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A Predefined Channel Coefficients Library for Vehicle - to - Vehicle Communications

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Abstract - It is noticeable that most of VANETs communications tests are assessed through simulation. In a majority of simulation results, the physical layer is often affected by an apparent lack of realism. Therefore, vehicular channel model has become a critical issue in the field of intelligent transport systems (ITS). To overcome the lack of realism problem, a more robust channel model is needed to reflect the reality. This paper provides an open access, predefined channel coefficients library. The library is based on 2x2 and 4x4 Multiple – Input – Multiple – Output (MIMO) systems in V2V communications, using a spatial channel model extended SCME which will help to reduce the overall simulation time. In addition, it provides a more realistic channel model for V2V communications; considering: over ranges of speeds, distances, multipath signals, sub-path signals, different angle of arrivals, different angle departures, no line of sight and line of sight. An intensive evaluation process has taken place to validate the library and acceptance results are produced. Having an open access predefined library, enables the researcher at relevant communities to test and evaluate several complicated vehicular communications scenarios in a wider manners with less time and efforts.

Keywords—VANETs; V2V; MIMO; Channel Model; SCME; NLOS; LOS; Channel Coefficients; Channel Capacity; CDF.

I. INTRODUCTION

Wireless communications among vehicles, as well as between vehicles and other infrastructure along the roads has been identified as a crucial technology for enhancing road traffic safety [1]. The technology has also been hailed as a fundamental breakthrough in advancing driving comfort and increasing economic and ecological efficiency [2]. Over the recent years, Vehicle-to-Vehicle (V2V) communications have attracted a lot of attention due to their potential in facilitating the implementation of Intelligent Transportation Systems (ITS). V2V is a form of Vehicular Ad-hoc Networks VANETs, which is an automobile technology designed to comprises a wireless communications between vehicles in order to get information about what they are doing. V2V is classified as a WiFi network that uses 5.9GHz of spectrum. The transmission range between vehicles can be reach up to 300 meters or 1000 feet LOS [3]. V2V is most likely to be a mesh network, where vehicles represent the nodes that relays data for the network. A wide range of safety and non-safety applications can be utilised in V2V, these applications with regard to vehicle safety, traffic management, direction of travel, vehicle speed and location base services such as the nearest restaurant, fuel station. These

applications are important to satisfy the driver's requirements. In this regard, various applications have surfaced with an aim of facilitating effective communications between vehicles.

Many current channel models are geared towards the enhancement of road safety and reduce the impact of road traffic on the environment. In the near future, it is expected that the current technology in V2V communications will facilitate the development of vehicle networks that enable the exchange of high rate multimedia data between vehicles [4]. The challenges faced by the conventional V2V communications models represented by signal propagation such as multipath/sub-path fading, the dynamic environments. In addition, most of the obtained results that evaluate the channel performance in V2V are based on simulation, these results hardly reflect the reality of the V2V channel performance [5]. However, to more closely reflect reality, high computational power is needed to determine it during the simulation time, therefore there is a need to an open access predefined library for V2V channel to be calculated offline.

The paper is organized as follows. In Section II, information on channel models utilised in VANETs communications are provided. A modified spatial channel model extended is explained in Section III. Next, a predefined channel coefficients library for V2V communications is provided and discussed in section IV. Evaluating the simulation results are presented in Section V. Finally, Section VI is concludes the paper.

II. CHANNEL MODELLING IN V2V

The development of real-time safety and non-safety applications for use in VANETs, calls for a good understanding of the dynamics that underlie its network topology characteristics. This is mainly due to the fact that these dynamics influence the performance of any given application utilising the VANETs model. Using several key metrics of interest such as neighbour distribution, node degree, link duration, and number of clusters, are important factors in order to obtain appropriate results for VANETs simulations [6]. Considering the research carried out on VANETs; the focus within the design of procedures can be seen to be dependent on simulations because of the preventive deployment cost. The development of a realistic simulation environment for VANETs

is critical in ensuring high performance. Any environment for simulating VANETs needs to be realistic and include a precise representation of vehicle movements and passing of signals among different vehicles. It should also be efficient, considering the needs of a high computational power during the simulation, which consumes a lot of time. To represent the movement of the vehicles in a realistic manner and using a realistic layout; a precise, small movement model and database traffic model is necessary where it is easier to detect the errors and correct them. However, the existing simulation tools cannot simulate the exact physical conditions of the real world, so that results can be unsatisfactory when compared with real world experiments [7]. According to a simulation study conducted by [8], the researchers presented various propagation models that can be used to develop VANETs environment. From an implementation perspective, these models can be either probabilistic or deterministic [8]. This section aims at reviewing some deterministic and probabilistic channel models which are used in VANETs communications.

