Quality of Service Assessment in Connected Vehicles

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Abstract— **In recent years, there has been a huge interest in Machine-to-Machine connectivity under the umbrella of Internet of Things (IoT). With the UK Government looking to trial autonomous (driverless) cars this year, connected vehicles will play a key part in improving and managing existing road safety and congestion, leading to a new generation of intelligent transport systems. This is also well aligned to the current initiatives by the automotive industry to improve the driver's experience on-board. However, the wireless channels most suitable for this application have not been standardized. In this paper, we review the wireless channels suitable for vehicle-2-vehicle (V2V) and Vehicle–to-x (V2x) connectivity. We further present preliminary analysis on the factors that impact the Quality of Service (QoS) of connected vehicles. We use the open access GEMV^2 data to carry out Analysis of Variance (ANOVA) and Principal Component Analysis (PCA) on the link quality and found that both line of sight and non line of sight has a significant impact on the link quality. The work presented here will help in the development of connected vehicle network (CVN) prediction model and control for V2V and V2x connectivity. It will further contribute towards unfolding and testing key research questions in the context of connected vehicles which may otherwise be overlooked.**

Keywords-QoS; V2V; V2x; ANOVA; PCA; CVN.

I. INTRODUCTION

Improving road safety and traffic management on existing infrastructure has huge societal and economic impacts. While users' perception of vehicular experience is fast evolving, existing transport infrastructure is still playing catch up. There is a disadvantage in using proprietary wireless standard as it limits customizability due to the lack of open source movement. Therefore, standardization of wireless channels is a first step to addressing this challenge as it allows for interoperability and user multiplier effect. The availability and presence of wireless communications and connectivity in vehicles is shaping customers' on-board experience. In the same manner that mobile phones have evolved in the last ten years, vehicles are evolving with some form of vehicle-2-vehicle (V2V) connectivity. According to a market research report, connected vehicles will be worth $46.69 billion by 2020 [1]. Connected vehicles are defined as a set of moving networked computer systems with dozens of electronic control units (ECUs), hundreds of sensors and million lines of code [2]. Research investigating the suitability of wireless channels is a significant starting point to them becoming a reality in the near future [3][4]. The benefits of V2V connectivity especially in areas of collision avoidance and congestion management are huge, V2V is becoming a reality and automobile industry is currently working towards standardization.

A number of developed countries are trialling autonomous cars on the roads in the near future. Google's cars have driven 1.2 million miles in USA, with Germany, China and the UK [5], also looking to open trials. Connected vehicles will play a key part in traffic management of autonomous cars. Within the next five years there will be some form of autonomous driving on UK roads. It is therefore important to investigate the best wireless channels in this application so as to fully understand the challenges and be able to address them effectively. This will also help towards the modelling of wireless channels for connected vehicles.

A number of researchers have presented findings both on technique [6] and a network model [7]. Petri nets are proposed in [6] for such time critical distributed communication and control systems. GEMV^2, a geometry-based V2V channel model has been presented in [7], which measures link quality by factoring outlines of vehicles, buildings, and foliage to distinguish between the three types of links; the links are Line of Sight (LOS), Non-LOS due to vehicles and Non-LOS (NLOS) due to static objects. In addition, the link quality is calculated with the large-scale signal variation deterministically and the small scale-signal variation stochastically based on the number and size of surrounding objects. GEMV^2 is freely available to be used by researchers.

The objective of this paper is to identify and present those challenges and opportunities associated with Quality of Service (QoS) in connected vehicles and to identify the modelling direction for Connected Vehicle Network (CVN) by conducting Analysis of Variance (ANOVA) and Principal Component Analysis (PCA) on the factors that impact link quality. Here, we define CVN as the network between V2V and V2x and where the position and /velocity of the vehicle is predicted from the previous vehicle/x. The 'x' in V2x represents vehicle/infrastructure/roadside sensors/anything else deemed suitable. The vision for CVN is that each vehicle on the road will be able to communicate with other vehicles and this set of data and communication

