Performance of LTE Advanced for Different Releases

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***Abstract*—3GPP employs a parallel "Release" approach that provides developers with a stable base for implementing features at a specific moment and then allows for the addition of new capabilities in successive Releases. 3GPP began work on LTE radio-access technology in November 2004, and the initial LTE standards were finalized in December 2007 as part of 3GPP Release 8. With each consecutive iteration, LTE radio-access technology has progressed in many areas, resulting in improved performance and expanded capabilities. Direct device-to-device (D2D) communication was introduced in Release 12 and was later expanded with device-based relaying functionality in Release 13. V2X (Vehicular-to-Vehicular, Vehicular-to-Infrastructure, Vehicular-to-Network) communication is regarded as a critical new use case for cellular networks. 3GPP Release 14 was the first to deliver LTE upgrades in this area, such as improved QoS and V2V support based on the direct device-to-device functionality introduced in Release 12. The paper's main work is to extend examination of the important components of 5G V2X and V12: throughput and Block Error Rate (BLER). We also go over the use cases, system design, evaluation methodology, and simulation propositions for V12 and 5G V2X. Lastly, we compare V2X and V12 advancements, as well as those in Release 12 and Release 14.**

***Keywords*—vehicular-to-vehicular, 3GPP, throughput**

I. INTRODUCTION

V2X was presented to 3GPP in Release 14 by extending LTE to support the car industry (Fig. 1). Release 14 V2X makes basic traffic safety features possible by exchanging location, speed, and direction messages with adjacent vehicles, infrastructure, and pedestrians. LTE Advanced Pro to LTE Significant advancements have been made since the initial LTE system design, which was published in 2009 and was deemed a pre-4G system. TDD devices can use a variety of uplink-downlink combinations across component carriers in version 12. Release 12 improved carrier aggregation even more by enabling aggregation between FDD and TDD to maximize an operator's overall spectrum use.

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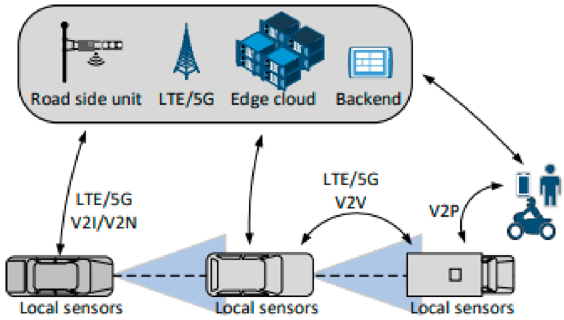

Figure 1. Vehicle-to-everything diagram (V2X).

Chawla and Sharma [1] gave an outline of the essential components that 3GPP considers for LTE-B.

Support for increased local area access, multi-antenna upgrades, improved support for large MTC, and direct device-to-device communications were also provided. Theoretical and simulated BER results for LTE-B are compared to LTE-A based on various features and user counts.

Khan and Bahram *et al.* [2] provided a full review of LTE-advanced CA. According to the literature assessment, as spectrum resources grow scarcer, carrier aggregation will become a critical scheme in future communications systems. The author also presented the fundamental ideas of carrier aggregation and system capacity optimization for LTE-Advanced.

Chen *et al.* [3] presented the C-V2X vision.

In order to highlight the technical transition from LTE-V2X to new radio V2X, the demands of fundamental track safety and improved implementations, as well as the architecture, C-V2X fundamental technologies and standards are introduced. Particularly, the relevant works and advancements are also discussed based on the ongoing and dynamic advancement of C-V2X research, field-testing, and expansion in China.

Karoui *et al.* [4] provided an overview of both technologies by succinctly outlining how they communicate. Then, utilizing a networking and vehicular simulation environment, he compared their performances under various use situations. Results indicate that when there is concurrent LTE data traffic and V2X service, ITS-G5 operates better than LTE-V2X (mode 3).

Sepulcre *et al.* [5] demonstrated C-V2X or LTE-V Mode 4 communication performance. The research gives analytical models for various transmission types of faults that can occur in C-V2X Mode 4 as well as for the average PDR (Packet Delivery Ratio) as a function of transmitter and receiver distance. For a wide variety of transmission characteristics and traffic densities, the models are validated.

