under responsibility of the Conference Program Chairs.

Keywords: Intelligent Transportation Systems; Vehicular Adhoc Networks; Agnostic Communications Architecture;

1. Introduction

The increasing mobility of people, vehicles and "things", is having a great economic and social impact. The automotive industry is now considering the network of these linked sources of information on streets, roads and highways as complex autonomous systems. The fast growth on the number of existing vehicles, mainly in the urban environment, leads to an increased number of accidents and traffic jams, to higher levels of pollution and consumption of energy. Traffic accidents have been taking thousands of lives each year and caused critical injuries to millions

E-mail addresses: b7215@algoritmi.uminho.pt (Susana Sousa)., alex@di.uminho.pt (Alexandre Santos)., costa@di.uminho.pt (António Costa)., bruno.dias@di.uminho.pt (Bruno Dias)., b7214@algoritmi.uminho.pt (Bruno Ribeiro)., b7207@algoritmi.uminho.pt (Fábio Gonçalves)., macedo@di.uminho.pt (Joaquim Macedo)., joao@dsi.uminho.pt (Maria João Nicolau)., b2583@algoritmi.uminho.pt (Óscar Gama).

1877-0509
Peer-review under responsibility of the Conference Program Chairs.
10.1016/j.procs.2017.06.101

of persons. The next logical step is to create a way to control these interactive systems, by developing intelligent transportation management mechanisms and equipping vehicles with technology to enhance efficiency, safety and comfort. A new type of communications networks is needed, where vehicles, personal smart devices and other type of mobile equipment are able to communicate and exchange information such as traffic conditions or safety warnings. Intelligent Transportation Systems (ITS) deal with these scenarios making use of specific communications frameworks.

The scientific community has developed a special communications architecture to be applied on these environments, known as VANET, which refers to a particular type of Mobile Adhoc Network, where nodes that form the network are vehicles equipped with one or more "on board" wireless communication devices. Vehicles, acting as network nodes, can communicate spontaneously with each other without any infrastructure support, but also with the infrastructure when in range of any fixed Road Side Units (RSU). VANETs include Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I) and Vehicle to Pedestrian (V2P) communication, or, more generically Vehicle to X (V2X). In VANETs vehicles communicate directly within signal range, or using multi-hop paths between source and destination nodes, computed in a cooperative way using specific routing protocols, in Unicast or Broadcast mode. Since vehicles move at very high speeds along restricted and predictable road paths, VANETs have distinctive characteristics and communication requirements. Short contact time, connectivity disruption, packet losses, frequent topology changes, high channel load in dense environments, are examples of the characteristics that make VANETs a very challenging communication environment, but also full of potential for interesting new applications. For that reason, many research efforts have been directed to VANETs in latest years.

Nowadays it is common for vehicles to be equipped with great communication capabilities, materialized in multiple and various wired and wireless interfaces. Wired communication technologies such as CAN, LIN and FlexRay tend to coexist well in vehicle environments, although the tendency is for manufacturers to start implementing Ethernet solutions, due to their benefits in terms of complexity, cost or even cabling weight. Although IEEE 802.11p is the most popular solution for wireless vehicle communications, when applications require long range communications (more than one km) or have high bandwidth demands (typically infotainment applications), it may be necessary to resort to solutions like cellular networks or WiMax. Other technologies like ZigBee, Bluetooth or LiFi are considered for very specific problems such as connecting the vehicle to the driver's smart-phone, or taking advantage of the existing traffic lights infrastructures to disseminate traffic information.

Several standardization institutions around the world have defined deployment architectures to model various aspects of ITS. Some of these standards instantiate generic models defined for VANETs into existing standard technologies and protocols. They take into consideration real implementation scenarios faced by (and forced by) the automotive industry, which impose additional technological, social, legal and security constrains when deploying communications architectures. So, the most common approach in the automotive industry when developing ITS stations and VANET applications is to comply with standard specific access technologies for low level communications and broader functional requirements for some well known applications but each manufacturer relies on an adapted proprietary architecture that actually renders the interoperability between applications by different manufacturers impossible. Furthermore, in this closed development context, it is very difficult for software makers to implement ITS applications to compete in the automotive market independently of the manufacturers. All software is developed and deployed as an entire block, from the user interface in the applications down to the low level medium access technologies and everything in the middle.

