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Validating the Channel Capacity in V2V Communication based on SCME Channel Model with Turbo-BLAST Coding

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ABSTRACT

This paper presents spatial channel model extended with Turbo- Bell Laboratories Layer Space-Time coding to estimate the channel capacity for a wideband Line-of-Sight Vehicle-to-Vehicle communication environment for different propagation delays. The transmitter and receiver are equipped with massive Multiple-Input and Multiple-Output antenna arrays and different scenarios. Three velocities (20, 60 and 100 km/h) and three distances between vehicles (20, 60 and 100 meters) are considered. Furthermore, the performance of the suggested model is assessed using the Transmission Rate of R bps/Hz and the Cumulative Distribution Function. The simulation tests showed acceptable results that fit the theory results, which indicate that the proposed model could be suitable to be employed as a Vehicle-to-Vehicle channel model.

1. Introduction

Vehicular communication is one of the attractive wireless technologies that aims to improve the driving safety and comfortability during the journey. The employment of Multiple-Input and Multiple-Output (MIMO) systems in Vehicle-to-Vehicle (V2V) communication can useful in different aspects such as the channel capacity and bandwidth efficiency [1]. The V2V channel model with MIMO systems has been extensively examined. However, because of the moving transmitter and receiver as well as the rapidly changing channel characteristics, compared to traditional fixed-to-mobile channels, the basic V2V channels differ significantly. Stated differently, in practical communication circumstances, the V2V channels ought to exhibit non-stationarity and time-variant statistical characteristics [2]. Numerous V2V channel models that take into account the temporal variation non-stationary features have been studied recently. These studies looked at the statistical characteristics of MIMO channels and the V2V model. However, a new investigation method is needed to distinctly show howchanges in velocity affect the channel properties. This can be achieved by the employment of a robust coding technique such the Turbo-Bell Labs Layered Space-Time T-

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BLAST to improve the channel capacity in V2V communication.

The rest of this paper is organized as follows. In Section II, the related work is presented. Section III and IV respectively give a background knowledge about the channel capacity and the BLAST coding. In Section V, the simulation and validation are carried out. Section VI provides the conclusions at the end.

2. Related Work

The growth of wireless communication technologies added crucial challenges to the enhancement and the development of wireless channel models. Numerous research efforts have been done to invent, develop and test the V2V channel models. Some of these tests are reliable as the data provided from these tests are repeatable and are widely agreed upon [3]. This section reviews some of recent and important research that been done on V2V channel models.

The authors in [4] considered the NLoS case to propose a non-stationary V2V channel model. They have employed the Temporal Correlation Function TCF to be derived and analyzed for the proposed model. The derived TCF includes stationary scenarios, constant velocities of terminals, or fixed scatterers. According to the simulation results, using derived TCF has enhanced V2V communication system performance under realistic conditions.

A non-stationary V2V-MIMO practical channel model has been presented in the same context in [5]. The Taylor series expansions is considered to accurately simplify the output phase of Doppler frequency. The authors stated that the new V2V model is suitable for generating the channel coefficient with arbitrary velocities and paths for both transmitter and receiver. In addition, different parameters have been investigated and analyzed for the path delay and power. Additionally, using the Von Mises distribution as a basis, the Temporal Autocorrelation Function (TACF) and Spatial Cross-Correlation Function (SCCF) were obtained along with the Angle of Arrival (AoA) and Angle of Departure (AoD). By contrasting the theoretical, simulated, and measured data, the suggested model was verified.. However, a real-world validation is needed to evaluate the proposed model under realistic scenarios.

In [6], a 3D wideband two-cluster V2V-MIMO channel model have been presented. The authors discussed the distribution of clusters in roadside environments by introducing multiple confocal semi-ellipsoid models. The clusters distribution will give an opportunity to collect the statistical properties for different propagation delays in order to derived and investigate them. Also, the dynamic characteristics of clusters on both the array and time axes have been simulated by adopting the birth-death process. This process is employed to efficiently characterize the non-stationarity of massive MIMO communication systems. In addition, the presented model considered Temporal Auto-correlation Functions ACF of the propagation links for both transmitter receiver. The authors stated that the simulation results demonstrate that the proposed model is suitable for describing real massive MIMO V2V communication environments. However, a real-world validation is needed to evaluate the proposed model under realistic scenarios.

Similarly, a V2V-MIMO channel model for congested curved-street have been presented in [7]. The presented model is built based on the employing of massive MIMO antenna array on both the transmitter and receiver. In addition, 3D spherical antenna arrays are introduced in the model, rather than two-dimensional planar wavefront assumption used in traditional MIMO channel models. Furthermore, different factors have been intended to analyze the proposed model including the closed expressions for the probability density functions of the azimuth angle of departure, the elevation angle of departure, the azimuth angle of arrival, and elevation angle of arrival. Likewise, the authors have followed the proposed approach in [5] to analyze the SCCF corresponding to the single and double bounced scattering propagation paths. The authors showed that the simulation results were consist compared with the previous channel models and better performances in terms of channel correlations.