Sepulcre *et al.* [6] presented a case based scheduling approach for LTE-V2X Mode 3 that uses the geographical position of the vehicle to dynamically modify its operation such that all cars suffer a similar amount of interference when resources should be divided. DIRAC (adaptive spatial Reuse of radio resources) is an analytically validated scheduling scheme whose performance is evaluated using system level simulations. DIRAC outperforms existing LTE-V2X Mode 3 and Mode 4 scheduling schemes in the evaluation, assuring a network that is more scalable and reliable as channel load and congestion increase.

Bennis *et al.* [7] concentrated on V2I (Vehicle to infrastructure is a communication paradigm that allows automobiles to exchange data with the components that support a country's transportation system. Overhead RFID readers and cameras, traffic signals, lane markings, lighting, signs, and parking meters are examples of such components) and V2V transmission of multilane motorway scenario covered by the LTE-A roadside unit (RSU) network. Furthermore, He investigated increases in the chance of meeting goal throughputs, and performance was assessed using comprehensive system-level simulations. According to the findings, the suggested approach offloads poor-quality V2I connections to more powerful V2V lines, boosting the likelihood of successful transmission from 93% to 99.4%.

Nkenyereye *et al.* [8] defined the concepts used in the literature to assess software-defined-based vehicular network systems based on their modeling and implementation techniques. He began by reviewing the existing literature on C-V2X technology for V2X applications. The different LTE-V2X designs and underlying system models are then presented. The author then went over the key concepts behind software-defined networks and how they apply to V2X services. Finally, he offered a comparison of presenting SDN-based vehicular grid systems, grouped by simulation and modeling approaches.

Martinez *et al.* [9] concentrated on the interconnections between LBT and semi-persistent scheduling (SPS), two methodologies employed by the LTE-V2X Sidelink mode 4 for autonomous resource allocations, and decentralized congestion management (DCC) mechanisms. Strategies to mitigate them are offered. Simulations run under various conditions revealed counterproductive interactions that resulted in performance degradations.

Cecchini *et al.* [10] gave a comparison by referencing the literature and using large-scale simulations in realistic urban and highway environments, as well as attempting to isolate the effect of the physical and media access control layers.

Sevcik *et al.* [11] compared both systems in an urban environment in a V2I communication scenario by using a thorough simulation analysis. He also analyzed the average end-to-end latency and Packet Delivery Ratio (PDR) of the DSRC, LTE-I, and LTE-D2D mode 3 under different communication settings, which are achieved by varying the communication perimeter, message generation frequency, and level of traffic. The outcomes are discussed in relation to the networking and connection needs of the majority of widely used V2I C-ITS services.

Costandoiu and Leba *et al.* [12] provided a brief overview of existing technologies, offered and analyzed the standardization landscape, and he discussed the capacities of standing technologies. He also covered spectrum harmonization plans, as well as the advantages and disadvantages of both old and new V2X technologies, emphasizing the impact of various automobile and industries groups on the evolution and implementation of these V2X communication systems.

Saifuddin *et al.* [13] investigated the applicability of analogous congestion control to C-V2X with a particular focuses on transmission power control. The author includes basic safety messages that are sent on a regular basis as well as top seniority event messages that are sent when an event, such as sever braking, occurs. According to his findings, although power management does not increase packet delivery performance of primary integrity messages, it does improve packet delivery of high priority event communications.

Onishi *et al.* [14] looked into two LTE-based V2X methods: Uu-based LTEV2X, which uses infrastructure, and PC5-based LTE-V2X, and D2D (Fig. 2) communication. Before providing quantitative performance evaluation, the author highlighted the merits and downsides of these two CWA approaches. Despite the fact that PC5-based LTE requires more functions than existing LTE, the findings reveal that it performs substantially better than Uu-based LTE.

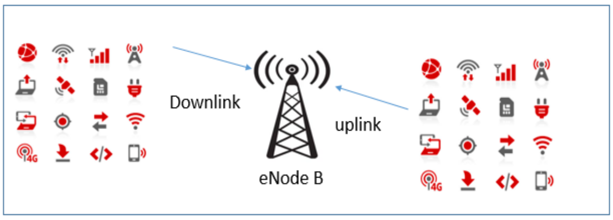

Figure 2. Device-to-device architecture.