A- Deterministic Channel Model

Deterministic models facilitates the computation of the received signal strength on the basis of real-time environmental characteristics, such as the distance between a receiver and transmitters. An example of this type of model is the free space model, also known as the Friis model [9]. According to Friis channel model, the received power is dependent only on the transmitted power, distance between sender and receiver, and antenna gain. Thus, as the radio wave moves away from an omnidirectional antenna, power decreases relative to the square of the distance. Ray tracing model [10] is another example of the deterministic model which also accounts for a reflection through the ground in relation to the dielectric properties of the earth, as well as LOS. More accurate predictions at longer range as compared to the free space model can be provided by Ray tracing model. Ray tracing is based on the evaluation of the VANETs topology characteristics over space and time for highway scenario. In order to achieve the objectives, some real-time road topology are utilised, as well as real-time information obtained from the Freeway Performance Measurement System PeMS, and integrate the same into a microscopic mobility model that can be used in generating traffic flow along the highway. However, Ray tracing is often impractical due to the need for a detailed description of the specific propagation environment [11]. An earlier research study by [12] involved a recap of the channel workflows and the physical layer modules of the VANETs models, and a brief survey of the mostly utilised packet and propagation errors frameworks in the network simulators for this specific type of networks. Numerical models were used in the comparison of these propagation models operating with realistic and simple packet error framework. The obtained results [12] suggested that no propagation models are more conservative than others, and that the frameworks are considered conservative based on the capacity of the channel. It is also worth noting that separate propagation frameworks specifically for VANETs, produce outputs that are very close to their intermediate capacities. The

researchers have [13] evaluated the effect of packet error modeling as applied in VANETs. The study was geared towards the measurement of losses, number of hops, and end-to-end delay scenarios. The densities of three different nodes, as well as three channel capacities are considered. The simulation results showed that basic packet error model has the potential to generate similar results as those obtained through a realistic packet error channel model [14], especially when the configuration and design of the former is precisely set at low or medium channel capacities given that stochastic models are not efficient in evaluating the radio communications between vehicles in a simulation environment [15], for this reason a realistic computationally simulation model for IEEE 802.11p in urban environments was developed. On the basis of real-time measurements through the use of IEEE 802.11p/DSRC devices, where they estimate the effects of building and other obstacle influence on radio communications between vehicles. The proposed model considers building geometry and sender/receiver positions, its model relies on building outlines, which are commonly available in modern geodatabases as Open Street Map. In order to keep model computationally inexpensive the idea of [16] is used to consider only the line of sight between sender and receiver.

B- Probabilistic Channel Model

The probabilistic models enable more sensible modeling of radio wave propagation [17]. Essentially, a probabilistic model utilises a deterministic model as part of its output parameters in order to achieve a mean transmission range [18]. Probabilistic (stochastic) model determines the physical characteristics of the vehicular channel in a totally stochastic manner without making presumptions for any underlying geometry [19]. In stochastic modelling technique, the distance-dependent path loss, large-scale and small-scale fading distributions are the major parameters that need to be estimated in the stochastic model [20]. In this technique, the path loss is representative of the local mean received signal power, a relative function of the transmit power is a function of the total distance between the receiver and the transmitter. The surrounding obstacles may include mobile objects such as other vehicles or static objects such as buildings. Most of the modeling activities aim at addressing the additional attenuation brought about by the obstacles, this results in a log-normal distribution around the average received signal power, especially in urban areas. When it comes to vehicle mobility model, the realistic representation of vehicle mobility calls for the use of precise microscopic mobility modeling [21], real-data based traffic demand modeling, and real-world road topology [22]. In an attempt to extend the development of analytical models and the utilisation of hybrid simulations, [23] proposed an analytical model that encompasses distance-dependent losses, as well as small-scale fading and shadowing. In order to achieve this objective, the researcher [23] presented some closed-form expressions of the packet reception probability, packet forwarding in circumstances where there are no simultaneous transmissions. A simplified approach [23] for propagation of the signal