An estimated wideband geometry-based channel model for V2V communication has been proposed in [8]. The proposed model is designed upon the estimation algorithm of both AoD and AoA. The estimation algorithm is considered to help in the determination of the ellipse scattering region and the V2V channel characteristics for different propagation delays. The authors have also considered derived Spatial Cross-Correlation Functions CCFs to investigate different propagation delays. The simulation results demonstrated that the CCFs of the proposed model are affected by the movement directions of both the transmitter and receiver. Finally, the authors stated that the proposed model is useful to be efficient guidance for providing designing V2V communication systems in future wireless networks.

The issue of presenting an accurate characterisation of the V2V propagation channel has been studied in [9]. The authors claimed that most of the existing proposed V2V channel models tend to only consider the distribution of multipath components in the horizontal dimension, and they have ignored the vertical dimension. So, the results are inconsistent and did not reflect the actual channel. Moreover, the authors have also mentioned that the dynamic clusters of multipath components have not been well-modelled in the existing V2V models. Therefore, they aimed to propose a 3D cluster-based better model for the V2V channel. The main idea was the distribution of multipath component clusters in both horizontal and vertical dimensions. Tow algorithms were considered to extract the multipath components and to identify and track the clusters of dynamic multipath components. The multipath components clusters have been classified into global clusters and scatterer clusters. The characteristics of the LOS and ground reflection cluster components are described by the global-cluster parameters; the characteristics of the various multipath component clusters are reflected by the scatterer-clusters plus inter-cluster parameters; the characteristics of the multipath components within each cluster are reflected by the intra-cluster parameters. The suggested model offers a practical simulation method for assessing V2V communication systems' performance.

The statistical properties of wideband V2V-MIMO scenarios were investigated in [10]. The authors proposed a channel model for different propagation delays. On one hand, the Unitary transformation method was introduced to estimate the propagation delay, and it is considered before the movement of both the transmitter and receiver. On the other hand, the estimation of the real-time angular parameters has been done based on the estimated delay and moving time, directions and velocities of the transmitter and receiver. Besides, the characterize the physical properties of the proposed channel model was estimated using the expressions of the real-time complex channel impulse responses. The authors claimed that the obtained results of the channel characteristics fit the theory results very well. However, these results can be implemented and tested to be validated in real-world scenarios.

The authors in [11] evaluated the performance of the physical layer in V2V communication by utilising the Spatial Channel Model SCM-MIMO as a V2V channel model. The authors claimed that the other existing channel models i.e., Rayleigh / AWGN are general channel models and not specifically designed to represent the V2V channel model. They have considered Vertical Bell Laboratories Layer Space-Time V-BLAST as channel coding. The simulation scenarios covered different parameters such as speed, distance, AoD, AoA, modulation etc. The simulation results showed that the SCM-MIMO with the V-BLAST model can overcome or reduce the propagation issues such as path loss, multipath fading and shadowing loss.

In a similar study, the authors in [12] extended the SCM for V2V communications. The proposed model subdivided the effective scattering objects into three categories of clusters according to the relative position of clusters. Furthermore, they have introduced a birth-death process to model the appearance and disappearance of clusters on both the array and time axes. Moreover, a closed-form expression of channel impulse response (CIR) is derived from an extension of SCM and cluster-based models. Accordingly, the spatial and frequency statistical properties of the reference model are investigated. The simulation results showed that the proposed model is validated and can be effectively used in V2V communication.

3. Channel Capacity

The channel capacity is one of the fundamental results in communication theorem. It defined to be the maximum rate at which information can be transmitted through a channel [13]. According to the fundamental theorem of information theory, an error control code can be created whose likelihood of error is arbitrarily minimal at any rate below channel capacity. Claude Shannon made significant contributions to the mathematical theory of communication that underlies channel capacity in the late 1940s [14]. The idea of mutual information between a channel's input and output provides the basis for this theory. Shannon specifically described channel capacity as the mutual information of the channel that is maximized over all potential input distributions. This mathematical concept was important since it proved Shannon's coding theory and its opposite. The coding theorem demonstrated the existence of a code capable of operating at a data rate near to capacity with a very low probability of error. Contrarily, it was demonstrated that any data rate greater than the available bandwidth could not be attained without a bounding of the error probability from zero. The high data rates Shannon anticipated for telephone channels and his theory that coding may lower error probability without lowering data rate or causing bandwidth expansion were highly groundbreaking at the time.

Understanding the underlying radio propagation channel is necessary to evaluate the effects of actual propagation conditions while creating effective V2V communications systems. The maximum upper limit on the volume of data that may be reliably conveyed through a communication channel is known as channel capacity [15]. As a result, the temporal evolution of this value is an efficient criterion for characterizing vehicular communication networks. Due to its increased transmission quality and capability to transmit larger data rates for wireless communications in multipath situations, the MIMO technology has grown to be the most widely used transmission method in wireless systems. In addition, the importance of channel capacity in V2V communication performance with different MIMO Channels scenarios is demonstrated.