Yoon and Kim [15] suggested modifying the rate control function to respond to congestion more laxly so that the power control actively contributes to the overall traffic management. The author noted that the balanced control element discussed in this research should be taken into account during the design phase of any future efforts to establish the standard congestion management algorithm for the C-V2X environment.

In [16], in contrast to traditional, remote cloud-based cellular architecture, Emara and M. Filippou *et al.* proposed that implementing Multi-access Edge

Computing (MEC) infrastructure could drastically reduce E2E communication latency. A detailed simulation-based advantage comparison of the traditional network architecture and the MEC-assisted network architecture supports our contention.

Luoto *et al.* [17] took the potential for using beamforming in LTE-V2X into consideration in this paper. A downlink V2I scenario is constructed with a Singular Value Decomposition (SVD) receiver and precoder, and performance on a multi-lane throughway scenario is simulated and tested. The findings demonstrated that in an ideal situation, the SVD receiver offers gain in matching to the traditional MRC and MMSE receivers. Additionally, matched to the depleted antenna pattern, the performance was improved with customized antenna patterns.

Bera *et al.* [18] constructed an LTE downlink system based on 3GPP specifications, with subcarrier spacing of 15 kHz, and performed a performance study for the MTC scenario. The study is done with two distinct antenna configurations and compared in terms of BER, FER, and QPSK constellation of NPDCCH and NPDSCH.

Software simulations were utilized to assess the various criterion settings in order to determine which options provide the best efficiency and cost trade-offs for creating an LTE network in [19]. The results reveal that data sent in smaller Transport Block Size (TBS) blocks has fewer mistakes than data sent in larger blocks.

This research assesses the LTE network strength in Nigeria's South-West area [20]. Questionnaires were distributed to consumers in these locations. The findings revealed that 9Mobile and MTN have the greatest LTE network quality in South-West Nigeria, and that the LTE network is not yet operational in Osun and Ekiti States.

The LTE system's network architecture is designed to enable packet-switched traffic with seamless mobility and outstanding network quality of service. As a result, the authors of [21] investigated LTE operations, opportunities, and challenges utilizing the LTE system architecture diagram.

Kim *et al.* [22] described a platform for obtaining scheduling information from a long-term evolution (LTE) cellular system without connecting to the network. The author validated the platform's dependability by comparing it to real-world data from mobile phones and service providers. The difference in resource block consumption is about 0.28% on average.

LTE-A used new functionalities to the existing LTE standards in order to offer very high data rate transmission. Carrier aggregation, heterogeneous network enhancement, coordinated multipoint transmission and reception, enhanced multiple input and multiple output, and development relay nodes with universal frequency reuse are some of the most significant characteristics introduced in LTE-A [23]. This review article provides an overview of the LTE-A essential characteristics and functions described above. Based on this assessment, author analyzed the present technological problems for future broadband mobile communication systems in the conclusion.

As seen in earlier references, substantial advancements have been made since the initial LTE system design, which was published in 2009 and was deemed a pre-4G system. LTE Release 10 improved LTE capabilities to meet the International Telecommunication Union's (ITU) 4G system criteria. Using Carrier Aggregation and advanced multi-antenna methods implemented in LTE Release 10, the resulting system, dubbed LTE-Advanced, may deliver peak data speeds of up to 3 Gbps on the downlink and 1.5 Gbps on the uplink. LTE Release 13 improved the LTE-Advanced system by including new features that go beyond 4G and are part of the 5G architecture. LTE Release 13 and 14 are referred to as LTE-Advanced Pro. Performance has already been demonstrated in several literatures [7, 12, 14–17], but none of them have been explained and compared between certain versions that we have studied.

In this paper, we analyze the following simulation parameters: BLER to SNR with varying transport block size, resource blocks, antenna number, signal reference channel estimator, and propagation channel mode such as Doppler frequency.

