Adaptive Transmission Scheme for Vehicle Communication System

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Abstract: Advances in Vehicle-to-Everything (V2X) communication attempt to enhance traffic safety by employing advanced wireless communication systems. V2X communication is a core solution to manage and advance future traffic safety and mobility. In this study, we design a system-level simulator (SLS) for Long Term Evolution (LTE)-based V2X and propose an adaptive transmission scheme for vehicle communication. The proposed scheme allocates the resource randomly in the time and frequency domains and transmits the message according to the probability of transmission. The performance analysis is based on the freeway scenario and periodic message transmission. Simulation results show that the proposed scheme can improve the cumulative distribution function (CDF) of the packet reception ratio (PRR) and the average PRR.

1 INTRODUCTION

Communication technology has been utilized for communication and provision of information between people. However, in recent years, the application of this technology has been expanded for device-to-people and device-to-device communication. In particular, vehicular communication (V2X: vehicle-to-everything) has many applications, including navigation and driver assistance, travel information, congestion avoidance, fleet management, payment transactions, and traffic control and safety.

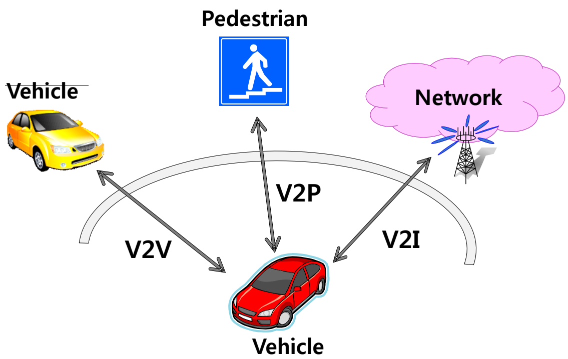

Figure 1: Types of V2X communication.

As shown in Figure 1, V2X communication may occur in multiple contexts: vehicle-to-vehicle (V2V) communication, vehicle-to-pedestrian (V2P) communication, and vehicle-to-infrastructure (V2I) communication. These applications are referred to as Intelligent Transport Systems (ITS). V2X applications range from personal communication and green transportation to societal mobility and safety in order to increase travel convenience, comfort, and safety.

V2X applications can be supported by two main communication classes: cellular-based communication systems (e.g., Long Term Evolution (LTE)) and Wi-Fi-based communication (e.g., 802.11p or 802.11n). These systems have different characteristics with respect to latency, coverage, reliability, and data rate. Although the latency of cellular communication systems decreases with the evolution of these systems, Wi-Fi systems provide a delay of only several milliseconds in most situations. In contrast, the coverage of Wi-Fi is significantly smaller when compared with cellular communication owing to the lower transmission power and higher frequency of 802.11p. The reliability of both the communication classes depends on the environment and on the other users within communication range. Typically, a cellular system provides higher reliability than a Wi-Fi based system; a cellular system also guarantees quality of service (QoS) for the V2X applications when compared with a Wi-Fi based system. However, Wi-Fi systems are operating in an unlicensed spectrum whereas the operators of

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cellular communications must pay for the frequencies. The data rate is similar for both the classes. Further, hybrid approaches, which combine the advantages of cellular-based and Wi-Fi-based communication systems, are suitable solutions for efficient V2X communication. LTE has introduced a device-to-device (D2D) communication link from Release 12; therefore, cellular D2D can be used instead of a Wi-Fi based system.

In this manuscript, we design a system-level simulator (SLS) for LTE-based V2X and propose an adaptive transmission scheme for vehicle communication. The proposed scheme allocates the resource randomly in the time and frequency domains and transmits the message according to the probability of transmission. The remainder of this manuscript is organized as follows. Section 2 presents the design and deployment of the V2X SLS. Section 3 describes the details of the proposed adaptive transmission scheme. Section 4 presents the performance analysis of the proposed scheme based on simulations. Section 5 states the conclusion of the study.

2 DEPLOYMENT OF V2X SYSTEM LEVEL SIMULATOR

In this section, we describe the V2X system structure. Figure 2 shows the block diagram of the V2X SLS. The V2X system consists of evaluation scenario, user equipment (UE) drop and mobility model, evolved Node B (eNB) and road side unit (RSU) deployment, a channel model and traffic model. In addition, we analyze the performance by using the packet reception ratio (PRR).

