Doppler Spectrum Evaluation on V2V Communication for Platooning

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Abstract:

5th generation mobile communication (5G) is being actively researched and developed. We focus on "Ultra-Reliable and Low-Latency Communication", with the goal of V2V communication in platooning; a highly anticipated function for autonomous driving. V2V direct communication plays a very important role in realizing platooning. Studies of V2V direct communication in platooning have found spectrum spreading in excess of the maximum Doppler frequency which depends on frequency and moving speed. This studies the characteristics and phenomena unique to platooning; we find that the direct wave basically has no Doppler shift. However, we show that Doppler shift of up of twice the maximum Doppler frequency is observed although at a weak level, and we clarify the communication environment by various experiments.

Keywords: 5G mobile Communication System, V2V direct communication, Platooning, Doppler Spectrum

Classification: Antennas and Propagation

References


http://www.nedo.go.jp/content/100552007.pdf

1 Introduction

Research and development on Fifth Generation Mobile Communication (5G) has been active in recent years but a full understanding of radio wave propagation characteristics is required in the frequency band expected to be allocated. 5G has three key features: enhanced Mobile Broadband (eMBB), massive connections for Machine Type Communication (mMTC), and Ultra-Reliable and Low Latency Communication (URLLC). We are conducting R & D on V2V Communication for Platooning and so are focusing on high reliability and low latency. [1]

In truck platooning, the trucks are controlled in an integrated manner by electronic linking technology (i.e. vehicle-to-vehicle direct communication), and two or more trucks move in a tightly-spaced convoy. Especially in Japan, studies are currently being conducted as to determine whether it is feasible to man just the lead vehicle with the following vehicles being unmanned. Truck platooning is expected to promote manpower savings (offsetting the driver shortage), to improve road traffic capacity, and reduce energy consumption. [2]-[5]

Platooning demands the exchange of control signals (accelerator, brake, steering angle) and monitoring data (camera image and sensor information) between vehicles, so vehicle-to-vehicle (V2V) direct communication plays a critical role. In order to maintain the convoy at all times, ultra-reliable (zero link disconnection) and low latency communication is essential. For this reason, V2V direct communication is multiplexed. Multiplexing is the target of various standards such as DSRC, 4 G / LTE, 5G, light wave communication and so on. Among them, 5G, which offers ultra-reliable and low latency communication is considered to be promising.

To implement V2V direct communication for platooning, it is necessary to clarify the propagation characteristics created by platooning, such as propagation loss, arrival direction, delay, and Doppler shift. This paper focuses on the Doppler shift by determining the characteristics and unique phenomena; we show that basically the direct wave isn’t Doppler-shifted. However, some Doppler shifted waves are observed at up to twice the maximum Doppler frequency, although at a weak level. The communication environment is clarified by various experiments.

2 Doppler Spectrum on V2V Communication for Platooning

2.1 Measurement set up

Fig. 1(a) outlines the Doppler frequency measurement set up for V2V communication in platooning. Two trucks are used; the lead vehicle holds the receiving system and the slaved vehicle holds the transmitter system. A standard signal generator (SG) is used to create an unmodulated continuous wave (CW). The
receiving system includes a spectrum analyzer (SA). Also, in order to improve frequency stability, a rubidium oscillator with GNSS signal reference is used in both the transmitting and receiving system; the reference signal is synchronized. The measurement parameters are listed in Table 1. Measurements were conducted in the 28 GHz band (expected 5G frequency). Both antennas were Quad-ridge horn antennas. The nominal distance between vehicles, 10 m, was set longer than the 4 m to 8 m expected in actual platooning service for safety; both vehicles were manned at all times. The antenna height was set to 0.75 m for both trucks as the cargo carried varies so high antenna mounts can not be assumed. This antenna height allows for chassis mounting. Also, the same antenna height was used because it makes it easier to evaluate the measurement results.

2.2 Driving Experiments
The Doppler spectrum was measured while both trucks were driven at the same speed. Fig. 1(b) plots the spectrum recorded at the driving speeds of 0 km/h, 30 km/h, and 60 km/h. The horizontal axis is the frequency centered on the transmission frequency i.e. indicating the frequency shift, and the vertical axis shows the reception level. The maximum Doppler frequency, \( f_D \), is given by the following equation.

\[
f_D = \left( \frac{v}{c} \right) \cdot f_c
\]

where:
- \( v \): Speed differential
- \( c \): Speed of light
- \( f_c \): Source center frequency

According to the above equation, a stationary observer experiences maximum Doppler shift frequencies of 775 Hz and 1550 Hz at the driving speeds of 30 km/h and 60 km/h, respectively. However, since both vehicles are running, the relative speed of the vehicles is 0 km / h. Therefore, it is conceivable that Doppler shift does not occur. It is understood from Fig. 1(b) that the direct wave is dominant and exhibits no Doppler shift. However, some spectrum spreading is observed at up to about twice the maximum Doppler frequency although at a weak level, so it can be understood that the V2V links contains some Doppler shift components.