The major contribution of this paper includes:

1) For version 12, simulation results of throughput under various antenna settings are presented.
2) BLER simulation results for various Doppler frequency values are presented.
3) The simulation results of BLER f for various RB values are shown.
4) The simulated throughput results for two Release 12 and Release 14 at the same SNR setting are shown.

The primary goal of this work was to calculate the throughput given by the LTE standard using various numbers of antennas and Doppler frequencies. The other goal of this work was to assess the performance given by the LTE standard using the block error rate and signal to noise ratio, although there are other critical performance indicators that may be considered. Throughput and message delivery time at different Doppler frequencies, for example, are crucial performance measures. This work can serve as a foundation for additional research into such areas. Finally, this research will help researchers understand the major features of V2X, V2V, and V2I in order to apply them in many domains such as agriculture, smart cities, and other sectors with IOT applications.

The paper is organized as follow: Part II covers the general aspects of V2X and V12 applications. Part III presents assessment and results of simulations, as well as a diagrammatic comparison of several LTE Releases utilizing different parameters. Part IV shows the conclusion.

II. General Aspects of V2X and V12 Applications

Starting in 2008, LTE, or fourth generation mobile network, was defined by 3GPP Rel-8 with a higher peak data rate, enhanced support for Quality of Service (QoS), and enhanced support for cell edge employers. The next is a brief overview of 3GPP releases related to the V12 and V2X applications:

- LTE D2D Rel-12: A number of new features, including Device to Device (D2D) communication, were added to LTE-advanced (Rel-12). A Cat 0 UE was specified in 3 GPP Release 12 with the main goal of reducing device complexity to be comparable to a GSM/GPRS mobile station (user device). It offers simplifications such as letting the device to operate with only one RX chain, allowing half-duplex operation, and lowering the peak rate for both the uplink and downlink to 1Mbps. This category will have very limited commercial availability.
- LTE-V2X Rel-14: In Rel-14, The first LTE V2X communication was investigated and standardized. For D2D communication in LTE, four resource allocation modes were examined, two of which were designed for V2X applications (mode 3 and 4). Broadcast communication was the sole cast type supported by LTE-V2X. LTE-V2X supported all coverage scenarios (in-coverage, out-of-coverage, and partial coverage). The primary goal of LTE-V2X was to provide use cases for providing road safety while meeting stringent accuracy and latency criteria. Fig. 1 depicts the chronology of 3GPP Releases from 12 to 16.

III. Simulation and Analysis

Significant advancements have been made since the initial LTE system design, which was published in 2009 and was deemed a pre-4G system. LTE Release 10 improved LTE capabilities to meet the International Telecommunication Union's (ITU) 4G system criteria. The resultant LTE-Advanced system may deliver peak data speeds of up to 3 Gbps on the downlink and 1.5 Gbps on the uplink thanks to Carrier Aggregation and better multi-antenna methods implemented in LTE Release 10. LTE Release 13 improved the LTE-Advanced system by including new features that go beyond 4G and are part of the 5G architecture. LTE Release 13 and 14 are referred to as LTE-Advanced Pro. Fig. 3 compares the many stages of development.

The following is the paper simulation architecture and scenario (Fig. 4).

3GPP Release 12 included LTE V2X (vehicle-to-everything) capability to allow linked vehicular services, with the goal of enabling safer, cleaner, quicker, and more efficient transportation.

V2X supports a variety of modes of operation, including vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-pedestrian (V2P) direct communication that does not require network participation for scheduling. Some of the advantages of V2X over the Release 12 device-to-device sidelink are as follows:

- Requirements for low latency and good dependability
- Due to the high relative speeds, there is a significant Doppler shift.
- A huge number of nodes and a high density of nodes
- synchronization difficulties, particularly when out of coverage

The following procedures are conducted for the throughput and BLER computation on a subframe by subframe basis for each SNR point:

- To build the baseband waveform to broadcast, a resource grid populated with PSCCH and/or PSSCH is formed and OFDM modulated.
- This waveform is sent into a noisy fading channel.
- Receiver operations are carried out (SC-FDMA demodulation, channel estimation, and equalization).
- The block CRC is obtained by decoding the equalized symbols.
- The performance of the PSCCH and/or PSSCH is governed by the block CRC result at the channel decoder's output.