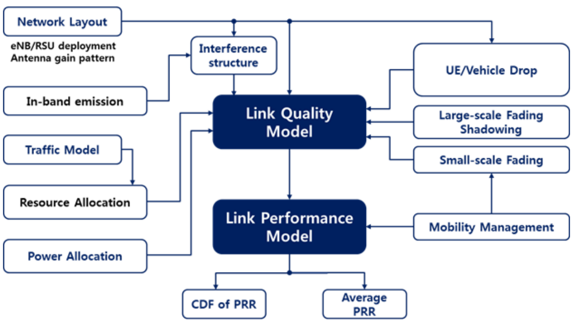

Figure 2: Block diagram of V2X system-level simulator.

2.1 Evaluation Scenarios

We define two vehicle UE drop scenarios: Urban scenario and Freeway scenario. The UE drop model and mobility model are described in Section 2.2. Further, the channel model for each scenario is described in Section 2.4.

Macro eNB may or may not be deployed in the evaluation. If it is deployed, the assumptions in Section 2.3 should be used. If it is not deployed, a simple wrap around can be used.

2.2 UE Drop and Mobility Model

Vehicle UEs are dropped on the roads according to the spatial Poisson process. The vehicle density is determined by the vehicle speed assumption, and the vehicle location should be updated once every 100 ms in the simulation. In the urban scenario, a vehicle changes its direction at the intersection as follows:

- Go straight with probability 0.5
- Turn left with probability 0.25
- Turn right with probability 0.25

Figures 3 and 4 illustrate the road configuration for the two scenarios.

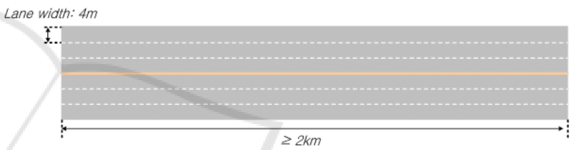

Figure 3: Road configuration for urban scenario.

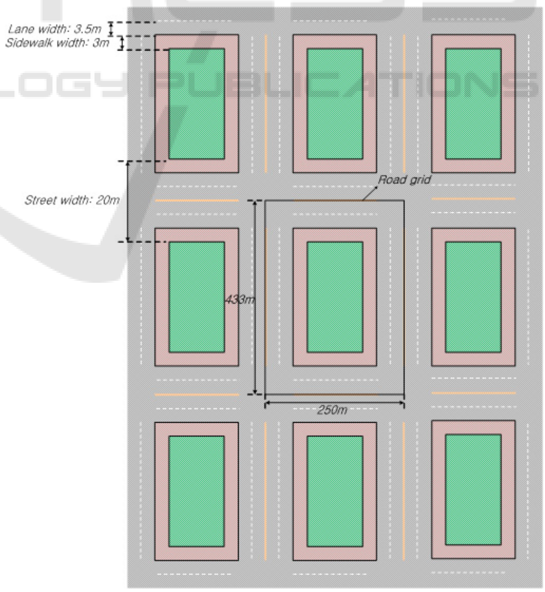

Figure 4: Road configuration for urban scenario.

2.3 eNB and RSU Deployment

If macro eNBs are deployed in the freeway scenario, the eNBs are located along the freeway at a distance 35 m away with an ISD of 1732 m, as shown in

Figure 5. If macro eNBs are deployed in the urban scenario, the inter-site distance (ISD) of the macro eNB is 500 m, and the wrap around model is as shown in Figure 6.

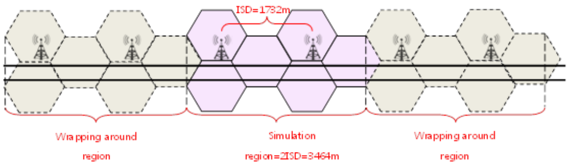

Figure 5: Wrap around model for urban scenario.

