Vehicle MIMO System for High Reliability and Low Latency in NR-based eV2X

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***Abstract*—The 3rd Generation Partnership Project (3GPP) has recently developed enhanced vehicle-to-everything (eV2X) communication. The requirements of the eV2X service are significantly higher than those of existing V2X, with the required data transmission rates ranging from tens of Mbps to up to 1000 Mbps. In addition, communication should be performed with an extremely low error probability within a time delay of several to several tens of ms. In this study, a low-density parity-check code and 256 quadrature amplitude modulation (QAM), which are new radio technologies, are applied to meet the low-latency, high-reliability, and high-data-rate requirements of eV2X. In addition, we propose a vehicle multiple-input multiple-output system. The proposed system increases reliability through transmit diversity and lowers latency through a short transmission time interval. Simulation results show that the proposed system exhibits high reliability, high data rate, and low latency.**

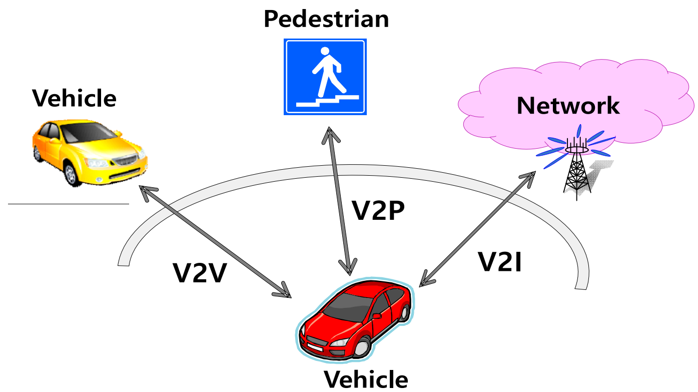
Keywords- eV2X; NR; sTTI; Transmit diversity.

I. INTRODUCTION

Communication technology has been used for communication between people and for providing information. However, in recent years, this technology has been applied to device-to-people and device-to-device communication. In particular, vehicular communication, which is also known as vehicle-to-everything (V2X), has several applications including navigation and driver assistance, travel information, congestion avoidance, fleet management, payment transactions, and traffic control and safety. As shown in Figure 1, V2X communication may occur in multiple contexts, i.e., vehicle-to-vehicle (V2V) communication, vehicle-to-pedestrian communication, and vehicle-to-infrastructure communication. These applications are referred to as cooperative-intelligent transport systems [1][2].

Autonomous vehicles will be developed in the future. These vehicles must exchange more data with neighboring vehicles, pedestrians, and road infrastructure with faster and higher reliability. The new requirement of autonomous vehicle service is limited by existing V2X communication technology, and there is a requirement for enhanced V2X (eV2X) technology to overcome this limitation.

The requirements of the eV2X service are significantly higher than those of existing V2X, with the required data transfer rates ranging from tens of Mbps to up to 1000 Mbps. In addition, communication should be performed with a considerably low error probability within a time delay of several to several tens of ms [3][4].



Figre 1. Types of V2X communication.

eV2X is being standardized in the 3rd Generation Partnership Project (3GPP), as shown in Figure 2. The 3GPP defines 5G technology from the Release 15 standard to be completion in June 2018. This technology consists primarily of long term evolution (LTE) and new radio (NR). NR is allowed to use a new physical channel structure and channel coding scheme with a new wireless access technology that is not compatible with existing LTE.

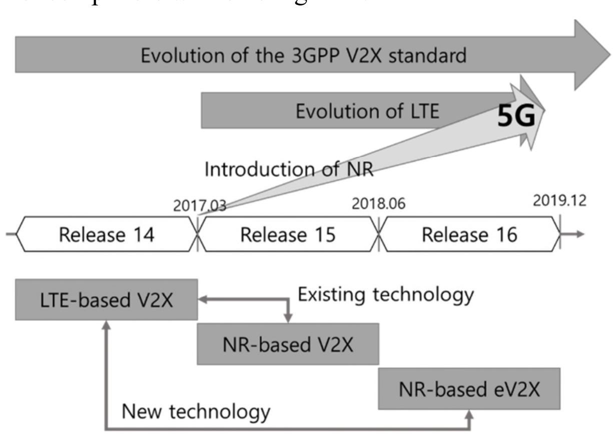


Figure 2. Standardization of eV2X in 3GPP.

