Performance Analysis of V2X with Enhanced Power Control

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***Abstract* — High transmission reliability is one of the most important service requirements in Vehicle-to-Everything (V2X) communication for driving control and information exchange between V2X vehicles. In a V2X service environment where direct communication is performed between V2X terminals, the terminal density of the communication coverage is a very important factor that determines the quality of service. Higher terminal density increases the possibility of communication conflicts and degrades connection reliability. To address this problem, research on distributed congestion control (DCC) is being conducted. DCC can be classified into transmission rate control and transmission power control. In this paper, a novel transmission power control method is proposed for efficient congestion control. Simulation results are also provided to evaluate the performance of the proposed method. The results show that the proposed method can be adaptively used in various V2X environments to improve service reliability and efficiency.**

Keywords—5G, V2X, Sidelink, Congestion, Power Control

I. Introduction

V2X is a communication technology that enables vehicles to exchange information with other vehicles or other V2X-related entities around them. Early V2X technology was developed based on IEEE 802.11p, a wireless access standard for use in vehicles. Wireless Access in Vehicular Environment (WAVE) is the US version of the IEEE 802.11p-based V2X standard developed primarily by IEEE and Society of Automotive Engineers (SAE), and ITS-G5 is the European version. Research has been conducted on V2X techniques using cellular communication to meet the higher level of V2X requirements such as mobility and delay and Cellular-V2X (C-V2X), a 3GPP LTE-based V2X, has been developed. Currently, 3GPP is standardizing New Radio (NR), a new wireless communication technology that supports high reliability, low latency and high data rate, and developing NR-V2X technology based on it [1]. Sidelink, one of the key technologies of the NR standard, is a direct communication mainly performed by the terminal, which enables the support of new application services such as V2X [2]. Through NR-V2X, which supports very low transmission delay and high reliability, autonomous driving services can provide high-level services such as remote driving, advanced driving, sensor information sharing and platooning [3].

To make efficient use of limited radio resources in a mobile communications environment, it is essential to detect available resources and avoid transmission conflicts. V2X terminals performing direct communication autonomously select, reselect, schedule, and manage resource allocation for transmission based on a channel sensing mechanism. As the number of V2X terminals in a direct communication environment increases, the possibility of multiple V2X terminals selecting the same resource increases [4]. Collision in resource selection causes problems such as data loss and transmission failure, and degrades transmission efficiency by increasing transmission delay. Therefore, DCC is being studied to address this problem.

The SAE J2945/1 specification for Vehicle-to-Vehicle (V2V) safety communication provides a DCC method that utilizes transmit rate control and transmit power control [5]. Transmit power control using Channel Busy Ratio (CBR), a radio channel status information, can adjust the communication range and reduce interference with neighboring terminals. The transmit power, Ptx of SAE DCC is calculated as in Equation 1 using CBR. CBR is the fraction of subchannels whose RSSI exceeds the threshold.

$$P_{tx} = \begin{cases} P_{max} & ,CBR \le U_{min} \\ P_{max} - \left(\frac{P_{max}-P_{min}}{U_{max}-U_{min}}\right)\cdot(CBR - U_{min}) & ,U_{min} < CBR < U_{max} \\ P_{min} & ,U_{max} \le CBR \end{cases} \quad (1)$$

Where P_{min} and P_{max} are the lower and upper power limits, and U_{min} and U_{max} are the lower and upper CBR thresholds.

C-V2X processes high-priority services or data first, using a priority-based congestion control scheme. The C-V2X congestion control scheme basically utilizes CBR and Channel occupancy Ratio (CR), which is the total number of subchannels occupied by the terminal for transmission. In the case of NR-V2X, congestion control is handled based on CBR and CR information in a similar manner to C-V2X.

NR-V2X is expected to satisfy higher service requirements in various communication scenarios compared to C-V2X. Therefore, it is necessary to research and develop a congestion control algorithm suitable for NR-V2X.

