Influence of the Shadowing on the Information Transmission Distance in Inter-Vehicle Communications

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Abstract—To achieve efficient traffic control, Intelligent Transportation System (ITS) has been widely deployed in many regions such as America, Europe, Australia, Japan, and Taiwan. To prevent the unnecessary losses, ITS adopts the inter-vehicle communications to inform the drivers if there are accidents nearby. However, the ability of effective transmission distance of the emergency information depends notably on the percentage of the vehicles equipped with communication device and the characteristics of radio wave propagation. The vehicles which are not equipped with these communication devices will block the radio propagation and result in the undesirable shadowing attenuation. This paper surveys the impact of the shadowing effect for the inter-vehicle communications via the computer simulations and the field measurements. Besides, a modified three-ray shadowing model suitable for the inter-vehicle communication is proposed. With the proposed model, the influence of the showing effect on the effective transmission distance will be evaluated.

Keywords- inter-vehicle communication (IVC); knife-edge diffraction model; shadowing effect.

I. INTRODUCTION

To achieve efficient traffic control, Intelligent Transportation System (ITS) adopts the mobile communication technique to transmit traffic information in many vehicular applications such as the inter-vehicle communications (IVC) and the vehicle-road communications (VRC) [1], [2]. With the IVC and VRC, ITS can intelligently inform the drivers if there are accidents or emergencies nearby. For example, Dedicated Short Range Communication (DSRC) technology is a wireless communication system for the IVC and VRC that provides the short or medium-range distance communication services. It can provide emergency rescue services to relieve traffic accidents and improve the driving safety. If the vehicle has a high risk of collision, an emergency signal will be transmitted to reduce the property loss and personal injuries. Basically, the longer distance of the emergency signal is transmitted, the more safety can be achieved for the drivers because they will have enough time to avoid or reduce the damage. However, the ability of effective transmission distance of the vehicular information depends notably on the percentage of the vehicles equipped with IVC communication device; i.e., the penetration rate [3], [4] and the characteristics of radio wave propagation. Those vehicles which are not equipped with the communication devices will block the vehicle information communication and result in the undesirable shadowing attenuation.

In literature, some research works have surveyed the relation between the effective transmission distance and the penetration rate in the IVC [3], [4]. Nevertheless, the shadowing effect of the vehicles without the IVC communication devices is neglected in all these simulations. Actually, to the best of the authors’ knowledge, there is not a proper wireless channel modeling suitable for the IVC analysis. Therefore, this paper surveys the impact of the shadowing effect to the information transmission distance for the IVC via the computer simulations and field measurements. With the field measurements, a modified three-ray shadowing model suitable for the IVC is also proposed. The proposed modification can be applied to the well-known knife-edge, the Bullington’s and the Giovanelli shadowing models [5-7]. This paper is organized as follows: Section II will review the knife-edge diffraction model and the Bullington’s method and the Giovanelli method. Besides, a modified three-ray shadowing modification suitable for the IVC is also proposed. In Section III, the field measurements of the shadowing effect for the IVC are conducted and compared the modified method to the conventional methods. With the modified model, the influence of the showing effect to the effective transmission distance will be evaluated. Finally, some conclusions for the survey are given in Section IV.

II. METHODS DESCRIPTIONS

The knife-edge diffraction model has been widely used to calculate the diffraction loss for a single shield object. For the multiple shield objects case, an equivalent obstacle can be derived from the Bullington’s method or the Giovanelli method to estimate the diffraction loss.

A. Knife-Edge Diffraction Model

In wireless communications, the knife-edge diffraction model is adopted frequently to simulate the signal diffraction...
loss from the shadowing effects of hilly terrain, ground objects, or buildings. In Fig.1, assume \( h_t \) and \( h_r \) denote the height of the transmitter (\( T_t \)) and the receiver (\( R_r \)), a shield object \( M \) exists between the \( R_r \) and the \( T_t \). The transmitted signal diffracts at the top of the shield object and cause the electric field \( E_d \) at the \( R_r \) as

\[
\frac{E_d}{E_0} = F(v) = \frac{1 + j}{2} \int_v \exp\left( -\frac{j\pi\nu^2}{2} \right) dt
\]

\( (1) \)

\[
v(d_1, d_2, h) = h \sqrt{\frac{2(d_1 + d_2)}{2d_1d_2}} = \alpha \sqrt{\frac{2d_1d_2}{2(d_1 + d_2)}}\]

\( (2) \)

where \( E_0 \) is the free space field strength, \( F(v) \) is the complex Fresnel integral expression and \( v \) is the Fresnel-Kirchoff diffraction parameter. \( d_1 \) is the distance between the \( T_t \) and the \( M \) and \( d_2 \) is the distance from the \( R_r \) to the \( M \), \( h \) is the effective height from the top of the shield object to the link of the \( T_t \) and the \( R_r \). \( \alpha \) is the diffraction angle. According to the knife-edge diffraction method, the diffraction loss \( L_d \) (dB) is

\[
L_d(dB) = 20 \log\left| F(v) \right|
\]

\( (3) \)

