QoS Assessment and Modelling of Connected Vehicle Network within Internet of Vehicles

Asiya Khan and Sanjay Sharma
School of Engineering,
University of Plymouth, Plymouth, PL4 8AA UK
Email: asiya.khan;sanjay.sharma@plymouth.ac.uk

Cindy Goh[1] and Cheng Leong Lim[2]
[1]School of Engineering, Glasgow University,
Glasgow G12 8LT UK
[2]NXP Semiconductors, Singapore 138628
Email:cindy.goh@glasgow.ac.uk;
chengleong.lim@nxp.com

Abstract—**Connected vehicles have huge potential in improving road safety and traffic congestion. The primary aim of this paper is threefold: firstly to present an overview of network models in connected vehicles; secondly to analyze the factors that impact the Quality of Service (QoS) of connected vehicles and thirdly to present initial modelling results on Link QoS. We use the open access Geometry-based Efficient Propagation Model (GEMV^2) data to carry out Analysis of Variance, Principal Component Analysis and Classical Multi-Dimensional scaling on the link quality for vehicle-2-vehicle (V2V) and vehicle-2-infrastucture (V2i) data and found that both line of sight and non-line of sight has a significant impact on the link quality. We further carried out modelling using system identification method of the connected vehicle network (CVN) in terms of Link QoS based on the parameters identified by the QoS assessment. We evaluated the CVN in terms of a step response achieving steady-state within 80 seconds for V2V data and 500 seconds for V2i data. The work presented here will further help in the development of CVN prediction model and control for V2V and vehicle-2-anything connectivity.**

Keywords-QoS; IoV; ANOVA; PCA; CMD; CVN; V2V; V2x;

I. INTRODUCTION

The autonomous car phenomenon is underway in most developed economies. While we are many years away from full autonomy of vehicles, partial autonomy is becoming a reality. Connected vehicles offer huge potential in improving road safety and congestion. Authors in [1] have conducted quality of service (QoS) analysis on connected vehicle network which has been extended in this paper. According to a recent report from the Department of Transport, from October 2015 to September 2016, there was around 183,000 casualties resulting from traffic accidents of which 1,800 were fatal and over 25,000 were life changing [2]. Therefore, the vision is that vehicle-2-anything (V2x) connectivity will reduce this figure by at least 76%. A number of developed countries are trialling fully and semi-autonomous cars on the road. Google's cars have driven 1.2 million miles in USA, with Germany, China and the UK, 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 the roads of UK.

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 [3]. Research investigating the suitability of wireless channels is a significant starting point to them becoming a reality in the near future [4][5]. This will also help towards the modelling of wireless channels for connected vehicles. The benefits of vehicle-2-vehicle (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.

The emerging Internet of Vehicles (IoV) is offering the platform to provide real time exchange of information to realize the opportunity of improving road safety and congestion. It has huge applications in autonomous car revolution, intelligent transportation system and smart city. IoV integrates three networks – an inter-vehicle network, an intra-vehicle network and vehicular mobile Internet. Therefore, IoV integrates these three networks and is defined as "a large-scale distributed system for wireless communication and information exchange between V2x according to agreed communication protocols and data standards" [6].

There are a number of challenges within the IoV network based on the priority of data exchange messages. For example, priority has to be given to safety critical messages, whereas on-board messages related to infotainment will be lower on that scale. The work presented in [7] proposes an abstract network model for IoV based on individual and swarm activities. Petri-nets have been used recently in vehicular authentication [8], modelling and control of vehicular networks [9] and traffic signal analysis in [10]. The work presented in [11] models vehicular networks using spatio-temporal locality and information-centric networks (ICN) are presented in [12] to model the connected networks. Recently, the concept of Network of Things (NoT) with Internet of Things (IoT) has been presented in [13].

