Communication Infrastructure and Data Requirements for Autonomous Transportation

Piyush Dhawankar[1], Mohsin Raza[1], Hoa Le-Minh[1], Nauman Aslam[2]
[1]Math, Physics and Electrical Engineering Department
[2]Department of Computer Science and Digital Technologies
Northumbria University, UK

***Abstract*—Autonomous driving technology has been regarded as a promising solution to reduce road accidents and traffic congestion, as well as to optimize the usage of fuel and lane. However, one of the main challenges in autonomous driving is a limited sensing from single vehicle that causes warning and dead-lock situation. The network management in Vehicular network is challenging and demands mobility, location awareness, high reliability and low latency of data traffic which are not feasible or efficiently implemented with today's network architecture. In this paper, we propose the novel communication architecture for vehicular network with Fifth generation Mobile Networks (5G) and SDN technologies to gain more flexibility and support multiple core networks for vehicular networks and to tackle the potential challenges raised by the autonomous driving vehicles.**

Keywords*— Autonomous driving Vehicles (ADVs); Software Defined Network (SDN); Network Function Virtualization (NFV); Vehicle-to-Vehicle (V2V); Vehicle–to-Infrastrructure(V2I); Vehicle-to-Everything (V2X).

I. INTRODUCTION

The automotive industry has recently shifted from developing advanced vehicles to smart transportation which, focuses on the evolution of new intelligent vehicles with autonomous driving control capability [1]. The autonomous driving vehicles (ADVs) is a highly-complex multidisciplinary product which integrates sensor system, automotive control, information processing, artificial intelligence and ultrafast communication capabilities. Governments and society can substantially benefit from autonomous driving, as it will minimize the of road accidents, would help in traffic regulating, and optimal usage of fuel and road resources [2]. In order to realize autonomous driving, vehicles need to be capable of sensing the surrounding environment as well as performing control and path planning without any human intervention [3]. Global automakers and information technology companies, such as General Motors, Volkswagen, Toyota, and Google, expect to have ADVs on the market in 2020 and 25 percent of the vehicles out on the road to be ADVs by 2035 [4]. Nevertheless, several challenges still need to be fully addressed for autonomous driving [5, 6], such as:

- To have knowledge of the exact position of the vehicle and to decide how to reach the destination optimally.

- To comprehensively sense the surrounding environment, including other road users and the road infrastructure, in order to avoid any types of collision and accident.

- To detect the road signs as well as other static infrastructure details such as lanes, crosswalks, speed bumps, etc.

In existing technologies, sensor systems with a range of cameras, radar, laser range finders, and advanced autonomous driving algorithms are employed for this purpose. Nevertheless, it is still far from perfection. Furthermore, due to the lack of communication ability among the neighbouring vehicles the autonomous driving vehicles cannot fully predict the behaviour of the neighbouring vehicles. Moreover, the main approach to detect the surrounding environments utilizes sensor systems which could be highly affected in different driving conditions (e.g., road/user obstacles, other vehicle behaviours, poor weather conditions). Thanks to the rapid development of recent wireless communication technologies, vehicular networks are expected to support and boost the development of autonomous driving, and employ vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication techniques, which can be effectively used to detect surrounding conditions [7]. V2V and V2I communication can serve as a second layer of protection in autonomous driving where every vehicle can periodically broadcast safety-related messages about its current parameters to its neighbouring vehicles, which is helpful for other vehicles to accurately know their surrounding environment [8].

This paper focuses on Vehicle-to-Everything (V2X) communication technologies for future autonomous driving vehicles. The paper presents a novel communication infrastructure for ADVs. The requirements for V2V, V2I communications and vehicular networks is presented keeping in view the safety requirements and critical time margins. Finally a four lane road infrastructure is presented and the data requirements for different V2V network ranges is evaluated.

The rest of the paper is organized as follows. Section II presents the literature review. System Model of vehicular networks and autonomous driving infrastructure is presented in Section III. The data communication requirements and critical communication and response times are presented in section IV. Finally, Section V concludes the paper and gives the future directions.