B. Bullington’s Method

Consider the case that when there are two or more shield objects between the \( R_r \) and the \( T_t \), the Bullington’s method [5] represents the shield objects as a single equivalent obstacle. Thereafter, the knife-edge diffraction model can be applied to simulate the diffraction loss for the multiple obstacles scenario by using the equivalent obstacle depicted in Fig.2.

\[
h'_1 = h_1 - \frac{d_1H}{d_1 + d_2 + d_3}
\]

\( (4) \)

\[
h'_2 = h_2 - \frac{d_2h_1}{d_2 + d_3}
\]

\( (5) \)

where \( H = h_2 + md_1 \), \( m = (h_2 - h_1) / d_2 \). The diffraction loss \( L_d \) from the shadowing effect can be approximated as

\[
L_d(dB) = 20 \log\left| F(v(d_1, d_2 + d_3, h'_1)) \right| + 20 \log\left| F(v(d_2, d_3, h'_2)) \right|
\]

\( (6) \)

C. Giovanelli Method

A geometric illustration of the Giovanelli method is depicted in Fig.3. First we use Eq.(2) to find the \( v \) parameters for all shield objects. The largest \( v \) represent the main shield object. In the left and right regions of the main shield object, the Giovanelli method adopts Eq.(2) again to find the secondary shield object. The effective height \( h'_1 \) of the main shield object and the effective height \( h'_2 \) of the secondary shield object are

\[
h'_1 = h_1 - \frac{d_1H}{d_1 + d_2 + d_3}
\]

\( (4) \)

\[
h'_2 = h_2 - \frac{d_2h_1}{d_2 + d_3}
\]

\( (5) \)

where \( H = h_2 + md_1 \), \( m = (h_2 - h_1) / d_2 \). The diffraction loss \( L_d \) from the shadowing effect can be approximated as

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\]

\( (6) \)

D. The Proposed Three-Ray Concept

For the conventional knife-edge, the Bullington’s and the Giovanelli methods, all consider only the wave propagation through the top of the shield object. In the scenario of the IVC, these methods are not suitable because the vehicles affect the shadowing degradation only on the portions blocking the radio propagation from the \( T_t \). Therefore, a simple three-ray modification for the IVC can be shown in Fig.4. If there are shield vehicles between the \( R_r \) and the \( T_t \), \( R_r \) receives the
signal come mainly from three propagation paths, i.e., one is diffracted from the top of the vehicle and the other two are diffracted at the both door-edges of the vehicle (Fig.4). We also assume that each path suffers the attenuation which can be estimated from the conventional knife-edge method or the equivalent obstacle of the Bullington’s and the Giovanelli methods.

The procedures of the proposed modification can be summarized as:

1) Use the Bullington’s method to represent the shield objects as a single equivalent obstacle.
2) Calculate the three effective heights: one is from the top of the shield object to the link of the \( R_x \) and the \( T_x \) while the other two effective heights are determined from the both door-edges of the vehicle.
3) Use the knife-edge method for the three paths to predict the resulted electric fields.
4) Sum up three electric fields and predict the path loss.

Similar procedure can be applied to the Giovanelli method.

### III. EXPERIMENT AND SIMULATION RESULTS

In the experiment and simulation results, we compared the proposed three-ray modification with the knife-edge method in the single vehicle case. For the two shield vehicles case, the modified method is compared to the Bullington’s method and the Giovanelli method.

In the measurements, two omni-directional antennas were installed at the height of one meter on the road and connected to the port#1 and port#2 of the vector network analyzer (VNA) as the \( T_x \) and the \( R_x \) respectively (Fig.5). The VNA can be controlled by a personal computer (PC). We also connected the \( T_x \) and the \( R_x \) to a power amplifier (PA) and a low noise amplifier (LNA) to increase the measured distance. The center frequency of the signal is 2.4GHz with 200MHz bandwidth. Two kinds of vehicles were tested in this experiment (Fig.5). The details of the vehicles are shown in Table I.

#### A. Single Shield Vehicle Case

Consider the case with only one shield vehicle exists between the \( R_x \) and the \( T_x \) (Fig.6). Two different distances between the \( R_x \) and the \( T_x \) are tested in this experiment, i.e., 50m and 70m. The vehicle moved from the \( R_x \) to the \( T_x \). The received power of the line-of-sight (LOS) channel (i.e., without the shield vehicle) was recorded as the reference (0dB) in the

#### TABLE I. MODEL PARAMETERS OF THE SHIELD VEHICLES

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Length</th>
<th>Height</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle-1: SUV (Nissan Xtrail)</td>
<td>4.51m</td>
<td>1.68m</td>
<td>1.765m</td>
</tr>
<tr>
<td>Vehicle-2: Sedan (Ford Tierra)</td>
<td>4.47m</td>
<td>1.42m</td>
<td>1.695m</td>
</tr>
</tbody>
</table>
calculation of the diffraction loss. Fig. 7 illustrates the field measurements and simulation results for the modified three-ray method and the knife-edge method. Obviously, the proposed three-ray modification can approximate the field-measured results more accurate than the conventional knife-edge method. Besides, we can note that the shadowing effect is very serious when the shield vehicle is about 10 meters near the \( R_i \) or the \( T_i \). Other than the 10m regions, the shadowing degradation remains a constant. (-8dB in this experiment)

B. Two Shield Vehicles Case

Consider the influence of two shield vehicles on the shadowing effect in the IVC, the distance between the \( R_i \) and the \( T_i \) is at 70m. As shown in Fig. 8(a), the vehicle-1 was fixed at the middle location between the \( R_i \) and the \( T_i \) and the vehicle-2 moved from the \( R_i \) toward the fixed vehicle. Fig. 8(b) is another case where the vehicle-1 was fixed near the \( R_i \) and the vehicle-2 was moving from the fixed vehicle to the \( T_i \).

