Throughput Improvement in Vehicular Communication by Using Low Density Parity Check (LDPC) Code

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***Abstract*—The vehicular community is moving towards a whole new paradigm with the advancement of new technology. People rely on the technology included in the vehicles undoubtedly. As a result, Road conditions are becoming more dynamic and complex as cars having autopilot or autonomous vehicles are evolving faster than before. Vehicular communication plays a vital role to improve traffic and passenger safety and provide entertainment services. Traffic safety will be compromised if the performance of vehicular communication degrades with the growth of technology enabled traffic. The performance of vehicular communication depends on bit error rate (BER) and throughput. A good communication system can be defined by having high throughput while maintaining low BER. Multiple Input Multiple Output (MIMO) has the potential to provide high throughput and Low Density Parity Check Code (LDPC) has the potential to provide low BER. Therefore, we propose a PHY layer model containing both LDPC and MIMO in the Wireless Access for Vehicular Environments (WAVE) standard supported by Dedicated Short-Range Communication (DSRC). Our experimental results show that our proposed approach can achieve more than 3 times better throughput while keeping the BER lower compared to the existing approach.**

Index Terms*—IEEE 802.11p, WAVE, V2X, DSRC, OFDM, MIMO, LDPC, bit error rate, throughput

I. Introduction

Vehicular communication has got a new dimension with the enhancement done in the vehicular community by introducing electric cars as well as cars having autopilot. New generation technologies are being introduced and vehicular communication frameworks are evolving to cope up with the new technologies. The prime goal of vehicular communication is to ensure traffic and passenger safety [1]. Since expectation from the vehicular community is increasing, people are demanding a more comfortable driving experience besides traffic safety. With the increased number of vehicles, devices, and services the existing communication framework might not be able to provide the expected services at a good quality. As a result, the vehicular communication framework needs to evolve so that it can accommodate new technology to meet the expectations. The communication structure for vehicular communication is known as Vehicle-to-Everything (V2X) communication. Two major divisions are found in the V2X communication which are Vehicle-to-Infrastructure (V2I) communication and Vehicle-to-Vehicle (V2V) communication. V2I communication happens between vehicle and roadside unit (RSU) and V2V communication happen in between two or more vehicles [2].

Dedicated Short-Range Communication (DSRC) enables a range of services in V2X communication. V2X communication was investigated for multimedia transmission over LTE-A in an OMNET++ simulated environment [3]. DSRC was primarily developed to provide vehicle safety services. The idea of the DSRC-based safety application is that the basic information such as location, speed, etc. of each vehicle would be broadcast in continuous frequency. Accordingly, other DSRC enabled vehicles will receive that information and take necessary steps to alert the driver. The U.S Department of Transportation (DOT) calculated that if DSRC based V2X communication is implemented efficiently it can reduce 82% of all road accidents in the United States [4], [5]. Moreover, DSRC has the potential to provide several infotainment services like toll payment, parking payment, congestion warning, traffic light warning, navigation assistance, media streaming, and many more. There are several obstacles for the DSRC based services to function which are different traffic scenarios, adverse road conditions, various mobility patterns, unfavorable weather conditions, varying speed of vehicles, and many more [6], [7]. These obstacles produce noise in the channel which can damage the transmitting signal severely by causing bit error. As a result, the performance of vehicular communication degrades.

There are several works that have been done before to improve the performance of vehicular communication. An improved MAC layer scheme called WAVE-based Hybrid Coordination Function (W-HCF) was used to communicate alternately using centralized and distributed channel access methods. [8] This scheme keeps enough bandwidth for non QoS-sensitive services while fulfilling the requirements of QoS-sensitive services. [9] A modified PHY layer model was proposed to improve bit error rate by using Alamouti Space-

Time Code as MIMO technique for two transmitting antennas and two receiving antennas. [10], [11] MIMO provides better spectral and energy efficiency by expanding the capabilities of transmitting and receiving antennas. [12]–[14] Transmit Diversity and Spatial Multiplexing are the two major forms of MIMO that can improve communication performance by using diversity gain. [15] A MIMO-enabled PHY layer model using Orthogonal Space-Time Block Codes (OSTBC) was proposed for more robust communication. MIMO technique was also proposed to employ in between vehicle and infrastructure units in [16]. The communication link was implemented using Software Defined Radio (SDR) to improve bit error rate and throughput. Spatial Multiplexing MIMO was also proposed to use on top of DSRC in [17]. Spatial Multiplexing MIMO has the potential to improve the throughput twice compared to the existing model while keeping the bit error rate lower than the conventional model. [18] Spatial Multiplexing MIMO was also used along with 5G NR on top of DSRC which enhances the data rate much better than the combination of MIMO and DSRC while keeping the bit error rate the same as MIMO enabled existing DSRC model. Selective MIMO was employed in [19] to improve reliability for safety services and data rate for non-safety services.