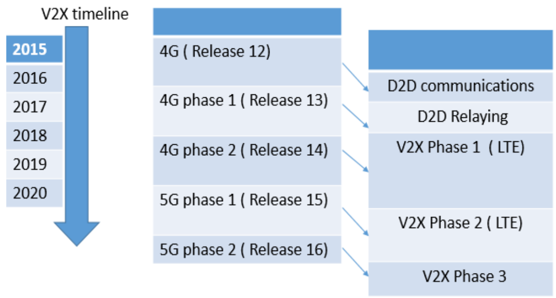

Figure 3. History of 3GPP relasese.

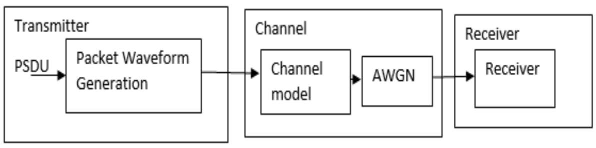

Figure 4. Packet error rate and SNR simulations.

The transport block size (TBS) regulates how many bits are sent from the MAC layer to the Physical layer each Transmission Time Interval (TTI), (defined as 1ms). Because TBS is influenced by modulation, bandwidth, and assigned RB, we can calculate the maximum TBS on V2X transmission. As seen in Fig. 5, for a given number of TBS to be broadcasted by the PSCCH, a smaller number results in improved BLER performance. To be more precise for low number of TBS situations, the conventional 10% BLER's signal-to-noise ratio (SNR) may be greatly lowered, resulting in dramatically enhanced performance. As seen in Fig. 6, for a specific amount of TBS broadcast by the PSCCH, a smaller number results in higher throughput performance. To be more precise for low number of TBS situations, the throughput can be significantly increased at which we have 50 % than others, leading to much improved performance. An RB is made up of 12 consecutive subcarriers with the same SCS; hence, the bandwidth of an RB is determined by the SCS value of each subcarrier. We can observe from Fig. 7 that, for a resource block to be used in the PSCCH, a specified number leads to improved throughput performance. To be more precise when RB is equal to 30, the throughput can be significantly increased at which we have 50 % than others, when the SNR is more than 0 dB. Table I displays the simulation parameters.

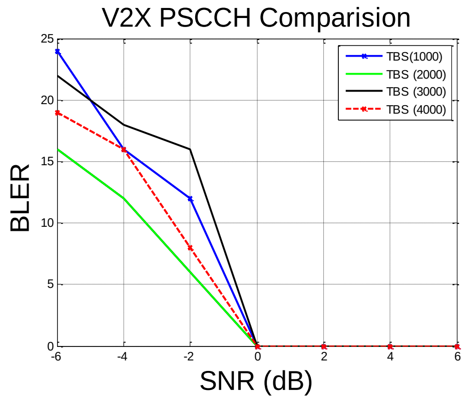

Figure 5. BLER with different numbers of TBS. The unit of horizontal axis is dB.

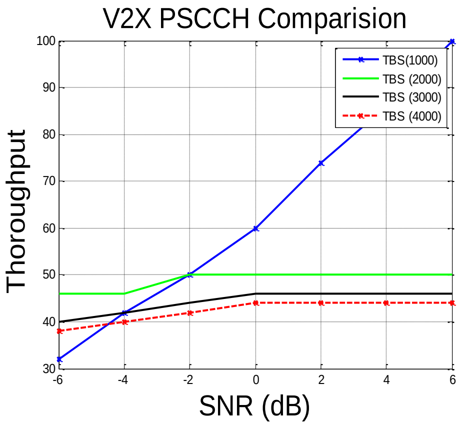

Figure 6. Throughput with different numbers of TBS. The unit of horizontal axis is dB.

