Inter-Cell Interference Suppression at Wireless Vehicle Access Networks with Distributed Subcarrier Mapped OFDM

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Abstract: In the wireless vehicle access networks (WVAN), the inter-cell interference (ICI) is the main barrier of the stable and fast vehicular communication services. We propose a ICI suppression technique by using the Distributed Subcarrier Mapped Orthogonal Freqeuncy Division Multiplexing (DS-OFDM) for WVAN. Compared to the Localized Subcarrier Mapped OFDM (LS-OFDM), DS-OFDM has a merit of reducing the intensity of inter-cell interference in fast moving vehicle circumstances thanks to Doppler spreading effect. Numerical results show that DS-OFDM outperforms LS-OFDM in terms of outage probability espeically when we set the threshold SINR lower than the average of SINR.

Keywords—**Vehicle to vehicle communication, OFDM, Wireless vehicle access network, Inter-cell interference**

1. Introduction

The diffusion of smart devices such as smart phones, tablets, and sensors has led to the explosion of wireless data traffic. Especially in public transportation vehicles, vehicle users need high data traffic not only for infotainment services but also for Intelligent Transportation System (ITS). There are many researches about Vehicles to Vehicles (V2V) and Vehicle to Infra (V2I) networks to support the increasing traffic demand for vehicular services [1]-[2]. Unlike V2V and V2I, there are few researches about WVAN even with the increasing number of passengers who are eager to access the core data networks wirelessly.

With the limited radio resource of WVAN, ICI is an unavoidable issue to serve the increasing requests of high data rate of passengers. Especially in the circumstance of fast moving vehicles, the cell cooperative ICI suppression scheme is difficult to be implemented. Even though, the intensity of ICI is reduced by Vehicle Penetration Loss (VPL) which is the reduction in power of a certain signal as it propagates through the metallic body of vehicles [3]. In ultra-dense urban scenario, Y. Sui et al showed that the performance of WVAN is still limited by ICI [4].

Our goal in this paper is to suppress ICI at WVAN. Specifically, we focus on the scheme which works in distributed manner. Based on the analysis of Doppler spreading effect, we propose to use DS-OFDM rather than LS-OFDM. We first describe the difference between DS-OFDM and LS-OFDM. Then we calculate the average and the variance of SINR of DS-OFDM and LS-OFDM. Finally, we compare the outage probability of DS-OFDM and LS-OFDM through the numerical simulation.

2. System Model

In this paper, we consider WVAN which uses the same radio resource with V2V and V2I networks. Therefore there are inter-cell interferences among V2V, V2I, and WVAN. Even though the metal frame of vehicles reduces the power level of inter-cell interferences by VPL, in the ultra-dense urban scenario the total sum of inter-cell interferences from other networks is not negligible. The Doppler effect is the frequency shift due to moving of a transmitter or a receiver. The Doppler frequency offset is defined as

$$f_D = \frac{f_c \Delta v}{c}, \tag{1}$$

where f_c is the carrier frequency, Δv is the velocity difference between a transmitter and a receiver, and c is the speed of light. Note that since vehicles are moving, there is Doppler frequency offset among the target WVAN, other WVAN, and infra networks.

3. Distributed Subcarrier Mapped OFDM

The main difference of DS-OFDM and LS-OFDM is the way of subcarrier allocation. DS-OFDM allocates subcarriers sparsely, but LS-OFDM does consecutively [5]. We can

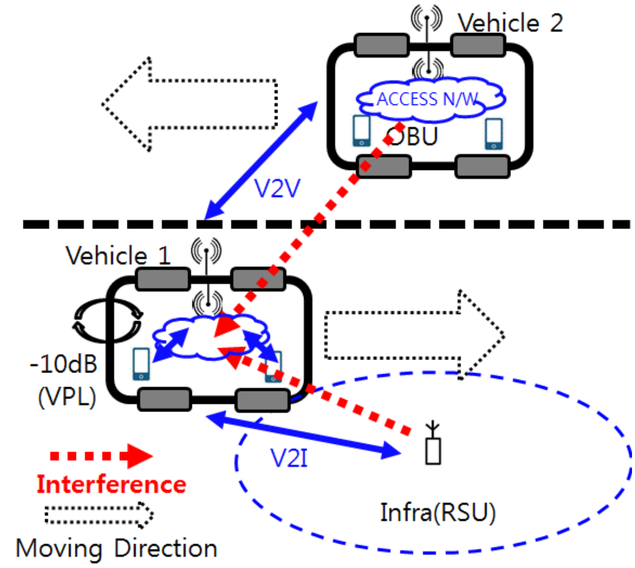

Figure 1. Vehicle access network

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express nth transmitting DS-OFDM/LS-OFDM symbols x_n at time m as:

$$x_{n\_DS-OFDM}(m) = \sum_{k=0}^{N-1} X_{n,k} e^{j2\pi(n+r\times k)m/N_{total}}, \quad (2)$$

$$x_{n\_LS-OFDM}(m) = \sum_{k=0}^{N-1} X_{n,k} e^{j2\pi(n+k)m/N_{total}}, \quad (3)$$

where $X_{n,k}$ is the modulation symbol applied to the k^{th} subcarrier during the n^{th} OFDM symbol interval, N is the number of all assigned subcarriers, N_{total} is the total number of all subcarriers in channel, n is the index of the first assigned subcarrier, and r is the period of the subcarrier assignment.

Compared to LS-OFDM, DS-OFDM has an advantage of reducing the intensity of ICI. The interference from other cells gets spread to adjacent subcarriers due to Doppler spreading effect. In case of DS-OFDM, this spread interference to adjacent subcarriers does not affect the received SINR since the adjacent subcarriers of DS-OFDM are null subcarriers. Unlike DS-OFDM, the adjacent subcarriers of LS-OFDM are not null subcarriers, so the spread interference still affects the received SINR.

The total inter-cell interference for LS-OFDM and DS-OFDM can be expressed as follow:

$$\begin{aligned} I_{LS-OFDM} = &\sum_{i\in V'} (P_{v,i} - Pathloss_{v,i} - 2\times VPL) \\ &+ \sum_{i\in S'} (P_{s,i} - Pathloss_{s,i} - VPL), \end{aligned} \quad (4)$$

$$\begin{aligned} I_{DS-OFDM} = &\sum_{i\in V} (P_{v,i} - D_{atten} - Pathloss_{v,i} - 2\times VPL) \\ &+ \sum_{i\in S} (P_{s,i} - D_{atten} - Pathloss_{s,i} - VPL), \end{aligned} \quad (5)$$

where V and S are the set of all vehicle access networks and infra networks, V' and S' are the subset of V and S which use same radio resource with the interested vehicle access network, and D_{atten} is the reduced intensity of interference by spreading. VPL denotes the dB value of vehicle penetration power loss. In case of interferences from other vehicle access network, VPL affects twice since signals have to propagate two vehicles' metallic bodies.

4. Simulation Result

We assume that there are 100 subcarriers at WVAN, V2V, and V2I networks. One LS-OFDM symbol uses 10 consecutive subcarriers, and one DS-OFDM symbol uses 10 sparse subcarriers. Among cells, there is frequency offset which is set as from 0 to 0.3 randomly. VPL is set as 10 dB.

The SINR is defined as

$$SINR \triangleq \frac{P}{I+N}, \quad (6)$$

where P is the received signal power, I is the interference power, and N is the noise power. Both DS-OFDM and LS-OFDM symbol use same transmitting power and we asuume

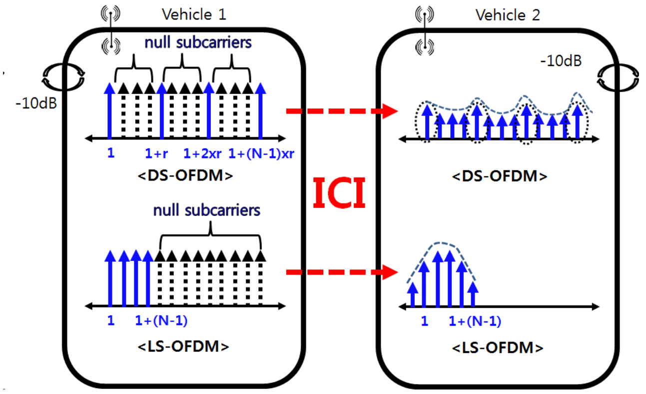

Figure 2. DS-OFDM/LS-OFDM

that the frequency of offset of desired signal of WVAN is perfectly compensated. Therefore the received signal power of DS-OFDM and LS-OFDM are same. The ICI differences are the main contributor of SINR difference of DS-OFDM and LS-OFDM. First, we calculate the probability distribution of SINR of users, and compare the average and variance of SINR of LS-OFDM and DS-OFDM at WVAN when there are 150 interference sources at Figure.3 . The average and variance values are:

$$\begin{aligned} \text{E}[SINR_{LS-OFDM}] &= 45.3479 \text{ dB} \\ \text{E}[SINR_{DS-OFDM}] &= 43.4980 \text{ dB} \\ \text{Var}[SINR_{LS-OFDM}] &= 74.3910 \text{ dB} \\ \text{Var}[SINR_{DS-OFDM}] &= 11.4754 \text{ dB} \end{aligned}$$