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will support a new generation of active safety applications and systems [8]. Wireless technologies and their potential challenges in providing vehicle-to-x connectivity are presented in [4]. An overview of applications and associated requirements of vehicular networks are presented in [9]. Internet mobility in vehicular scenarios along with their challenges is presented in [10]. With ever increasing connectivity and a vision that migrates towards smart cities, security issues and the challenges such as propriety networks, inter-operability between networks, etc. therein are immense. Work in [11] presents some of the security challenges in vehicular ad hoc networks (VANET), whereas [12] focuses on the four working groups on scientific foundations of vehicular networking and presents their findings. Connected Vehicle Network is modelled using a black-box approach that comprises of vehicles with wireless V2V communication using link length estimator to identify the number of vehicles in the network [13], whereas [14] presented modelling of future state of a vehicle in a platoon based on preceding vehicle position and velocity.

In this paper, we use the data from GEMV^2 to carry out ANOVA and PCA. Doing so, helps us to better understand the QoS relationship between the link quality and the factors that impact it. We chose four factors that impact link quality as LOS, NLOS, number of neighbours per vehicle and the neigh-thresh per vehicle. The parameters are described in Section III.

The work presented in this paper differs from the ones listed above since it provides an in depth analysis on the various wireless channels available for connected vehicles based on our QoS assessment of the GEMV^2 data. Therefore, the contributions of the paper are two-fold:

- to present an overview of wireless channel requirements in connected vehicles.
- to present ANOVA and PCA on GEMV^2 data to understand the impact of line of sight, non line of sight, neighbours and neigh-thresh per vehicle on link quality. This enables us to present our modelling directions for CVN.

The rest of this paper is organized as follows. Section II gives an overview of the connected vehicle channel requirements. Section III describes the QoS assessment on GEMV^2 data, whereas Section IV discusses the research directions for CVN modelling. Conclusions and future work is presented in Section V.

II. CONNECTED VEHICLES CHANNEL REQUIREMENTS: AN OVERVIEW

The concept diagram of connected vehicles is presented in Figure 1, which illustrates V2V and V2x connectivity using various access networks which is in turn connected to the core network. The concept behind Figure 1 is that connected vehicles will be able to communicate with each other and with an intelligent transport system (ITS) using different wireless channels such as Wi-Fi, 4G/LTE, etc. QoS in such application will be critical as vehicles come out of one network into the other especially at handover points. Connected vehicles are the building blocks of emerging Internet of Vehicles (IoV) and Network of Things (NoT) [15], which is defined on five primitives as sensors, aggregator, communication channel, external utility and decision trigger. All vehicles or 'x' will have sensors connected that will be able to transmit/receive 'useful' information. This information is converted by an aggregator, defined as a mathematical function implemented in software that transforms raw data into some 'useful' meaning. This is underpinned by the communication channel, e.g., WiFi, 4G, etc. The external utility can be a software/hardware and will execute processes into the overall workflow of NoT. Finally, the decision trigger creates the final result needed to satisfy the requirements of NoT.

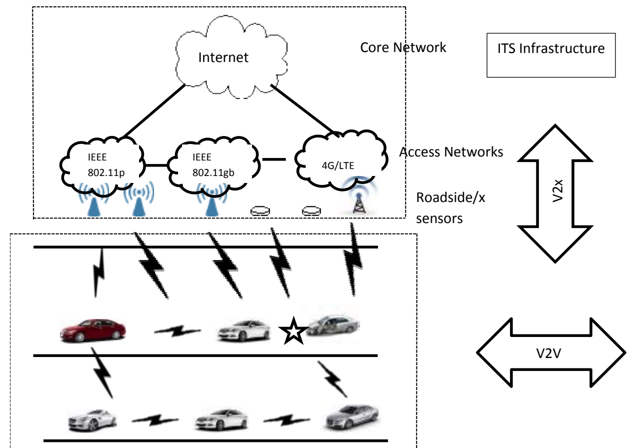

Figure 1. V2V and V2x concept diagram

The ITS reference architecture from [16] has been adapted and is presented in Figure 2. It is a protocol stack inspired from the Open Systems Interconnection (OSI) model and defines three layers as 'access', which will support the wireless access networks/wireless channels, a network & transport layer which supports the routing protocols, data transfer, etc. Above it sits the facilities layer which will support the application/information. Here, we define the position/velocity of the vehicle in this layer. The layers of application, management and security run across both horizontally and vertically and provides cross layer commands and information.