II. Power Control

A. Sidelink and Power Control

The purpose of uplink transmit power control in cellular networks is to optimize the power consumption required for transmission, thereby increasing the energy efficiency of the system and minimizing interference with other entities to ensure better communication performance. In the case of terminals, service time can be increased by minimizing unnecessary power consumption, and in the case of service providers, service quality can be improved through efficient management and optimization of network resources. Uplink power control in 3GPP LTE and NR is based on a combination of Closed-loop and Open-loop power control (OLPC) to achieve appropriate performance levels and reduce implementation complexity. OLPC estimates the transmission loss of the terminal and compensates the transmit power according to predefined values and methods accordingly. Therefore, the advantage of OLPC is that implementation is simple and power control can be performed quickly. However, since power control cannot be performed dynamically in response to changes in the environment and channel conditions and the transmit power level is fixed, optimization is difficult and unnecessary power consumption or interference problems may occur. Closed-loop power control according to the explicit power control command compensates for the residual loss of the OLPC. Optimal communication performance can be achieved by minimizing interference and energy consumption by dynamically responding to changes in the environment and channels in real time. However, the implementation is complex and the processing load is heavy.

NR Sidelink is a key technology for direct communication service between terminals through 5G NR air interface. NR Sidelink makes it possible to realize a higher level of V2X service by satisfying major requirements such as high reliability, low delay, and improved radio environment that LTE V2X cannot meet. In Sidelink communication, the terminal performs transmission by applying only the OLPC scheme. Sidelink power control is applied to PSCH, PSSCH, PSFCH and S-SSB signal transmission [6]. The terminal estimates the loss of the transmission signal based on the quality of the received signal. Then, the transmission is performed using the preconfigured default value and the expected loss. The transmit power of a Sidelink signal can be briefly expressed as follows.

$$P_{tx} = min\{P_{max}, P_{calculated} + \alpha \cdot PL\} \quad (2)$$

Where P_{max} is the maximum power configured by default and $P_{calculated}$ is the value calculated using the default power and radio settings. α is the pass loss compensation factor and PL is the estimated transmit pass loss.

α, also known as the fractional power control (FPC) factor, determines the degree of compensation for path loss. As α gets closer to 1, the estimated path loss is fully compensated, and as it gets closer to 0, it is less compensated. Increasing the compensation increases the transmit power and the transmission success rate to the target terminal, but also increases the interference to other terminals, resulting in a degradation of the overall system performance. In the opposite case, the transmission power is reduced and interference with neighboring terminals is reduced, but the transmission performance is severely degraded unless the transmission distance between terminals is sufficiently short. That is, FPC is a factor that determines the level of compensation for estimated path loss and is used to adjust the transmit power in a communication system. In general, the default system configuration is equally applied to the service area. If the transmit loss compensation is performed appropriately, the transmission and energy efficiency of the system can be improved. It can also contribute to reducing overall interference and optimizing network performance [7]. Therefore, research on a power control method that is suitable for the service environment and performs loss compensation in response to environmental changes dynamically and appropriately is very important to improve the transmission performance of the terminal and increase the service efficiency of the system.

B. Proposed Method and Simulation

According to previous V2X studies, terminal density and interference in the direct communication service area are closely related. This means that when the terminal density is high, interference increases, and when the density is low, interference decreases. In addition, in the case of low-density short-range transmission, the transmit control of the terminal is to set to the default config value of P_{max}, so it is highly likely to operate in an overpowered state greater than the appropriate output. This causes serious interference to neighboring terminals, resulting in a problem of degrading overall performance.

This paper proposes a transmit power control method using an adaptive and dynamic loss compensation technique in Sidelink communication for V2X service. The proposed loss compensation method estimates an appropriate FPC for the terminal using a stochastic model of the V2X terminal distribution. The path loss compensation for the terminal can be applied statically by applying the stochastic characteristics of the target V2X communication service model. It can also be used as a dynamic method to adjust the degree of path loss compensation using the characteristics extracted through statistical model analysis of the measured V2X service data during the operation. When power control is performed using the characteristics of the terminal distribution model according to the proposed method, the level of path loss compensation increases as the distribution measure approaches the service model. On the other hand, as the difference between the terminal distribution measure and the service model increases, the level of path loss compensation decreases. This can reduce interference and improve transmission performance in both low-density, short-range and high-density, long-range communication environments.

For performance analysis, simulations were performed on the power control method using the general open-loop compensation scheme, the DCC type compensation scheme and the proposed modified FPC scheme. Figure 1 shows the three types of FPC for a range of vehicle density values.