Based on the discussion above, it is clear that MIMO has the capability to provide better service quality in vehicular communication. Nevertheless, Forward Error Correction (FEC) portion in the DSRC standard also helps to maintain the service quality. So, improvement in FEC will enhance the service quality. There are two types of FEC available which are Block Code and Convolutional Code. [20] The traditional DSRC framework uses Convolutional Code in the FEC portion but Block Code has the potential to beat the former one. Low Density Parity Check (LDPC) code is a popular block code that can play a vital role to improve communication performance even more. LDPC code was first developed by Robert G. Gallager at the Massachusetts Institute of Technology (MIT) in 1960 [21]. It did not get to the application level at that time due to the lack of parallel computing power. But it has become popular again at the moment as it can easily be implemented using advanced technological power. The authors in [22] developed several strategies to design the LDPC codes in a way so that the performance of the codes comes very close to the asymptotic theoretical bound of the Shannon capacity. The code was also optimized in [23] by using curve fitting on extrinsic information transfer charts to work on the Additive White Gaussian Noise (AWGN) channel and MIMO fading channel. This optimization operates within 1.25 dB of Shannon capacity for the MIMO channel and outperforms the Turbo Code. More improved algorithms were used to construct LDPC codes in [24] which perform within 0.0045 dB within the Shannon capacity for code rate 1/2 in binary AWGN channel. Moreover, LDPC code was evaluated in an Orthogonal Frequency Division Multiplexing (OFDM) communication system for different time varying channels and found that it can achieve better bit error rate efficiency and low implementation complexity in frequency selective fading and rayleigh fading channel [25]. The performance of regular LDPC code was evaluated in a simplified DSRC system for three different channels (AWGN, Rayleigh Fading, Rician Fading) separately and found that LDPC code can perform better than Convolutional Code [26]. The performance of LDPC code is also evaluated in OFDM and MIMO systems separately in [27], [28]. An iterative turbo decoding algorithm having two LDPC encoders and two LDPC decoders was used to improve the performance of LDPC code in MIMO system.

There are plenty of opportunity to make the vehicular communication structure more robust by using LDPC code and MIMO together. MIMO can enhance the data rate significantly and LDPC code can improve bit error rate efficiency. So, using LDPC code and MIMO together will improve throughput at a lower bit error rate. Hence, we combined both of them to employ in the DSRC standard. We modified the existing PHY layer in the DSRC standard to accommodate both technology and evaluated the performance in comparison with the conventional DSRC model.

The rest of the paper is organized as follows: Section II describes on DSRC standard elaborately. It displays the channelwise 5.9 GHz spectrum analysis. It also explains the existing PHY layer model and radio channel parameter values. It also demonstrates how the signal can be affected due to various channel characteristics. Section III contains the essence of employing LDPC and MIMO in the existing DSRC standard. Then, the details on experimental setup are depicted in section IV and it also describes two metrics based on which the simulation results are evaluated. After that, experimental results are displayed in section V and comparative analysis on those results is presented. Finally, section VI concludes the work by mentioning possible future plans for this work.

II. Details on DSRC Standard

DSRC is a short to medium range wireless communication protocol for vehicular communication. Federal Communication Commission (FCC) approved DSRC in the United States in 1992 [9]. DSRC was included in the IEEE 802.11 standard in 2004. DSRC provides high speed communication links among vehicles and roadside units. DSRC defined the PHY layer of vehicular communication in the IEEE 802.11p standard.

A. PHY Layer in V2X Communication

Fig. 1 demonstrates the block diagram of the existing structure of the DSRC PHY layer. According to this figure data produced by the sending device is pushed to the PHY layer. The PHY layer prepares the data to be transmitted through the air medium. There are several steps in the PHY layer at the transmitter side which are FEC Coding, Signal Modulation, and OFDM Modulation. The FEC Coding portion converts the data bits into codeword bits using a specified coding scheme and coding rate. The bit error rate can be reduced by using an efficient coding scheme and coding rate. Then the coded data is passed through the Signal Modulation portion where the codeword bits are modulated using a specified modulation technique. The Signal Modulation portion prepares the coded data bits to be transmitted through the air medium. After that, the modulated data is passed through the OFDM Modulation step where modulated data symbols are prepared to combat against interference caused by multipath fading in the air medium. Then, the OFDM modulated data symbols are sent through the 10 MHz channel. On the receiver side, similar demodulation and decoding techniques are applied to the received data to get the best approximation of the transmitted data. The OFDM specifications for the 10 MHz channel are presented in Table I.

B. Radio Channel for V2X communication

There is a specific bandwidth defined by FCC for V2X communication which is defined in 75 MHz spectrum in 5.9 GHz band. [4] This 75 MHz spectrum is divided into seven 10 MHz channels with a 5 MHz guard band which is shown in Fig. 2. The two most influential channel characteristics are multipath fading and doppler effect. A signal is affected most by these two characteristics. Multipath fading is defined as when the transmitted signal is distorted because of reflection, diffraction, or scattering by objects on the way to the receiver. Doppler effect is defined when the transmitted signal is distorted by the movement of the vehicles against other vehicles and roadside units. We designed our experiment in such a way so that the transmitting signal can have the effect of doppler effect, multipath fading, and randomise channel noise. We specified a certain doppler value and added it in our experiment so that it can make a significant impact on the signal which could have happened in a real scenario. We generated random channel noise by using an Additive White Gaussian Noise (AWGN) channel model. Moreover, we used the MIMO channel model having rayleigh fading property by using randomized path gain, path delay, and sampling frequency. Path delay was calculated according to the channel specific value of sampling frequency and delay spread.