A number of applications ranging from infotainment, for example, media downloading to traffic safety applications, such as driving assistance co-operative awareness impose diverse requirements on supporting vehicular networking technologies. There will be a huge emphasis on inter-networking between the different standards in order to achieve seamless communications. In addition, there are different requirements for inter-vehicle (V2V or V2x) and intra-vehicles networks. Intra-vehicle is defined as all the ECUs within the vehicle communicating to the driver and includes infotainment. Hence, all the wireless channels described in this section may play a role in the connected vehicle application. Therefore, this section provides an overview on the wireless channels available and the connectivity challenges required in a V2V or V2x communication type.

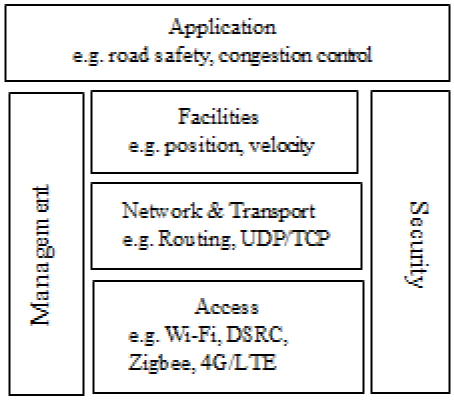

Figure 2. ITS reference traffic structure (adapted from [16])

A. DSRC/Wave

Dedicated short-range communications with wireless access in vehicular environments (DSRC/WAVE) as defined by IEEE 802.11p and IEEE1609 (higher layer standard based on IEEE 802.11p) is a key enabling wireless technology for both V2V and V2R communications. DSRC works in 5.9GHz band with a bandwidth of 75MHz in the US and 30MHz in Europe and an approximate range of 1000m. It is designed for both one way and two way communication. DSRC are not compatible in Europe, Japan and US. Currently, DSRC is the default broadcast communication protocol used. Some limitation of DSRC includes its dedicated spectrum in supporting V2V communication type [17] and lack of QoS support. Key application for DSRC is roadside sensors which transmit information about hazardous conditions, road surface and distance between vehicles and anti-collision information.

B. Zigbee

Zigbee is based on IEEE 802.15.4 specification intended for wireless personal area network applications with low power and cost. Zigbee also has applications in V2R connectivity where the moving vehicle exchanges information with the roadside sensors [18]. The Zigbee enabled roadside sensors then updates traffic status to an intelligent control system seamlessly. It also has application in intra-vehicle networking where a small wireless sensor network is established between the sensors.

C. Visible Light Communication (VLC)

The use of visible light communication (VLC) for V2R communication is proposed in [19]. VLC is defined by IEEE 802.15.7 standard and can support data rate up to 96Mb/s through fast modulation of LED light sources [19]. It is an emerging area of research given the possibility of augmenting existing infrastructure such as traffic lights. However, one key limitation of VLC is any poor weather conditions such as rain and fog could ultimately degrade its communication reliability.

D. Wi-Fi

Wi-Fi standards are based on IEEE 802.11 series, mainly using the 2.4/5GHz band. A number of automobile manufacturers are building new cars with in-built Wi-Fi capability, providing infotainment applications. V2V connectivity could also foster the integration of bicycles and pedestrians into the networks [10] using Wi-Fi. This has a huge potential in improving road safety and reducing the number of accidents as a result of blind spots.