assumes a deterministic attenuation of signal power in relation to the transmission distance. Thus, the packets are received with optimal certainty within the intended communication range, but reception becomes almost impossible at greater distances. In the same context, a study by [24] considered the fair access problem in VANETs and implemented an analytical framework for examining the performance of the Distributed Coordination Function DCF based fair channel access protocol by IEEE 802.11 [25] in a less-saturated state. An association between the probability of transmission and the size of minimum contention window [26] was established together with a relationship between transmission probability and the size of the smallest contention window. Based on [24] analytical framework, the smallest contention window size for a given velocity can easily be established, with the aim of achieving fair access among the different vehicles. In VANETs scenarios, multiple vehicles require access to the same infrastructure concurrently through a single channel, which in most cases causes data collision and the fair access problem. In order to avoid data collision and the fair access problems it is necessary to employ an efficient medium access control MAC protocol to organize the access of the channel to multiple vehicles. Among the most used MAC standards is the IEEE 802.11 standard [25], where it is mainly applied in wireless communications networks. DCF is the primary method of access in the IEEE 802.11 standard [27]. The DCF is a random access mechanism that is based on the Carrier Sense Multiple Access CSMA [28] with collision avoidance. VANETs exhibit unique properties in contrast to the traditional wireless networks. The unique attributes make IEEE 802.11 DCF unable to align the access to the channel in a VANETs efficiently presenting new disputes in the MAC protocol design for VANETs [24]. One problem arising with a VANETs is the fair access problem in which case, vehicles moving at higher speeds are not offered the same opportunity to communicate to the Roadside Side Unite RSU as vehicles travelling at lower speeds [29]. Most existing MAC protocol designs do not take this problem into account. In a comprehensive analysis [30], researchers proposed a new analytical model for highway inter-vehicle communications systems. An unsaturated VANETs cluster was modelled using the Markov chain and the introduction of an idle state [30].

III. DEVELOPING SCME CHANNEL MODEL FOR V2V COMMUNICATIONS

The proposed model in this paper is built upon 3GPP channel model [31]. It mainly follows the approach of a modified version of Spatial Channel Model Extended SCME to be used as V2V channel model. The proposed model takes into consideration both LOS and the No-line-of-sight NLOS conditions. Due to the nature of V2V environment, the values of angle of departure AoD and angle of arrival AoA are set to (180 ± 5) in microcell urban (up to 300 meters LOS and 1km NLOS coverage distance). In order to obtain the estimated channel fading, channel capacity and the power delay for the IEEE 802.11p standard, different speeds are considered at 5.9GHz carrier frequency in different multipath scenarios. The channel model

is constructed under the condition of 2x2 MIMO and 4x4 MIMO systems for different disruptions levels. Figure 1 is a schematic diagram which shows the number of possible multipath and the number of sub-paths clusters associated with the derived SCME mathematical model. The derived mathematical model is utilised in V2V communications to estimate the channel parameters in microcell urban for both cases LOS and NLOS.

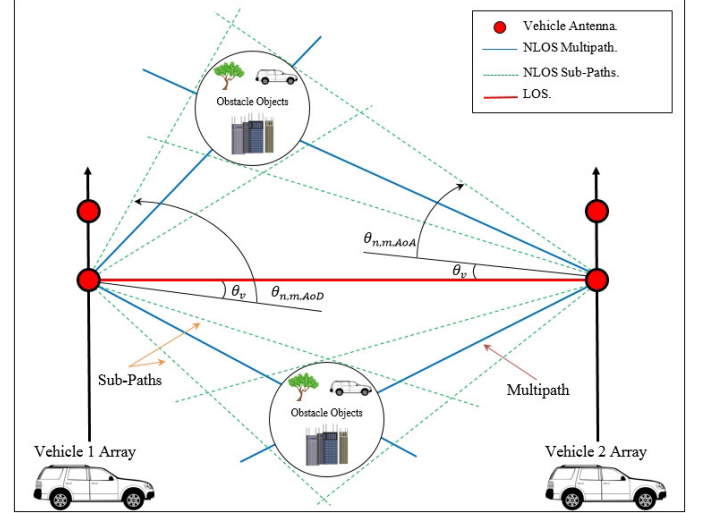


Fig.1. V2V Channel Modelling Approach

A- V2V Mathematical Channel Model for NLOS

Equation (1) is SCME NLOS mathematical model for MIMO systems [32].

$$h_{u,s,n}^{(i)}(t) = \sqrt{\frac{P_n}{M}} \sum_{m=1}^M \left[\sqrt{GV_1} (\theta_{n,n,AoD} \exp[j(kd_s \sin(\theta_{n,n,AoD}) + \Phi_{n,m})]) \times \sqrt{GV_2} (\theta_{n,n,AoA} \exp[j(kd_u \sin(\theta_{n,n,AoA}))]) \times \exp(jkv \cos(\theta_{n,n,AoA} - \theta_v)t) \right] \quad (1)$$

Where,

P_n : is the power of the multipath.