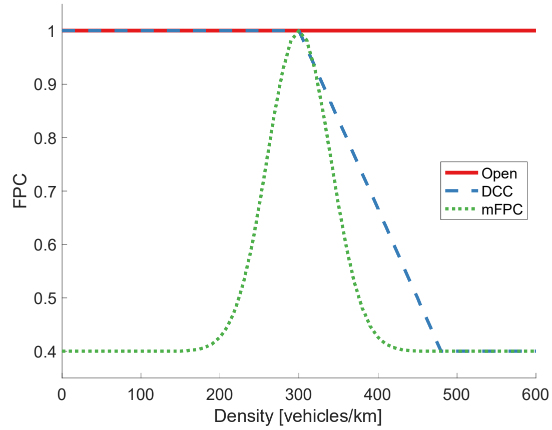

Figure 1. Vehicle density and FPC

The performance of the three power control methods was investigated using a modified open source V2X simulator, WiLabV2Xsim. In the transmission process, fractional path loss compensation is applied using the FPC coefficient corresponding to each terminal density. The main simulation settings used in the experiment are summarized in Table 1. It is assumed that the average terminal density of the V2X service is 300 vehicles/km and the variance is 40 vehicles/km.

TABLE I. SIMULATION PARAMETERS AND SETTINGS

Parameters and Settings	Values
Road layout	Highway, 3 + 3 lane
Density	100, 200, 300, 400, 500 vehicles/km
Technology	NR-V2X
Average speed	70 km/h (7 km/h std.)
Bandwidth and carrier frequency	10 MHz @ 5.9 GHz
MCS	11
SCS	15
Subchannel size	10 PRBs
Transmission power	23 dBm
Antenna gain	3 dBi
Noise figure	6 dB
Propagation model	WINNER+, Scenario B1
Shadowing	3 dB variance, decorr. dist. 25 m
Payload size	512 bytes
Payload generation	every 100 ms
RSRP threshold	-126 dBm

The packet reception ratio (PRR) is used to evaluate the performance of each power control method. PRR is the ratio of successfully decoded packets to the total number of message packets transmitted to neighboring terminals within a certain range. Figure 2 shows the PRR for different distances between Tx and Rx vehicles, for vehicle densities of 100, 200, 300, 400 and 500 per km. From the figure, it can be seen that the proposed power control method is superior to the other method of the general open-loop scheme or the DCC scheme in all cases except 300 vehicles/km with the same FPC value. Especially in the case of low terminal density, the performance improvement of the proposed method can be clearly confirmed.

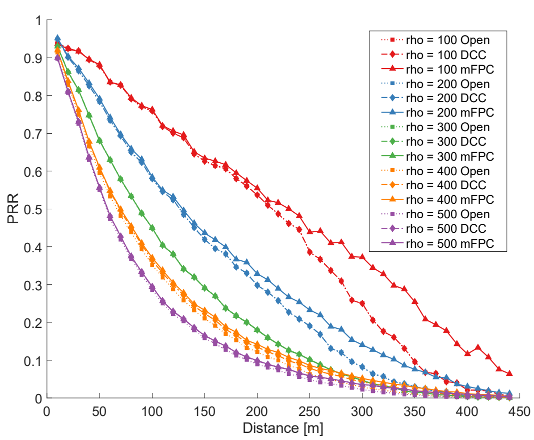

Figure 2. PRR vs. distance for various vehicle densities

III. CONCLUSIONS

V2X is considered to be the most important element of 3GPP next generation services. In order to provide enhanced V2X services, an access technology with low-delay and high-reliability is required. NR-based Sidelink is a direct communication technology that satisfies the requirements of advanced V2X services. In a V2X service environment, the density of terminals is directly related to the transmission collision rate and is a factor that determines transmission efficiency. Accordingly, it is essential to mitigate interference between terminals by adjusting the transmitting power appropriately in accordance with the transmission environment. This paper proposes an improved power control method for NR-V2X communication. The proposed method performs fractional path loss compensation adjusted according to the terminal distribution information by exploiting the stochastic characteristics of the target V2X service. The efficiency of the proposed scheme and other schemes has been verified and compared through simulation. The proposed method shows better performance than other methods, especially in a low density environment. Through this, it can be seen that transmit power control can be performed adaptively to the V2X service environment to improve the transmission performance of the terminal and to enhance the service quality of the system.

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