II. LITERATURE REVIEW

V2X communications in future cellular/5G (and beyond) mobile network technology is not only relying on evolution of the radio technologies, but new End-to-End (E2E) converged network and cloud infrastructures, will also play a significant role in smart transportation [9]. From the vehicular network perspective, the developing 5G architecture needs to provide high flexibility, low latency, load balancing for data routing and high-capacity of nodes in order to support extremely-dense-and-heterogeneous scenarios (EDHs) where multiple road users are connected by a robust, reliable and dynamic network, allowing for rapid data transmission with sub-millisecond latency requirements [10].

Software Defined Network (SDN) and Network Function Virtualization (NFV) are the key technologies to address all the above technical networking challenges posed by the 5G infrastructures for V2X [11]. SDN controls the network in a centralized, systematic and programmable manner by decoupling the forwarding function (data plane i.e., user equipment) and network controls (control plane i.e., SDN controller/server), improving the efficiency of vehicular networks by fulfilling the requirements of ADVs [12]. With software-based controller, network operators are much more flexible in programming, modifying, manipulating and configuring protocols in a centralized way which improves network functionalities in terms of resource allocation and handling immense network loads in vehicular networks. Whereas, NFV aims at realizing network functions on the standard high-performance servers/switches and storage devices using a standard IT virtualization technology [13]. Network functions are modularized and connected by software interfaces. The network can be sliced by network virtualization technology and each slice can apply its own network function combination. The dynamic network and resource allocation can be achieved by network management and orchestration module i.e. MANO system [11].

For ADVs it is important to acquire and communicate information related to position, acceleration, deceleration, speed, steering tilt angle, separation between the vehicles and object tracking. The following objectives are achieved with multiple sensors including Accelerometer, Radar System, Vehicle Dynamics Control (VDC), Differential Global Positioning System and Digital Steering Angle System. These sensors serve five important aspects of autonomous driving: Localization, Perception, Planning, Vehicle Control and System Management [14]. Technical details of the selected sensors is provided in Table 1. The sampling rate and the data bits required for communicating the listed sensor values in Table 1, define the data requirements for individual vehicle and can be linearized to larger networks. Furthermore, technical requirements and Key Performance Indicators (KPIs) for autonomous vehicles, V2X use cases are listed as under.

- **End-to-end latency for automated overtaking (ms):** Maximum tolerable elapsed time from the instant, data packet is generated at the source application (ADVs) to the instant it is received by the destination application (Vehicular Network) should be approximately 10 ms to create the necessary gap in time to avoid a collision with an oncoming vehicle [15] .
- **Reliability (** 10^{-x}¿ : Maximum tolerable packet loss rate at the application layer, will be -5 ¿ $10^{¿}$ within the maximum tolerable latency [15].
- **Data rate (Mbit/s):** Minimum required data rate for the multiple ADVs applications to function correctly is in a range of 3 to 27 Mbps for exchanging Basic Safety Message (BSM) which contains information on GPS location, speed, direction and vehicle related information [7].
- **Communication range (m):** Maximum distance between source and destination(s) of a radio transmission within which the application should achieve the specified reliability, the typical range will be 100 to 300 meters [15].
- **Node mobility (Km/h):** Maximum relative speed under which the specified reliability should be achieved, considering minimum 25 km/hr and 120 km/hr maximum [16].
- **Network density (vehicles/** km^2¿: Maximum number of vehicles per unit area under which the specified reliability should be achieved, the saturation point per square kilometres is 2000 vehicles [15].