In this paper we describe a new approach on communications architectures for ITS that intends to open up the development process of ITS applications and services to a larger community of software makers. The underlying strategy is to adapt existing communications models defined by the most important standardization institutions into a more specific and modular architecture that could be more easily adopted by the manufacturers and still be open to research, development and integration of independent application level software.

A brief presentation of the most relevant standards on ITS communications architectures is made on the next section, which is followed by a discussion of the proposed approach. The article ends with a brief conclusions section.

2. Standard VANET Architectures

Vehicular networks are heterogeneous. In the future, and regarding communications, vehicles may be equipped with a variety of wireless communication interfaces such as Wi-Fi, Dedicated Short Range Communications (DSRC)[1 2] and Wireless Access in Vehicular Environment (WAVE)[3]. Ideally, the vehicle should be able to choose the best interface or use multiple interfaces in parallel to communicate with other vehicles or servers. This requires the simultaneous use of different protocols at the lower communication layers. For example, when using Wi-Fi and WAVE, the network layer needs to interact with the link layer through the Logic Link Control (LLC) sub-layer[4].

Considering diversity in the vehicular environment, to allow a rapid and incremental deployment of VANET applications and technologies, it is desirable that applications be agnostic relatively to the underlying medium-access communication framework. To attain this objective, the concept of an agnostic middle-ware layer was introduced. This is a layer that should provide information management from multiple sources, allowing heterogeneous devices to be supported over different communication stack protocols. This type of layer should give freedom to vehicular applications developers and communication stack providers to focus on the optimization of its components. Indeed, such a type of middle-ware has already been proposed on the standard architectures reviewed on the next subsection. This would serve to mask the diversity and distribution of the vehicular resources, to provide common services to different V2V applications, and to provide a unified application programming model. But, this approach relies that all applications must use directly this middle-ware. So, such a middle-ware must be supported on all operating systems of all communication stacks, which is a very daunting task. Also, management of application multiplexing is very difficult to implement.

The ISO 21217:2014 standard[5] describes the ITS station reference architecture, which consists of six parts (Applications, Management, Facilities, Networking & Transport, Access and Security). Although this standard specifies all the ITS Station elements, whether or not a particular element is implemented is dependent on the specific communication requirements. Until now, the most relevant middle-ware support solution for application agnosticism was introduced by the standard ETSI ITS Facilities Layer[6]. More recent and specific alternatives were also proposed[7 8 9 10], but all of them are instantiations of the generic ETSI proposal, adding a set of specific service (information, communication and application) modules between the applications and the transport layer.

An implementation of such an application middle-ware layer might be a very complex task and software makers would lose the ability to intentionally choose a development paradigm for their applications, at least without any type of signaling mechanism supported by the facilities layer. Also, the usage of a particular transport layer would be bound to the usage of a particular medium access technology. The development environment for in-vehicle applications should support the industry trend of clearly separating (hardware and software wise) the services that are responsibility of the vehicle manufacturer and the rest of the services/applications that can be added by third party developers. It is most likely that the former services will be developed and implemented on closed OBUs and installed by vehicle manufacturers (or third party specialists under the responsibility of vehicle manufacturers) during the vehicle manufacturing process. The latter, which will implement higher-level ITS applications, can be developed by generic software developers and could be run on additional computational resources either inside the vehicle or at some fixed road side infrastructure. So, a new approach on an agnostic ITS architecture could adapt the ETSI ITS proposal to solve the referred constraints and make use of the full potential of future multi-medium access capabilities and without the integration of a facilities layer directly on top of the transport layer.

CALM is an architecture defined by the ISO Technical Committee 204 - Working Group 16 (TC204 WG16). It is designed to allow interoperability between ITS stations that abstract applications and services from the underlying communication layers. Its main goal is to establish an integrated technology that is able to provide a set of protocols and parameters for ITS communication using several different media[11]. The core concept of CALM is to enable vehicles to use any kind of communication media with seamless media handover. CALM introduces specifications for technologies such as Cellular Networks (2G, 3G), LTE, Infra-Red, M5 or Millimeter wave air interface but do not present solutions to their simultaneous use on the same ITS Station by several applications developed by different software producers.