TABLE I. SUMMARY OF WIRELESS CHANNELS FOR V2V AND V2X COMMUNICATION TYPES

Wireless Channels	Advantages	Disadvantages
DSRC/WAVE	Default broadcast network currently used	Limited coverage, (~1000m), QoS not supported
Zigbee	Mesh network, scalable, no need for centralized control	Low and limited data rate, not mature security, limited coverage (10-100m)
VLC	Infrastructure already there, 1-2000m range	Early stages/cost of conversion
Wi-Fi	Widely implemented, 35m indoor and 115m outdoor	Interoperability with other protocols
4G/LTE	Existing infrastructure, several Km range	Interoperability with other protocols

E. 4G/LTE

Long-Term Evolution (LTE) is a standard for high speed communications for mobile phones and data terminals. The standard is developed by 3GPP. The key advantage of LTE-connected cars [4] is having cars connecting directly to the Internet through existing 4G-LTE cellular network. Work in [20] presents a hybrid scheme that can achieve seamless IP communication over mobile Internet access.

F. Summary of CVN Channel Requirements

Table I summarize the various wireless channels, their standard requirements and potential advantages and disadvantages for V2V and V2x. The current industry trends are choosing DSRC and 4G/LTE as the best way to offer connectivity between cars. Many critical applications are linked to safety applications, e.g., air bag control, automatic braking, etc. Inter-operability between these networking standards will be an important milestone. Work presented in [21] concludes that DSRC configuration choice has an impact on safety messages successfully transmitted. In addition, as suggested in [22][23], an upper limit on information provided to the vehicle may be necessary to prevent overloading drivers with information. This poses additional requirements and challenges towards the standardization of wireless channels for vehicle communication. Depending on the communication type e.g., V2V or V2x, all of the wireless channels presented in Table I will be relevant and the CVN modelling has to take that into account.

III. QOS ASSESSMENT IN CONNECTED VEHICLES

This section presents the QoS assessment using Analysis of Variance (ANOVA) and Principal Component Analysis

(PCA) on GEMV^2 data for V2V and V2I. This will help us in understanding the interaction between the four parameters chosen and their impact on the link quality and lay the foundation in establishing the modelling direction for CVN.

A. GEMV^2

GEMV^2 (Geometry-based Efficient Propagation Model for V2V communication) [7] data is freely available and is implemented in MATLAB. GEMV^2 measures large-scale variation calculated deterministically and small-scale signal variation stochastically based on the number and size of the surrounding objects. Both the signal variation is measured in decibels. We use the GEMV^2 data of large-scale and small-scale signal variation under the influence of four different conditions - they are LOS, NLOS, the number of neighbouring vehicles and the neigh-thresh per vehicle. The data is available for both V2V and V2I. The communication channel is IEEE802.11p.

Table II. ANOVA RESULTS FOR MAIN AND INTERACTION EFFECTS FOR V2V & V2I DATA

Source	Sum of Squares	Degree of freedom	Mean Squares	F-statistics	p-value
			V2V		
LOS	23646.7	38	622.283	5.37	0
NLOS	18100	39	464.102	4	0
Neighbours	6377.9	41	155.558	1.34	0.0828
Neigh-thresh	189.3	4	47.321	0.41	0.8028
LOS*NLOS	66.9	1	66.9451	17.73	0.0007
LOS*Neighbours	141	3	47.0094	12.45	0.002
NLOS*Neighbours	24.6	1	24.64.13	6.52	0.0212
Neighbours*Neigh-thresh	34.4	1	34.3572	9.1	0.008
			V2I		
LOS	340.4	7	48.625	2.5	0.0181
NLOS	12669.6	20	633.479	32.63	0
Neighbours	60.3	7	8.614	0.44	0.8733
Neigh-thresh	1248.2	6	208.027	10.72	0
LOS*NLOS	69.4	2	34.71	0.52	0.6244
LOS*Neighbours	0	2	0.017	0	0.9998
NLOS*Neighbours	33	14	2.357	0.04	1
Neighbours*Neigh-Thresh	0	1	0	0	0.9995

LOS links have an unobstructed path between communicating vehicles, whereas NLOS is obstructed by vehicles and buildings. Neighbours is defined as the number of transmitting vehicles in the network and neigh-thresh is defined as the number of neighbouring vehicles whose received power was above the threshold.

B. ANOVA on GEMV^2 Data

ANOVA was carried out on the GEMV^2 dataset. ANOVA is chosen as it enables us to understand the interaction between the four parameters on link quality. Table II presents the results. ANOVA was carried out on large-scale signal variation only for both V2V and V2I as the interaction between parameters was found to be not as significant for small-scale variation.

