# Performance Improvement in Cellular V2X (CV2X) by Using Low Density Parity Check (LDPC) Code

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***Abstract*—Cellular Vehicle-to-Everything (CV2X) has recently piqued the interest of both industry and academia. CV2X extends communication coverage by using the cellular infrastructure as a standard for vehicular communication. CV2X also enables the communication between vehicles and pedestrians, vehicles and the cellular network, along with vehicle to vehicle communication. The CV2X standard's expectations are gradually rising as the number of vehicles, cell phone users, smart devices connected to vehicles, and other factors increase. A more efficient CV2X framework is needed to fulfill these expectations. We focused on the PHY layer of the CV2X standard and proposed a model featuring Low Density Parity Check (LDPC) code. Our experimental results suggest that our proposed model is able to improve reliability by reducing the bit error rate compared to the existing PHY layer framework. In addition, our proposed model can increase the throughput up to 1.4 times and 2 times at 10 MHz and 20 MHz channels, respectively.**

***Index Terms*—CV2X, DSRC, OFDM, MIMO, LDPC coding, Turbo coding, throughput, bit error rate**

## I. Introduction

Information is exchanged between vehicles, between vehicles and infrastructure, and pedestrians using vehicular communication. This information will allow both vehicles and pedestrians to accurately assess their surroundings to predict any imminent adverse situation and take appropriate action after being in an adverse situation. A better communication framework is always welcome in this regard. A better communication framework can be defined by having a better bit error rate and throughput. There are two communication frameworks available for vehicular communication which are Cellular V2X (CV2X) and Dedicated Short Range Communication (DSRC). Both frameworks have different structures and are not interoperable. [1] DSRC covers two types of communication scenarios which are Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I). CV2X covers two more communication scenarios along with V2V and V2I which are Vehicle-to-Network (V2N) and Vehicle-to-Pedestrian (V2P). V2V communication can be used to transfer safety information like collision avoidance warnings. V2I communication can be used to transfer traffic signal information, intersection warning message, and so on. V2N communication can be used to transfer real-time traffic/routing information, cloud service information, and so on. V2P communication can be used to transfer information like safety alerts to pedestrians, bicyclists, and so on. Ensuring passenger and traffic safety are the prime targets of vehicular communication [2]. Statistics from The U.S Department of Transportation (DOT) suggested that 82% of all road crashes in the United States can be addressed if an efficient vehicular communication framework is implemented [3]. Communication hindrances like unfavorable weather conditions, various mobility patterns, different traffic scenarios, varying speed of vehicles, adverse road conditions, and so on produce noise which can affect the transmitting signals severely [4].

Researchers have been trying to improve the performance of DSRC and CV2X in recent years by evaluating different techniques and methods. A system level simulator [5] and a test bed [6] were designed to simulate the CV2X communication scenarios and assess the quality of service more accurately. [7] An LTE based vehicular communication scenario was evaluated in an OMNET++ simulated environment for multimedia transmission. A model for vehicular communication is proposed in [8] to evaluate CV2X under different propagation scenarios. A model was proposed in [9] to support Mobile Edge Computing (MEC) for performance improvement. [10] Multiple Input Multiple Output (MIMO) is a technology that can improve energy and spectral efficiency by employing multiple antennas at both the transmitter and the receiver sides. [11] Two types of MIMO are more beneficial for improving communication performance which are Transmit Diversity and Spatial Multiplexing. A more robust vehicular communication structure was proposed in [12] which includes Orthogonal Space-Time Block Codes (OSTBC) enabled MIMO technique. A PHY layer including MIMO was proposed to conduct communication in V2I in the DSRC standard to improve throughput and bit error rate with the help of Software Defined Radio (SDR) [13]. Spatial Multiplexing MIMO and 5G NR were used on top of DSRC to improve vehicular communication performance [14], [15]. An improvement in throughput for non-safety services and improvement in reliability for safety services was done in [16] using the selective MIMO technique.