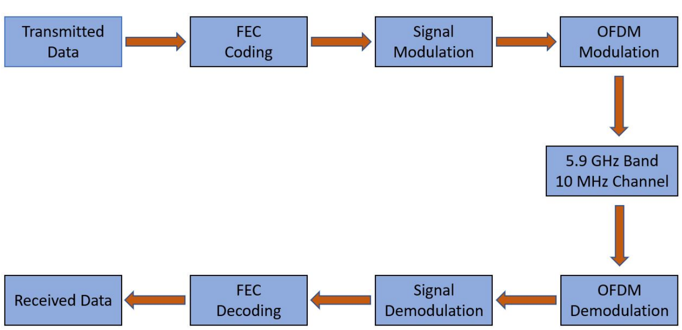

Fig. 1. Block Diagram of DSRC PHY layer.

TABLE I
OFDM CHANNEL CHARACTERISTICS FOR 10 MHZ CHANNEL

Parameter	Value
Number of Data Subcarriers	48
Number of Pilot Subcarriers	4
Number of Total Subcarriers	52
Subcarrier Frequency Spacing	156.25 KHz
Guard Interval (GI)	1.6 μsec
Symbol Interval (including GI)	8 μsec

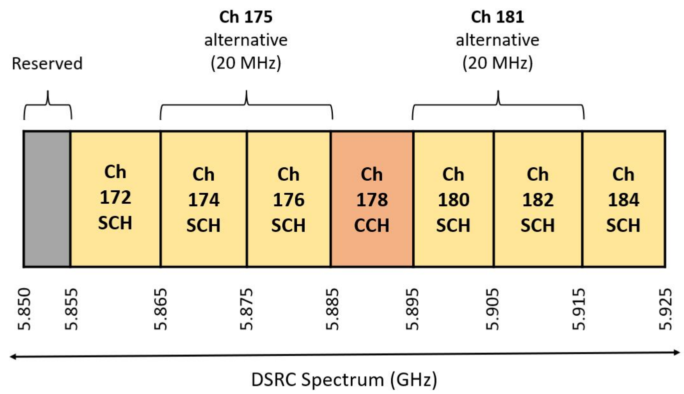

Fig. 2. Channelwise DSRC spectrum division in United States.

III. LDPC AND MIMO IN V2X COMMUNICATION

LDPC is a block code that can work based on different block length codes. [20] In LDPC, the original message is divided into fixed-sized blocks of bits and extra bits are added to these blocks. The block codes are represented in a matrix format which is termed as parity check matrix. The parity check matrix consists of data bits and parity bits which are generated using the LDPC algorithm. The parity check matrix is a sparse matrix that has a small number of 1's per row and a small number of 1's per column, both of which are very small compared to the block length [27], [28].

MIMO is a key technology in the context of wireless communication due to its high spectral efficiency and high reliability. MIMO consists of more than one antenna at both the transmitter and the receiver sides. There are two major forms of MIMO which are Transmit Diversity and Spatial Multiplexing. Transmit Diversity increases bit error rate by transmitting the same data bits through all the antennas whereas Spatial Multiplexing increases the data rate by transmitting different data bits through each antenna.

Due to the continuous movement of vehicles, vehicular communication induces more noise and fading effect in the signal during transmission. Doppler effect has a significant impact on the signal since the vehicle's speed is considerably higher on highways relative to other vehicles and roadside units. MIMO can achieve a certain amount of reliability and throughput. If the noise in the channel and fading effect increases significantly then only diversity gain through the MIMO technique may not be sufficient to maintain the required reliability and data rate. In that case, an improvement in the channel coding segment (FEC) may be helpful. As a result, we tried a different FEC technique to improve the communication performance even more. LDPC is such a channel coding scheme that has the potential to play a remarkable role in the vehicular communication arena. Thus we used the LDPC coding technique instead of the regular convolutional coding technique on top of MIMO in the DSRC standard. We then evaluated the performance of LDPC compared to convolutional code under different coding rates. We designed our proposed model to simulate the modification in the DSRC standard according to the discussion above.

IV. Experimental Description

Spatial Multiplexing MIMO can transmit a large amount of data at a high data rate and at a good quality by having multiple transmitting and receiving antennas. In addition, LDPC improves the bit error rate which impacts the data rate as well. So, the combination of LDPC and MIMO can provide good quality communication in worse scenarios. We employed both LDPC and MIMO techniques in the existing DSRC framework. The block diagram of our proposed PHY model is presented in Fig. 3.