A number of researchers have presented findings both on technique [9] and a network model [14]. Petri nets are proposed in [15] for such time critical distributed communication and control systems. GEMV^2, a geometry-based V2V channel model has been presented in [14], 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 aim 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), Principal Component Analysis (PCA) and Classical Multi-Dimensional scaling (CMD) on the factors that impact link QoS. We further apply the concept of NoT to the emerging IoV as presented by NIST [13] and review the connected network models presented in literature identifying the challenges and solutions. Here, we define CVN as the network between V2V and V2x and where the position/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 will support a new generation of active safety applications and systems [15]. Wireless technologies and their potential challenges in providing vehicle-to-x connectivity are presented in [5]. An overview of applications and associated requirements of vehicular networks are presented in [16]. Internet mobility in vehicular scenarios along with their challenges is presented in [17]. 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. The work in [18] presents some of the security challenges in vehicular ad hoc networks (VANET), whereas [19] 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 [20], whereas [21] 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, PCA and CMD. Doing so, helps us to better understand the QoS relationship between the link QoS and the factors that impact it. We chose four factors that impact link quality as Line of Sight (LOS), Non-Line of Sight (NLOS), number of neighbours per vehicle (neighbours) and the number of neighbouring vehicles whose received power was above the threshold (neigh-thresh). Based on the QoS assessment [1], we model the parameters to predict the Link QoS using System Identification method [22]. 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.

The rest of this paper is organized as follows. Section II formulates the problem statement, whereas, Section III gives an overview of the network models for connected vehicles. In Section IV the channel requirements for CVN is presented. Section V describes the QoS assessment on GEMV^2 data, whereas, Section VI presents the modelling of Link QoS. Section VII discusses the research challenges in CVN modelling. Conclusions and future work are presented in Section VIII.

II. PROBLEM STATEMENT

The sheer volume of traffic leads to congestion during (increasing long) peak periods, and high traffic density increases the probability of collision. If each vehicle in the system is a node in a communication system, then drivers can be provided with easier warning of impending issues. This IoV would enable dynamic planning in the event of local constrictions in traffic flows. These systems are equally applicable to drivers and to autonomous vehicles. Successful implementation of such systems should lead to shorter journey times, more efficient use of resources (minimized travel time and fuel use), and avoidance of accidental damage and consequent financial loss and human injury/death. These systems need to be resilient and while communication distances are short in heavy traffic the system should be capable of working to the same QoS in the early hours when traffic is sparse. QoS in this context is the minimum acceptable quality of the connected vehicle network to enable V2V or V2x communication type.

The intelligent transport system (ITS) reference architecture from [23] has been adapted and is presented in Figure 1. 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 application layer supports vehicle operations based on parameters of reliability, security, latency, etc. measured in terms of LOS, NLOS, etc. The layers of application, management and security run across both horizontally and vertically and provides cross layer commands and information.
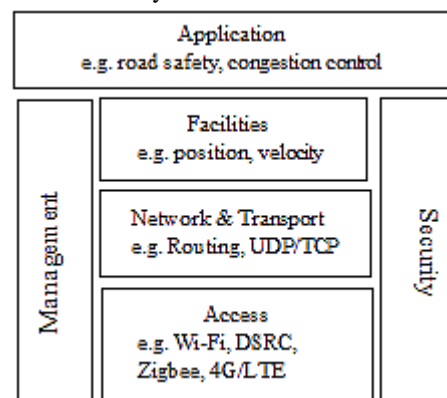

Figure 1. ITS reference traffic structure (adapted from [23])