4. The Bell Labs Layered Space-Time

Innovative methods that provide higher spectrum efficiency and channel capacity are required for high-speed data transmission. The Bell Labs Layered Space-Time (BLAST) design, often known as the Diagonal-BLAST (D-BLAST) or Vertical-BLAST (V-BLAST) architecture, implements these requirements by utilizing multiple transmitting and receiving antennas, where the number of receiving antennas is greater than the number of transmitting antennas [6]. The information-carrying signal from a user is divided into parallel sub-streams, and the array of transmitting antennas is employed to simultaneously convey the sub-streams while maintaining a constant total power. In comparison to other multiplexing techniques such as CDMA and OFDM, this design offers extremely high spectral efficiency because each transmitting antenna functions in a co-channel fashion and utilizes the entire channel bandwidth. It is possible to have high bit-rate communications by using spatial diversity to create a robust wireless link between the transmitter and receiver. However, co-antenna interference method CAI is the main cause of channel degradation in the spatial multiplexing. A robust multi-transmit multi-receive antenna system is needed to mitigate the degrading effects of CAI. This is accomplished in D-BLAST by taking advantage of the independent channels that connect the transmitting and receiving antennas. The individual code blocks are distributed along space-time diagonals in this attractive diagonally layered coding system. In an environment with independent Rayleigh scattering, this is the essential characteristic that results in high capacity. However, because it employs a sophisticated coding scheme, D-

BLAST suffers from implementation complexity. Employing a straightforward vector coding scheme such as V-BLAST could overcomes this restriction; but, because it does not take use of transmit diversity, it experiences the issue of error propagation and has a smaller information capacity. Turbo-BLAST (T-BLAST) uses a vector encoder, an inter-sub-stream interleaver, and the identical forward error correction (FEC) code for each sub-stream [17]. Although it doesn't simplify the system design, using the same FEC is not a prerequisite for the system. It is possible to think of FEC codes and space-time interleaving as a way to introduce more receiver variety. The T-BLAST transmitter's design results in an iterative Turbo receiver that can decode the data being delivered simultaneously [18].

5. Simulation Results and Discussion

The validation of the channel capacity for the proposed model focuses on the spectral efficiency in V2V communication. The simulation experiments were built upon the vehicular standard IEEE 802.11p [19]. These experiments considered the Line-of-Sight LoS case for three different distances 20, 60 and 100 meters. In MIMO system, the antenna spacing is one of the major factors which direct effects on the spectral efficiency and the channel capacity communications systems. For this reason, this paper followed the 3rd Generation Partnership Project 3GPP recommendation to match the antenna spacing [20], where, 0.5 λ, 4λ and 10 λ antennas spacing have been chosen for evaluation. Cumulative Distribution Function CDF and the Transmission Rate of R bps/Hz were used to evaluate the performance of the V2V channel for different MIMO scenarios and three velocities (20, 60 and 100 km/h).

The simulation results in Figure (1A-C) shows a notable enhancement in the transmission rate when 0.5λ spacing has been considered. For instance, at CDF=0.3, the higher number of antennas in 2x8, 4x8, 8x8 MIMO systems the better transmission rate (bps/Hz).

Figure (2B) shows 4x4 MIMO scenario. At CDF=0.3, this scenario has a better rate compared to the other scenarios of Figure (2A) and (2C), this is due to the nature of the signal disruptions at a certain time in this particular scenario.

In Figures (2A-C) and (3A-C) respectively, the consideration of both 4λ and10λ spacing have a better performance than 0.5λ spacing in Figure (1 A-C). Generally, the channel capacities in Figures (6 and 9) with 10λ spacing were slightly better than 4λ spacing in Figures (5 and 8) and both are better than 0.5λ spacing as shown in Figures (4 and 7). However, the increase in the number of antennas is closely related to the cost. Therefore, the use of (2-by-x) or (x-by-2) MIMO with 4λ spacing can be chosen as an optimum/cost effective solution which can overcome the issue high disruptions environment in V2V.

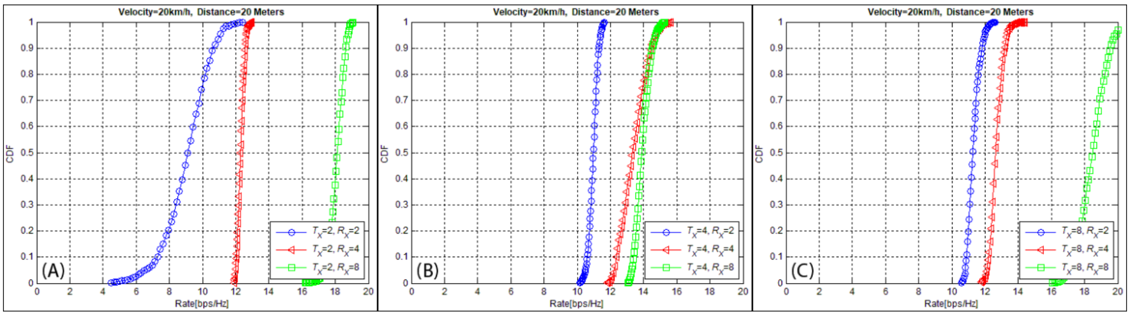

Figure (1 A-C): CDF vs. Rate [bps/Hz], Velocity (20km/h), Distance (20 meters), Spacing 0.5λ
(A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