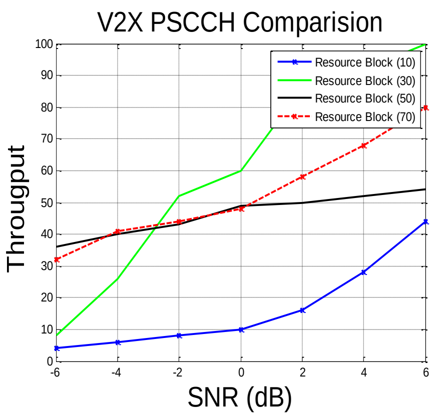

Figure 7. Throughput with different numbers of RBs. The unit of horizontal axis is dB.

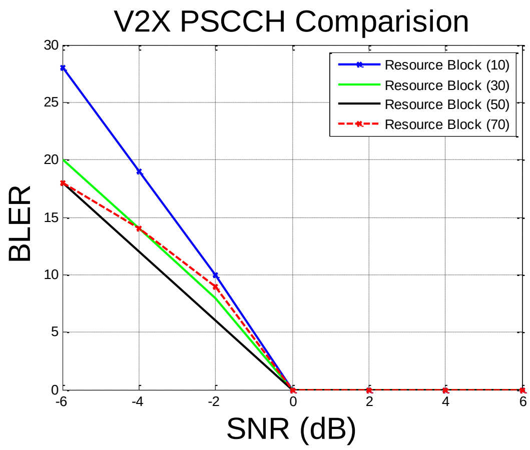

Figure 8. BLER with different numbers of RBs. The unit of horizontal axis is dB.

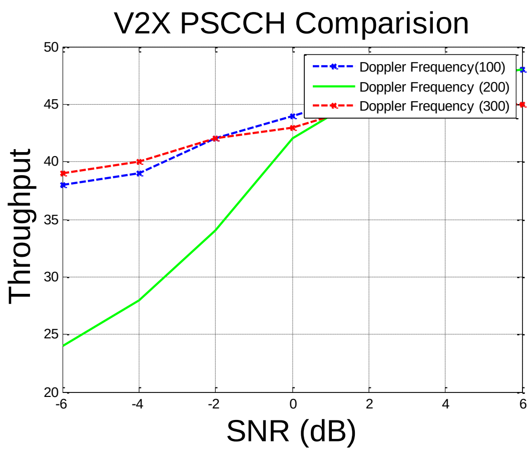

Figure 9. Throughput with different numbers of values of Doppler frequencies. The unit of horizontal axis is dB.

In Fig. 8, the simulation results of BLER f under different values of RBs are supplied, we can see from the graph that, the impact of changing of RBs becomes very limited when SNRs are large (more than 0 dB), and the impact of RBs becomes very high when the SNRs are small (less than 0 dB). To be more precisely, BLER is around 28 when the value of RB is 10 and around 17 when the RB is 70. In Fig. 9, the simulation results of Throughput under different values of Doppler frequencies are provided, we can see from the figure that the impact of changing of Doppler frequency becomes very limited when SNRs are small (less than 0 dB), and the impact of Doppler frequency becomes very high when the SNRs are large (more than 0 dB). To be more precisely, the throughput is around 24 when the value of SNR is -6 dB (worse case at Doppler frequency 200 Hz) and around 38 when the Doppler frequency 300 Hz (best case). In Fig. 10, the simulation results of BLER under different values of Doppler frequencies are provided, we can see from the graph that, the impact of changing of Doppler frequency becomes very large when SNRs are small (less than 0 dB), and the impact of Doppler frequency becomes very limited when the SNRs are large (more than 0 dB). To be more precisely, the BLER is around 23 when the value of SNR is -6 dB (best case at Doppler frequency 300 Hz) and around 38 when the Doppler frequency 200 Hz (worse case). The MIMO method is only restricted to 2x2 up to 2 layers in Release 16 side link transmissions. Because it is possible to place additional antennas on a car, MIMO systems with more layers are expected to be released in the future to boost data speeds. In Fig. 11, the simulation results of throughput under different values of antennas are supplied, we can see from the graph that the impact of changing of antennas becomes very large when SNRs are large (more than 0 dB). To be more precisely, the throughputs are around 100, 60, and 30 at zero dB for one antenna, two antenna and third antenna, respectively. This means that the achievement performance with three antennas is more than 1.8 with two antennas and greater than 3.3 with one antenna.