QoS of this IoV is affected by a number of parameters. These parameters can be divided in access network, facilities and application levels. In the access network layer QoS can be characterized as:

$$QoS = f(PER, delay, jitter, latency, …..)$$

In the facilities level, QoS is given as:

$$QoS = f(Vehicle\ speed, Vehicle\ location)$$

In the application level, QoS is given as:

$$QoS = f(Vehicle\ length, LoS, NLoS, …..)$$

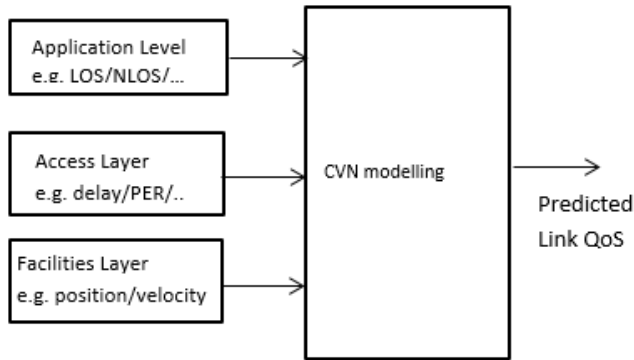Figure 2 shows the overall modelling direction combining parameters from all three layers.

Figure 2. Prediction of Link QoS

Therefore, the contributions of the paper are three-fold:

- to present an overview of network models and wireless channel requirements in connected vehicles.
- to present ANOVA, PCA and CMD 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.
- to present initial modelling results on Link QoS.

III. An Overview of Network Models in CVN

This section presents an application of NoT to IoV and an overview of the two network models [24] presented in literature.

A. *NoT applied to IoV*

The concept diagram of connected vehicles is presented in Figure 3, which illustrates V2V and V2x connectivity using various access networks which is in turn connected to the core network. The concept behind Figure 3 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) [13], 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.
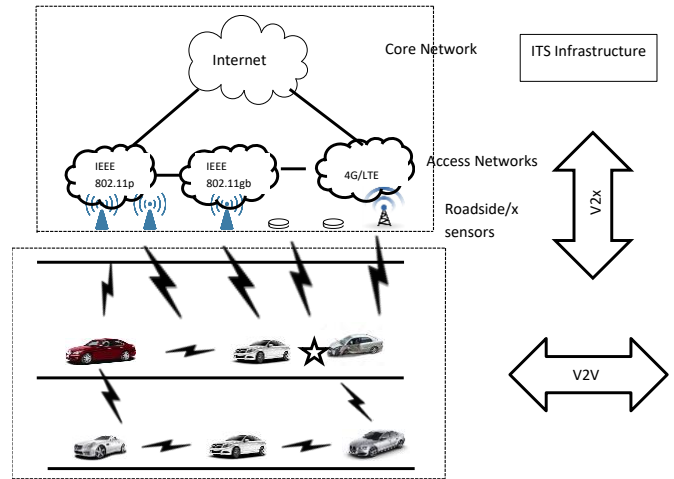

Figure 3. V2V and V2x concept diagram

Within the NoT [13] all vehicles 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. Both Sensor and Aggregator are shown as Roadside sensors in Figure 3. This is underpinned by the communication channel, e.g. WiFi, 4G, etc. Again, Figure 3 shows the wireless channels such as Wi-Fi/4G etc. between V2V and V2x. 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. The External Utility and Decision Trigger is combined together and presented within ITS in Figure 3.

TABLE I.   IoV Primitives

NIST Primitives	Proposed Primitives	Feature
Sensor	Sensing Technologies	Wireless and wired, sensors, RFID,
Aggregate		
Communication Channel	Communication Channel	DSRC/Wave, Zigbee, Bluetooth, Wi-Fi, 4G/LTE
External utilities	Data Processing	Data created by connected vehicles, and how it is processed
Decision Trigger		

Based on these NoT primitives [13], we present three primitives. We combine the primitives of Sensor and Aggregator as just Sensing Technologies, Communication Channel and again combine External Utility (eUtility) and Decision Trigger as one and call it Data Processing as shown in Table I. In Table I, feature describes the potential features for each primitive.