In Fig. 8, the Bullington’s method is used to obtain an equivalent obstacle from the two shield objects. Then the diffraction loss is calculated by the knife-edge diffraction model and the modified three-ray knife-edge diffraction model. Fig. 9 depicts the final simulation and measurement results. Similar as the single shield vehicle case, the modified three-ray method has a better approximation than the Bullington’s and the Giovanelli methods.

C. Transmission Distance under the Shadowing Effect

Here, we conduct a simulation to analyze the relation of the effective transmission distance versus the penetration rate (the percentage of the vehicles equipped with the communication device) via using the proposed modified three-ray shadowing model. The channels used in the simulation can be divided into two cases: one is the LOS, and the other is the non-LOS (NLOS). That is, if there is no shield vehicle between the \( R_i \) and the \( T_i \), the transmission channel is modeled as a LOS scenario and the instantaneous received power is calculated via the Friis equation with the Rician fading. Otherwise, the transmission channel is modeled as a NLOS scenario and the instantaneous received power is calculated by the Friis equation with the Rayleigh fading and the shadowing effect [8], [9]. The received power \( P_r \) is calculated as

\[
P_r = \frac{P G G_s \lambda^2}{(4\pi)^2 d^2 L} \left[ \frac{(x_i + \sqrt{2K})^2 + y_i^2}{2(K + 1)} \right] \tag{7}
\]

where \( P_r \) is the transmitted power, \( G_s \) is the transmitted antenna gain, \( G_r \) is the received antenna gain, \( \lambda \) is the wavelength, \( d \) is the distance between the transmitter and receiver, and \( L \) is the system loss factor. \( x_i \) and \( y_i \) are Gaussian random variables and \( K \) is the Rician factor. \( K = \infty \) and \( K = 0 \) denotes the Gaussian and Rayleigh distribution respectively. \( E \left[ \left( \frac{(x_i + \sqrt{2K})^2 + y_i^2}{2(K + 1)} \right) \right] \) = 1, \( E(.) \) denotes the expectation operator.

The time headway [3] of vehicles in this simulation can be depicted in Fig. 10. It is the statistic distribution of the time interval between two successive vehicles on the expressways. Multiply by the speed of the vehicle, the distance between the two successive vehicles can be calculated.
Furthermore, we can adopt the penetration rate to determine whether or not the following vehicle has equipped with the IVC communication device. If it does not, the vehicle will have the shadowing effect for the signal transmission. The transmitted power of the signal is 10dBm and the sensitivity of the received power is -85dBm. If the received power is higher than the -85dBm threshold, we add the distance between the vehicles to the accumulated distance. Then the vehicle of $R_x$ emits an equal power signal as the $T_x$ (10dBm). The calculation of the transmission distance will be terminated if the received signal power is below the sensitivity and the final transmission distance is equal to the accumulated distance from the first $T_x$ [10]. In this simulation, assume the speeds of all the vehicles are the same and only vehicles behind the $T_x$ vehicle can receive the information.

Fig.11 depicts the effective transmission distance versus the penetration rate with or without the shadowing effect for different speeds of the vehicles. Intuitively, the effective transmission distance will be increased as the penetration rate increases. Besides, the vehicle with low speed will have longer transmission distance than the high-speed vehicle at the same penetration rate. Fig.11(b) is the re-plot of Fig.11(a) at the range of 0%~50% penetration rate. We can note that with the shadowing effect, the effective transmission distance of the IVC will be dramatically degraded. For example, if the speed of the vehicle is 100km/hr, the transmission distance is 120m rather than 210m at the 25% penetration rate. And if the safe transmission distance should be above the 200m [3], the penetration rate must be higher than 37% rather than 24% if considering the shadowing effect according to the simulation results. Actually, the influence becomes more significant when the speed of the vehicle is low. This comes from the fact that the shadowing effect will be very serious if the shield vehicles are near the $R_x$ or the $T_x$.

IV. CONCLUSION

This paper surveys the impact of the shadowing effect for the IVC via the computer simulations and the field measurements. A modified three-ray shadowing model suitable for the inter-vehicle communication is proposed. With the proposed model, the influence of the showing effect on the effective transmission distance is also evaluated. According to the simulation results, the shadowing effect will degrade the effective transmission distance of the IVC over 40%; and the influence becomes more significant when the speed of the vehicle is low.

REFERENCES


Figure 11. Relations between signal transmission distance and the penetration rate.