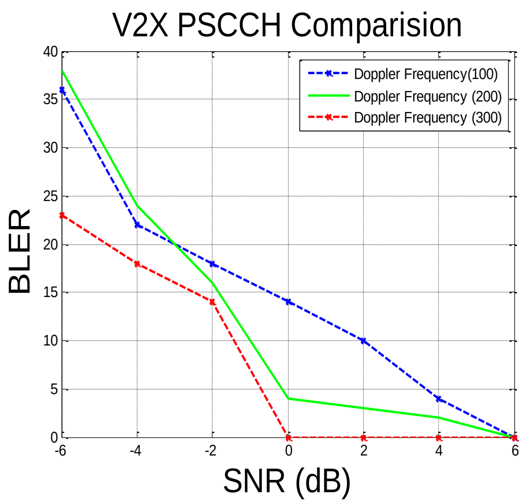

Figure 10. BLER with different values of Doppler frequencies. The unit of horizontal axis is dB.

In Fig. 12, the simulation results of throughput under different values of antennas are provided for release 12, we can observe from the figure that the impact of changing of antennas relatively small. To be more precisely, the throughput in release 14 is much higher than in release 12 at the same value of SNR, for example in our simulation the throughput for release 14 at 0 SNR and two antennas is 60, while release 12 is 1.5.

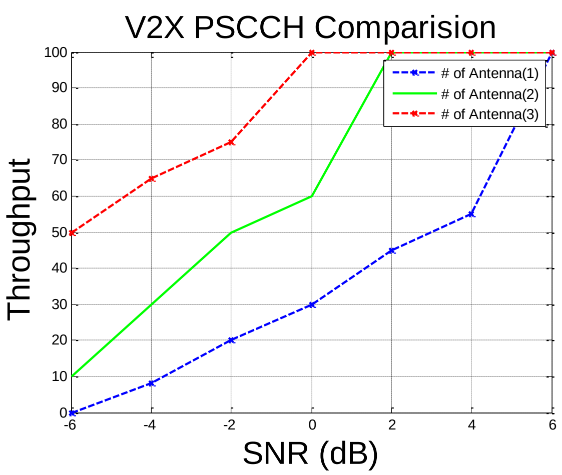

Figure 11. Throughput with different values of antennas (MIMO). The unit of horizontal axis is dB.

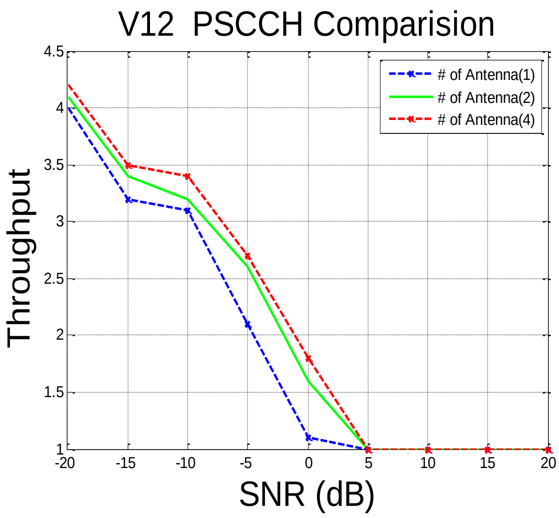

Figure 12. Throughput with different values of antennas (MIMO). The unit of horizontal axis is dB.

TABLE I. SIMULATION PARAMETER

Parameter	Configuration
Number of antenna	2 T_X, 2 R_X
Number of allocated resource block (NPRB)	10
Transport block size (TBS)	872
Bandwidth	10 MHz
Doppler frequency	500 Hz
Symbol modulation	QPSK
Frequency window size	27
Duplex mode	FDD
Type of noise	AWGN

A. Comparison of LTE V2X and V12:

LTE Direct is a fresh new air interface for device-to-device identification and communication introduced in 3GPP Release 12. LTE Direct offers D2D services operated by operators by exploiting existing LTE Advanced infrastructure and spectrum.