Both of these standard strategies are oriented to development of applications by closed ecosystems, in general controlled by manufacturers or manufacturers consortia. There is no separation of development ecosystems (and its responsibilities) on smaller separated components or different protocol stacks (like applications on one side and

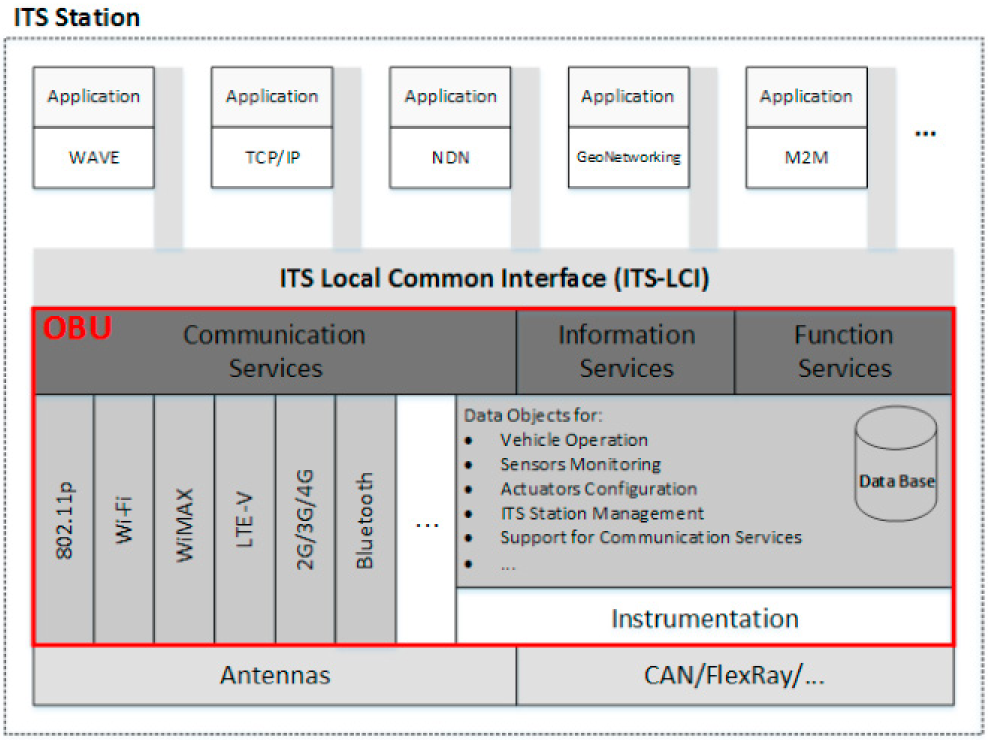

Fig. 1. Agnostic Architecture for VANETs

OBUs on the other, for example). This generates less opportunities for research and development independently of the automobile industry as application development is to dependent on the entire framework or stack of communications protocols. There is no development of third party solutions collaborating with original manufacturers equipment, services and functionalities. Finally, it makes very difficult to create applications to be deployed as services.

Furthermore, some recent communication technologies could be very important for the near future of ITS systems, but are not easily supported on present standard ITS communication architectures. This is the case of Named Data Networks (NDN)[12], that can overcome the performance limitations of Content Delivery Networks and Peer 2 Peer networks[13] (as these mechanisms are implemented at the application layer and the routing strategy is maintained based on end-to-end paradigm, using TCP or UDP). In the new NDN paradigm, data is completely decoupled from container and session, making it well suited for mobility scenarios. Another case is the Machine to Machine (M2M) paradigm[14].The influence of M2M communications will constantly increase in next years, considering the augmentation of autonomous communications among computers, embedded processors, smart sensors, actuators and mobile devices without or with limited human intervention.