We modified the general block diagram of the DSRC PHY layer model shown in Fig. 1 to accommodate LDPC and MIMO. We added a MIMO transmitter block in between OFDM Modulation and Channel blocks at the transmitter side and added another block named the MIMO receiver in between Channel and OFDM Demodulation blocks at the receiver side. We used two MIMO configurations of Spatial Multiplexing, one is 2x2 (two transmitting antennas and two receiving antennas) configuration and the other one is 4x4 (four transmitting antennas and four receiving antennas) configuration. We applied LDPC coding scheme in the FEC Coding and FEC Decoding blocks beside the Convolutional Coding scheme. We evaluated the performance of LDPC in the traditional DSRC structure and compared the performance with convolutional code. We also evaluated the performance of LDPC in combination with MIMO against the traditional DSRC system. We applied four different coding rates for both the convolutional coding scheme and LDPC coding scheme which are 1/3, 1/2, 2/3, and 3/4. We evaluated the performance of each of the coding rates under the LDPC coding scheme. Moreover, we used the QPSK modulation scheme in the Signal Modulation and Signal Demodulation segments. We configured the OFDM Modulation and OFDM Demodulation segments based on the IEEE 802.11p specifications. In the MIMO Receiver block, we used Minimum Mean Squared Error (MMSE) equalization method for both the 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 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.

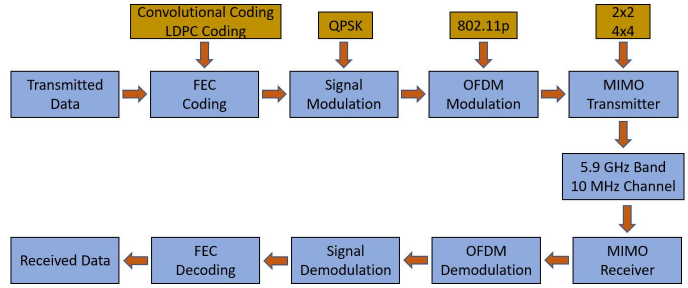

Fig. 3. Block diagram of the proposed model.

TABLE II
EXPERIMENTAL SPECIFICATION

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

V. Experimental Result and Analysis

We designed our simulation based on the proposed model presented in the experimental description section. We divided our simulation into two segments. In the first segment, we ran our simulation for convolutional code and LDPC code of rate 1/3 for conventional DSRC, 2x2 MIMO configuration, and 4x4 MIMO configuration. In the second segment, we ran our simulation for LDPC code of rates 1/3, 1/2, 2/3, and 3/4 for conventional DSRC, 2x2 MIMO configuration, and 4x4 MIMO configuration. We recorded BER and throughput from both the segments and presented a comparative analysis below.

A. First Segment of the Experiment

Fig. 4 displays BER comparison among Conventional DSRC, 2x2 MIMO, and 4x4 MIMO using both Convolutional Code and LDPC code of rate 1/3. From Fig. 4, it is evident that LDPC code performs better than convolutional code in all three configurations (Conventional DSRC, 2x2 MIMO, and 4x4 MIMO). The reason for that is, LDPC has a large length of blocks in the parity check matrix which helps to induce less error in the signal compared to convolutional code.

Fig. 5 displays cumulative throughput comparison among Conventional DSRC, 2x2 MIMO, and 4x4 MIMO using both Convolutional Code and LDPC code of rate 1/3. From Fig. 5 it is observed that LDPC code performs significantly better than convolutional code. That is because having less BER using LDPC code impacts less error in the data frames than convolutional code. As a result, more error free frames are received while using LDPC code than convolutional code which impacts the throughput greatly.

The final throughput of Conventional DSRC, 2x2 MIMO, and 4x4 MIMO at the end of the simulation is presented in Table III. From Table III, it is obvious that the throughput for LDPC code is 1.3 times better compared to convolutional code in Conventional DSRC setup. In addition, the throughput

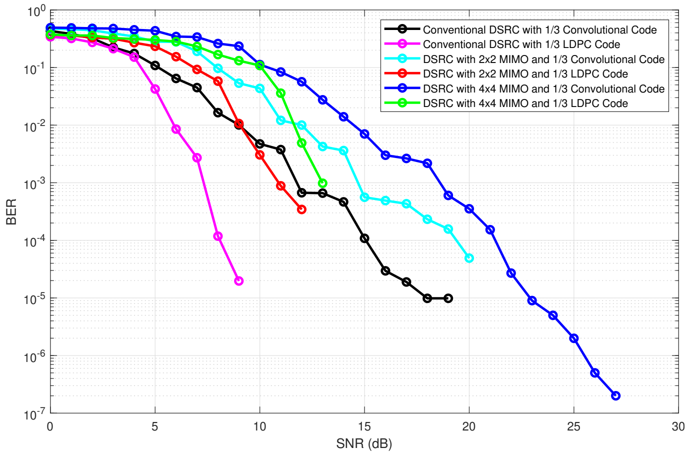

Fig. 4. BER comparison among Conventional DSRC, 2x2 MIMO, and 4x4 MIMO using both Convolutional Code and LDPC code of rate 1/3.