Tables II shows the results of the ANOVA. The p-value is derived from the cumulative distribution function of F [24] and a small p-value indicates that the link quality is significantly influenced by the corresponding parameter. Between V2V communications, both LOS and NLOS have significant impact on the link quality, whereas between V2I communications, NLOS is slightly more significant than LOS and the Neigh-thresh have a higher impact on link quality. However, for V2V, all four parameters have small p-values indicating that they all in varying degree are significant. However, it is interesting to note that, in V2I, the number of neighbours per vehicle is not that significant. For V2V, the combined interaction between LOS and NLOS and NLOS and Neighbours is most significant. Whereas, for V2I, the combined interactions are less significant compared to the individual. To better understand the interactions, PCA investigation is carried out.

C. PCA on GEMV^2 Data

PCA was chosen as it reduces the dimensionality of the data while retaining as much information as possible. PCA involves calculating the eigenvalues and their corresponding eigenvectors of the covariance or correlation matrix. Covariance matrix is used where the same data has the same set of variables and correlation matrix is used in the case where data has a different set of variables. In this paper, covariance matrix was used because of the same dataset.

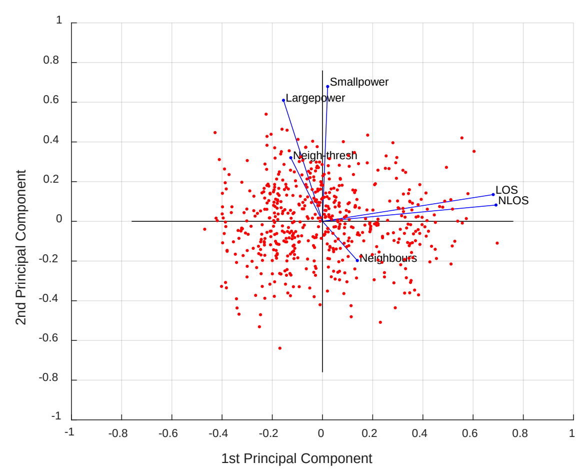

Figure 4a. PCA results for V2V

Figures 4a and 4b show the PCA results for V2V and V2I respectively. In addition to the four factors, both large-scale (Largepower) and small-scale (Smallpower) signal variation is used. The horizontal axis represents the first principal component and the vertical axis the second. Each

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of the parameters is represented by a vector. There are six components in Figures 4a and the first three components account for more than 90% of the variance. Figure 4a shows the first principal component contributes largely to LOS and NLOS.

Figure 4b shows the PCA results for V2I. Similar to Figure 4a, Figure 4b the first three components account for over 80% of the variability. Points on the edge of the plot have the lowest scores for the first principal component.

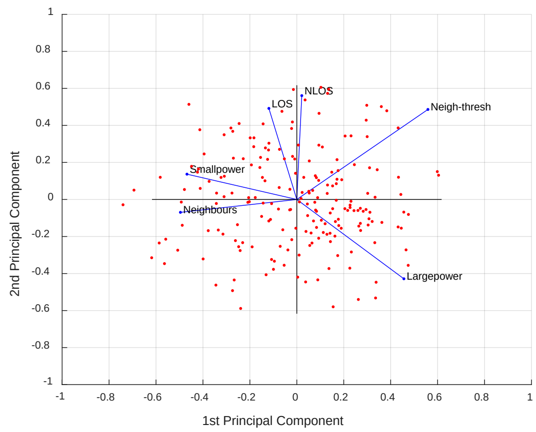

Figure 4b PCA results for V2I

IV. Research Directions for CVN Modelling

QoS assessment will enable us to choose parameters in modelling the CVN. Our small-scale QoS assessment highlighted some of the research challenges and hence potential opportunities for further work are as follows:

(i) Overcoming QoS issues in connected vehicles is fundamental to the successful deployment of V2x connectivity. The QoS can be affected by networking parameters such as bandwidth, delay and latency. In addition, parameters such as the distance between vehicles, road-side sensors and the speed of the vehicle all play a part towards the QoS of the V2x network thus integrating connected vehicles into IoT ecosystems [25]. QoS will be further divided between V2x service reliability for safety related applications where parameters such as time-sensitivity during message transfer, guarantee of message delivery, etc. are highest priorities. While, QoS of on-board applications e.g., infotainment will be lower in priority.

