MEASUREMENTS OF INTER-NET PROPAGATION AND DATA TRANSMISSION AT 60 GHz BAND

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1. Introduction

The Intelligent Transport Systems (ITS) is a fusion technology between the vehicles and communication, and provides drivers and passengers with comfortable and safety traveling environment. In ITS, Inter-Vehicle Communications (IVC, communications among vehicles, not depending on infrastructure of road side) is expected to play an important role for assisting safe driving, and supporting automatic driving such as Automated Highway Systems (AHS). The quality of such system is a matter of life or death for many users of transportation systems. Therefore, real-time and robust communication must be secured for ITS.

Utilization of millimeter-wave band for IVC system has many advantages, as like low-interference against sun light, low absorption by rainfall or snowfall, high space-efficiency for large absorption by oxygen, and sharing the RF section between IVC system and millimeter-wave radar system for collision avoidance. On the other hand, the condition of millimeter-wave propagation for IVC is very severe because of Doppler shift, shadowing by vehicle bodies, and strong interference by multipath wave from the road surface [1-3]. The estimation of channel condition of millimeter-wave by experiments is needed to confirm of stable communication media as a lifeline of ITS.

In this paper, we present the measurement results of inter-vehicle propagation and data transmission using millimeter wave at 60 GHz band. In the experiment, we measured received powers and bit error rates (BERs) for data transmission between a transmitter on a front vehicle and two receivers on a following vehicle. We confirmed of validity of two-ray model as the propagation characteristics between the vehicles from the comparison between measurement results and calculated results. We also measured propagation and data transmission characteristics between two running vehicles with a constant distance on an expressway.

2. Experiments

The wireless data transmission with a carrier frequency of 59.1 GHz was examined between a transmitter (Tx.A) on a front vehicle and two receivers (Rx.B, C) on a following vehicle. To confirm of validity of two-ray model for the propagation characteristics of IVC system, we investigated the relationship between the received power and the horizontal distance between two vehicles. Figure 1 shows the experimental scenery. The test course is straight two-lane pavement and about 240 m long and there were few objects that cause the reflection, and there was no obstacle between the Tx and Rxs. The front vehicle was parked at the edge of the road, and the following vehicle moved slowly from the another edge of the road to the Tx. Table 1 shows the experimental setup for the measurement. The transmitted power was -4 dBm. Each antenna at Tx and Rxs was a standard horn antenna with the gain of 24 dBi, and these were placed at height of 46 cm (Tx.A), 85 cm (Rx.B), and 38 cm (Rx.C) respectively. The bit error rate (BER) was measured each one-second and the received powers were also measured simultaneously at the rate of 18750 points per second. Diversity threshold value of absolute level is set at -70 dBm and that of difference level is set at 10 dB and timing delay is set at 10 μs.
We also examined an experiment of data transmission between two running vehicles with almost constant distance on the expressway. Two vehicles with the distance of about 100 m ran in a same lane on the expressway at almost constant speed of around 80 km/h for a travel time of about 20 minutes, and the BER and received power was measured. The transmitted power was +9 dBm. RF sections were placed at height of 44 cm (Tx.A), 84 cm (Rx.B), and 36 cm (Rx.C) respectively. Diversity condition, antennas were the same as the experiment mentioned-above.

The two-ray propagation model between direct wave and reflected wave from the pavement was applied for estimation of propagation characteristics of millimeter wave. Figure 2 is schematic view of the two-ray propagation model. In this model, the received power $P_r$ is expressed approximately as

$$P_r = \frac{P_t G_t G_r}{L(r)} \left( \frac{\lambda}{4\pi r} \right)^2 \sin \left( \frac{2\pi h_r h_t}{\lambda d} \right)$$

where $P_t$ is the transmitted power, $G_t$ and $G_r$ are the antenna gains at the transmitter and the receiver, $L(r)$ is the absorption factor by oxygen, $\lambda$ is the wave length, $r$ is the distance between the antennas, $d$ is the horizontal distance between the antennas, $h_t$ and $h_r$ are heights of the transmitter and the receiver, respectively. In this model, the reflection coefficient of the pavement is assumed as -1 and the directivity of antenna is ignored. Absorption of oxygen is assumed as 16 dB/km.

3. Measurement Results

Figure 3(1), (2) show the measurement results of relationship between the received power and BER, and horizontal distance between the vehicles at each Rx position with each receiving antenna height (Rxh). The estimated received power using two-ray propagation model also indicated by dashed line in Fig. 3. Bit error rates are also shown in Fig. 3 as circular markers, where the $10^{-10}$ shows the error free. The results of measured receiving power give fairly good agreement with those obtained by the two-ray propagation model. In this graph, it is found that the bit error rates are degraded when the received power is not sufficient.

Figure 4(1),(2) show the measurement results of the relationship between the received power and horizontal distance between the running vehicles on the expressway. The characteristics of received power is different from that of two-ray model. This reason will be why the condition of interference

![Fig. 2. Two-ray model for propagation of millimeter wave in IVC.](image)
between direct wave and reflected wave from the road surface was changed by the fluctuation of height of the vehicles. Figure 5(1),(2) show the cumulative distributions of measured received power traveling on the expressway. The distributions of measured received power without diversity have a tendency to the Rayleigh distribution. The instantaneous propagation characteristic, which follows the two ray model, have a large sensitivity for the change of height of running vehicles, which occurs randomly. Thus we recognized that the tendency of distribution is caused mainly by such vehicles fluctuation. Figure 5(1) shows the data traveling whole of the expressway, and figure 5(2) is a part of same data without shadowing. The distribution for (2) has stronger relationship with Rayleigh than that of (1). It seems that these difference depends on the frequency of shadowing. Figure 6(1),(2) show the cumulative distributions of measured BER traveling on the expressway. Although the shadowing by other vehicles was occurred many times, the error-free transmission with speed at 1 Mbps was realized for the period of over 80% of the travel time on the expressway. Especially, these graph show that the space diversity of vertical direction is effective to improve the condition of data transmission channel.

4. Conclusion

We presented the measurement results of inter-vehicle propagation and data transmission using millimeter wave at 60 GHz band. We measured received powers and bit error rates with parameters as horizontal distance between the transmitter on the stationary vehicle and the two receivers on the vehicle moving toward the transmitter. The measurement results of relationship between the receiving power and the horizontal distance gave fairly good agreement with those obtained by the two-ray propagation model. We also examined an experiment of data transmission between two running vehicles with almost...
constant distance on the expressway. The improvement of data transmission characteristics by the
vertical space-diversity receiving was confirmed. From these results, we confirmed the feasibility of
IVC system using the millimeter-wave band to serve such as control of vehicles.

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Fig. 5. Result of cumulative distribution of received power traveling on the expressway.
Fig. 6. Result of cumulative distribution of BER traveling on the expressway.