Table 1: Sensor Data

Sensor Type	Reference	Manufacturer	Bits/ Sample	Sample/s	Sampling Rate (Hz)
Accelerometer [18] [19]	SCA3100-D04	VTI Tech	36	2000	2000
	MM5.10	Bosch	36	1000	2000
Mid-Range Radar (MRR) [20]	Front	Bosch	-	-	-
	Rear	Bosch	-	-	-
LiDAR System [21]	LUX	IBEO	14	50	50
VDC [22]	SMB 225	Bosch	16 bits/s	100	57/ 180
Roll-over [23]	SMB 200	Bosch	10 bits/s	-	52
DGPS [24]	DSM132	Trimble	-	-	1,2,5, 10
Steering angle [25]	6002	Bourns	8	100	200

Table 2: Safe Breaking and Following Distance [16]

Speed (mph, ft./sec)	Perception distance (ft.)	Overall Stopping Distance (ft.)	Safe following distance	
			Good (ft.)	Marginal (ft.)
(25,37)	37	74.16	111	222
(35,52)	52	103.83	166	312
(45,66)	66	133.497	198	396
(55,81)	81	163.163	243	486
(65 , 96)	96	192.829	288	576
(75,111)	111	222.495	333	666
Time separation between the vehicles (3 seconds /Good weather), (6 seconds / Critical weather)				

For vehicle safety requirements each vehicle has to maintain the safe following distance (3 seconds) from the vehicles in front and back. These requirements can significantly change with weather (rain, fog and snow), lightning, traffic and road conditions. Therefore in an inclement situations 6 to 9 seconds margin should be maintained [17]. With the safe following distance it is also important to know how fast the vehicle is moving to predict its stopping time and distance. For different speeds, the stopping distance and perception time/distance is presented in Table 2. Since the average driver would take one-half to three-quarters of a second to perceive a need to hit the brakes, and another three-quarters of a second to move its foot from the gas to the brake pedal. This perception and reaction time in autonomous vehicles is very important and appropriate information must be communicated within due time to take suitable actions.

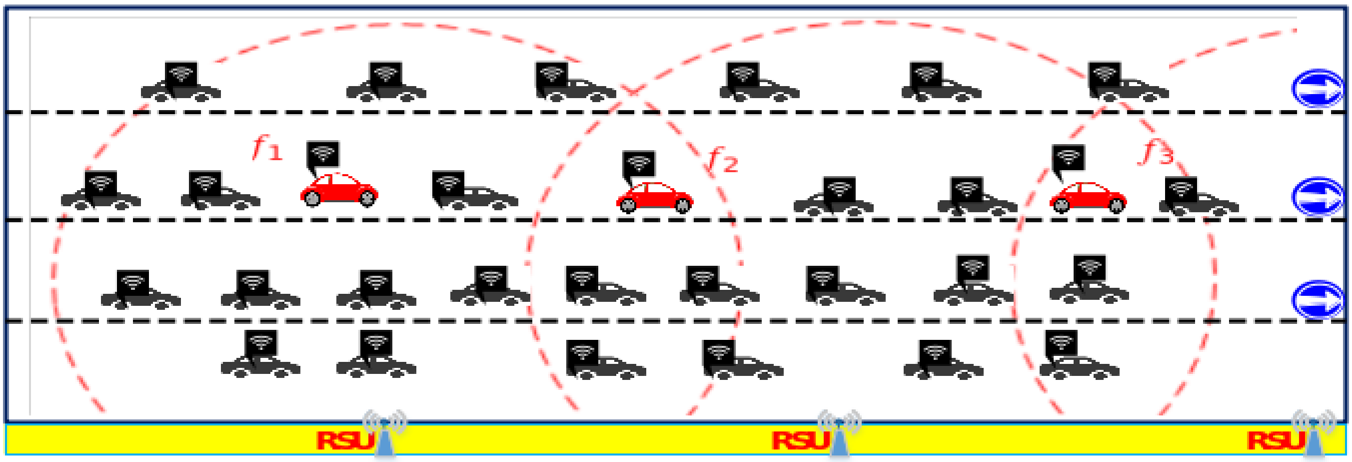

Figure 1: Four Lane Road Infrastructure for ADVs

III. SYSTEM MODEL

For V2V communication we use Time Division Multiple Access (TDMA) based channel access which allow vehicles to communicate in dedicated slots to reduce interference. Furthermore, the interference between the two clusters is mitigated by using cellular structure with *n* Frequency sets.