There are two major ways to improve vehicular communication performance which are using more transmit antennas and receive antennas and using a better channel coding mechanism. CV2X already uses MIMO technology so, an improvement in the channel coding portion can help in improving the performance. Turbo code is used in the CV2X standard as a channel coding technique. Low Density Parity Check (LDPC) code has the potential to perform better than the turbo code. Robert G. Gallager developed the LDPC code in 1960 at the Massachusetts Institute of Technology (MIT) [17]. At that time it did not succeed due to a lack of enough computational power as it has a more complex design than convolutional code and turbo code. However, LDPC code has become popular nowadays as it can be implemented using advanced software and hardware. Several strategies were proposed in [18] like the curve fitting technique on extrinsic information transfer charts [19] to design an optimized LDPC code. LDPC code was constructed with more improved algorithms in [20] which performs very close to Shannon capacity in binary AWGN channel for a coding rate of 1/2. Moreover, the LDPC code was found to have a high bit error rate efficiency in rayleigh fading and frequency selective fading channels when applied in an Orthogonal Frequency Division Multiplexing (OFDM) communication system [21]. LDPC code was found to be performing better than convolutional code in AWGN, rayleigh fading, and rician fading channels. The performance of LDPC code was also evaluated using an iterative turbo decoding algorithm to improve the communication performance in an OFDM-MIMO system. [22] LDPC code was employed in the DSRC standard as well for throughput improvement.

Ample opportunities are available to prepare the CV2X structure for more efficient communication by leveraging LDPC code. efficiency in bit error rate can be achieved using LDPC code which eventually affects the throughput. We proposed a modified PHY layer for the CV2X standard to employ LDPC code and assessed the performance and compared the performance with the turbo code.

The remaining portions of the paper are designed as follows: Section II demonstrates V2X communication in detail. It shows the block diagram of the PHY layer of CV2X and the allocated spectrum for CV2X communication in the 5.9 GHz band. Section III presents how the LDPC code can be employed in the CV2X standard. Then, section IV contains the experimental details and the metrics to evaluate the results from the simulation. After that, section V displays the experimental results and comparative analysis of the results. Finally, the paper is concluded in section VI which mentions reasonable future plans for this work.

## II. V2X Communication

Federal Communication Commission (FCC) determines vehicular communication protocols and standards in the United States. FCC approved DSRC in 1992 for physical (PHY) layer specification. IEEE 802.11 family adopted DSRC in the IEEE 802.11p standard in 2004. In 2021, FCC adopted CV2X to define a new PHY layer specification for vehicular communication. [1] CV2X leverages the framework of the cellular communication PHY layer to define the PHY layer of vehicular communication and uses the cellular infrastructure for data transmission.

### *A. PHY Layer in CV2X Communication*

The block diagram of the PHY layer structure of the CV2X standard is presented in Fig. 1. According to this figure, the PHY layer gets the bit streams of the information generated by the application layer after processing through the other layers. In the PHY layer, the information data goes through several steps to be prepared for transmission. The steps on the transmitter side include FEC Coding (channel coding), Signal Modulation, SC-FDM Modulation, and MIMO Transmitter. The information bits are converted to codeword bits in the FEC Coding step based on the coding method and coding rate. The codeword bits are modulated in the signal Modulation step based on a specified modulation scheme. The SC-FDM Modulation step prepares the modulated symbols to be resistant to multipath fading and inter-symbol interference. The MIMO Transmitter step aligns the SC-FDM Modulated symbols to the appropriate transmit antenna ports using multi-antenna communication. On the receiver side, the same steps are followed in reverse order to reconstruct the transmitted information. [23], [24] The SC-FDM specifications of the CV2X standard is presented in Table I.

### *B. Radio Channel Details for Vehicular Communication*

There are two PHY layer standards available for V2X communication which are CV2X and IEEE 802.11p (Dedicated Short Range Communication). FCC specified 75 MHz spectrum in the 5.9 GHz band for V2X communication. The spectrum division is presented in Fig. 2. The lower 45 MHz spectrum is kept for unlicensed use and the higher 30 MHz is kept for V2X communication. The higher 30 MHz spectrum is divided into two bandwidths which are 10 MHz and 20 MHz. FCC allocated both the bandwidths for Cellular V2X use but IEEE 802.11p can only use 10 MHz bandwidth. Doppler effect and Multipath fading are the prime signal interfering factors during data transmission for a given bandwidth. Doppler effect is characterized as a distortion in the signal due to the relative motion of the transmitter and the receiver. Multipath fading is characterized as an interference in the signal when the signal is either reflected, diffracted, or scattered by objects on the way to the receiver. We built a MIMO channel model using the existing Matlab object which had rayleigh fading distribution and a certain doppler shift value. We specified the rayleigh fading distribution parameters by using random path delay, path gain, and sampling frequency. Channel specific values of delay spread and sampling frequency were used to calculate the path delays. We specified the doppler shift value in such a way that the communication can reflect a high mobility scenario. We also used the regular Additive White Gaussian

Noise (AWGN) channel model to have randomized channel noise in the signal.