In this study, a low-density parity-check (LDPC) code and 256 quadrature amplitude modulation (QAM), which are NR technologies, are applied to meet the low-latency, high-

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reliability, and high-data-rate requirements of eV2X. In addition, we propose a multiple-input multiple-output (MIMO) system that improves reliability through transmit diversity and reduces latency through a short transmission time interval (sTTI). The remainder of this paper is organized as follows: Section II presents NR-based eV2X communication. Section III describes the details of the proposed vehicle MIMO system. Section IV presents the performance analysis of the proposed scheme based on simulations. Section V states the conclusions of this study.

II. NR-BASED EV2X COMMUNICATIONS

In this section, we describe the LDPC code and 256 quadrature amplitude modulation (QAM), which are NR technologies.

A. LDPC

LDPC codes and polar codes, which are new channel coding techniques introduced in NR, can provide low latency and high reliability for eV2X. A channel coding scheme is a combination of error detection, error correcting, and rate matching as shown in Figure 3 [5]. In this study, the LDPC codes are applied as error correcting codes.

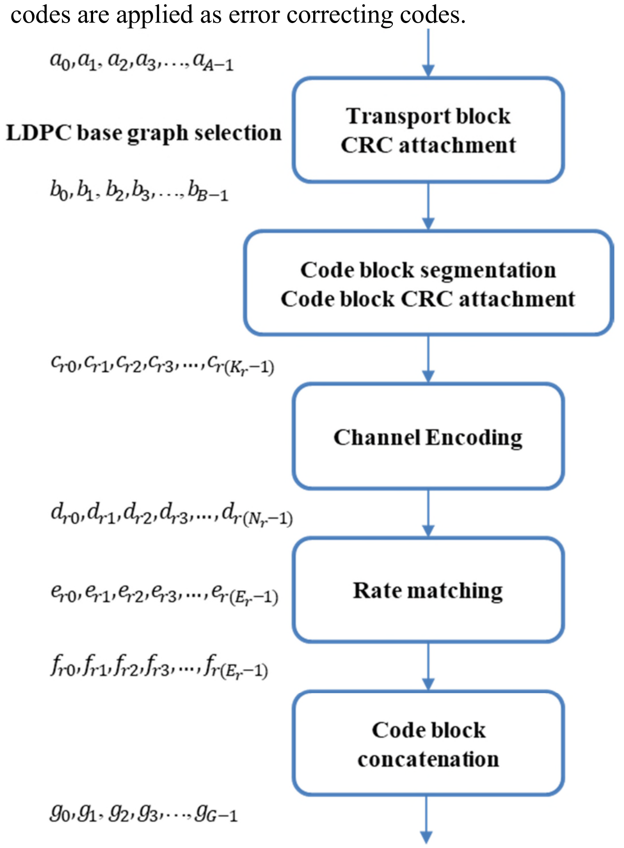

Figure 3. Transport block processing.

For the initial transmission of a transport block with a coding rate R and subsequent re-transmission of the same transport block, each code block of the transport block is encoded with either LDPC base graph 1 or 2 according to the following conditions:

- When (1) A ⩽ 292 or (2) A ⩽ 3824 and R ⩽ 0.67 or
(3) R ⩽ 0.25, LDPC base graph 2 is used;
- Otherwise, LDPC base graph 1 is used,

where A is the transport block size (TBS). Table I summarizes the LDPC base graph selection.