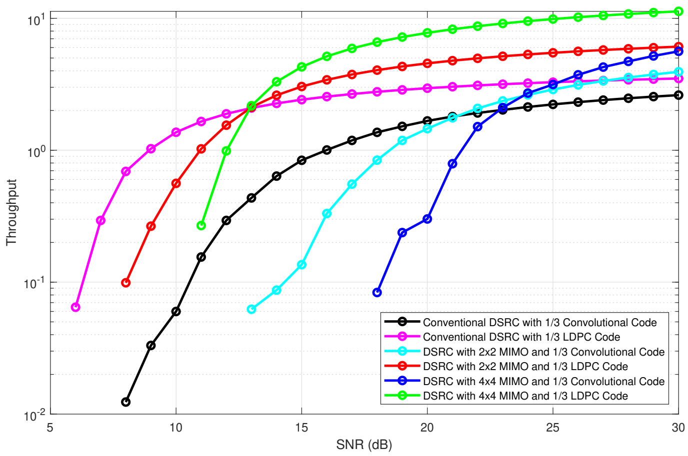

Fig. 5. Throughput comparison among Conventional DSRC, 2x2 MIMO, and 4x4 MIMO using both Convolutional Code and LDPC code of rate 1/3.

performance of LDPC code is 1.5 times and 2 times better compared to convolutional code for 2x2 and 4x4 MIMO configurations respectively. So, it can be inferred that the performance of LDPC code increases rapidly compared to convolutional code with the increase of antennas at both the transmitter and receiver.

B. Second Segment of the Experiment

Fig. 6, Fig. 7, and Fig. 8 display BER comparison among 1/3, 1/2, 2/3, and 3/4 code rates for Conventional DSRC, 2x2 MIMO, and 4x4 MIMO respectively. From Fig. 6, 7, and 8, it is evident that code rate 1/3 performs best, and code rate 3/4 performs worst among the four code rates. Code rate 1/2 performs worse than code rate 1/3 but better than code rate 2/3. Also, code rate 2/3 performs worse than code rate 1/2 but better than code rate 3/4. The reason for that is with a higher code rate, more data bits are encapsulated in the data frames. So, once noise and fading happen it affects more data bits while having a higher coding rate compared to a lower coding rate. However, The performance of code rates 2/3 and 3/4 is significantly drastic than code rates 1/3 and 1/2.

Fig. 9, Fig. 10, and Fig. 11 display Throughput comparison among 1/3, 1/2, 2/3, and 3/4 code rates for Conventional DSRC, 2x2 MIMO, and 4x4 MIMO respectively. From Fig. 9, it is observed that code rate 1/2 outperforms the other coding rates for all three configurations (Conventional DSRC, 2x2 MIMO, and 4x4 MIMO). The reason for that is the BER of code rate 1/2 is better than code rates 2/3 and 3/4. So, that impacts frame error and the throughput.

TABLE III
THROUGHPUT COMPARISON FOR 1/3 CODING RATE

Communication Configuration	Coding Scheme	Throughput (in Mbps)
Conventional DSRC	Convolutional Code	2.62
	LDPC Code	3.50
2x2 MIMO	Convolutional Code	3.93
	LDPC Code	6.09
4x4 MIMO	Convolutional Code	5.62
	LDPC Code	11.29

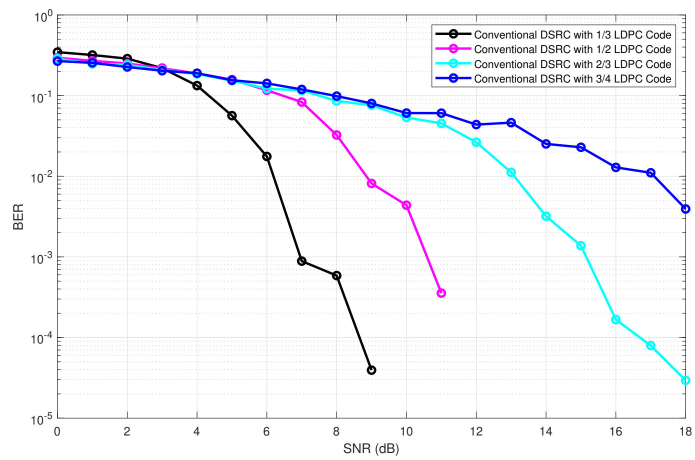

Fig. 6. BER comparison among 1/3, 1/2, 2/3, and 3/4 code rates while applying LDPC in Conventional DSRC.

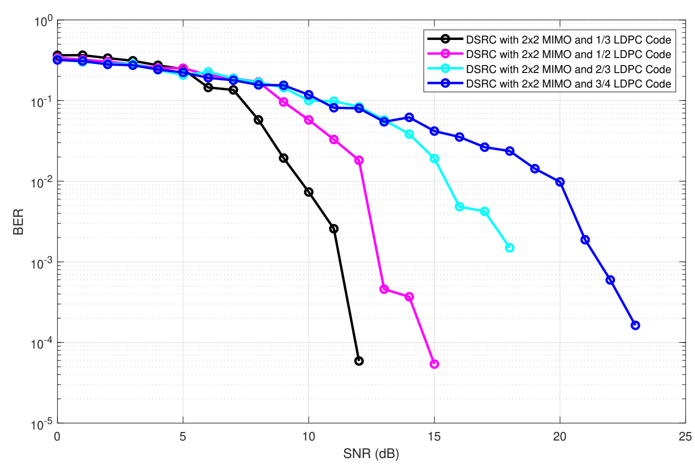

Fig. 7. BER comparison among 1/3, 1/2, 2/3, and 3/4 code rates while applying LDPC in DSRC along with 2x2 MIMO configuration.