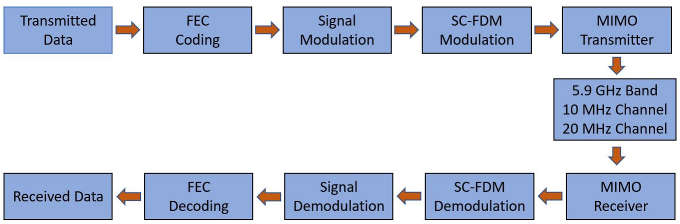


Fig. 1. Block Diagram of the PHY layer of CV2X.

TABLE I
SC-FDM CHARACTERISTICS OF CV2X

| Parameter | Value |
|---|---|
| Number of Subcarriers | 12 |
| Subcarrier Frequency Spacing | 15 KHz |
| Number of Symbols per Subcarrier | 14 |
| Guard Interval (GI) | 4.68 $\mu$sec |
| Symbol Interval (including GI) | 71.35 $\mu$sec |

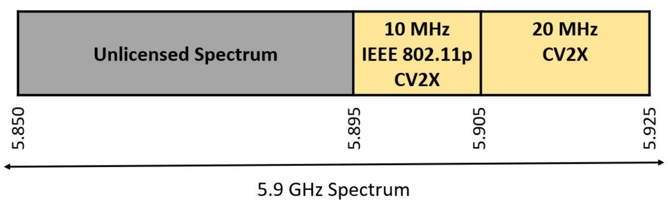


Fig. 2. 5.9 GHz spectrum division in United States.

## III. LDPC in Cellular V2X Communication

The LDPC mechanism transforms the information bits into codeword bits, where codeword bits contain the bits that represent the original message bits and parity check bits. The codeword bits come out as a matrix, which is called a parity check matrix. The parity check matrix contains a very small number of 1's per row and column compared to a large number of 0's, which makes the parity check matrix a sparse matrix. [25] LDPC algorithm can work on both small and large block data as well as maintain a given coding rate. The CV2X standard uses turbo coding as a channel coding mechanism, which is inherited from cellular communication standards. The signal in a vehicular communication scenario is supposed to have more multipath fading and doppler effect due to high mobility. A better channel coding mechanism can be a crucial factor in improving overall performance, such as bit error rate and throughput. So, we tried to incorporate the LDPC coding technique in the FEC Coding portion instead of the turbo coding mechanism. Then we tested the performance of LDPC code compared to turbo code based on different coding rates. Based on the discussion above, we prepared a modified PHY layer of the CV2X standard.

## IV. Experimental Description

MIMO is a technique that can improve the throughput of the communication link by transmitting a large amount of data by using multiple transmit and receive antennas. In addition, LDPC has the potential to improve the bit error rate. So, it is very likely that LDPC code can provide better performance in worse conditions than turbo code. That's why we employed LDPC code in the CV2X PHY layer which is displayed as a block diagram in Fig. 3.

We included the LDPC coding mechanism in both the FEC Coding and FEC Decoding steps shown in Fig. 1, along with the existing turbo coding technique. Two Spatial Multiplexing MIMO configurations were used which are the 2x2 (two transmitting antennas and two receiving antennas) configuration and the 4x4 (four transmitting antennas and four receiving antennas) configuration. We assessed the performance of LDPC code in the existing CV2X structure and compared the performance with turbo code. Moreover, four different coding rates (1/3, 1/2, 2/3, 3/4) were applied while considering both the LDPC coding scheme and turbo coding scheme. The performance of the coding rates under both coding schemes was evaluated. In addition, the QPSK modulation technique was used in the Signal Modulation and Signal Demodulation blocks. We configured the parameters of SC-FDM Modulation and SC-FDM Demodulation blocks based on the CV2X specifications. In the MIMO Receiver block, we used Minimum Mean Squared Error (MMSE) as the equalization method for both coding techniques. We implemented functionalities for all the blocks presented in Fig. 3 in the Matlab environment and ran the simulation as a complete package. We recorded the simulation results and presented them in the next section. The simulation parameter values are shown in Table II.

We evaluated our proposed model based on two metrics which are given below.