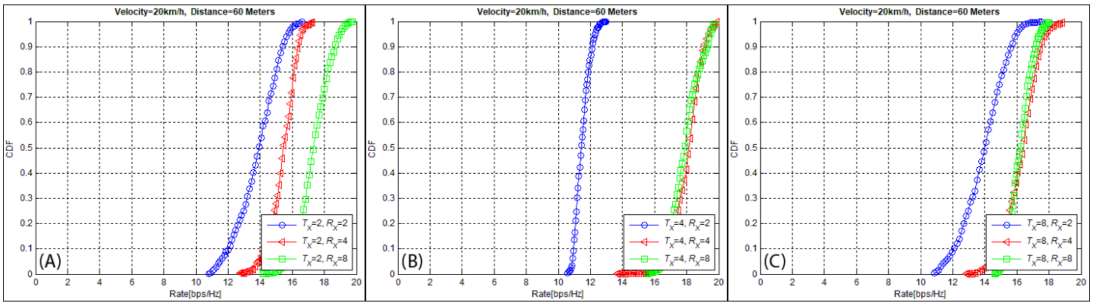

Figure (2 A-C): CDF vs. Rate [bps/Hz], Velocity (20km/h), Distance (60 meters), Spacing 4λ
(A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

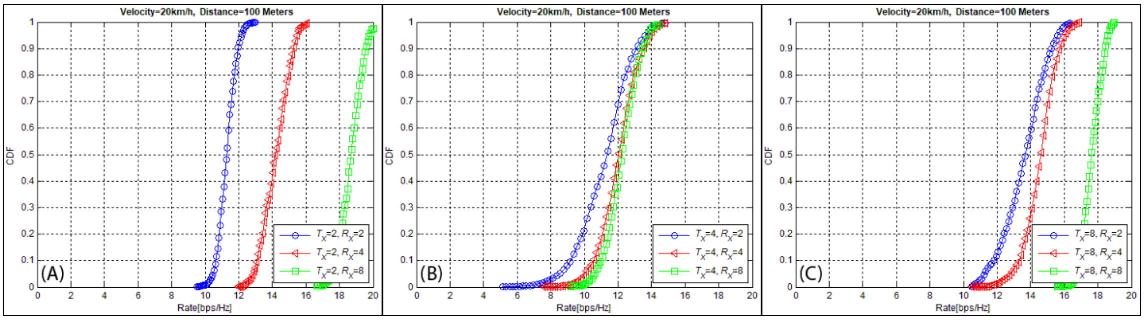

Figure (3 A-C): CDF vs. Rate [bps/Hz], Velocity (20km/h), Distance (100 meters), Spacing 10λ
(A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

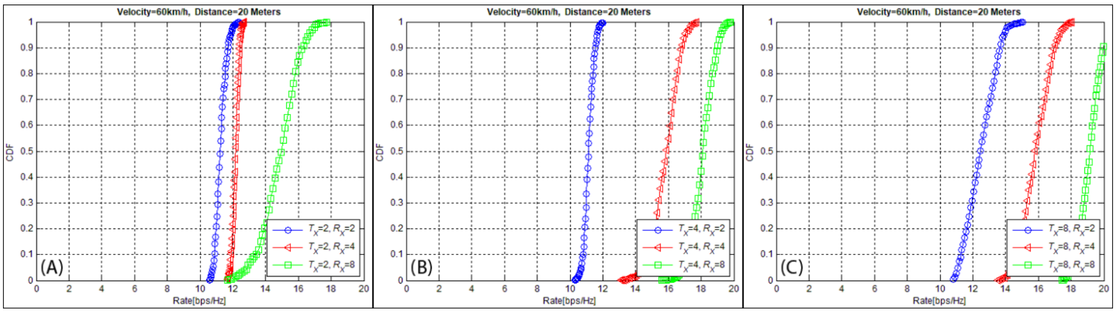

Figure (4 A-C): CDF vs. Rate [bps/Hz], Velocity (60km/h), Distance (20 meters), Spacing 0.5λ
(A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

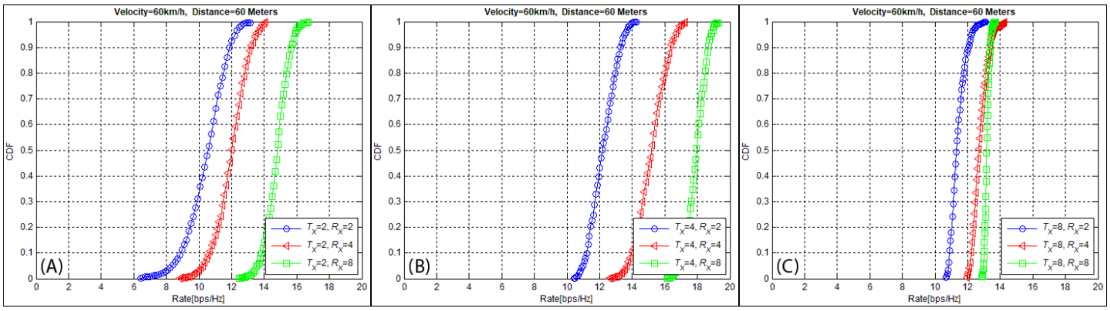

Figure (5 A-C): CDF vs. Rate [bps/Hz], Velocity (60km/h), Distance (60 meters), Spacing 4λ
(A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