3. Agnostic ITS Communications Architecture: a new approach on standards

An ITS architecture for the development of agnostic vehicular applications should present the OBU modeled like a black-box, implementing all lower/level in-vehicle communication services, information services and function services. These service modules would share the same interface technologies and the implemented functionalities would, at least, cover the same functionalities referred by the ETSI ITS facilities layer. As such, the proposed agnostic ITS architecture, as presented in Figure 1, would support all types of vehicular applications developed using any type of programming paradigm and taking full potential of a multi-medium access capable OBU.

The main component of the proposed ITS Station architecture is an On Board Unit (OBU) designed as a black-box, that is, it does not matter how the OBU developer implements the internals. Furthermore, due to the vehicle's industry safety and security requirements, these internals should be physically and logically protected from external direct manipulation that could lead to tampering the functional behavior originally intended by the developer/manufacturer. Every existing vehicle should be able to assume the role of sender, receiver and router, so that information can be disseminated in the network while assuring a safe and smooth traffic flow at the same time. To enable communication in vehicle communication systems, vehicles must be equipped with OBUs that enable the creation of VANETs. OBUs typically provide, as minimum, CAN bus, power supply, and one portable storage media as external interfaces. However, it is common to find communication technologies like DSRC/WAVE, Bluetooth or LTE that allow V2X communications. RSUs also play an important role in this systems, since they ease communication between vehicles when direct communication is not possible, and enables them to connect to the backbone network. The distribution of RSUs depends on the communication protocol or use case in question - some environments require an even distribution on the whole network, while others only require them at intersections or in a given region. All interactions should be done through the ITS-LCI using standard communication protocols and access technologies implemented on the three services modules:

Communication Services Module - This interface module will permit the sharing of all the available medium-access technologies available at the OBU by the different application stacks; it should implement adequate algorithms for multi-homing (the simultaneous use of several network providers on the same medium-access technology) and vertical hand-off (the simultaneous use of several medium-access technologies by the same application stack); this module should also implement all related functions to medium-access addressing, monitoring, parametrization and security, and also antennas configuration, when available. In general, due to the specific nature of the low-level functional requirements, including hardware requirements, of the medium-access technologies, their internal implementations will be done on a dedicated Central Control Unit (CCU). Direct access to communication functions by external processes (outside the OBU) should not be allowed. Instead, indirect access should only be possible through the communication services module (which is a logical module with higher-level functionalities, implemented on top of the available CCU functions) and using standard communication technologies. This module acts as a point of access to the medium technologies. This means that, whenever a packet of data is generated at the network level, regardless of the type of application stack used, the packet is sent to the medium using the best-performing communication technology at the moment. Although the figure only shows internal blocks/channels for medium-access technologies, external logical blocks/channels, implemented on devices outside the OBU, could be registered and used by the module, as long as the manufacturer's defined interface is supported. The communication services module requires a bidirectional adaptation, that is, whenever a Protocol Data Unit (PDU) arrives through one of the communication blocks/channels, its type must be identified so it can be correctly forwarded, through the ITS-LCI, to the adequate application stack at the network layer. Another requirement for this module is that it must implement efficient scheduling strategies depending on the type of PDUs.

Information Services Module - This interface module will permit access and manipulation of data generated by all sensors, actuators and other devices indirectly or directly connected to the OBU; this data includes, for example, sampled values from Electronic Control Units (ECU) connected to the Controller Area Network (CAN) of a vehicle (vehicle speed/acceleration, engine regime, engine/water/oil temperature, fuel/battery level, distance to obstacles in front/rear, tires pressure, vehicle longitudinal/traversal inclination/rotation, etc.), amount of power applied to antennas, sampled values from ambient sensors on the vehicle (interior/exterior temperature, interior/exterior humidity, altitude, video streams or photos images from video or image devices installed by the vehicle manufacturer, configuration parameters of the medium-access communication technologies, relative and global position (using GPS, RF-ID, etc.), vehicle identification, malfunctions, biometric values of the driver, security parameters, relevant past and event dates (mandatory inspections, manufacturer check-ups, etc.). It should be noted that the data should be collected and made available at rates and with a precision adequate for proper use on the most demanding applications, some of them almost in real-time. As such, and dependent on the running applications and on the type of the data itself, the sampling processes should be configurable (rate, precision, amount of sampled values retained, maximum retention time, etc.), including their security levels of access. Manipulation of data that abstracts configuration parameters should be available, preferably, through configuration functions implemented on the function services module but direct manipulation could also be available through the information services module, as long as adequate security mechanisms are supported.