TABLE I. LDPC BASE GRAPH SELECTION

Code rate \ TBS	TBS ≤ 292	292 < TBS ≤ 3824	TBS > 3824
R ≤ 0.25	Base graph 2		
0.25 < R ≤ 0.67	Base graph 2		Base graph 1
R > 0.67	Base graph 2	Base graph 1	

For LDPC base graph 1, a matrix of $\mathbf{H}_{\mathrm{BG}}$ has 46 rows with row indices $i = 0,1,2,\ldots,45$ and 68 columns with column indices $j = 0,1,2,\ldots,67$. For LDPC base graph 2, a matrix of $\mathbf{H}_{\mathrm{BG}}$ has 42 rows with row indices $i = 0,1,2,\ldots,41$ and 52 columns with column indices $j = 0,1,2,\ldots,51$. The elements in $\mathbf{H}_{\mathrm{BG}}$ with row and column indices are of value 1, and all other elements in $\mathbf{H}_{\mathrm{BG}}$ are of value 0.

The matrix $\mathbf{H}$ is obtained by replacing each element of $\mathbf{H}_{\mathrm{BG}}$ with a $Z_c \times Z_c$ matrix, according to the following steps:

– Each element of value 0 in $\mathbf{H}_{\mathrm{BG}}$ is replaced by an all zero matrix $\mathbf{0}$ of size $Z_c \times Z_c$;

– Each element of value 1 in $\mathbf{H}_{\mathrm{BG}}$ is replaced by a circular permutation matrix $\mathbf{I}(P_{i,j})$ of size $Z_c \times Z_c$, where i and j are the row and column indices of the element, respectively, and $\mathbf{I}(P_{i,j})$ is obtained by circularly shifting the identity matrix $\mathbf{I}$ of size $Z_c \times Z_c$ to the right $P_{i,j}$ times. The value of $P_{i,j}$ is given by $P_{i,j} = \mathrm{mod}(V_{i,j}, Z_c)$. The value of $V_{i,j}$ is given according to the set index i_{LS} and base graph. $\mathbf{H}_{\mathrm{BG}}$ is given according to tables 5.3.2-1 and 5.3.2-2 in 3GPP TS 38.212 [5].

After the parity check matrix is obtained, we generate the parity bit $\mathbf{w} = (w_1, w_2)$ such that $\mathbf{H} \times \begin{bmatrix} \mathbf{c} \\ \mathbf{w} \end{bmatrix} = \mathbf{0}$, where c is the bit sequence input for a given code block to channel coding; $\mathbf{0}$ is a column vector of all elements equal to 0.

The parity bits are calculated using Richardson's efficient and Raptor such as LDPC, as shown in Figure 4.

Step 1) Richardson's Efficient LDPC: $w_1 = (w_1^1, w_1^2)$

The matrix is divided into A, B, C, D, E, and T, as shown in Figure 5 $\boldsymbol{w}_1$ is calculated using

$$w_1^{1^T} = \phi^{-1}(-ET^{-1}A + C)c^T \quad (1)$$
$$w_1^{2^T} = -T^{-1}(Ac^T + Bw_1{}^T) \quad (2)$$

where $\phi = -ET^{-1}B + D$.

Step 2) Raptor like LDPC: w_2

The matrix is divided into A, B, C, O, and I, as shown in Figure 6. w_2 is calculated using

$$w_2{}^T = -C(c \;\; w_1)^T \quad (3)$$

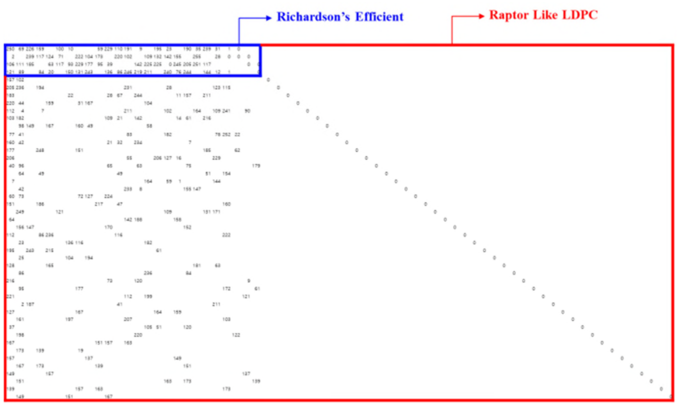

Figure 4. LDPC base graph 1: i_{LS}.