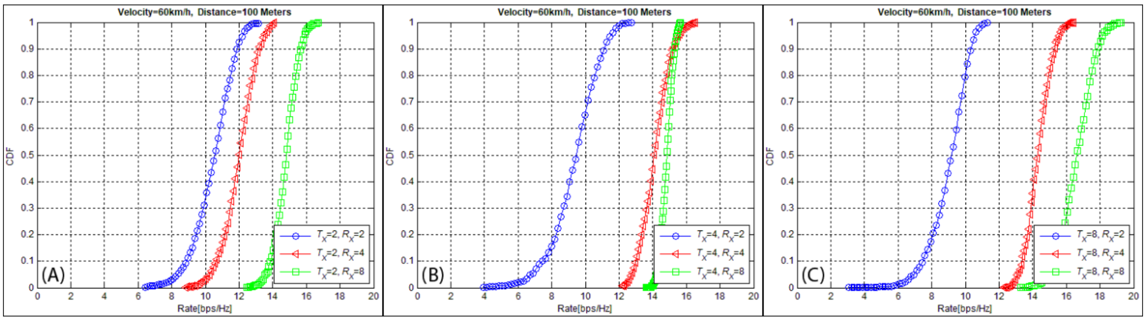

Figure (6 A-C): CDF vs. Rate [bps/Hz], Velocity (60km/h), Distance (100 meters), Spacing 10λ
(A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

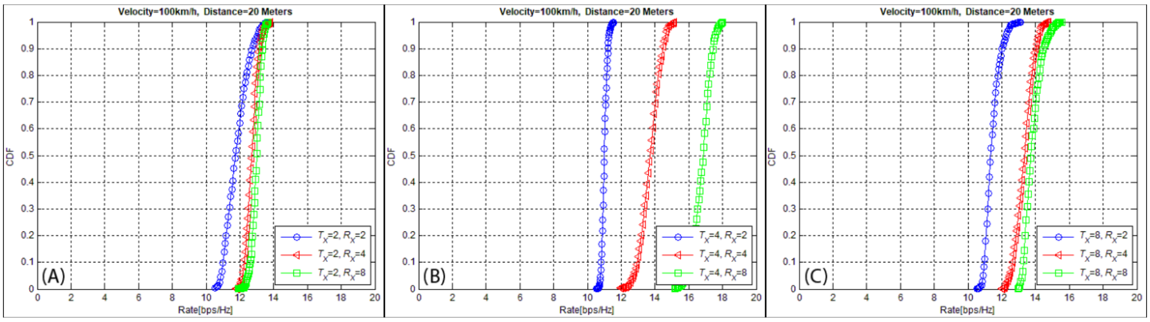

Figure (7 A-C): CDF vs. Rate [bps/Hz], Velocity (100km/h), Distance (20 meters), Spacing 0.5λ
(A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

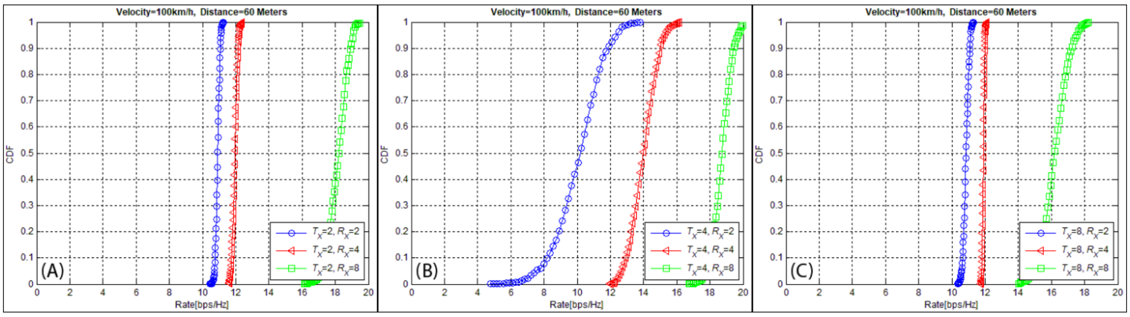

Figure (8 A-C): CDF vs. Rate [bps/Hz], Velocity (100km/h), Distance (60 meters), Spacing 4λ
(A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

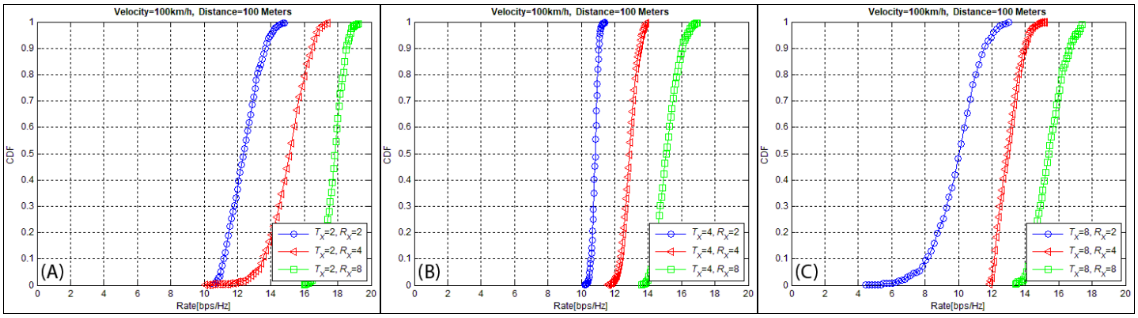

Figure (9 A-C): CDF vs. Rate [bps/Hz], Velocity (100km/h), Distance (100 meters), Spacing 10λ
(A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