Function Services Module - This interface module will permit access to lower-level functionality procedures. These are functions that the manufacturers, due to security, safety, performance and liability issues, should have the responsibility and the desire to implement (or closely control its implementation). These functions could implement atomic operational procedures (should not be interfered or use sub-procedures external to the OBU) like "maintain a distance of X meters from front obstacle" or "maintain a velocity of X km/h" or "maintain same lane for X kms" or "reduce velocity by X km/h during T minutes" or "light up emergency lights" or "set interior temperature to X", etc., or implement configuration procedures like "set driving mode to sport" or "reset malfunctions information" or "set automatic lighting" or "lock all doors" or "set engine rpm sample rate to X samples/sec maximum Y samples" or "set positioning precision to X meters" or "turn Wi-Fi communications on", etc. These atomic procedures could then be used to implement all type of external applications with a higher-level of functionality, like Platooning, Adaptive/Autonomous/Dynamic Cruise Control, Autonomous Driving, Adaptive ABS, etc.

ITS-Local Communication Interface (ITS-LCI) - This architecture is modular an open, as it allows the integration of any application protocol stack, such as WAVE, TCP/IP or NDN. And any type of vehicular application (safety, efficiency, comfort, management, etc.). The applications and communication protocols should be able to use any of the services modules through the ITS-Local Communication Interface (ITS-LCI). This represents a standard bidirectional communication technology (or group of technologies, protocols and mechanisms), which any device/ process/application in the vehicle should implement to be able to access and manipulate the data or use the functions provided by the three services modules. The context of its application is only local to the vehicle, which makes its technical requirements less demanding (for example, no routing or naming service would be necessary).

3.1. Deployment solutions

It seems appropriate, even critical, to implement a database, or repository, on the OBU to support the data access and manipulation requirements of the three services modules. Such strategy requires an adequate availability of computational power and energy supply that manufacturers should take into consideration. An instrumentation mechanism would need to be implemented in order to adapt the database technology to the available data access/manipulation technologies already available to vehicle manufacturers. Nevertheless, since neither the data nor the instrumentation mechanism can be directly accessed outside the OBU, their implementation strategy and used technologies can be freely chosen by the OBU developer, as long as the standard technologies defined for the interface with the services modules are supported. Applications should also be able to store relevant information on this repository, mainly data that is important to share with other applications, like information from safety applications or sample values from external user devices. Nevertheless, this procedure should only be supported through the standard interface technologies supported by the information services module.

The ITS-LCI should use a large bandwidth, low cost medium wired technology like Gigabit Ethernet, support a widely used transport/network stack like UDP over IP and an application management protocol like the Simple Network Management Protocol (SNMP)[15]. The SNMP protocol also seems to be an adequate solution to implement the interface technology to be supported by the three services modules in the OBU for access and manipulation of the referred data. Its use would be complemented by the definition of a standard automotive OBU Management Information Base (MIB) implemented on an SNMP agent inside the OBU. Furthermore, the MIB objects could convey enough semantic meaning as to provide the means to implement the atomic procedures to be available on the functions services module. Finally, a more performing communication technology (and also widely used) based on UDP encapsulation over IP could be used for access to the communications service module.