*a) Bit Error Rate (BER):* BER is defined by the number of error bits that are received per unit time. It is calculated by the ratio of the number of error bits at the receiver divided by the total number of bits transmitted during the simulation time.

*b) Throughput:* Throughput is defined by the total number of frames successfully received, divided by the total time over which the transmission is being held. Throughput is expressed in Mbps, which refers to channel capacity as well. In our experiments, we used 1 ms as a transfer time for each frame to calculate throughput.

## V. Experimental Result and Analysis

We designed our Matlab simulation according to the proposed model shown in the experimental description section. We ran our simulation for both turbo code and LDPC code of rates 1/3, 1/2, 2/3, and 3/4 in 2x2 MIMO configuration, and 4x4 MIMO configuration at both 10 MHz and 20 MHz channels. We stored throughput and BER values from the simulation and presented a comparative analysis below.

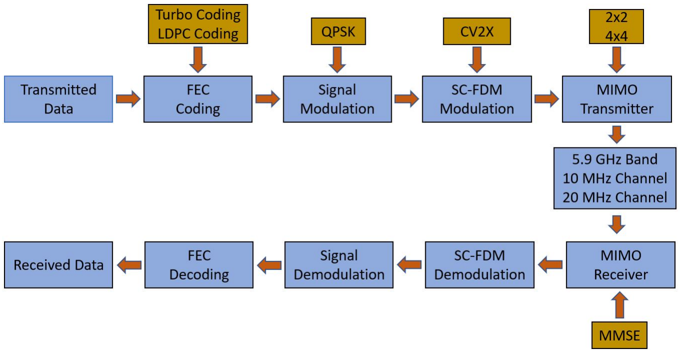


Fig. 3. Block diagram of the proposed model.

TABLE II
EXPERIMENTAL PARAMETERS

| Parameter | Value |
|---|---|
| Channel Model | Rayleigh Fading |
| Modulation Type | QPSK |
| Channel Bandwidth | 10 MHz & 20 MHz |
| Doppler Shift | 300Hz |
| SNR Range | 0 - 30 dB |
| CRC Code | 24 bit CRC Checksum |
| Coding Scheme | Turbo Code, LDPC Code |
| Coding Rate | 1/3, 1/2, 2/3, 3/4 |
| Maximum Number of Bits Processed | 2e5 |

Fig. 4 and 5 display the BER comparison of turbo code and LDPC code in CV2X framework using both the 2x2 and 4x4 MIMO configurations at 10 MHz channel. In both the figures, the cyan line, green line, red line, and blue line represent BER using the coding rates of 1/3, 1/2, 2/3, and 3/4 respectively. Also, the solid lines represent BER using turbo code and the dotted lines represent BER using LDPC code. From Fig. 4 and 5, it is observed that the BER performance of LDPC code is better than turbo code for all the coding rates. The reason for that is, the parity check matrix has blocks of large length which help to induce less error and recover more error bits in the signal compared to turbo code. In addition, the coding rate 1/3 performs the best and the coding rate 3/4 performs the worst for both the turbo code and LDPC code. The coding rate 1/2 is better than the coding rate 2/3 but worse than the coding rate 1/3. Similarly, the coding rate 2/3 is better than the coding rate 3/4 but worse than the coding rate 1/2 for both the turbo code and LDPC code. The reason for that is the data frames contain more data bits with a higher coding rate. So, more data bits are affected by noise and fading when a higher coding rate is applied compared to a lower coding rate.

Fig. 6 and 7 display the throughput comparison of turbo code and LDPC code in CV2X framework using both the 2x2 and 4x4 MIMO configurations at 10 MHz channel. In both the figures, the cyan line, green line, red line, and blue line represent throughput using the coding rates of 1/3, 1/2, 2/3, and 3/4 respectively. Also, the solid lines represent throughput

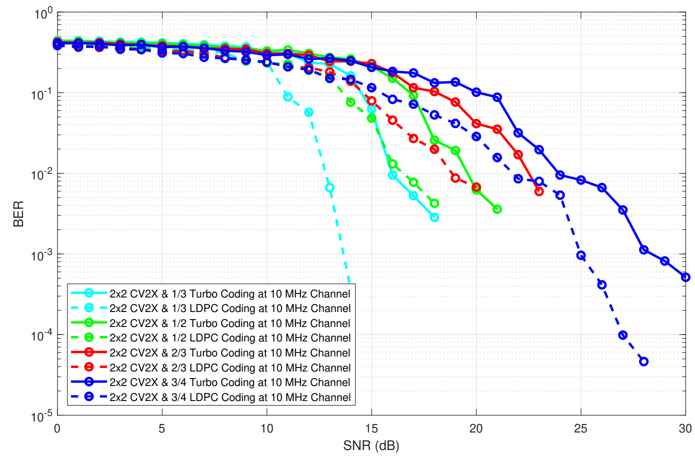


Fig. 4. BER comparison between turbo code and LDPC code using 2x2 MIMO configuration at 10 MHz channel.