It is already known that a frequency shift exceeding the maximum Doppler frequency can be observed when there is an independent object such as a vehicle moving in the next lane or people walking along the road, if the transmitting station is fixed while receiving station moves. In this experiment, there were no such independent moving reflectors, and thus these results suggest the existence of a hitherto unknown phenomenon.
(b): Result of Doppler spectrum measurement (while platooning)

(c): Measurement specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency band</td>
<td>28 GHz band</td>
</tr>
<tr>
<td>Distance between vehicles</td>
<td>10 m</td>
</tr>
<tr>
<td>Antenna</td>
<td>Quad-ridge horn</td>
</tr>
<tr>
<td>Antenna height</td>
<td>0.75 m</td>
</tr>
<tr>
<td>Polarization plane</td>
<td>V polarization</td>
</tr>
<tr>
<td>Beamwidth</td>
<td>20 deg.</td>
</tr>
</tbody>
</table>

Fig. 1. Experimental setup and measurement results in platooning

3 Verification experiments and consideration

Two verification experiments were conducted to clarify the principle underlying the spectrum spread of up to twice the maximum Doppler frequency. As shown in Fig. 2(a), the first experiment mounted the transmitting and receiving antennas side by side on the same moving vehicle. In the other experiment, shown in Fig. 3(a), either the transmitter or receiver while held stationary while the other moved.

3.1 Transmitter and receiver on same moving vehicle

Fig. 2(b) shows the measured results. With this set up, we can expect weak radio wave leakage from the transmitting antenna with no Doppler shift. While this expectation was satisfied, weak spectrum broadening was observed up to the twice the maximum Doppler frequency. This is explained follows.

As the transmitter is moving forward, the radio waves are shifted by the maximum Doppler frequency i.e. $+f_0$.

The waves are reflected and scattered by some stationary objects, and the shifted radio waves are reflected in the reverse direction.

As the reflected waves are captured by the moving receiver, which is of course moving forward, the waves are shifted by an additional $+f_0$. As a result, radio waves Doppler-shifted by $+2 \cdot f_0$ are observed.

3.2 Transmitter or Receiver stationary

Fig. 3(b) plots the results gathered with the arrangement shown in Fig. 3(a): the transmitter moves while the receiver is stationary. The measured spectrum shows two components with shifts of $+f_0$ and $+3 \cdot f_0$. It can be easily understood that the $+f_0$ wave is the direct wave with the expected Doppler shift. The other component arises because in this case the receiver is stationary, unlike Fig. 1(a). That is, the
upshifted wave is reflected from roadside objects so as to return to the moving transmitter which yields a \( + 2 \cdot f_D \) upshift. As this wave is reflected from the moving vehicle holding the transmitter, a \( + 3 \cdot f_D \) wave is generated. Fig. 3(c) shows the case of stationary transmitter and moving (departing) receiver. As expected, the direct wave has a \(- f_D\) shift. The wave reflected from the moving vehicle holding the receiver (shifted by \(- 2 \cdot f_D\)) is reflected again from the roadside objects to be captured by the departing receiver yielding at total shift of \(-3 \cdot f_D\).

Superimposing Fig. 3(b) and 3(c) and offsetting the spectra (by \(- f_D\) and \(+ f_D\), respectively) to account for the stationary vehicle yields Fig. 1(b).

(a): Overview of moving transmitter and receiver on same vehicle

(b): Measured Doppler spectrum shift

Fig. 2. Experimental setup and measurement results on same moving vehicle

(a): Moving transmitter and stationary receiver

(b): Measurement result of Doppler spectrum

(Transmitter moving toward static receiver)
4 Conclusion
Doppler shifts present in V2V communication for truck platooning were measured and the results were discussed. From the results, the direct wave is dominant but some spread spectrum components were observed up to twice the maximum Doppler frequency although their level was weak. Verification experiments, clarified that these components were caused by reflections among the truck bodies and roadside objects. For the application considered, truck platooning based on V2V, these Doppler shift components are so weak as to have insignificant impact on system performance. Future systems that use more advanced technologies such as full duplex may suffer from interference. In consideration of this point, further detailed verification experiments will be conducted.

Acknowledgments
This work was partially sponsored by the Ministry of Internal Affairs and Communications of Japan, under the grant, “Research and examination on technical requirements and others in 5G mobile communication system for realizing low latency communication of over-the-air 1ms and end-to-end 10ms”.