In Figure 1 the four lane road infrastructure for ADVs is considered and as an example scenario three clusters are represented. The ADVs in a cluster, exchange information amongs each other in regular intervals whereas the inter-cluster communication is executed by RSUs. Every cluster uses a dedicated frequency (*f1*, *f2*, *f3)* to mitigate inter-cluster interference. The proposed architecture for V2X communication is shown in Figure 2 whereas, the low level cellular infrastructure (as represented in Figure 1) is integrated with the higher hierarchy of the network model. In the proposed architecture the ADVs acts as dynamic nodes installed with wireless On-Board Units (OBUs) for communicating with other ADVs and infrastructure. The OBUs communicate in vehicular network with the help of Road Side Units (RSUs). The ADVs are equipped with multiple sensors like, pre-crash collision sensors, adaptive cruise control sensors, blind spot detection sensors and rear crash collision sensor etc. These sensors provide vehicles with complete perspective of road infrastructure and any objects in its proximity to facilitate smooth and safe driving. The proposed architecture is implemented using LTE network, SDN and Small cells to facilitate frequency reuse and to accommodate

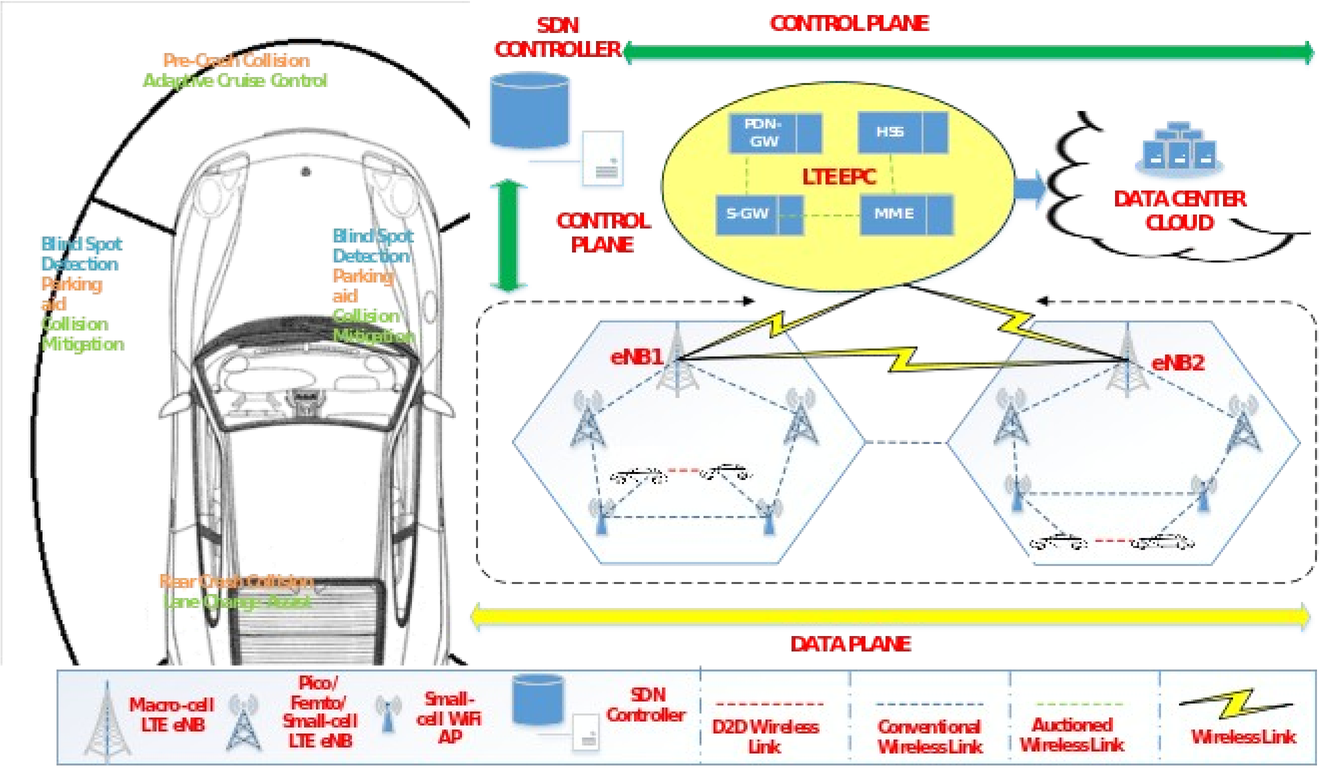

Figure 2: Proposed Architecture for Autonomous Driving Vehicles

large number of ADVs and related applications. The cluster of RSUs are connected to the RSU controller and it is responsible for forwarding data, storing local road information and performing emergency services. The cellular base station (eNB) is under the control of SDN controller and facilitates local vehicular network.

IV. RESULTS AND DISCUSSION

The proposed low level cellular infrastructure in Figure 1 is a four lane road scenario with 3 clusters labeled as A, B and C. Each cluster has number of vehicles which can be handled by the local vehicular network. The data requirement for each cluster is dependent on the number of ADVs and number of lanes (road). The data requirements vary with the lane traffic and different cluster sizes (In case the cluster represented in figure 1 is extended to multi-hops of communication area).

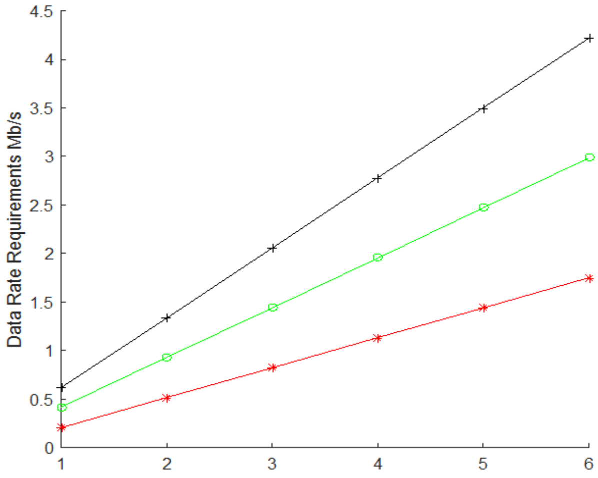

Figure 3 Data Requirements for Different Number of lanes