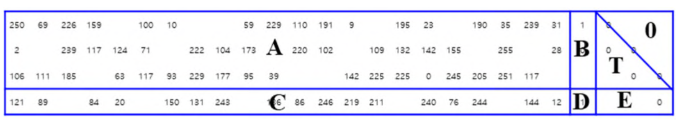

Figure 5. Richardson's Efficient.

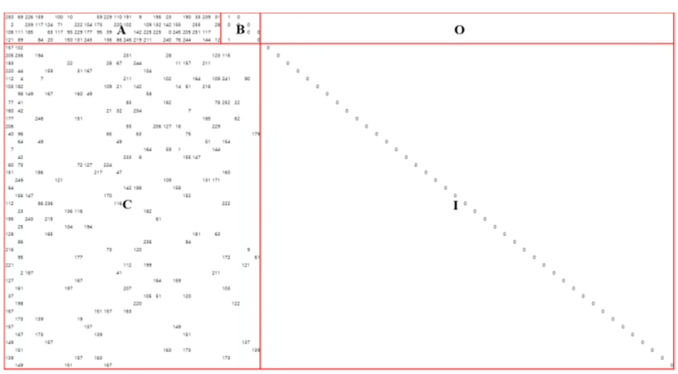

Figure 6. Raptor like LDPC.

B. 256QAM

256 QAM can be applied in order to provide a high data rate for eV2X. Figure 7 shows the constellation of 256 QAM. The eight input bits of 256 QAM, $(i), b(i+1), b(i+2), b(i+3), b(i+4), b(i+5), b(i+6), b(i+7)$, are mapped to complex-valued modulation symbols x, given below, as per the previous studies [6].

$$x = \frac{1}{\sqrt{170}}\{(1-2b(i))[8-(1-2b(i+2))[4-(1-2b(i+4))[2-(1-2b(i+6))]]] + j(1-2b(i+1))[8-(1-2b(i+3))[4-(1-2b(i+5))[2-(1-2b(i+7))]]]\} \quad (4)$$

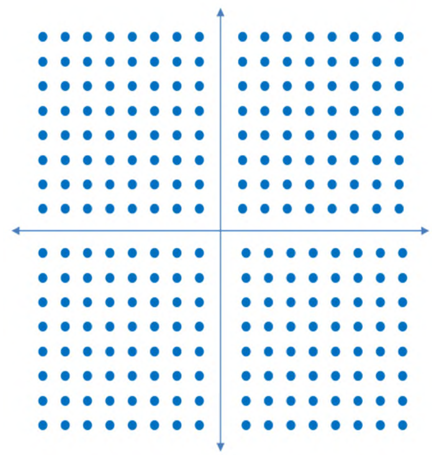

Figure 7. 256 QAM CONSTELLATION.

Therefore, 256 QAM improves the wireless transmission efficiency by 8/6 (or 1.33) times with 8 bit/symbol transmission of 256 QAM in 6 bit/symbol transmission of existing 64 QAM.

III. VEHICLE MIMO SYSTEM

In this section, we propose a vehicle MIMO system that improves reliability through transmit diversity and reduces latency through sTTI.

A. Transmit diversity

The eV2X service requires higher reliability and larger communication range in several use cases. All these requirements need physical layer enhancements. Transmit diversity can provide a gain on transmission reliability and potentially enlarge the communication range.

The symbols sent from two antennas, over two paired single-carrier frequency division multiple access (SC-FDMA) symbols form space time block coding (STBC), are as shown in Figure 8 [7].

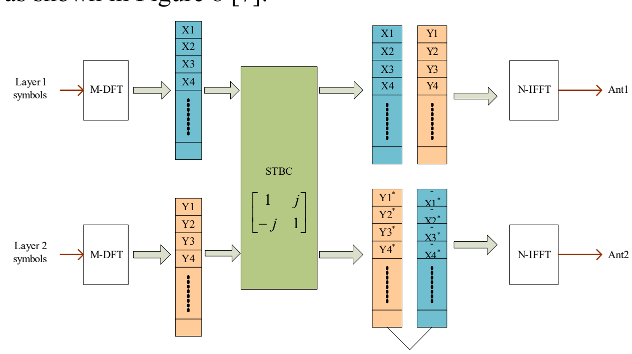

Figure 8. STBC transmit diversity.