3.2. Application example

Platooning is a well known ITS application that allows vehicles, normally trucks, to travel very close to each other with automated control of both longitudinal and lateral distance between them. In theory, this control application

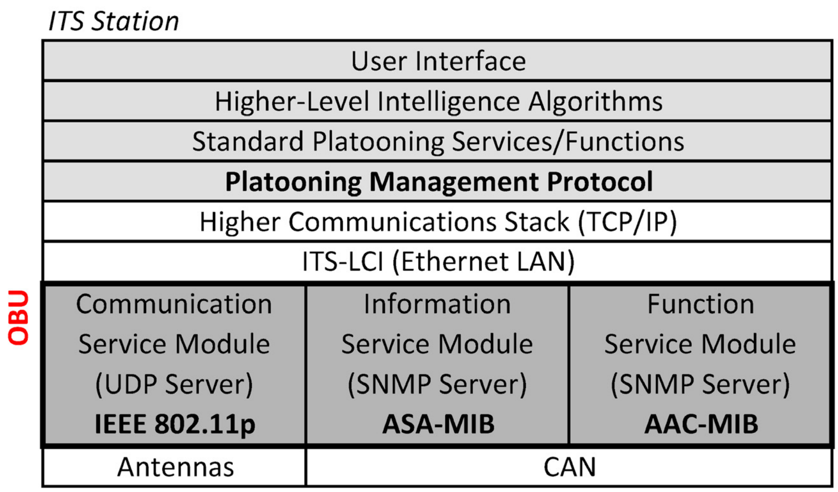

Fig. 2. Platooning deployment model

should enhance safety, traffic flow, road capacity, fuel savings and emission reduction. In practice, due to its complexity and thigh safety requirements, there are still no commercially available solutions. So, this is a good example of a type of application that could benefit from a research, development and deployment paradigm as defined by the new proposed architecture and depicted on Figure 2, as the Platooning application could be developed as a two-way process, including a management communication protocol implemented on an application level and a set of standard supporting lower-level vehicle control functions implemented on the OBU.

As can be seen, higher-level functional and security requisites can be implemented on an independent host system with a classic operating system albeit with an adaptation for interaction with the OBU communication service module with an UDP tunnel through the ITS-LCI (no adaptation is needed for interaction with the other OBU service modules as this is done through SNMP).

The higher-levels modules of the platooning application should take care of the algorithms for implementation of the more complex operation like drivers certificate verification, platooning overtake, platooning merge, leader substitution, maintaining string stability for maximization of fuel savings, safety or road capacity, or reducing travel time, etc. Standard functions should implement basic functional requirements like join or leave operations or configuration of the platoon parameters (maximum and minimum speed, maximum and minimum distances between vehicles, minimal technical requirements for vehicles and drivers, etc.). The platooning management protocol would be responsible for implementation of an application protocol with dedicated service primitives and protocol data units. All interactions between vehicles in the platoon should use this protocol. This could be implemented on top of a classic TCP/IP communications stack.

The vehicle manufacturer would be responsible to implement the service modules inside the OBU. For example, it could use the IEEE 802.11p medium access protocol or V2V communications and two MIB modules implemented on an SNMP agent/server. The Automotive Sensors & Actuators MIB module (ASA-MIB) would be dedicated to access to monitoring sensor data needed for platooning like speed, acceleration, global positioning (GPS) and relative positioning (through radar and video camera technologies) and the Automotive Automatic Controllers MIB module would be used to access lower-level control functions like Cooperative Adaptive Cruise Control and Automatic Emergency Braking.

4. Conclusions and Future Work

This paper presented a new approach for deployment of a communications architecture for VANETs (and therefore, for ITS Communications Systems). It adapts present solutions by clearly separating the roles of services implemented inside an OBU and the ITS/VANETs applications that will use them, specifying standard and common communication technologies/protocols for implementation of the ITS-LCI and for access to the modules services on the OBU, which are already commonly implemented by many vehicle Connectivity Control Unit's (CCU) device manufacturers.

By maintaining the lower-level medium-access communication and lower-level vehicle control functions inside the OBU, we can maintain the responsibility of its implementation on the automotive industry because its correct implementation is a delicate issue with both legal and social repercussions. On the other hand, higher-level control functions and high-level ITS applications can be independently researched and developed by third party software makers, with more expertise on efficient application software algorithms.

Taken into consideration the presented architecture, we plan to implement and test an OBU prototype (using an already existent commercial CCU available to the automotive industry), to implement and test a prototype of the ITS-LCI on a Linux host system where some prototype ITS applications can be tested (directly or indirectly through integration with simulation frameworks). Finally, we intend to integrate and test everything on a complete ITS prototype system.