For the communication in each cluster, data requirements can change drastically with for different number of lanes and cluster sizes. For three different cluster-sizes and different number of lanes the data requirements for vehicular communication networks is presented in figure 3. The data rate is evaluated using the sampling rate and quantization levels used for each sensor mandatory for giving sufficient information for autonomous driving. A TDMA based slotted channel access is implied and therefore, the control information necessary to handle the network traffic is also included in evaluation. It can be seen that the increase in a cluster size would be able to accommodate more number of ADVs for better network management however, the data requirements change significantly.

The data rate requirements are analytically calculated by the using the sensor data in Table 1. The sensors data is transmitted by radio frequency using TDMA schemes and the frequencies interference from inter-cluster interference (cluster overlap) are managed by the Frequency Division Multiple Access (FDMA) scheme. The transmitted data over the air can be affected by the neighboring vehicles and weather condition. For the safety related requirements the delay has to minimum and the transmission has to be interference free to get the Quality of Service (QoS) which is the utmost important for the ADVs.

V. CONCLUSION AND FUTURE DIRECTIVES

Autonomous driving technology can serve suitably for future vehicles. However, it is important that the autonomous driving system is extended to network level instead of a stand-alone solution to access the full benefits of the communication technology and to implement a secondary layer of safety. This paper presents a vehicular network which incorporates future 5G networks and SDN for establishing a reliable link between the vehicles and the intelligent traffic control infrastructure. Furthermore, the data requirements are also calculated to better represent the needs from the future communications technology.

REFERENCES

[1] Jo, K., et al., *Development of Autonomous Car&2014;Part II: A Case Study on the Implementation of an Autonomous Driving System Based on Distributed Architecture.* IEEE Transactions on Industrial Electronics, 2015. **62**(8): p. 5119-5132.

[2] Anderson, J.M., et al., *Autonomous vehicle technology: A guide for policymakers*. 2014: Rand Corporation.