N : is the number of multipath.

M : is the number of sub – paths per path.

S : is the number of the sender antenna element.

R : is the number of the receiver antenna element.

$\Phi_{n,n}$: is the phase of the sub – paths of multipath.

$\theta_{n,m,AoD}$: is the AoD for the sub – paths of multipath.

$\theta_{n,m,AoA}$: is the AoA for the sub – paths of multipath.

GV_1 : is vehicle1 antenna gain of each array element.

GV_2 : is vehicle2 antenna gain of each array element.

j : is the square root of -1 .

k : is the wave number $2\pi/\lambda$.

d_s : is the distance in meters from the sender antenna.

d_u : is the distance in meters from the recipient antenna.

v : is the relative velocity between vehicles.

Equation (2) is showing modified SCME model for the NLOS to be utilise in V2V communications. The modified model is derived from Equation (1).

Gain:

GV_1 and GV_2 are: Vehicle 1 and Vehicle 2 Gains.
 where, $GV_1 = GV_2$.
 $\sqrt{GV_1} \times \sqrt{GV_2} = GV$.

Distance:

In the case of V2V $d_s = d_u$ where $s = u$.

Wavelength:

k is the wave number $= 2\pi/\lambda$
 where, the value of k after the calculation $= 0.1235$.

Angles:

θ_v = angle between vehicles $= \pi$.

$$h_{u,s,n}^{(i)}(t) = \sqrt{\frac{P_n}{M}} \sum_{m=1}^M \left[GV \begin{bmatrix} (\theta_{m,n,AoD})(\theta_{m,n,AoA}) \\ \exp[j(0.1235 d \sin(\theta_{m,n,AoD}) + \Phi_{n,m}) \times \sin(\theta_{m,n,AoA})] \times \\ \exp(-j 0.1235 v \sin(\theta_{m,n,AoA})t) \end{bmatrix} \right] \quad (2)$$

B- V2V Mathematical Channel Model for LOS

Equation (3) is SCME LOS mathematical model for MIMO systems [32].

$$h_{s,u,n=1}^{LOS}(t) = \sqrt{\frac{1}{K+1}} h_{s,u,1}(t) + \sigma_{SF} \sqrt{\frac{K}{K+1}} \left[\frac{\sqrt{GV1}(\theta_{AoD}) \exp(jkd_s \sin(\theta_{AoD})) \times \sqrt{GV2}(\theta_{AoA}) \exp(jkd_u \sin(\theta_{AoA}) + \Phi_{LOS}) \times \exp(jkv \cos(\theta_{AoA} - \theta_v)t)}{\exp(jkv \cos(\theta_{AoA} - \theta_v)t)} \right] \quad (3)$$

Where,

Φ_{LOS} : is the phase of the LOS component.

θ_{AoD} : is the AoD for the LOS component.

θ_{AoA} : is the AoA for the LOS component.

j : is the square root of -1 .

σ_{SF} : is the lognormal shadow fading.

k : is the wave number $2\pi/\lambda$.

K : Number of Links.

Equation (4) is showing modified SCME model for the LOS to be utilise in V2V communications. The modified model is derived from Equation (3).

Gain:

GV_1 and GV_2 are: Vehicle 1 and Vehicle 2 Gains.
 where, $GV_1 = GV_2$.
 $\sqrt{GV_1} \times \sqrt{GV_2} = GV$.

Distance:

In the case of V2V $d_s = d_u$ where $s = u$.

Wavelength:

k is the wave number $= 2\pi/\lambda$.

where, the value of k after the calculation $= 0.1235$

Angles:

θ_v = angle between vehicles $= \pi$.