Acknowledgment

This work has been sponsored by the Portugal Incentive System for Research and Technological Development. Project in co-promotion nº 002797/2015 (INNOVCAR 2015-2018), and also by COMPETE: POCI-01-0145-FEDER-007043 and FCT - Fundação para a Ciência e Tecnologia within the Project Scope: UID/CEC/00319/2013.

References

1. E. C. for Standardization and E. C. for Standardization, "CEN EN 12253: "Road transport and traffic telematics - Dedicated Short Range, Communication (DSRC) - Physical layer using microwave at 5,8 GHz"," Tech. Rep., 2004.
2. E. Committee and F. Standardization, "CEN EN 12834: "Road transport and traffic telematics - Dedicated Short Range Communication (DSRC) - DSRC application layer"," Tech. Rep., 2003.
3. I. . W. Group, *IEEE Guide for Wireless Access in Vehicular Environments (WAVE) - Architecture*, 2014.
4. D. Jiang and L. Delgrossi, "IEEE 802.11p: Towards an international standard for wireless access in vehicular environments," in *Vehicular Technology Conference, 2008. VTC Spring 2008. IEEE*, IEEE. IEEE, may 2008, pp. 2036–2040.
5. "ISO 21217:2014 Intelligent Transport Systems – Communications Access for Land Mobiles (CALM) - Architecture, ISO Technical Committee 204 WG16," 2014.
6. ETSI, "ETSI EN 302 665 V1.1.1 (2010-09): Intelligent Transport Systems (ITS); Communications Architecture," ETSI - European Telecommunications Standards Institute, Tech. Rep., 2010.
7. S. Nour, R. Negru, F. Xhafa, F. Pop, C. Dobre, and V. Cristea, "Middleware for Data Sensing and Processing in VANETs," in *Proceedings - 2011 International Conference on Emerging Intelligent Data and Web Technologies, EIDWT 2011*. IEEE, sep 2011, pp. 42–48.
8. R. Miguel Correia Costa, P. Jorge Pires Ferreira Supervisor, and T. Maria Ferreira Va ao Vasques, "Agnostic Application Development Middleware for VANETs Communications Networks Engineering Examination Committee," 2013.
9. F. A. Silva, T. R. M. B. Silva, L. B. Ruiz, and A. A. F. Loureiro, "ConProVA: A smart context provisioning middleware for VANET applications," in *IEEE Vehicular Technology Conference*. IEEE, jun 2013, pp. 1–5.
10. I. Jawhar, N. Mohamed, and H. Usmani, "An overview of inter-vehicular communication systems, protocols and middleware," *Journal of Networks*, vol. 8, no. 12, pp. 2749–2761, dec 2013.
11. K. Dar, M. Bakhouya, J. Gaber, M. Wack, and P. Lorenz, "Wireless Communication Technologies for ITS Applications [Topics in Automotive Networking]," *Communications Magazine, IEEE*, vol. 48, no. 5, pp. 156–162, 2010.
12. L. Zhang, D. Estrin, J. Burke, V. Jacobson, J. D. J. Thornton, D. K. Smetters, B. Zhang, G. Tsudik, D. Massey, C. Papadopoulos, Others, D. Krioukov, D. Massey, C. Papadopoulos, T. Abdelzaher, L. Wang, P. Crowley, and E. Yeh, "Named Data Networking (NDN) Project," *Relatório Técnico NDN-0001, Xerox Palo Alto Research Center-PARC*, 2010.
13. G. Deng, L. Shi, R. Li, and X. Xie, "Efficient Inter-vehicle Internet Content Distribution based on Named Data," no. 61421061, 2015.
14. J. Wan, D. Li, C. Zou, and K. Zhou, "M2M communications for smart city: An event-based architecture," *Proceedings - 2012 IEEE 12th International Conference on Computer and Information Technology, CIT 2012*, pp. 895–900, 2012.
15. S. Network and M. Protocol, "Simple Network Management Protocol," *Management*, pp. 1–8, may 2008.