Moreover, the throughput of code rate 1/2 is much better than code rate 1/3 even though the BER of code rate 1/2

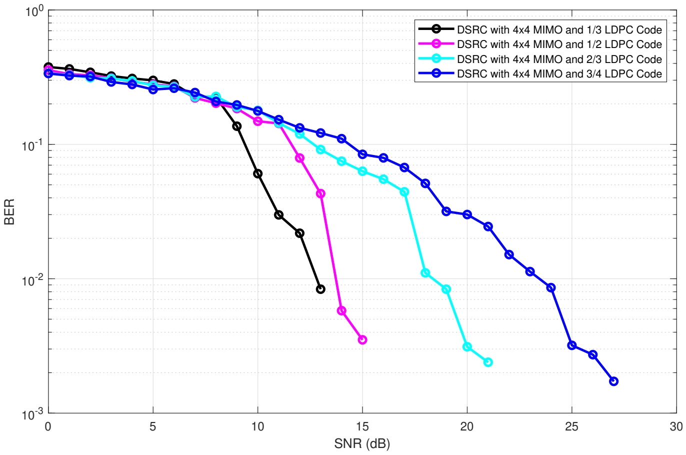

Fig. 8. BER comparison among 1/3, 1/2, 2/3, and 3/4 code rates while applying LDPC in DSRC along with 4x4 MIMO configuration.

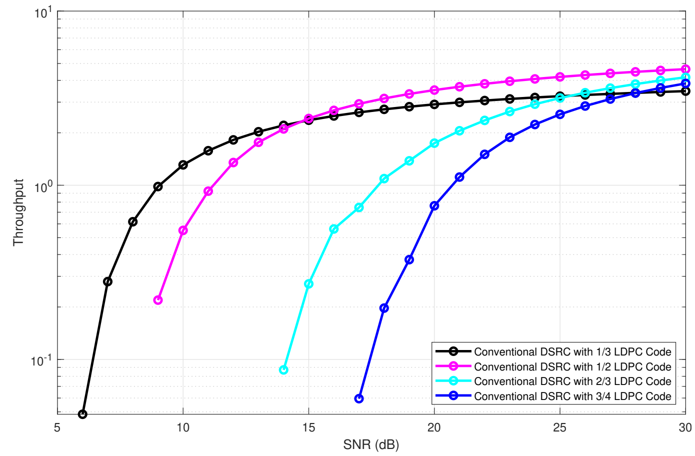

Fig. 9. Throughput comparison among 1/3, 1/2, 2/3, and 3/4 code rates while applying LDPC in Conventional DSRC.

is comparatively worse than code rate 1/3. That is because, frame size while using code rate 1/2 is comparatively bigger than code rate 1/3. So, the percentage of information bits in error free frames in proportion to corrupt frames while using code rate 1/2 is comparatively higher than code rate 1/3 which yields better throughput for code rate 1/2 than code rate 1/3.

Furthermore, the throughput of code rate 2/3 increases with the increase of SNR and eventually outperforms code rate 1/3 but the performance is not quite good. Also, the throughput performance of code rate 2/3 is never better than code rate 1/2. In addition, the throughput performance of code rate 3/4 is the worst among all the code rates. The reason for the throughput performance of the code rates 2/3 and 3/4 being worse is having much more bit error than code rates 1/3 and 1/2.

The final throughput using each of the coding rates for Conventional DSRC, 2x2 MIMO, and 4x4 MIMO at the end of the simulation is presented in Table IV. From Table IV, it is obvious that throughput using coding rates 1/3, 1/2, and 2/3 performs more than 1.7 times and more than 3 times better for 2x2 and 4x4 MIMO configurations respectively compared to Conventional DSRC. However, the coding rate 1/2 performs the best among all the coding rates. Moreover, the coding rate 3/4 performs 1.5 times and 2 times better for 2x2 and 4x4 MIMO configurations respectively compared to Conventional DSRC. The reason behind this is Spatial Multiplexing MIMO improves system throughput with the increase of the number of antennas at both the transmitter and the receiver. Hence, the coding rate 1/2 turns out to be performing the best among all the coding rates.

VI. Conclusion

Spatial Multiplexing MIMO and Low Density Parity Check (LDPC) code have their own advantages and drawbacks. Also, the performance of LDPC varies when different coding rates are applied. The BER performance of LDPC while using coding rates higher than 1/2 is drastically worse than when coding rates 1/2 and lower are used. Consequently, the percentage of throughput improvement of coding rates higher than 1/2