(ii) We also identified that the needs for trade-off between the amount of intelligence sitting with the vehicle for intra-vehicle connectivity and to that controlled remotely via an intelligent control system. Different wireless channels will be suitable for inter-vehicle vs intra-vehicle connectivity. For example, on-board sensors that can sense a motorbike/bicycle within the blind spot of the driver can greatly improve road safety and reduce accidents.

(iii) Prediction of CVN will be based on information centric network paradigm which is independent of location. The CVN will be predicted from the preceding state of the vehicle based on position/velocity.

Figure 5 shows an overview of real time sharing of sensor information between vehicles via cloud or V2Cloud (via DSRC or LTE-direct). It shows various scenarios of connectivity to clouds, ITS, other vehicles, pedestrians, etc. The Society of Automotive Engineers (SAE) has established communication standards for DSRC for connected vehicles (SAE J2735) [26]. This is the first step towards standardizing the CVN communication protocols as most vehicle manufacturers in the near future will be building cars with in-built Wi-Fi capability. An immediate application would be to reduce traffic congestion by relaying an accident/roadworks/incident to re-route traffic thus reducing the overall traffic congestion.

Therefore, the main research questions that emerge from existing literature and our QoS assessment on connected vehicles are:

- What are the QoS issues in V2x networks e.g., what impact(s) would weather conditions have on the QoS?
- What will the network standards for CVN be?
- Will there be different network protocols within CVN e.g., for V2V, V2R, V2I, etc. and what are the interoperability challenges here?
- How does CVN benefit autonomous car evolution?
- How to enhance security in CVN?
- What form(s) of connected vehicles will we see in the next five years on the roads of most developed economies?

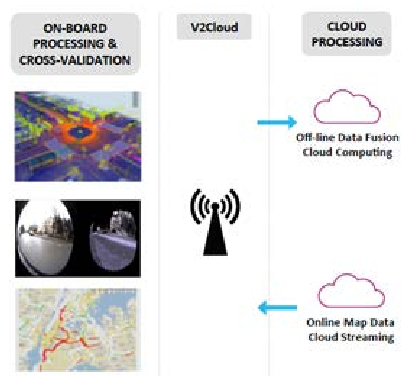

Figure 5. An overview of real-time sensor sharing V2Cloud [2]

V. Conclusions

This paper presents QoS assessment from ANOVA and PCA on the link quality of connected vehicles. We used data from GEMV^2. Our analysis shows that for V2V number of transmitting vehicles in the network (neighbours) has a bigger impact than in V2I on link quality. However, parameters of LOS and NLOS are significant in both types (V2V and V2I). This will help us determine the direction of modelling of the link network for CVN. It further addresses QoS challenges in connected vehicles and presents an overview of the various wireless channels and their applications in connected vehicles scenarios. The key issues identified will help lay the foundation for future research directions in this area. Some of the challenges that need to be addressed by wireless channels in connected vehicles are weather conditions and their impacts, for example how low visibility and extreme weather conditions can impact on the QoS of the connected vehicle. In addition, cameras and ultra-sonic sensors are limited to low distance. The overall reliability of the sensor data within connected vehicle communication is critical. As suggested in [3], for safety management, sensors that can detect fatigue levels of the driver by monitoring various bodily conditions can also be added. The first commercial vehicles to have onboard units installed are expected in summer 2017 from Cadillac [27].

The data information and filters necessary are also investigated, e.g., what is critical, necessary, add-on to process in the vehicle and what data to send/receive to/from the data centre. The challenge is to maintain the QoS of the real-time communication protocol and how to ensure data integrity of the process. With autonomous driving being trialled this year in the UK, what role will connected vehicles play? These are some of the imminent research questions highlighted from our research. Future direction of our research will aim to address the points raised in this paper and focus on modelling the CVN with some form of control.

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