B. Swarm and Individual Network Model

The model presented in [7] integrates human, vehicle, thing and environment. The individual model focuses on one vehicle and the swarm model focuses on multi-user, multi-vehicle, multi-thing and multi-network scenarios. Through swarm intelligence, crowd sensing and sourcing and social computing, IoV can provide services/applications. Factors such as network partitions, route failures, change in channel quality and data rate and network load are addressed using swarm intelligence computing at the service providing stage. This is shown in Figure 4.
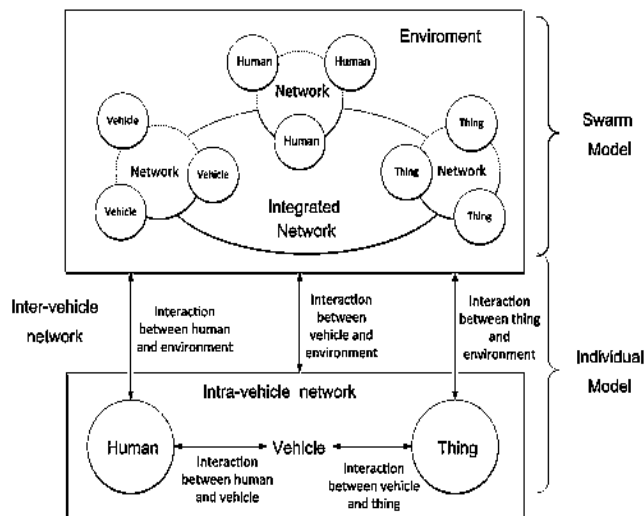

Figure 4. Swarm and Individual Network Model of IoV [7]

Authors in [7] also highlight that understanding the service limits is critical for sustainability, i.e. network resources under diverse high-dimensional data and limited bandwidth of the wireless network.

C. Cloud, Connection and Clients

Three major network elements of IoV are identified in [25] as cloud, connection and client as shown in Figure 5. The 'cloud' infrastructure provides a platform for a range of wireless access technologies. With the magnitude of traffic related information likely to drastically increase, it is ideal to handle the information using cloud computing framework. 'Connection', on the other hand, utilises Third Party Network Inter Operator (TPNIO) to reduce direct Service Level Agreement (SLA) between the operators of the networks, enabling seamless roaming without compromising the quality

and security of network operators. The 'client' element with the help of Wireless Access Technology (WAT) are broadly prioritized and split applications into safety and management oriented and business oriented.

Figure 5. The three network elements of IoV [25]

D. Summary of Network Models for CVN

The challenge for any network model in IoV is to be able to exchange information from V2V and V2x, where x can be a roadside sensor, another device or a person. In addition, there may be incompatibility among devices, different qualities and response time for Internet connections and limited access to data processing and storage. There will be additional complexity where some vehicles will be connected while others not.

Future and emerging vehicle applications will consume a huge amount of sensor data in a collaborative manner. Content centric [26] and information-centric networks [12] will play a key role. Vehicles move fast, therefore, in a content-centric networking style, vehicle position, speed and direction from the rest of the vehicles are continuously sent. Whereas, ICN focusses on what instead of where to fulfil primary demands from both content publishers and consumers. Vehicular-cloud and ICN will contribute to the 'cloud' to produce advance vehicular services, resource sharing and storing. Four categories of services are provided by cloud computing as - Software as a Service (SaaS), Platform as a Service (PaaS), Network as a Service (NaaS) and Infrastructure as a Service (IaaS). SaaS is mainly application working over the Internet, whereas, PaaS provides a platform to build application and services, virtual network are provided by NaaS to the users and IaaS provides computation and storage services. The proposed architecture for ICN – Named Data Networking (NDN) [27] has been extended to vehicular networks where content is found and not hosts or IP addresses.