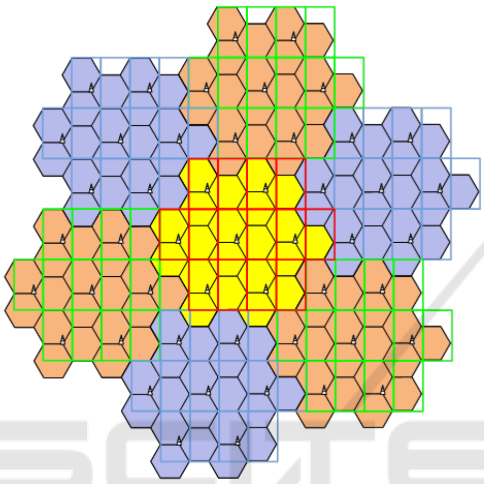

Figure 6: Wrap around model for urban scenario.

2.4 Channel Model

The assumptions for the channel between two vehicle UEs are given in Table 1.

Table 1: Channel model parameters.

Parameter	Freeway scenario	Urban scenario
Pathloss model	LOS in WINNER+ B1	WINNER+B1 Manhattan grid layout
Shadowing distribution	Log-normal	Log-normal
Shadowing standard deviation	3 dB	3 dB for LOS and 4 dB for NLOS
Decorrelation distance	25 m	10 m
Fast fading	NLOS in Section A.2.1.2.1.1 or A.2.1.2.1.2 in 3GPP TR 36.843 with fixed large-scale parameters during the simulation.	

2.5 Traffic Model

In the evaluation, we use two traffic models: periodic traffic scenario and event-triggered traffic scenario. The periodic traffic scenario is mandatory. The event-triggered traffic scenario can be evaluated optionally with or without periodic traffic. Every vehicle in the simulation generates messages according to the traffic model.

For periodic traffic, the working assumption for the message size is that one 300-byte message is followed by four 190-byte messages, and the time instant for the 300-byte size message generation is randomized among vehicles. The message size can be ignored while calculating the performance metric. For event-triggered traffic, the event arrival follows a Poisson process with the arrival rate of X (based on company choice) per second for each vehicle. Once the event is triggered, six messages are generated within a span of 100 ms. The working assumption for the message size of event-trigger traffic at L1 is 800 bytes.

2.6 Performance Metric

In the evaluation of the proposed schemes for V2V, the PRR will be considered. For one Tx packet, the PRR is calculated as X/Y, where Y is the number of UE/vehicles that are located in the range (a, b) from the Tx, and X is the number of UE/vehicles with successful reception among Y. The Cumulative Distribution Function (CDF) of PRR and the following average PRRs are used in the evaluation:

- CDF of PRR with a = 0, b = baseline of 320 m for freeway scenario and 150 m for urban scenario. Optionally, b = 50 m for urban scenario with vehicle speed of 15 km/h.
- Average PRR, calculated as (X1+X2+X3 ….+Xn)/(Y1+Y2+Y3…+Yn), where n denotes the number of generated messages in simulation, a = i×20 m, b = (i+1)×20 m, and i=0, 1, …, 25.

3 ADAPTIVE TRANSMISSION SCHEME

In this section, we propose an adaptive transmission scheme for vehicle communication. The proposed scheme allocates the resource randomly and transmits the message according to the probability of transmission.

The resource is allocated randomly in the time and frequency domains. The resource units are defined as illustrated in Figure 7. N_F represents the number of total resource blocks (RBs). M_{RB} denotes the number of allocated RBs. Therefore, the resource is allocated with a subchannel unit that consists of M_{RB} RBs in the frequency domain. In addition, M_{SF} denotes the number of subframes used for message transmission with the periodicity of T_P subframes.

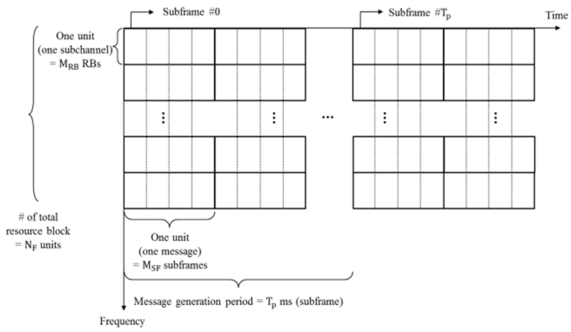

Figure 7: Resource unit structure.