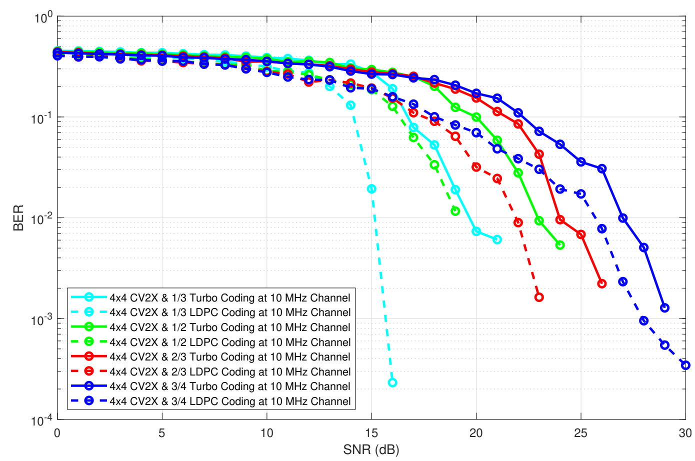


Fig. 5. BER comparison between turbo code and LDPC code using 4x4 MIMO configuration at 10 MHz channel.

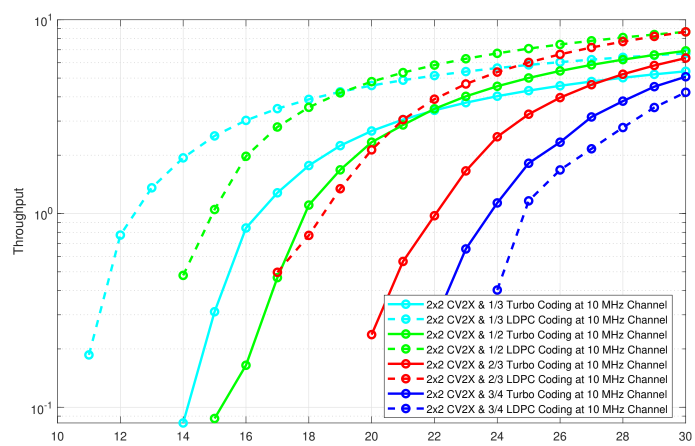


Fig. 6. Throughput comparison between turbo code and LDPC code using 2x2 MIMO configuration at 10 MHz channel.

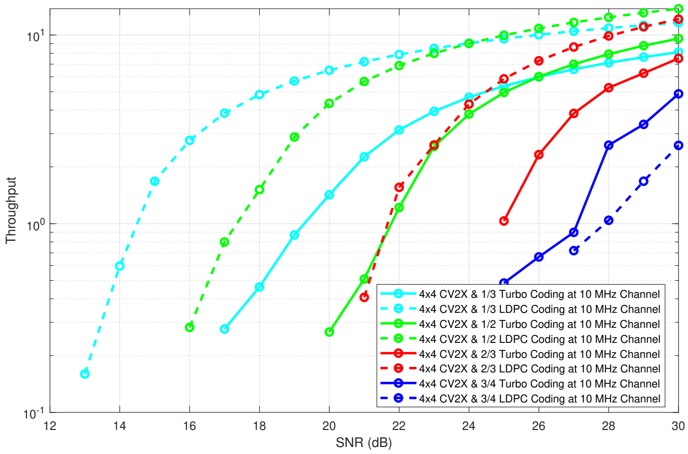


Fig. 7. Throughput comparison between turbo code and LDPC code using 4x4 MIMO configuration at 10 MHz channel.