The revealing of location information has huge concerns in vehicle privacy. In addition, location verification of neighbouring vehicle is also challenging due to the absence of trusted authority in vehicular communication. To capture vehicles in line of sight and away from sight presents yet another challenge due to the impact of moving and static obstacles in the network model. The integration of automotive and information technology will be promoted as a result of IoV. The biggest challenge in IoV implementation is the lack of coordination and communication. This paper aims to address the QoS issues in communication challenge. Some of the challenges identified are:

- Maintaining an accurate line of sight
- Accounting for vehicles/x that are outside the line of sight

- Position/velocity of the vehicle in order to model the dynamic platoon of vehicles
- Vehicles that are not connected
- Security considerations and protection from theft
- Integration of different wireless protocols e.g. DSRC, IEEE 802.11abgn Wi-Fi, 4G/5G cellular networks, VLC
- Device-to-Device (D2D) communication (defined as direct communication between devices in range proximity without the involvement of a network infrastructure) [28] based on LTE
- Safety vs comfort applications
- Integration with cloud architecture
- Big data analysis in IoV
- QoS guarantee – investigate into software defined networking techniques based on the combined information from multiple sources rather than individual

IV. CVN CHANNEL REQUIREMENT

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.

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 [29] 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 [30]. 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 [31]. 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 [29]. 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 [16] 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 II. 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 [32] presents a hybrid scheme that can achieve seamless IP communication over mobile Internet access.

F. Summary of CVN Channel Requirements

Table II summarizes 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. The work presented in [33] concludes that DSRC configuration choice has an impact on safety messages successfully transmitted. In addition, as suggested in [34][35], 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 II will be relevant and the CVN modelling has to take that into account.

V. QoS Assessment in CVN

This section presents the QoS assessment using Analysis of Variance (ANOVA), Principal Component Analysis (PCA) and classical multidimensional scaling (CMD) in MATLAB on GEMV^2 data for V2V and V2I. CMD has been introduced as an extension to the analysis conducted in [1] to further understand and confirm the results of the interactions. 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) [13] 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.

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 III 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.

Table III. 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	24.6413	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

Tables III shows the results of the ANOVA. The p-value is derived from the cumulative distribution function of F [36] 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. The 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, the covariance matrix was used because of the same dataset.
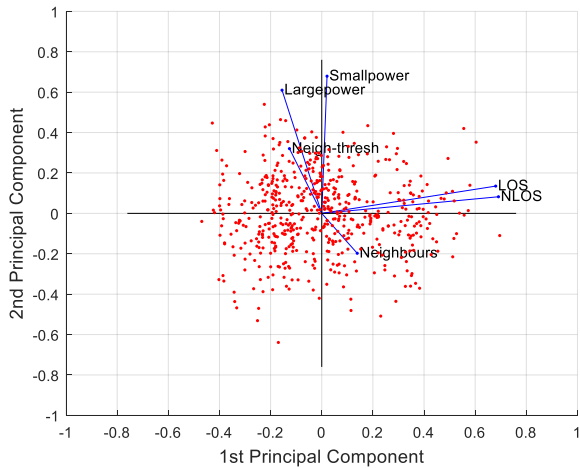

Figure 6a. PCA results for V2V

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 of the parameters is represented by a vector. There are six components in Figures 6a 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 6b. PCA results for V2I

Figure 6b shows the PCA results for V2I. Similar to Figure 6a, Figure 6b 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.

D. CMD on GEMV² Data

Classical multidimensional scaling (CMD) was carried out on the GemV^2 data. CMD takes a matrix of interpoint distances and creates a configuration of points. It allows data to be visualized to get a sense of how near or far points are from each other. Therefore, it offers a way of confirming the results obtained from PCA and ANOVA in terms of the interactions of the chosen parameters. A scatter plot of those points provides a visual representation of the original distances and can produce a representation of data in small number of dimensions.
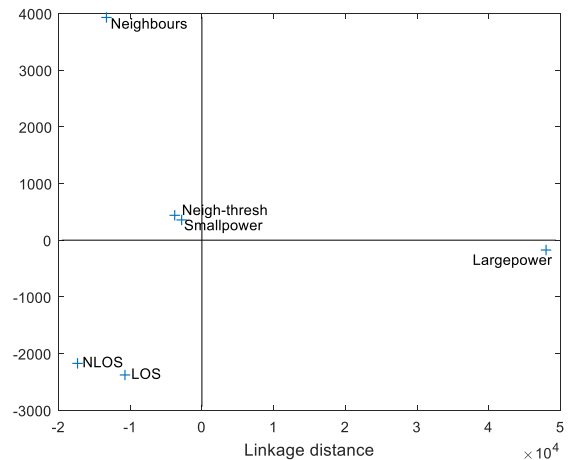