K is the number of links $= 1$ for V2V case.

$$h_{s,u,n=1}^{LOS}(t) = \frac{h_{s,u,1}(t)}{\sqrt{2}} + \frac{\sigma_{SF}}{\sqrt{2}} \left[\exp[j 0.1235 d (\sin(\theta_{AoD}) + \sin(\theta_{AoA}) + \Phi_{LOS})] \times \exp(-j 0.1235 v \sin(\theta_{AoA})t) \right] \quad (4)$$

IV. CHANNEL COEFFICIENTS LIBRARY FOR V2V COMMUNICATIONS

This paper provides an open access predefined channel coefficients library for V2V-MIMO communications. This library is determined based on Equation (2) and Equation (4) for NLOS and LOS respectively. The channel coefficients in 2x2 MIMO and 4x4 MIMO are formed as $H_{2 \times 2}$ and $H_{4 \times 4}$ matrices and they are varied over the time due to the dynamic environment of V2V-MIMO communications. Each signal path for LOS and NLOS has their own time variant channel coefficients. Specifying Microcell V2V environments over ranges of speeds, distances, multipath signals, different angle of arrivals and departures for LOS and NLOS is a very complex and time consuming process to determine the channel coefficients. Having precise channel model coefficients, a high computational power is needed to be determined during the simulation time, therefore there is a need to provide an open access predefined library for V2V channel to reduce the overall simulation time with a more realistic channel model for V2V which reflects the reality. The open access library for 2x2 MIMO and 4x4 MIMO are structured according to two major parts: LOS and NLOS, each part have 12 different relative vehicle speeds (10-120km/h), four different distances (100,300,500, 1000 meters), up to 18 signal multipath ($N \leq 18$) for NLOS and up to 6 diffused signals for LOS and each signals has up to 20 sub-paths ($M \leq 20$) for both LOS and NLOS, and the channel coefficients sampling time 1 msec (4000 channel coefficients per second for 2x2 MIMO and 16000 channel coefficients per second for 4x4 MIMO), more clarification in Figure 1. The total channel coefficients for 2x2 and 4x4 MIMO in both NLOS and LOS is 73728000, and they are all available online in <http://bit.ly/1ftiU3>.

V. VALIDATION OF V2V CHANNEL MODEL

The channel capacity of MIMO systems could be increased by the factor of the minimum antenna number of senders and receivers. In V2V communications, with such a dynamic environments, many parameters affect V2V signals and having a realistic V2V channel model is challenging. Most of the previous work used a simple idea of V2V channel modeling by converting the Rayleigh fading wireless channel in AWGN-like

channel without factual multipath fading. This paper provides a predefined V2V channel coefficients based on a catastrophic signal fading. The validation focuses on the spectral efficiency of the predefined V2V channel coefficients library. Urban Canyon Microcell scenario is considered to provide this library. NLOS and LOS are considered for distances less than 300 meters, and only NLOS used for distances between 300 to 1000 meters [33]. Up to 18 Multipath for NLOS, while only 6 diffused signals for LOS [33]. In MIMO system, the antenna spacing is one of the major factors which directly effect on the spectral efficiency and the channel capacity communications systems. 0.5λ , 4λ and 10λ antenna spacing are used for evaluation. Cumulative Distribution Function CDF and the transmission rate of R bps/Hz are used to measure the performance of the V2V channel as shown in Figure 2. At SNR=20dB for 2x2 MIMO and 4x4 MIMO, three distances (100,300 and 1000 meters), three speeds (20, 40 and 60 km/h) with three antenna spacing (0.5λ , 4λ and 10λ) are selected. The results in Figure 2 are varied from case to case, due to the urban Canyon Microcell scenarios as mentioned above. However, it's clear from the results, the higher number of antennas in MIMO system the better transmission rate (bps/Hz). Generally, at CDF=0.1, the longer distances between the vehicles the lower transmission rate, and the same observation for the vehicles relative speeds. Figure 2.A shown, at CDF=0.1, the 4x4 MIMO have better rate than 2x2 MIMO, while increase the antenna spacing do not always improve the rate due to the nature of the signal disruptions at a certain time in this particular scenario. This is one of the strong points of this library which is designed to nearly reflect the reality of V2V channel which is time variant characteristics. In Figure 2.I, at CDF=0.1, the 4x4 MIMO have better rate than 2x2 MIMO, the higher antenna spacing improve the rate.