Figures 8 and 9 show an example of the resource allocation structure for the periodic and event-triggered scenarios, respectively. In this figures, we set M_{RB}=10 with N_F=50 (for 10 MHz bandwidth) in the frequency domain. Thus, the random frequency range is 0 to 4 (0–(floor(N_F/M_{RB})-1)). In addition, we set $M_{SF,300B}$=3 and $M_{SF,190B}$=2 with T_P=100 ms in the time domain. Thus, the random time range is 0 to 97 ms (0–(T_P-$M_{SF,1}$)).

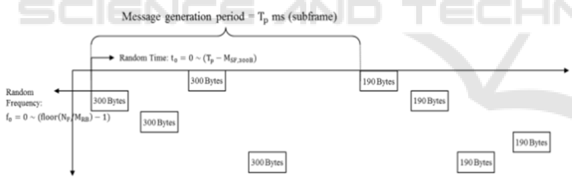

Figure 8: Resource allocation for periodic traffic.

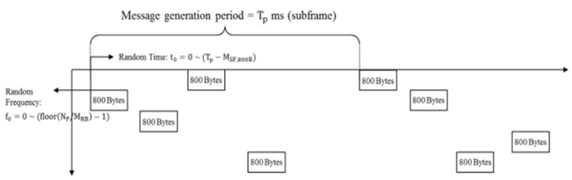

Figure 9: Resource allocation for event-triggered traffic.

In addition, Tx UE transmits the message with a probability P_{Tx}. Thus, the interference effect decreases and the performance improve because Tx UE does not transmit the message with a probability (1-P_{Tx}). If Tx UE does not transmit the message, we calculate the PRR that satisfies 100%.

4 SIMULATION MODEL AND PERFORMANCE ANALYSIS

4.1 Simulation Model and Simulation Parameters

A system-level simulation is performed to evaluate the performance of the proposed scheme. The simulation follows the 3GPP evaluation methodology. The simulation is based on the freeway case scenario in and periodic message transmission. Table 2 shows the general simulation parameters and defines the simulated environment.

Table 2: Simulation parameters.

<table>
<tr><th colspan="2">Parameter</th><th>Assumption</th></tr>
<tr><td colspan="2">Carrier frequency for PC5-based V2V</td><td>6 GHz</td></tr>
<tr><td colspan="2">Bandwidth</td><td>10/20 MHz</td></tr>
<tr><td colspan="2">Number of carriers</td><td>One carrier</td></tr>
<tr><td colspan="2">Synchronization</td><td>Frequency error ± 0.1 PPM.</td></tr>
<tr><td rowspan="7">Vehicle UE para-meters</td><td>In-band emission</td><td>In-band emission model with {W, X, Y, Z} = {3, 6, 3, 3} for single cluster SC-FDMA.</td></tr>
<tr><td>Antenna height</td><td>1.5 m</td></tr>
<tr><td>Antenna pattern</td><td>Omni 2D</td></tr>
<tr><td>Antenna gain</td><td>3 dBi</td></tr>
<tr><td>Maximum tx. power</td><td>23 dBm</td></tr>
<tr><td>Number of antennas</td><td>1 TX and 2 RX antennas</td></tr>
<tr><td>Noise figure</td><td>9 dB</td></tr>
<tr><td colspan="2">Number of lanes</td><td>3 in each direction</td></tr>
<tr><td colspan="2">Lane width</td><td>4 m</td></tr>
<tr><td colspan="2">Simulation area size</td><td>Freeway length >= 2000 m.</td></tr>
<tr><td colspan="2">Vehicle density</td><td>2.5 s × absolute vehicle speed</td></tr>
<tr><td colspan="2">Absolute vehicle speed</td><td>70 km/h, 140 km/h</td></tr>
<tr><td colspan="2">ISD</td><td>1732 m</td></tr>
<tr><td colspan="2">Pathloss model</td><td>LOS in WINNER+ B1</td></tr>
<tr><td colspan="2">Shadowing distribution</td><td>Log-normal</td></tr>
<tr><td colspan="2">Shadowing standard deviation</td><td>3 dB for LOS and 4 dB for NLOS</td></tr>
<tr><td colspan="2">Decorrelation distance</td><td>25 m</td></tr>
<tr><td colspan="2">Fast fading</td><td>NLOS in Section A.2.1.2.1.1 or A.2.1.2.1.2 in 3GPP TR 36.843 with fixed large-scale parameters during the simulation.</td></tr>
<tr><td colspan="2">Traffic Model</td><td>Periodic traffic</td></tr>
<tr><td colspan="2">Message size</td><td>One 300-byte message followed by four 190-byte messages</td></tr>
</table>

Further, the time and frequency resource in the simulation is defined according to the category and condition, as shown in tables 3 and 4, respectively.