Figure 7a. CMD results for V2V

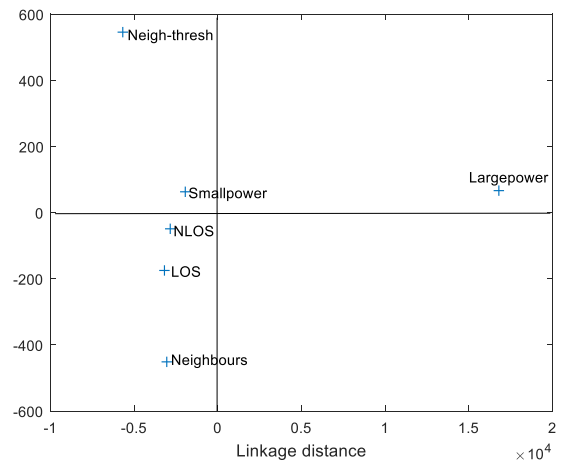Figures 7a and 7b show the CMD plot of V2V and V2I data respectively.

Figure 7b. CMD results for V2I

Comparing Figure Fig 7a to 6a, we get similar results and shows that both LOS and NLOS are closely correlated. Similarly, Figure 7b mirrors Figure 6b and shows close correlation between LOS and NLOS. CMD analysis confirms the results obtained by ANOVA and PCA earlier. The

cophenetic coefficient was 98.76% for V2V and 99.6% for V2I.

VI. CVN MODELLING

We modelled the CVN in terms of the Link Quality with the three QoS parameters – LOS, NLOS and neighbours. Figure 8 shows an overview of CVN modelling. Neigh-thresh was not chosen as it was not found to be significant from the QoS assessment.

In the future, we will extend this to include parameters from each layer, e.g., from the application layer, congestion modelled by number of vehicles, LOS, NLOS. Similarly, the access layer is modelled by parameters such as Packet Error Rate (PER) and delay and the facilities layer contributes the vehicles position and velocity.
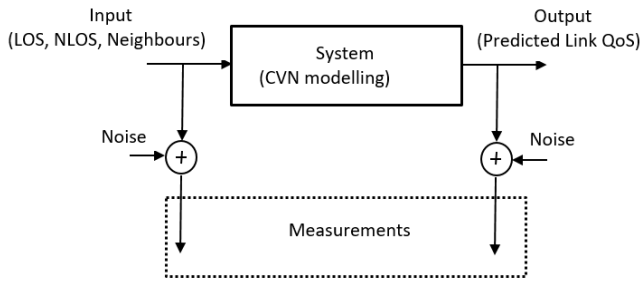

Figure 8. CVN modelling

We used System Identification toolbox in MATLAB on the GEMV^2 data to present the response of V2V and V2i when subjected to a step response. The advantage of this method is that it uses measured data directly to estimate the model. It uses Auto Regressive Exogenous (ARX) models based on the method of least squares to determine the best fit line to the data. The method generalizes to finding the best fit using simple calculus and linear algebra of the form:

$$y = a_1 f_1(x) + \ldots + a_K f_K(x) \qquad (1)$$

Where, $f_1, \ldots, f_k$ are given functions to find values of coefficients $a_1, \ldots, a_K$.

