A Study on a Road-Vehicle Communication System for the Future Intelligent Transport Systems

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Abstract

This paper presents an example of a supposed future intelligent transport systems (ITS) and the results of examination of the system configuration. And, this paper proposes a road-vehicle communication system for the future ITS. As an evaluation of the proposed system, propagation characteristics of the radio link using 45GHz band millimeter-wave are examined, such as the vehicular interval for the line-of-sight communication, the received power level at the mobile station in adopting the transmitting power control and the diversity and attenuation caused by rain, which will clarify the feasibility of this system.

1. Introduction

Recently, the function improvement of the automobile and the construction of road transportation control system have been advanced, with the progress of information processing technology and digital communication technology. Then, investigation, research and development on the intelligent transport systems (ITS) have been made, as the infrastructure which will support future transportation systems. In the ITS, the following four information communication systems become important key technologies to constitute the whole ITS:

E@ the advanced information communication network for efficiently carrying out collection and service of the vehicle information and management of road transportation;

E@ road-vehicle-communication (RVC) in which the information communication is carried out between road transportation infrastructure and vehicle in the travel:

E@ inter-vehicle communication (IVC) that the travel data is transmitted to each other between vehicles for cooperative cruise;

E@ the information network in vehicle in adaptation to the information society and the computerization of vehicle.

However, many research and practical development promoted at present on these information communication systems have been made respectively and originally. If it advances in present as, many systems and equipment will simultaneously come to exist in future. Therefore, it is considered that many users can not individually follow such situation because of the difficulty that they simultaneously introduce large number of systems. So, it is estimated that many these current information communication systems will be certainly integrated in the small number of systems in future. As the integrated form, road-vehicle communication system which can continuously communicate by two way interactive seems to become the main system, because it can be correspondent to much application.

Then, authors propose the road-vehicle communication system of the continuos-communication type using the millimeter wave, as the integrated mobile communication system realized in highway and high standard road. In this communication system, the line-of-sight communication is done between radio base station placed in the roadside in uniformly interval of several hundred meters and mobile station on vehicle, using direct sequence (DS) spread spectrum communication system[1]. Then, the communication with individual vehicle is controlled by mobile communication control system based on the IP address. In this system, the multimedia railway information communi-cation system in which the authors have advanced the study for future railway [2] is applied to the road by adopting the spread spectrum system, with the aim of transmitting in high-quality and surely not only voice and text signals but also quasi-video and video image signals for large number of users of vehicles in the travel.

In this paper, characteristics of radio link using 45GHz band millimeter wave are mainly examined, on the road-vehicle-communication system proposed as a mobile communication system for the ITS in next generation. As the result, it is shown that this system is enough applicable as road-vehicle communication system for future ITS.

2. An Example of a Supposed Future Intelligent Transport Systems

Mobile communication means by the radio are necessary in order to carry out the communication between vehicles at high-speed traveling and roadside infrastructure facilities, or inter-vehicle communication. For necessary information in the vehicle, there are the front-sheet information that is directly necessary for driver's seat, and the rear-seat information that is not directly concerned in the operation. For the former, the information of which the communication quality is high is mainly included, such as information with the immediacy and the certainty which concerns control of vehicle and the safety, and information with the high reliability which concerns the money like Electronic Toll

Collection (ETC), etc. For the latter, the information of which convenience and amusement are high is mainly included, such as generous position information like stores and parking lot in the neighborhood, and information without the dependence for position and regionality like telephones and electronic mail, etc. However, it seems to be a essential to take in the rear-seat information by multi-media such as electronic mail and internet information of which the importance increases more and more, when the popularization of future ITS is considered.

In the meantime, variously information communication such as traffic services, safety services, convenience and amenity services for vehicle users, safety and convenience services for pedestrians, and business communication services for the road operation enterprises, etc. are included, for the information communication in the ITS [3]. It is necessary to satisfy the following requirement on the information communication in order to realize above services:

Eall vehicles in the travel can constitute the communication link for the necessary interval;

Eth@high communication quality can be realized, in which the sure information transfer is possible;

Eth@delay of information transfer is enough short in the comparison with the mobile performance of the vehicle.