Release 12 laid the groundwork for 3GPP's new technology, which enables D2D discovery of 1000s of devices/services in around a kilometer. This enables new proximity services. R12 also introduced one-to-many D2D communications for public safety applications. Release 14 laid the groundwork for another critical emphasis area for LTE Direct by extending to new use cases, one of which being vehicle-to-vehicle and vehicle-to-infrastructure communications to improve road safety and reduce congestion.

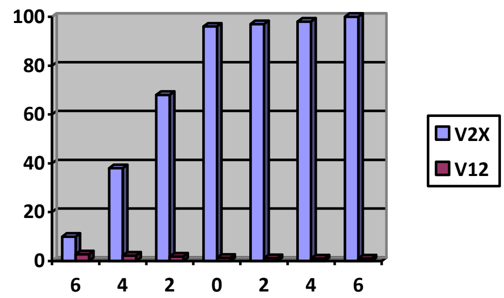

Figure 13. Throughput comparison between release 12 and release 14.

In Fig. 13, the simulation results of throughput for two Release 12 and Release 14 we can observe from the figure that, the BLER in release 12 is much higher than in Release 14 at the same value of SNR, for example in our simulation the BLER for release 14 at -6 SNR is 24 while Release 12 is 40. We can observe from Fig. 14 that, the BLER of Release 14 is substantially less than that of Release 12.

MATLAB is utilized to develop the aforementioned simulation model due to its simple vector and multi-core processing features, which helps to minimize the running time of large simulations.

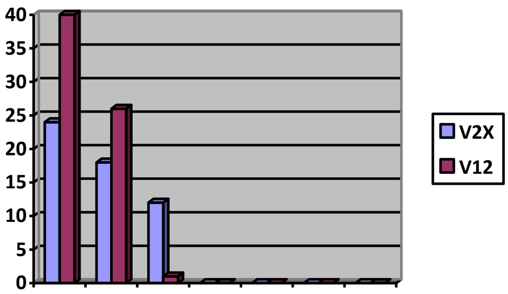

Figure 14. BLER: Comparison between release 12 and release 14.

IV. Applications and Future of LTE

Palestine is one of the fastest-growing economies in the Asian area. Its economy is expanding at a rapid pace. It is a country of around 5 million inhabitants. It has expanded in recent years in areas such as clothing, manufacturing, infrastructure, transportation, farming, and information technology, among others. Technology is continually advancing, and its applications are rapidly growing. Day-to-day work is getting considerably easier and faster because of the employment of current technologies. That is why we should now think about how we might use technology to better our daily lives, which will lead to greater national growth. Vehicle-to-vehicle (V2V) and vehicle-to-everything (V2X) are emerging IOT technologies based on LTE systems that might be highly valuable in the context of Palestine, which will employ 4G in the future. As previously noted, V2V is an acceptable technology in this scenario due to its low cost, compatibility with prior network technologies such as GSM, WCDMA, and so on, as well as lower implementation and maintenance complexity and expense. Palestine is currently deploying technology-based livelihood improvement solutions. It is paving the way for the creation of a smart city system, a smart grid system, an intelligent home automation system, an intelligent agricultural system, an intelligent industrial automation system, and so on.

V. Conclusion

The detailed operations of 3GPP are described in this publication. Side link transmissions have been thoroughly presented, including throughput, Block Level Error Rate. Through our simulation studies, in both V2X Release 14 and Release 12 side link transmissions, the MIMO schemes with more antennas are improved data rates or throughputs and leaded to a better BLER performance. Moreover, under a certain amount of transport block size to be broadcasted by the PSCCH, a smaller TBS leads to improve performance in terms of Throughput and BLER. Since a smaller TBS accommodates smaller bits, less bits imposed on a channel code to be inserted, this leads to a decreased channel-coding rate, which improves BLER and throughput performance. On the other hand, given a certain value of Doppler frequency, a larger number of Doppler frequencies leads to improve performance in term of BLER, and worse performance in term of throughput.

Conflict of Interest

The submitted work was not subjected to any conflict of interest. Further, the authors declare "no conflict of interest".

Author Contributions

Daraghma R. took responsibility of mathematical modeling and implementation, while the author Shabaneh A. helped in reviewing and correcting the simulation results and documentation. All authors had approved the final version.

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