"ARX model structure, in discrete time", is a difference equation with the following form:

$$y(t) + a_1 y(t-1) + \cdots + a_{n_a} y(t-n_a) = b_1 u(t-n_k) + \cdots + b_{n_b} u(t-n_k-n_b+1) + e(t) \qquad (2)$$
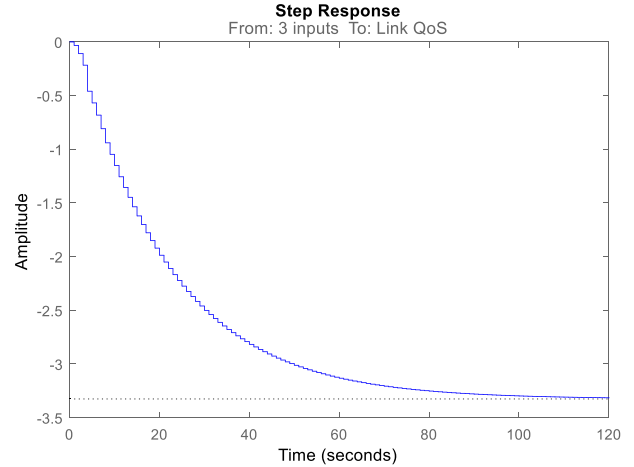

Figure 9a. Step response for V2V data

Where, $y(t)$ it's the output at time t , $u(t)$ is the input at time t, n_a is the number of system poles, n_b is the number of 'b' parameters and 'b' is equal to number of zeros plus 1, n_k is the number of delays in the system. The error function in eq. (2) is given by $e(t)$ and is defined as the white-noise disturbance value and given as noise in Figure 8. The discrete time transfer function can be defined as:

$$H(z) = \frac{Y(z)}{U(z)} = \frac{b_1 z^{-1} + \cdots + b_{n_b} z^{-n_b}}{1 - a_1 z^{-1} - \cdots - a_{n_a} z^{-n_a}} \qquad (3)$$

Figures 9a and 9b show the step response of the 3 inputs on the Link QoS for v2v and v2i data.

The step response in Figure 9a shows that the link QoS has a steady state response (~-3.4) with the three inputs chosen for V2V.
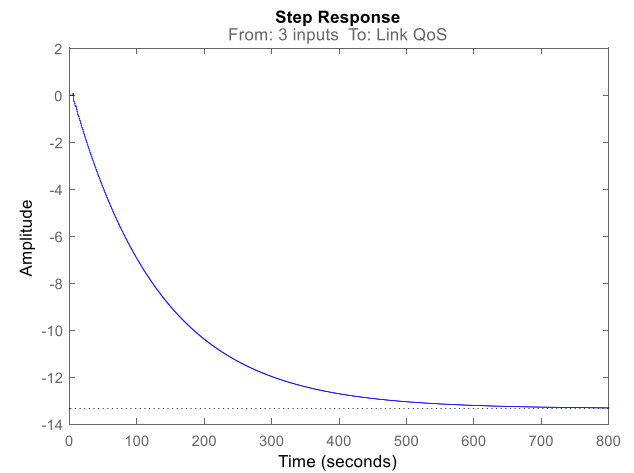

Figure 9b. Step response for V2i data

The step response in Figure 9b shows that the link QoS has a steady state response (~-13.2) with the three inputs chosen for V2i. This enables us to extend our inputs in the future into other layers as shown in Figure 2 to give a better prediction for the CVN model.

VII. RESEARCH CHALLENGES IN 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 [37]. 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.

The Society of Automotive Engineers (SAE) has established communication standards for DSRC for connected vehicles (SAE J2735) [38]. 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.

VIII. CONCLUSIONS

This paper presents QoS assessment and modelling of CVN. QoS assessment was conducted using ANOVA, PCA and CMD on the Link QoS 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 enabled us to model the three parameters of LOS, NLOS and Neighbours on Link QoS and subject it to step response. The step response result shows that the system settles on a steady state. It further addresses QoS

challenges in connected vehicles and presents an overview of the various network models and 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 [39].

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 refining the modelling of CVN with some form of control.

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