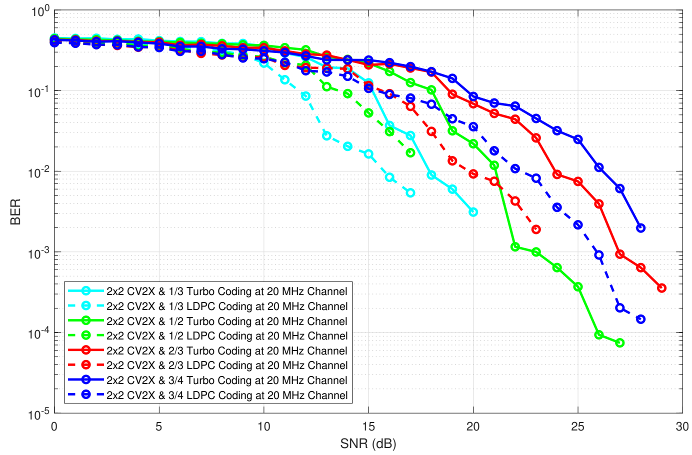


Fig. 8. BER comparison between turbo code and LDPC code using 2x2 MIMO configuration at 20 MHz channel.

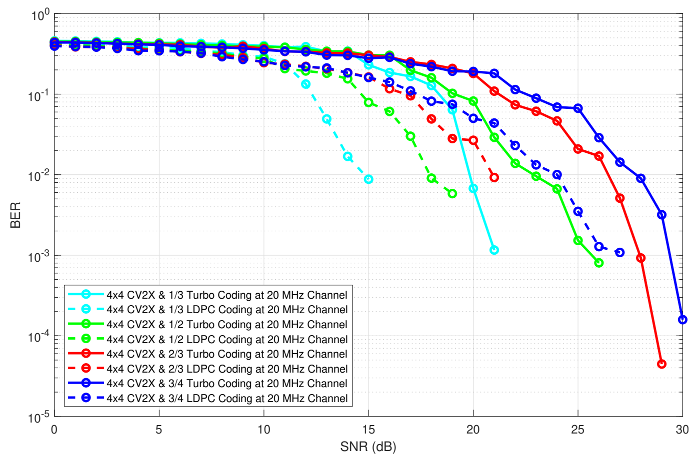


Fig. 9. BER comparison between turbo code and LDPC code using 4x4 MIMO configuration at 20 MHz channel.

using turbo code and the dotted lines represent throughput using LDPC code. From Fig. 6 and 7, it is observed that the coding rates 1/3, 1/2, and 2/3 using the LDPC code performs better than the turbo code but coding rate 3/4 using the LDPC code performs worse than the turbo code. That is because less number of data frames are affected due to having less BER using LDPC code than turbo code. As a result, more error free frames are received while using LDPC code than turbo code which impacts the throughput greatly. However, the coding rate 3/4 does not follow the trend because of having a very large number of data bits in the code blocks. In addition, coding rate 1/2 performs the best and coding rate 3/4 performs the worst using both turbo code and LDPC code for both the 2x2 and 4x4 MIMO configurations. That is because the BER using coding rate 1/2 is better compared to code rates 2/3 and 3/4. So, that impacts frame error and the throughput. The performance of coding rates 1/3 and 2/3 fluctuates based on MIMO configuration. Moreover, the throughput using coding rate 1/2 is much better than coding rate 1/3 even though the BER of coding rate 1/2 is comparatively worse than coding rate 1/3. That is because frame size while using coding rate 1/2 is comparatively bigger than coding rate 1/3. So, the percentage of data bits in error free frames in proportion to corrupt frames while using coding rate 1/2 is comparatively higher than coding rate 1/3 which yields better throughput for coding rate 1/2 than coding rate 1/3.

Fig. 8 and 9 display the BER comparison of turbo code and LDPC code in CV2X framework using both the 2x2 and 4x4 MIMO configurations at 20 MHz channel. In both the figures, the cyan line, green line, red line, and blue line represent BER using the coding rates of 1/3, 1/2, 2/3, and 3/4 respectively. Also, the solid lines represent BER using turbo code and the dotted lines represent BER using LDPC code. From Fig. 8 and 9, it is observed that the BER performance of LDPC code is better than turbo code for all the coding rates. The reason for that is, the LDPC has a large length of blocks in the parity check matrix which helps to induce less error and recover more error bits in the signal compared to turbo code. In addition, the coding rate 1/3 performs the best and the coding rate 3/4 performs the worst for both the turbo code and LDPC code. The coding rate 1/2 is better than the coding rate 2/3 but worse than the coding rate 1/3. Similarly, the coding rate 2/3 is better than the coding rate 3/4 but worse than the coding rate 1/2 for both the turbo code and LDPC code. The reason for that is more data bits are encapsulated in the data frames with a higher coding rate. So, more data bits are affected by noise and fading while having a higher coding rate compared to a lower coding rate.