Transmission rate (bps/Hz) vs. SNR were used to evaluate the performance of the proposed system as shown in Figures (10, 11, 12, 13, 14, 15, 16, 17 and 18). Same simulation parameters values (distances, speeds, antenna spacing and number of antennas) have been considered to produce the results. However, it can be seen from the results that the higher the number of antennas in MIMO system the better is the transmission rate (bps/Hz). Generally, at SNR 20-30 [dB], the longer the distances between the vehicles the lower is the transmission rate.

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 the results that the effect of having wider antenna spacing functions is better in the longer vehicles’ distances.

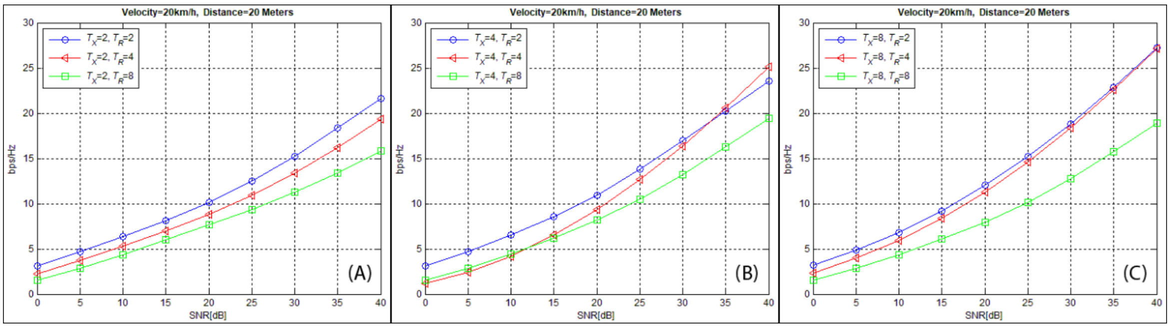

Figure (10 A-C): Rate [bps/Hz] vs. SNR [dB], Velocity (20km/h), Distance (20 meters), Spacing 0.5λ
(A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

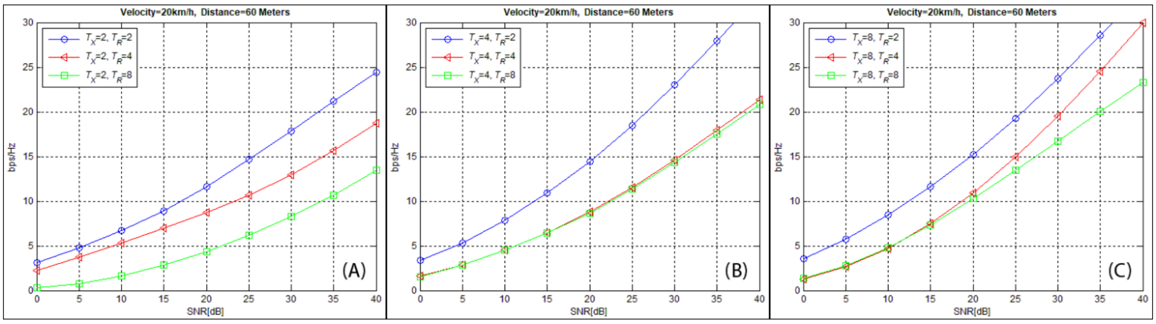

Figure (11 A-C): Rate [bps/Hz] vs. SNR [dB], Velocity (20km/h), Distance (60 meters), Spacing 4λ
(A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

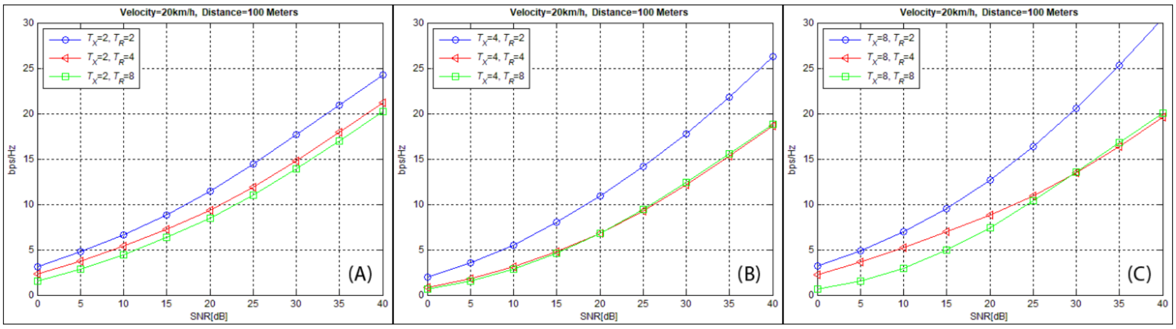

Figure (12 A-C): Rate [bps/Hz] vs. SNR [dB], Velocity (20km/h), Distance (100 meters), Spacing 10λ
(A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