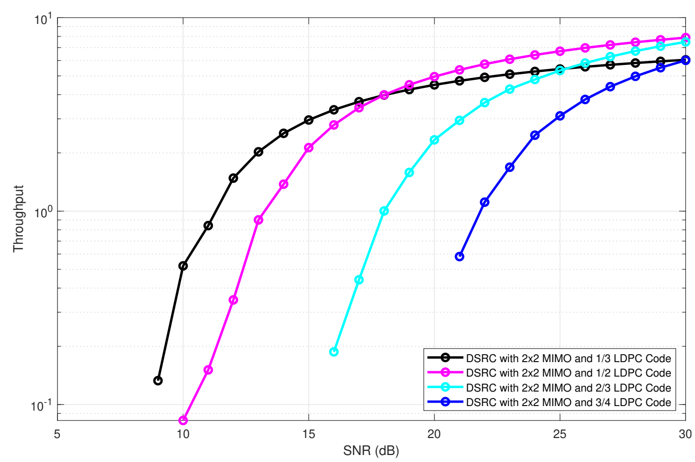

Fig. 10. Throughput comparison among 1/3, 1/2, 2/3, and 3/4 code rates while applying LDPC in DSRC along with 2x2 MIMO configuration.

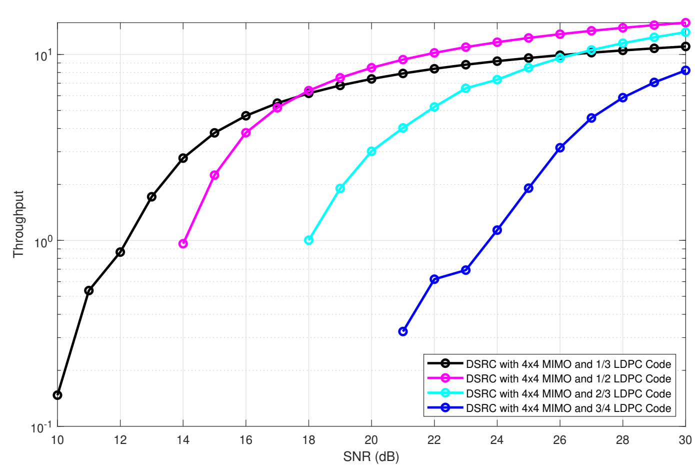

Fig. 11. Throughput comparison among 1/3, 1/2, 2/3, and 3/4 code rates while applying LDPC in DSRC along with 4x4 MIMO configuration.

TABLE IV
THROUGHPUT COMPARISON AMONG 1/3, 1/2, 2/3, AND 3/4 CODING RATES USING LDPC

Communication Configuration	Coding Rate	Throughput (in Mbps)
Conventional DSRC	1/3	3.47
	1/2	4.64
	2/3	4.17
	3/4	3.84
2x2 MIMO	1/3	6.06
	1/2	7.89
	2/3	7.49
	3/4	6.02
4x4 MIMO	1/3	11.04
	1/2	14.82
	2/3	13.18
	3/4	8.21

is worse than when coding rates 1/2 and lower are used. A modification in the PHY layer is proposed so that LDPC and MIMO can be utilized to improve the communication performance significantly. Without having much change in the hardware specification, this kind of communication framework is going to be required in the near future as the number of vehicles are increasing day by day. Our experimental results corroborate that, choosing the correct coding rate while using LDPC and MIMO in the vehicular communication framework can improve the system performance significantly. Moreover, we are trying to explore the Polar Code in the context of vehicular communication. Our future work includes checking the compatibility of the Polar Code in the DSRC framework. Our curiosity also grows on how would be the performance of Polar Code in terms of reliability and data rate if included in the existing DSRC standard.

REFERENCES

[1] H. Peng, L. Liang, X. Shen, and G.Y. Li, "Vehicular communications: A network layer perspective," in *IEEE Transactions on Vehicular Technology*, vol. 68, no. 2, pp. 1064-1078, 2019.

[2] P.K. Singh, S.K. Nandi, and S. Nandi, "A tutorial survey on vehicular communication state of the art, and future research directions," in *Vehicular Communications*, vol. 18, p. 100164, 2019.

[3] S. Majumder, D.C. Mandava, J. Kim, and A.Y. Javaid, "Multimedia Transmission for V2X Communication over Legacy LTE-A Network Infrastructure - A Performance Evaluation," in *2020 11th IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON)*, pp. 0028-0034, 2020.

[4] J. B. Kenney, "Dedicated Short-Range Communications (DSRC) Standards in the United States," in *Proceedings of the IEEE*, vol. 99, no. 7, pp. 1162-1182, 2011.

[5] E. Hossain, G. Chow, V.C. Leung, R.D. McLeod, J. Misic, V.W. Wong, and O. Yang, "Vehicular telematics over heterogeneous wireless networks: A survey," in *Computer Communications*, vol. 33 on. 7, pp. 775-793, 2010.

[6] W. Chen and S. Cai, "Ad hoc peer-to-peer network architecture for vehicle safety communications," in *IEEE Communications magazine*, vol. 43 no. 4, pp. 100-107, 2005.

[7] S. Biswas, R. Tatchikou, and F. Dion, "Vehicle-to-vehicle wireless communication protocols for enhancing highway traffic safety," in *IEEE communications magazine*, vol. 44, no. 1, pp. 74-82, 2006.

[8] M. Amadeo, C. Campolo, and A. Molinaro, "Enhancing IEEE 802.11 p/WAVE to provide infotainment applications in VANETs," in *Ad Hoc Networks*, vol. 10 no. 2, pp. 253-269, 2012.