Fig. 10 and 11 display the throughput comparison of turbo code and LDPC code in CV2X framework using both the 2x2 and 4x4 MIMO configurations at 20 MHz channel. In both the figures, the cyan line, green line, red line, and blue line represent throughput using the coding rates of 1/3, 1/2, 2/3, and 3/4 respectively. Also, the solid lines represent throughput using turbo code and the dotted lines represent throughput using LDPC code. From Fig. 10 and 11, it is observed that LDPC code performs better than the turbo code for all the coding rates. That is because having less BER using LDPC code impacts less error in the data frames than turbo code. As a result, more error free frames are received while using LDPC code than turbo code which impacts the throughput greatly. In addition, coding rate 1/2 performs the best and coding rate 3/4 performs the worst using both turbo code and LDPC code for both the 2x2 and 4x4 MIMO configurations. The reason for that is the BER using coding rate 1/2 is better than code rates 2/3 and 3/4. So, that impacts frame error and the throughput. The performance of coding rate 1/3 and 2/3 fluctuates based on MIMO configuration. Moreover, the throughput using coding rate 1/2 is much better than coding rate 1/3 even though the BER of coding rate 1/2 is comparatively worse than coding rate 1/3. That is because frame size while using coding rate 1/2 is comparatively bigger than coding rate 1/3. So, the percentage of data bits in error free frames in proportion to corrupt frames while using coding rate 1/2 is comparatively higher than coding rate 1/3 which yields better throughput for coding rate 1/2 than coding rate 1/3.

The final throughput using four coding rates and two MIMO configurations at both 10 MHz and 20 MHz at the end of the simulation is presented in Table III and Table IV respectively. From Table III it is evident that the throughput of LDPC code using coding rates of 1/3, 1/2, and 2/3 are at least 1.2 times better compared to turbo code whereas the throughput of LDPC code using the coding rate of 3/4 is worse than turbo code for both the 2x2 and 4x4 MIMO configuration. From Table IV it is obvious that the throughput of LDPC code using coding rates of 1/3, 1/2, and 2/3 are at least 1.3 times better compared to turbo code for 2x2 MIMO configuration. Similarly, the throughput of LDPC code using coding rates of 1/3, 1/2, and 2/3 are at least 2 times better compared to turbo code for 4x4 MIMO configuration. In addition, the performance of coding rate 3/4 is the same for both the LDPC code and turbo code for 2x2 MIMO configuration and the performance of LDPC code using the coding rate of 3/4 is 4 times better compared to turbo code for 4x4 MIMO configuration. Taking the analysis above into consideration it is observed that LDPC code performs better compared to turbo code for coding rates of 1/3, 1/2, and 2/3 for both the MIMO configurations at both 10 MHz and 20 MHz channels. Moreover, the coding rate of 1/2 seems to be the optimal choice for both the LDPC code and turbo code. Having said that, the throughput of LDPC code of coding rate 1/2 is 1.3 and 1.4 times better compared to turbo code for 2x2 and 4x4 MIMO configurations respectively at the 10 MHz channel. Also, the throughput of LDPC code of coding rate 1/2 is 1.5 and 2 times better compared to turbo code for 2x2 and 4x4 MIMO configurations respectively at the 20 MHz channel.

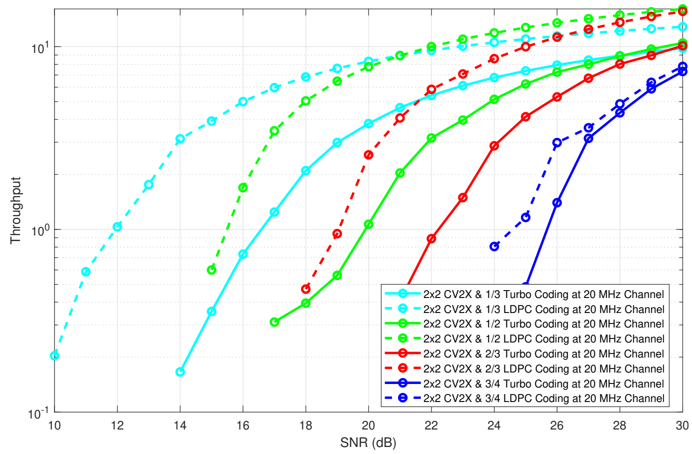


Fig. 10. Throughput comparison between turbo code and LDPC code using 2x2 MIMO configuration at 20 MHz channel.