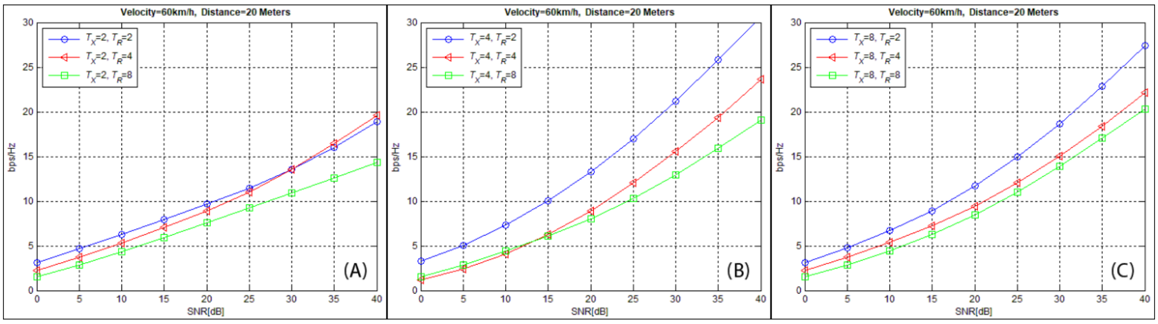

Figure (13 A-C): Rate [bps/Hz] vs. SNR [dB], Velocity (60km/h), Distance (20 meters), Spacing 0.5λ (A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO),(B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

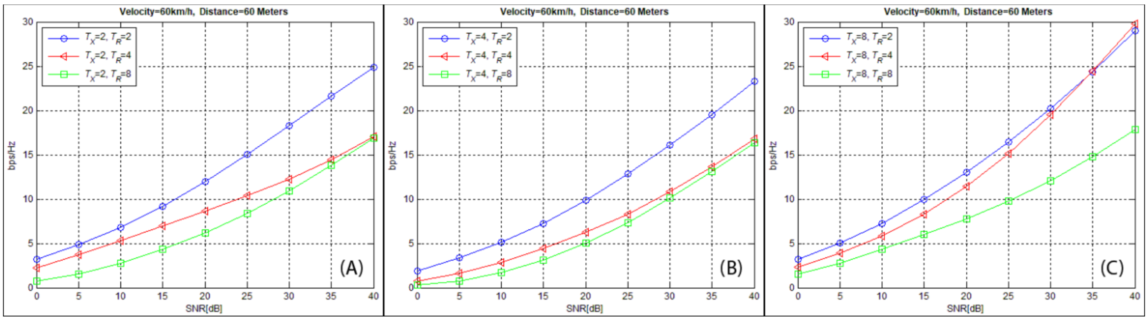

Figure (14 A-C): Rate [bps/Hz] vs. SNR [dB], Velocity (60km/h), Distance (60 meters), Spacing 4λ (A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

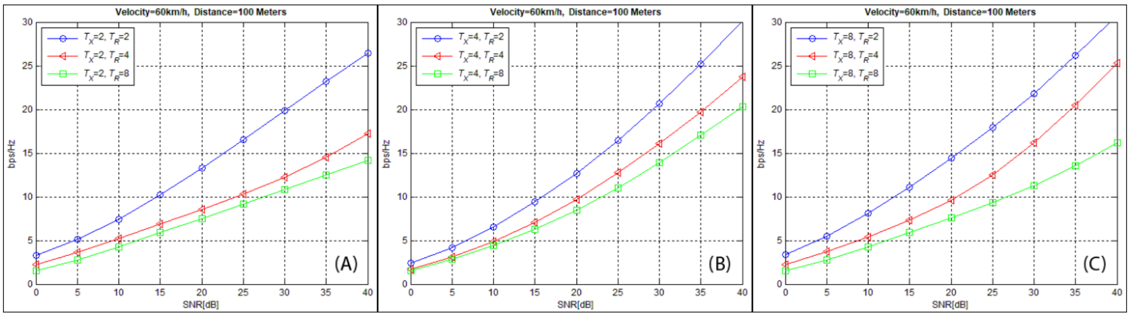

Figure (15 A-C): Rate [bps/Hz] vs. SNR [dB], Velocity (60km/h), Distance (100 meters), Spacing 10λ (A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

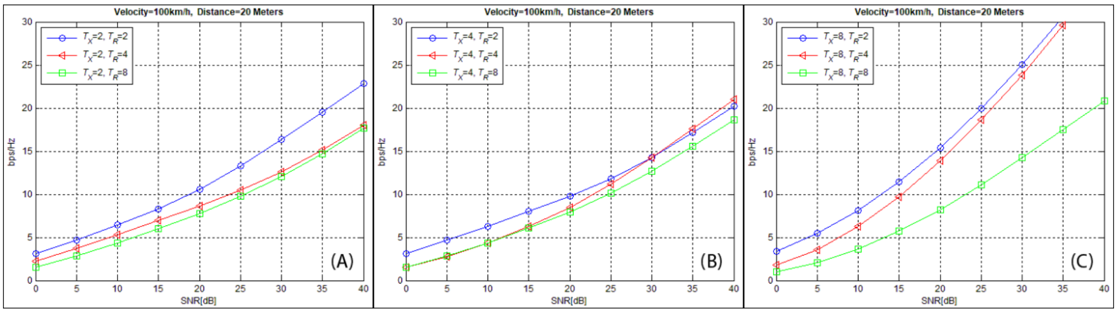

Figure (16 A-C): Rate [bps/Hz] vs. SNR [dB], Velocity (100km/h), Distance (20 meters), Spacing 0.5λ (A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