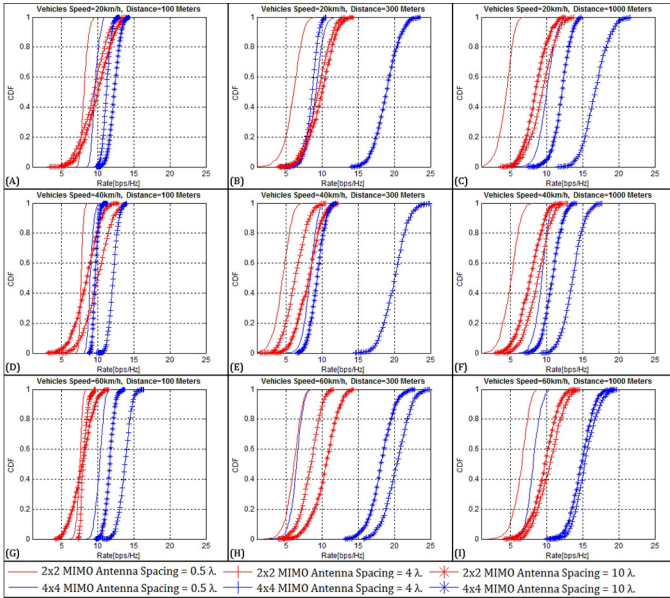


Fig.2. CDF vs. Rate [bps/Hz] for V2V channel in urban canyon microcell scenarios with different 2x2 and 4x4 MIMO with three antenna spacing (0.5λ , 4λ and 10λ)

Transmission rate (bps/Hz) and the signal to noise rate (SNR) are used to measure the performance predefined library as shown in Figure 3. For constituency, same distances, speeds, antenna spacing values and urban canyon microcell scenarios are used to produce the results in Figure 3. However, it's clear from the results, the higher number of antennas in MIMO system the better transmission rate (bps/Hz). Generally, at SNR 20-30 dB, the longer distances between the vehicles the lower transmission rate, and the same observation for the vehicles relative speeds.

Taking into consideration, LOS and NLOS are both employed in 100 and 300 meters distances scenarios while only NLOS is employed in 1000 meters distances scenarios [33]. The antenna spacing is the major key of shaping any MIMO system spectral efficiency, consequently for V2V communications that would be the main factor to achieve an optimum spectral efficiency and transmission rate with minimum cost. It's noticed from Figure 2 and Figure 3. The effect of having wider antenna spacing functions better in the longer vehicles' distances.

The deployed methodology to measure and assess the performance of the predefined V2V channel coefficients library is consistent among all parameters and other variables. Therefore, the results confirm the validity of this library meets the expectations. The results are simulated/produced using MATLAB and the V2V channel coefficient library as well.

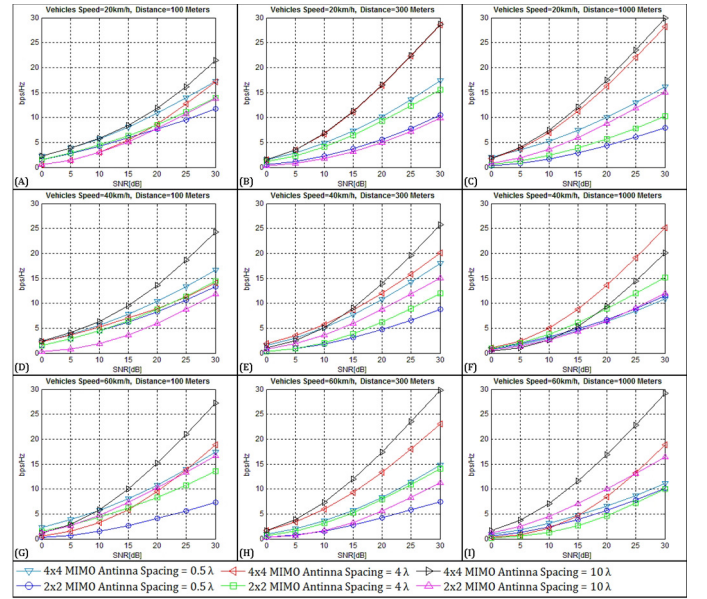


Fig.3. Rate [bps/Hz] vs. SNR [dB] for V2V channel in urban canyon microcell scenarios with different 2x2 and 4x4 MIMO with three antenna spacing (0.5λ , 4λ and 10λ)

VI. CONCLUSION

Almost all vehicular communications simulators use determined random channel coefficients during the simulation time which leads to (a) have a non-realistic channel representation (b) time consuming especially in a large scale scenarios; therefore be necessary to have a predefined library

available for simulators to precede large scale scenarios in large cities with thousands of vehicles would be a very cost effective and more accurate approach. The mathematical model is derived to represent V2V communications channel model to estimate the channel parameters for both LOS and NLOS. Consequently, several distances, speeds, antenna spacing values and urban canyon microcell scenarios are intensively considered to produce and verified this library as well.

Having such open access library, enables the researcher at relevant communities to test and evaluate several vehicular communication scenarios in wider manners with less time and efforts.

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