B. *sTTI*

TTI is the time interval at which the transport blocks are scheduled and generally corresponds to the time required to transmit one transport block. TTI is defined as 1 subframe corresponding to 1 ms in the LTE standard.

As specified in Release 14 for V2V communication, the number of sidelink demodulation reference signal (DMRS) symbols per subframe is increased to 4 to combat a large Doppler effect in a high-speed scenario. For slot level short TTI, the structure of the second slot is a suitable choice where two DMRS symbols are evenly distributed in the time domain and a guard symbol is at the end.

In addition, STBC requires even number of SC-FDMA symbols, which can obtain full diversity gain. Therefore, the slot level sTTI is constructed as shown in Figure 9.

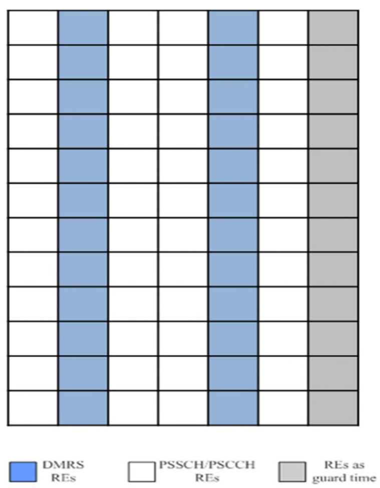

Figure 9. Structure of slot level sTTI.

The latency according to the TTI length is determined based on the frame alignment time by a 1/2 TTI time length, the processing time in each terminal or the base station and the data transmission time in a physical layer by one TTI time length, and the hybrid automatic repeat request (HARQ) BLER ($p = 0.1$) is the increase due to retransmission determined by round trip time (RTT). Assuming that the processing time is 0.2 ms, the latency of the user plane at 5G with time length is

$$0.5T_{TTI} + 2 \times 0.2 + T_{TTI} + p \times RTT\ [ms] \qquad (5)$$

Assuming that RTT is equal to 8 TTI, the final latency in Eq. (5) is

$$0.4 + (1.5 + 8p)T_{TTI} \qquad (6)$$

IV. SIMULATION MODEL AND PERFORMANCE ANALYSIS

In this section, we analyze the performance of the vehicle MIMO system. The simulations are based on the NR-based V2V system [8], and the simulation parameters are shown in Table II.

TABLE II. SIMULATION PARAMETERS

Parameters	Assumptions	
Carrier frequency	6 GHz	
Number of antenna	$1 \times 2, 2 \times 2$	
Vehicle speed	Urban: 15 km/h	Freeway: 140 km/h
Channel model	Urban: UMi LoS	Freeway: UMa NLoS
Modulation	16, 64, 256 QAM	
Channel coding	LDPC 1/2	

Figure 10 shows the BLER performance according to the antenna configuration. Based on the BLER 10^{-1}, the performance of transmit diversity is improved by 1.2 dB and 1 dB in urban areas and highways, respectively.

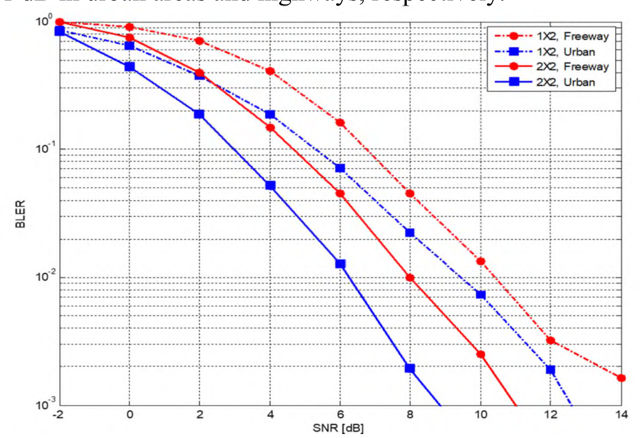

Figure 10. BLER performance according to antenna configuration.

Figures 11 and 12 show the throughput performance according to the modulation in the urban areas and highways, respectively. It can be seen that the maximum throughput of 16, 64, and 256 QAM is 2.43 Mbps, 3.60 Mbps, and 5.15 Mbps, respectively.