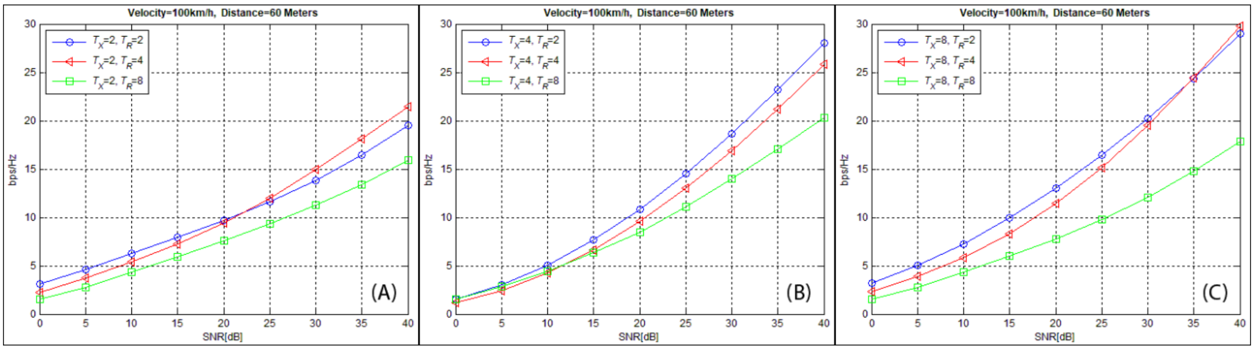

Figure (17 A-C): Rate [bps/Hz] vs. SNR [dB], Velocity (100km/h), Distance (60 meters), Spacing 4λ
(A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

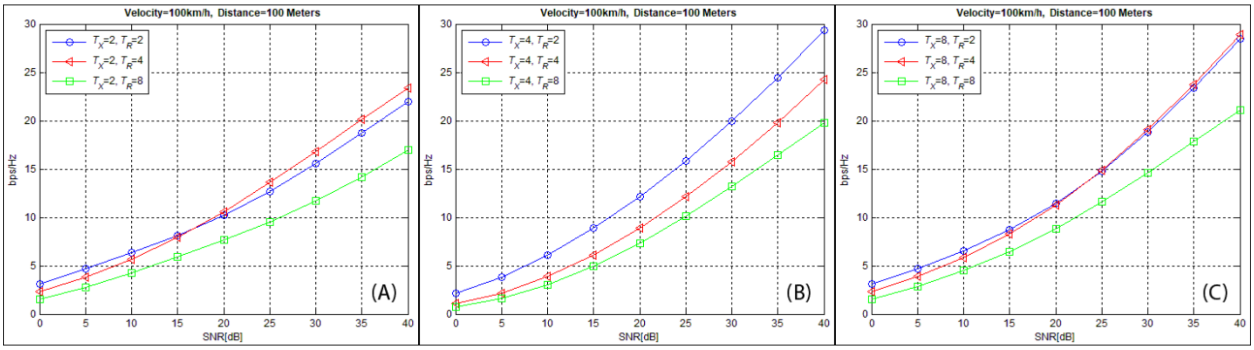

Figure (18 A-C): Rate [bps/Hz] vs. SNR [dB], Velocity (100km/h), Distance (100 meters), Spacing 10λ
(A): (2x2 MIMO, 2x4 MIMO, 2x8 MIMO), (B): (4x2 MIMO, 4x4 MIMO, 4x8 MIMO), (C): (8x2 MIMO, 8x4 MIMO, 8x8 MIMO)

6. Conclusion

This paper validates the channel capacity in V2V communication in different scenarios. The SCME is utilized as a V2V channel model with the employment of T-BLAST as channel coding in the experiments. The simulations are designed upon three different sets of MIMO systems (2x2, 2x4, 2x8), (4x2, 4x4, 4x8) and (8x2, 8x4, 8x8). In addition, three different velocities cases 20, 60 and 100km/h are considered in terms of low, medium and high speeds. Furthermore, the distances are set to be 20, 60 and 100 meters. The CDF and the Transmission Rate of R bps/Hz are used to evaluate the channel performance. In one hand, the simulation results show that the higher number of antennas in 2x8, 4x8, 8x8 MIMO systems the better transmission rate (bps/Hz). In the other hand, 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. Therefore, the use of (2-by-x) or (x-by-2) MIMO with 4λ spacing can be chosen as an ideal cost-effective solution which can overcome the issue high disruptions environment in V2V. However, real-world measurements are required to validate the simulation results and conclusions obtained in this work.

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