Radio Wave Propagation Simulation Considering Doppler Shift Caused by Other Vehicles

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Abstract:

Generally, maximum Doppler frequency can be derived from velocity of moving vehicle. However, frequency shifts beyond the maximum Doppler frequency are observed in actual measurement. In this paper, Doppler shift is calculated in consideration with the shift caused by other moving vehicles. Numerical results show that the actual measured Doppler shift can be reproduced with high accuracy by considering the frequency shift at the other moving vehicles.

Keywords: radio wave propagation, Doppler shift, Doppler spread, ray tracing

Classification: Antennas and propagation

References

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1 Introduction
In mobile communication, frequency shift occurs due to Doppler effect, and transmission quality will be degraded. Generally, maximum Doppler frequency can be derived from velocity of the moving vehicle. And Doppler shift of each path are calculated based on maximum Doppler frequency and arriving angles. Various methods for modeling propagation and obtaining Doppler spectra have been proposed [1-4]. The formula for calculating the Doppler frequency never exceeds the maximum Doppler frequency. However, in case of actual measurement, frequency shifts beyond the maximum Doppler frequency are observed [5]. This paper aims to show the mechanism of the Doppler shift that exceed the maximum Doppler frequency. Doppler shift is calculated in consideration with the shift caused by other moving vehicles using the angles of arrivals and the number of reflections. It is shown that the calculated result is well agree with the measured one.

2 Analysis model
Figure 1 (a) shows a simulation model for ray-tracing. This is the reproduced model of the area where the actual measurements ware conducted. The receiver and vehicles are arranged at the hatched area (on the road) in Fig. 1. Frequency and velocity of the vehicle is 4.64GHz and 30km/h, respectively. Also, the transmitting antenna and receiving antenna are omni-directional. Other specifications of the simulation and measurement are shown in Table 1.
Table 1. Simulation and measurement specifications

| (a) Ray-tracing simulation | (b) Measurement |
|----------------------------|-----------------|
| Frequency                  | 4.64GHz         | Frequency                  | 4.64GHz |
| Moving velocity            | 30km/h          | Moving velocity            | 30km/h |
| Transmitting antenna       | Isotropic       | Power                      | 40dBm  |
| Height (Transmitter)       | 45m             | Height (Transmitter)       | 60m    |
| Receiving antenna          | Isotropic       | Receiving antenna          | Omni   |
| Height (Receiver)          | 1.5m            | Height (Receiver)          | 1.5m   |
| Maximum reflections        | 10 times        |                             |        |
| Maximum diffraction        | 2 times         |                             |        |
| Physical property value of | Relative permittivity |                     |        |
| buildings (concrete)       | 7               | Electrical conductivity    | 0.0023 S/m |
|                           |                 |                             |        |
| Physical property value    | Relative permittivity | 3                         |        |
| value of road surface      | 7               | Electrical conductivity    | 0.01 S/m |
| (asphalt)                  |                 |                             |        |

3 Doppler shift due to reflection on other vehicle

3.1 Measured Doppler spectrum

When the Doppler shift occurs at the mobile receiver, maximum value of the Doppler shift (maximum Doppler frequency: \( f_{D_{\text{max}}} \)) can be calculated by eq. (1) in generally.

\[
f_{D_{\text{max}}} = \frac{v}{\lambda}
\]

(1)

Here, \( v \) and \( \lambda \) is moving velocity and wavelength. And each incoming wave Doppler shift \( f_D \) is (2).

\[
f_D = f_{D_{\text{max}}} \cdot \cos \phi
\]

(2)

\( \phi \) is angle of arrivals in the horizontal plane based on direction of travel. The Doppler shift at the other vehicle is calculated from (1,2) as same as the Doppler shift at the mobile receiver [1-4]. The Doppler shift on the propagation path is shown in Fig.1 (b) and explained as follows:

Case A) Transmitted radio wave is reflected at the mobile receiver's body first. Then, the wave is also reflected at the other vehicle that travels the same direction and velocity with the mobile receiver, and received by the mobile station antenna. Doppler shift occurs when reflection and receiving. When reflecting at the mobile receiver and other vehicle, Doppler shifts are negative and positive, respectively. Assuming these two vehicles' velocity and direction of travel is the same and regular reflection, Doppler shifts are canceled each other that occurs at these
reflections. As a result, only the Doppler shift at receiving remains. So, it will not exceed $f_{D_{\text{max}}}$ in this path. Doppler shift is determined by direction of arrival and $f_{D_{\text{max}}}$.

Case B) First, radio wave is reflected at other vehicle's body moving in the opposite direction to the mobile receiver. And it is received at the mobile station. This reflection causes positive Doppler shift. Doppler shift occurs twice on incidence and reflection at the other vehicle. Doppler shift in reception is also positive. Therefore, triple $f_{D_{\text{max}}}$ can occur at most in this path. Actual Doppler shift is $3f_{D_{\text{max}}}$ or less, because it varies with angle of incidence, reflection and arrival.

Case C) In case of A and B, reflection at other vehicles were considered. However even the path reflected at stationary objects, Doppler shift may exceed $f_{D_{\text{max}}}$, When reflection at the receiver's body and reception, positive Doppler shift occur. On the other hand, Doppler shift doesn't occur when reflected by stationary object. Therefore, up to $3f_{D_{\text{max}}}$ Doppler shift is observed. Doppler shift varies with relationship between mobile receiver and other vehicle velocity and moving direction. As an example, Doppler spectrum in the actual environment is shown in Fig. 2 (a). In this measurement environment, $f_{D_{\text{max}}}$ is approximately 128Hz, and it can be seen that the Doppler shift of 2 to 4 times of $f_{D_{\text{max}}}$ is observed in the measurement.

3.2 Simulated Doppler spectrum
In the simulation, following two cases is examined to calculate the Doppler shift.

Case I. Doppler shift caused at other vehicles is not considered.
Case II. Doppler shift caused at other vehicles is considered.
The result is shown in Fig. 2 (b) and (c). In Case I, there are no frequency shift beyond the maximum Doppler frequency because of using only velocity of receiver. On the other hand, in Case II, considering Doppler shift at other vehicles causes a shift that exceeds the maximum Doppler frequency.

4 Cumulative distribution function of Doppler spread
Cumulative distribution function of Doppler spread in the analysis area of Fig. 1(a) is shown in Fig. 3. If a frequency shift at the other vehicle is not considered, the Doppler spread of simulated result is lower than that of measured result. By considering the frequency shift at the other vehicles, the actual measured Doppler spread can be reproduced with high accuracy.

5 Conclusion
The frequency shift beyond the maximum Doppler frequency was studied. When Doppler shift caused by other vehicle was considered, Doppler spread in actual environment could be reproduced by radio wave propagation simulation.
Fig. 2. Doppler shift and Doppler spread in mobile receiving station