Table 3: Category for simulation.

Category	Total number of RBs (N_F)	Probability of transmission (P_{Tx})	Number of transmissions (R)
1	100	1	4
2	100	1	2
3	50	1/2	4
4	50	1/2	2

Table 4: Condition for simulation.

300 Bytes	Number of RBs	10
	Number of subframes	3
	Code rate (Modulation/I_{TBS})	0.3030 (QPSK/5)
190 Bytes	Number of RBs	10
	Number of subframes	2
	Code rate (Modulation/I_{TBS})	0. 2879 (QPSK/5)

4.2 Simulation Results and Performance Analysis

4.2.1 Resource Status

In this section, we analyze the resource status according to the category in the simulation area, as shown in Figure 6. The number of collision RBs, unused RBs, and used RBs per subframe are listed in Table 5 and Table 6 according to the vehicle speed, category (CAT).

The number of allocated RBs (N_F) is 100, and the number of transmissions (R) is 4. Thus, the number of collision RBs is the highest because the number of used RBs is the highest. In the case of category 2, N_F is 100, and R is 2. Thus, we observe that the number of collision RBs is lower than that in category 1 owing to the decrease in the number of used RBs that use a reduced number of transmissions. In the case of categories 3 and 4, the number of collision RBs decreases because the probability of collision increases when the number of allocated RBs is reduced to 50; however, categories 3 and 4 do not transmit with a probability 1/2. In addition, the value of R for category 3 and 4 is 4 and 2, respectively. Thus, the number of collision RBs decreases as the number of transmissions decreases.

Table 5: Resource status: velocity 70km/h.

CAT	Collision RBs	Unused RBs	Used RBs
1	67.4	12.1	87.9
2	37.9	30.4	69.6
3	31.6	8.3	41.7
4	19.6	13.3	36.7

Table 6: Resource status: velocity 140km/h.

CAT	Collision RBs	Unused RBs	Used RBs
1	36.3	32.6	67.4
2	17.4	51.5	48.5
3	20.8	14.1	35.9
4	9.3	24.1	25.9

4.2.2 PRR

The CDF of PRR and the average PRR are used in the evaluation. Figures 10 and 11 show the CDF of PRR for vehicle speeds of 70 km/h and 140 km/h, respectively. Figure 12 and Table 7 show the average PRR for a vehicle speed of 70 km/h. Figure 13 and Table 8 show the average PRR for a vehicle speed of 140 km/h.

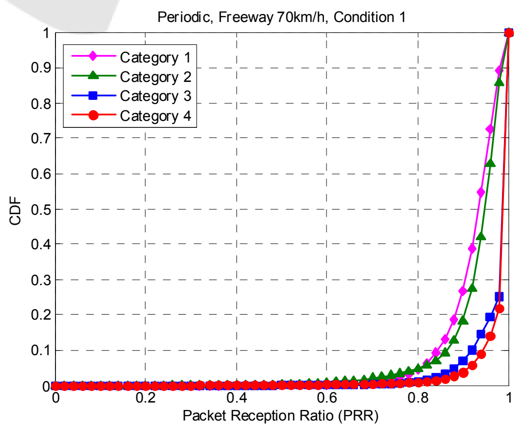

Figure 10: CDF of PRR: velocity 70km/h.

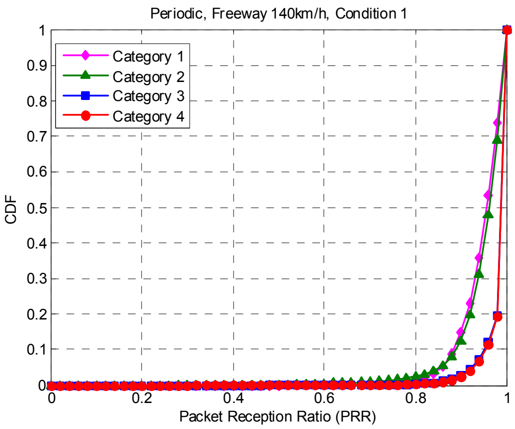

Figure 11: CDF of PRR: velocity 140km/h.