We observe that between DS-OFDM and LS-OFDM, the average of SINR is almost same but the variance of SINR is about 7 times different. We can confirm that interference spreading effect on DS-OFDM reduces SINR differences among vehicle users. This is because the interference spreading by Doppler effect makes the highs and lows of interference of vehicle users average out in case of DS-OFDM. Given the target SINR T, the outage probability is defined as [6]

$$P_{out}(T) \triangleq P(SINR < T). \quad (7)$$

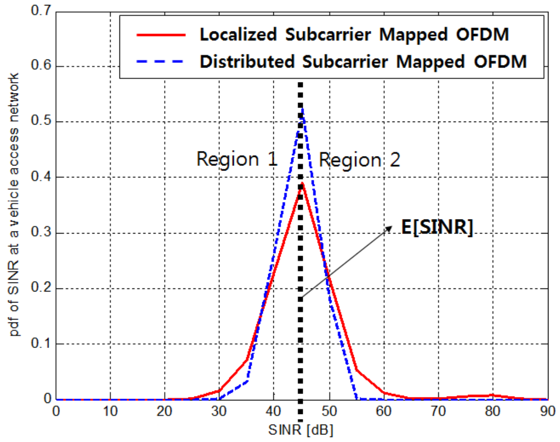

Figure 3. Probability distribution of SINR

By calculating area of probability distribution, we can estimate that if target SINR is lower than average SINR, then the outage probability of DS-OFDM is lower than one of LS-OFDM, and if target SINR is higher than average SINR, then the outage probability of LS-OFDM is lower than one of DS-OFDM. In order to compare the performance of DS-OFDM and LS-OFDM when the target SINR is lower than average SINR, we measure the outage probability of a randomly chosen vehicle user who set its threshold SINR 30dB in Figure 4. The simulation results show that the outage probability of DS-OFDM is lower than that of LS-OFDM.

Interesting observation is that the performance gap decreases as the total number of interference sources increases. When there are 150 interference sources, the outage probability of LS-OFDM is 225 times higher than one of DS-OFDM. But when the number of interference sources increases to 450, the outage probability of LS-OFDM is only 2.58 times higher than one of DS-OFDM. This is because in case of DS-OFDM, interference gets spread to almost all subcarriers by Doppler effect, and this increases the number of users who are affected by ICI. When the overall received SINR becomes low, the impact of the increased number of users who are affected by ICI becomes dominant, and the impact of the reduced intensity of ICI decreases.

5. Conclusion

In this paper, we propose a ICI suppression techinique by using DS-OFDM for WVAN. We show that ICI become a critical issue for high data rate at the WVAN. From the numerical simulation results, we show that DS-OFDM outperforms LS-OFDM when the target threshold SINR is lower than the average of SINR in terms of outage probability performance. Especially, since the required SINR for maximum modulation and coding scheme (MCS) is 30dB in 802.11, the superior performance of DS-OFDM in Figure 4. is meaningful for the high data transmission rate and low interference scenario.

As a future work, we will design the algorithm to select mode between DS-OFDM and LS-OFDM. To choose the best mode, user need to know the average SINR of network. In fast moving vehicles, estimating the SINR of network should be based on probability estimation. We will design the estimation process which works in distributed manner.

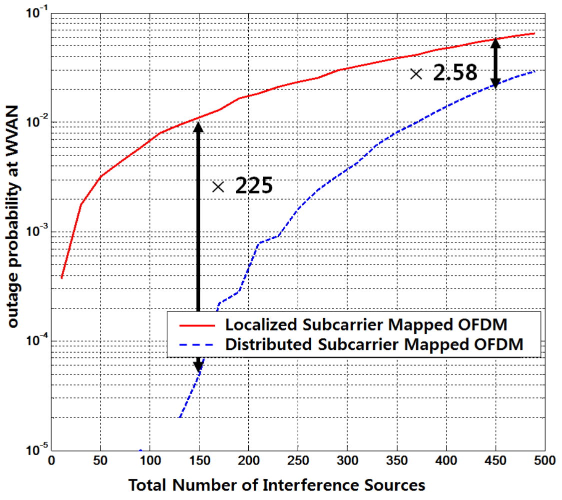

Figure 4. Outage probability of access network

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