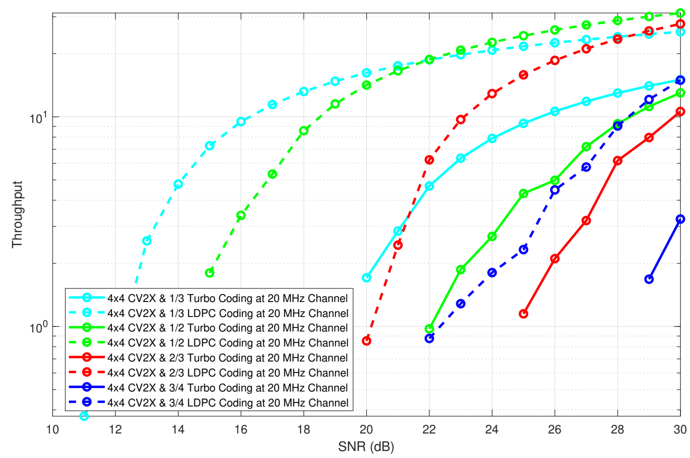


Fig. 11. Throughput comparison between turbo code and LDPC code using 4x4 MIMO configuration at 20 MHz channel.

TABLE III
THROUGHPUT COMPARISON AT 10 MHZ CHANNEL

| MIMO Configuration | Coding Scheme | Coding Rate | Throughput (in Mbps) |
|---|---|---|---|
| 2x2 | Turbo Coding | 1/3 | 5.42 |
| | | 1/2 | 6.91 |
| | | 2/3 | 6.34 |
| | | 3/4 | 5.08 |
| | LDPC Coding | 1/3 | 6.71 |
| | | 1/2 | 8.66 |
| | | 2/3 | 8.66 |
| | | 3/4 | 4.22 |
| 4x4 | Turbo Coding | 1/3 | 8.11 |
| | | 1/2 | 9.57 |
| | | 2/3 | 7.51 |
| | | 3/4 | 4.88 |
| | LDPC Coding | 1/3 | 11.62 |
| | | 1/2 | 13.77 |
| | | 2/3 | 12.13 |
| | | 3/4 | 2.6 |

TABLE IV
THROUGHPUT COMPARISON AT 20 MHZ CHANNEL

| MIMO Configuration | Coding Scheme | Coding Rate | Throughput (in Mbps) |
|---|---|---|---|
| 2x2 | Turbo Coding | 1/3 | 9.8 |
| | | 1/2 | 10.48 |
| | | 2/3 | 10.12 |
| | | 3/4 | 7.32 |
| | LDPC Coding | 1/3 | 12.84 |
| | | 1/2 | 16.09 |
| | | 2/3 | 15.6 |
| | | 3/4 | 7.8 |
| 4x4 | Turbo Coding | 1/3 | 13.01 |
| | | 1/2 | 15.03 |
| | | 2/3 | 10.6 |
| | | 3/4 | 3.25 |
| | LDPC Coding | 1/3 | 25.42 |
| | | 1/2 | 31.26 |
| | | 2/3 | 27.74 |
| | | 3/4 | 14.95 |

## VI. CONCLUSION

Low Density Parity Check (LDPC) code is complex in design but provides efficient performance compared to turbo code. With the advanced computation power LDPC code can be applicable easily. Although the BER and throughput performance of LDPC code in CV2X framework varies based on different coding rates but provides the best performance at the coding rate of 1/2 using both 2x2 and 4x4 MIMO configuration at both the 10 MHz and 20 MHz channels. A modification in the PHY layer of the CV2X standard is proposed to accommodate LDPC code instead of turbo code. This kind of improved performance will be required in near future as vehicle users and cellular consumers are going to be using the same cellular framework. Our experimental results corroborate that, choosing the optimal coding rate while using LDPC code in the CV2X framework can improve communication performance significantly. Moreover, we are trying to explore the Massive MIMO optimization algorithms in the context of vehicular communication. Our future work includes checking the compatibility and performance of the Massive MIMO optimization in the CV2X framework.

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