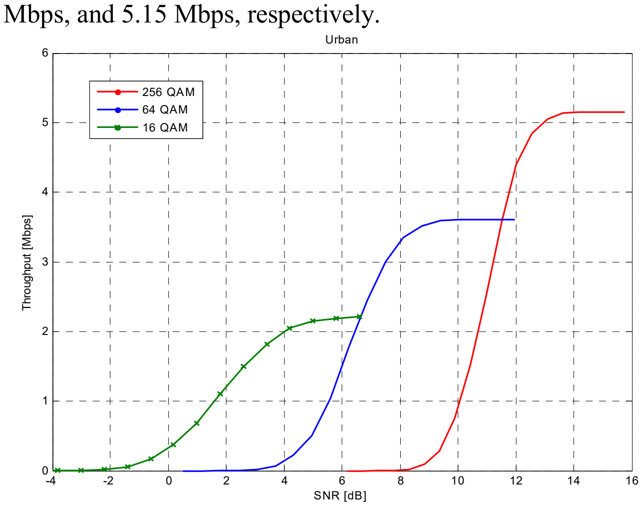

Figure 11. Throughput performance according to modulation in the urban area.

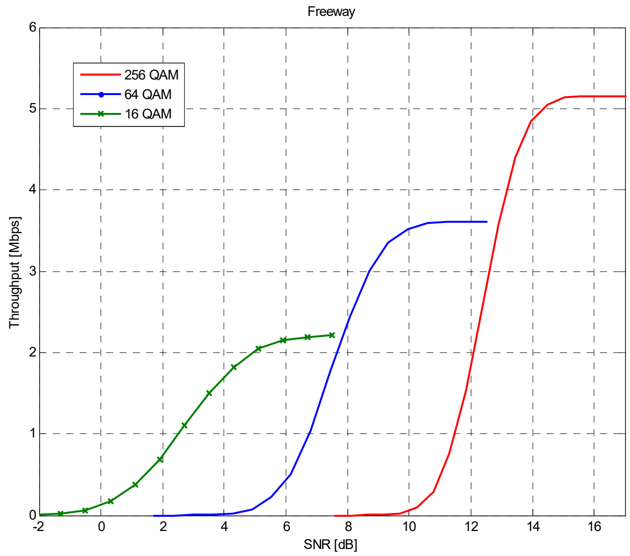

Figure 12. Throughput performance according to modulation in the freeway.

Figure 13 shows the delay time of the user plane according to the given TTI length using (6). The latency of 0.5 ms TTI compared to 1 ms TTI is reduced by 0.61 and 0.57 times, for p = 0.0 and 0.1, respectively.

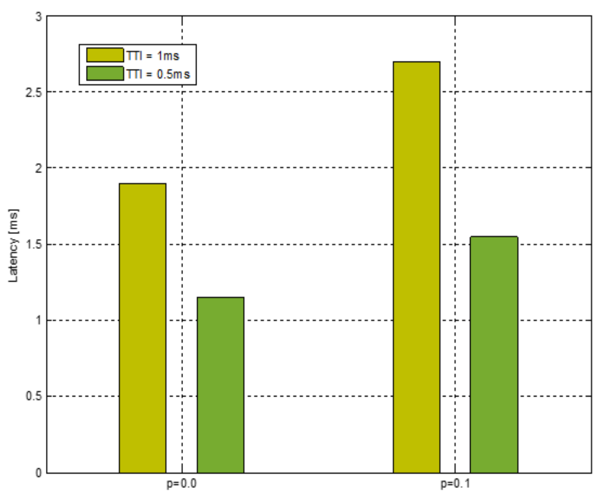

Figure 13. User plane latency for different TTI lengths.

V. Conclusion

In this study, the LDPC code and 256 QAM of NR technology were applied to meet the low latency, high reliability, and high data rate requirements of eV2X. In addition, we proposed a vehicle MIMO system. The proposed system increases reliability through transmit diversity and lowers latency through sTTI. Simulation results show that the proposed system has high reliability, high data rate, and short latency.

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