[9] A.B. Al-Khalil, A. Al-Sherbaz, and S.J. Turner, "Enhancing the physical layer in V2V communication using OFDM-MIMO techniques," in *Northampton Electronic Collection of Theses and Research (NECTAR)*.

[10] R. Chataut, R. Akl, and U.K. Dey, "Least Square Regressor Selection Based Detection for Uplink 5G Massive MIMO Systems," In *2019 IEEE 20th Wireless and Microwave Technology Conference (WAMICON)*, pp. 1-6, 2019.

[11] R. Chataut, R. Akl, and U.K. Dey, "An Efficient and Fast-convergent Detector for 5G and Beyond Massive MIMO Systems," In *2021 11th IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON)*, 2021.

[12] A.J. Paulraj, D.A. Gore, R.U. Nabar, and H. Bolcskei, "An overview of MIMO communications-a key to gigabit wireless," in *Proceedings of the IEEE*, vol. 92 no. 2, pp. 198-218, 2004.

[13] J.C. Guey, M.P. Fitz, M.R. Bell, and W.Y. Kuo, "Signal design for transmitter diversity wireless communication systems over Rayleigh fading channels," in *IEEE Transactions on Communications*, vol. 47 no. 4, pp. 527-537, 1999.

[14] H. Bölcskei, D. Gesbert, and A. J. Paulraj,"On the capacity of OFDM-based spatial multiplexing systems," in *IEEE Transactions on Communications*, vol. 50, no. 2, pp. 225-234, 2002.

[15] S. Moser, L. Behrendt, and F. Slomka, "MIMO-enabling PHY layer enhancement for vehicular ad-hoc networks," in *2015 IEEE Wireless Communications and Networking Conference Workshops (WCNCW)* pp. 142-147, 2015.

[16] S. Poochaya, P. Uthansakul, and M. Uthansakul, "Preliminary study of DSRC using MIMO technique and software defined radio for ITS," in *2012 9th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, pp. 1-4, 2012.

[17] U. K. Dey, R. Akl, and R. Chataut, "High Throughput Vehicular Communication Using Spatial Multiplexing MIMO," in *2020 10th Annual Computing and Communication Workshop and Conference (CCWC)*, pp. 0110-0115, 2020.

[18] U.K. Dey, R. Akl, R. Chataut, and M. Robaei, "Modified PHY Layer for High Performance V2X Communication using 5G NR," in *2020 11th IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON)*, pp. 0137-0142, 2020.

[19] U. K. Dey, R. Akl, and R. Chataut, "Selective MIMO in Vehicular Communication for Reliable Safety Services and High Speed Non-Safety Services," in *2021 11th IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON)*, 2021.

[20] P. Dhivya Lakshmi, "Constructing Low-Density Parity-Check Codes in Digital Communication System," in *ICTACT Journal on Communication Technology*, vol. 11 on. 2, pp. 2198-2202, 2020.

[21] R. Gallager, "Low-Density Parity-Check Codes," in *IRE Transactions on information theory*, vol. 8 on. 1, pp. 21-28, 1962.

[22] T. J. Richardson, M. A. Shokrollahi, and R. L. Urbanke, "Design of Capacity-Approaching Irregular Low-Density Parity-Check Codes," in *IEEE transactions on information theory*, vol. 47 on. 2, pp. 619-637, 2001.

[23] S. Ten Brink, G. Kramer, and A. Ashikhmin, "Design of Low-Density Parity-Check Codes for Modulation and Detection," in *IEEE transactions on communications*, vol. 52 on. 4, pp. 670-678, 2004.

[24] S. Y. Chung, G. D. Forney, T. J. Richardson, and R. Urbanke, "On the Design of Low-Density Parity-Check Codes within 0.0045 dB of the Shannon Limit," in *IEEE Communications letters*, vol. 5 on. 2, pp. 58-60, 2001.

[25] A. Y. Kuti and A. E. Abdelkareem, "Evaluation of Low-density parity-check code with 16-QAM OFDM in a time-varying channel," in *2021 IEEE International Conference on Communication, Networks and Satellite (COMNETSAT)*, pp. 128-134, 2021.

[26] N. Khosroshahi and T. A. Gulliver, "Low Density Parity Check Codes for Dedicated Short Range Communication (DSRC) Systems," in *2009 IEEE Pacific Rim Conference on Communications, Computers and Signal Processing*, pp. 802-807, 2009.

[27] H. Futaki and T. Ohtsuki, "Low-Density Parity-Check (LDPC) Coded OFDM Systems," in *IEEE 54th Vehicular Technology Conference. VTC Fall 2001. Proceedings (Cat. No. 01CH37211)*, vol. 1, pp. 82-86, 2001.

[28] H. Futaki and T. Ohtsuki, "Low-Density Parity-Check (LDPC) Coded MIMO Systems with Iterative Turbo Decoding," in *2003 IEEE 58th Vehicular Technology Conference. VTC 2003-Fall (IEEE Cat. No. 03CH37484)*, vol. 8, pp. 342-346, 2003.