[3] Urmson, C., et al., *Autonomous driving in urban environments: Boss and the urban challenge.* Journal of Field Robotics, 2008. **25**(8): p. 425-466.

[4] Bierstedt, J., et al., *Effects of next-generation vehicles on travel demand and highway capacity.* FP Think Working Group, 2014: p. 10-11.

[5] Choi, J., et al., *Environment-Detection-and-Mapping Algorithm for Autonomous Driving in Rural or Off-Road Environment.* IEEE Transactions on Intelligent Transportation Systems, 2012. **13**(2): p. 974-982.

[6] Yu, R., et al., *Optimal Resource Sharing in 5G-Enabled Vehicular Networks: A Matrix Game Approach.* IEEE Transactions on Vehicular Technology, 2016. **65**(10): p. 7844-7856.

[7] Frenzel, L. *Major Wireless Development Driving 2017 Agendas*. 2016 [cited 2017 09/01]; Available from: http://electronicdesign.com/wireless/major-wireless-developments-driving-2017-agendas.

[8] Sasaki, K., et al. *Vehicle control system coordinated between cloud and mobile edge computing*. in *Society of Instrument and Control Engineers of Japan (SICE), 2016 55th Annual Conference of the*. 2016. IEEE.

[9] Vilalta, R., et al. *Experimental demonstration of distributed multi-tenant cloud/fog and heterogeneous SDN/NFV orchestration for 5G services*. in *Networks and Communications (EuCNC), 2016 European Conference on*. 2016. IEEE.

[10] 5GPP. *The 5G infrastructure Public Private Partnership: the next generation of communication networks and services (White paper)*. 2015 [cited 2017 09/01]; Available from: https://5g-ppp.eu/wp-content/uploads/2015/02/5G-Vision-Brochure-v1.pdf

[11] Fengyi, Y., et al., *A flexible three clouds 5G mobile network architecture based on NFV & SDN.* China Communications, 2015. **12**(Supplement): p. 121-131.

[12] Truong, N.B., G.M. Lee, and Y. Ghamri-Doudane. Software defined networking-based vehicular adhoc network with fog computing. in Integrated Network Management (IM), 2015 IFIP/IEEE International Symposium on. 2015. IEEE.

[13] Chiosi, M. *Network Functions Virtualization: An Introduction, Benefits, Enablers, Challenges & Call for Action* 2012 [cited

2017 09/01]; Available from: http://portal.etsi.org/NFV/NFV_White_Paper.pdf

[14] Coppola, R. and M. Morisio, *Connected Car: Technologies, Issues, Future Trends*. ACM Comput. Surv., 2016. **49**(3): p. 1-36.

[15] 5GPP, E.C. *5G Automotive Vision*. 2015.

[16] Missouri, D.o.R., *Missouri Driver Guide*. 2017, Missouri Department of Revenue. : Jefferson City, MO

[17] James, L. *Maintain a Safe Following Distance (The 3 Second Rule)*. 2008 [cited 2017 15/02]; Available from: http://www.smartmotorist.com/traffic-and-safety-guideline/maintain-a-safe-following-distance-the-3-second-rule.html

[18] VTI Technologies, "SCA3100-D04 3-Axis High Performance Accelerometer With Digital SPI Interface Datasheet," ed, 2015.

[19] Bosch, " Acceleration Sensor MM5.10 Datasheet," ed, 2016

[20] Bosch, " Mid-range radar sensor (MRR) for front and rear application Datasheet ," ed, 2015.

[21] IBEO, " LUX Lidar Sensor Datasheet," ed, 2010.

[22] Bosch, " Low-g accelerometer for vehicle dynamics control SMB225 Datasheet," ed, 2013.

[23] Bosch, " Low-g accelerometer for rollover applications SMB200 Datasheet," ed, 2013.

[24] Trimble, "DSM132 DGPS Receiver Datasheet," ed, 2005.

[25] Bourns, " Non-Contacting Steering Angle Sensor Type 6002 Datasheet," ed, 2013.