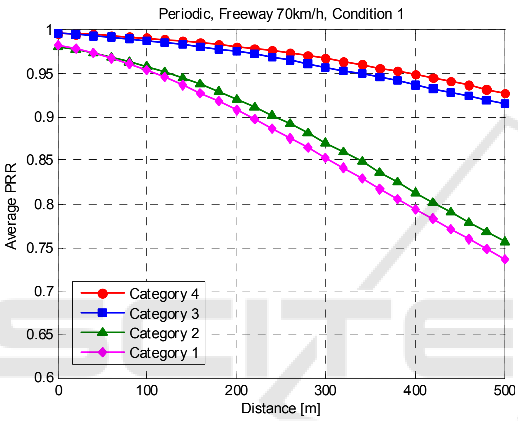

Figure 12: Average PRR: velocity 70km/h.

Table 7: Average PRR: velocity 70km/h.

Range (m)	CAT 1	CAT 2	CAT 3	CAT 4
20~40	0.9778	0.9770	0.9941	0.9948
60~80	0.9673	0.9682	0.9912	0.9928
100~120	0.9538	0.9576	0.9877	0.9902
140~160	0.9365	0.9443	0.9830	0.9870
180~200	0.9177	0.9291	0.9774	0.9829
220~240	0.8973	0.9111	0.9715	0.9781
260~280	0.8754	0.8920	0.9648	0.9729
300~320	0.8530	0.8700	0.9570	0.9666
340~360	0.8294	0.8482	0.9491	0.9596
380~400	0.8054	0.8245	0.9409	0.9520
420~440	0.7830	0.8013	0.9325	0.9441
460~500	0.7593	0.7787	0.9238	0.9359
500~520	0.7366	0.7566	0.9148	0.9273

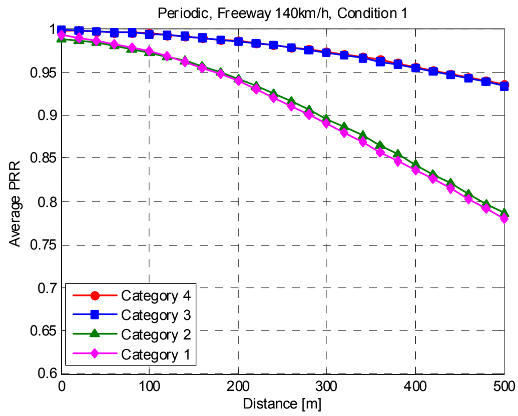

Figure 13: Average PRR: velocity 140km/h.

Table 8: Average PRR: velocity 140km/h.

Range (m)	CAT 1	CAT 2	CAT 3	CAT 4
20~40	0.9895	0.9863	0.9975	0.9970
60~80	0.9822	0.9805	0.9958	0.9957
100~120	0.9736	0.9721	0.9938	0.9939
140~160	0.9617	0.9623	0.9911	0.9909
180~200	0.9472	0.9493	0.9876	0.9876
220~240	0.9298	0.9335	0.9833	0.9832
260~280	0.9102	0.9157	0.9776	0.9786
300~320	0.8904	0.8959	0.9722	0.9731
340~360	0.8686	0.8756	0.9658	0.9664
380~400	0.8464	0.8542	0.9585	0.9593
420~440	0.8257	0.8316	0.9506	0.9513
460~500	0.8029	0.8086	0.9419	0.9434
500~520	0.7797	0.7865	0.9336	0.9347

5 CONCLUSIONS

In this study, we designed an SLS for an LTE-based V2X and proposed an adaptive transmission scheme for vehicle communication. We allocated the resource randomly in the time and frequency domains and transmitted the message according to the probability of transmission. The performance analysis was based on the freeway scenario and periodic message transmission. Simulation results show that our proposed scheme can improve the CDF of PRR and the average PRR.

In future work, we will consider the resource allocation algorithm in order to improve the reliability of the LTE-based V2X system.

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