Real-time, immediacy, continuity, reliability, safety are required in the operation, and in addition, reduction of the system operation cost and expansibility of the system, etc. are required. Therefore, it is necessary that sensor function which detects the road transportation environment, control function which controls the movement of vehicles and various information communication function are included, for infrastructure facility which realizes future ITS.

The information communication system composed like Fig.1 is assumed for the future ITS that satisfies these requirements. That is to say, the information communication system are composed of roadside access-network which communicates with the roadside facility including radio base station (RBS) and the

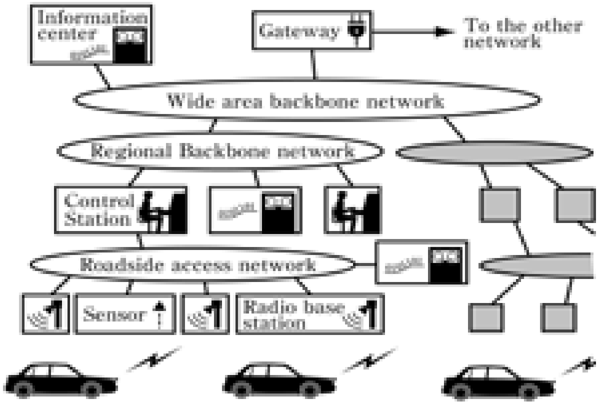

Fig.1 The assumed communication system for future ITS

sensor, regional backbone network which connects the control stations (CS) for traffic control and network and are processed in these facilities. And in necessary, the processed information is sent to the vehicle through the RBS as ITS service information. The communication control with individual vehicle is carried out by mobile communication control system based on IP address in CS.

Future ITS assumed like the above is considered a system on the road transportation constructed on the multi-media mobile radio communication platform. And in the information communication system, how the communication between roadside network and vehicle is carried out, is a large theme.

3. Examination of the System Configuration

The technical subjects shown in Table1 must be examined in order to clarify the possibility in which to offer multi-media service and function described above is possible on the integration mobile communication system in the next generation ITS. In the following, research result is described on main matter in Table 1.

(1)Transmission rate and frequency band for service content

At present, the RVC and IVC are considered as the Dedicated Short -Range Communication System (DSRC). It seems that the

TABLE 1. Technical subject s of a road-vehicle multimedia communication system for the future ITS

Design Requirement	Subjects to be studied	Subjects to be evaluated
● Communication to high speed vehicle (ex.:~200 km/h) ● High bit rate and Large capacity information (ex. 2~10 Mbps) ● Multimedia communication (Text, Voice, Data and Video signals) * Transmission of signals with varied bit-rate and quality * Transmission of stream type signals and burst type signals ● Security, maintainability, expandability and economic operation	● Frequency band (enough broad bandwidth for video signal transmission ?) ● Sell size(propagation between vehicles and radio base station is in the line-of-sight?) ● Antennas (unidirectional ?) ● Diversity and combining system ● Multiple access (FDMA/TDMA/CDMA?) ● Radio channel control -high speed handoff -timing with high speed mobility ● Error control (FEC/ARQ) ● Wireless ATM ● Modulation/Demodulation ● Feeder Links to radio base station etc.	● Received power level -high speed fading fluctuation due to multipath ● Attenuation and circuit interruption due to rain ● Channel interference (Co-channel, Overreach wave) ● BER, ● Diversity effect ● CNR(at radio links and feeder links) ● Transmission loss (at radio links and feeder links) ● Delay time at the handoff in radio links ● High speed handoff ● Cost etc.

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multimedia dedicated communication system shown in Fig.2 shoulders the role, as information communication system which composes the regional backbone network described in Fig.1 and offers the above service, in the ITS in the next generation.

Authors consider that image are indispensable besides voice, text and still-picture. for the real-time information interchange of dangerous warnings of collisions, etc. and cooperative cruise, etc. in the ITS in next generation. And, it is regarded as rear-seat requiring the transmission of image information such as the video on demand and the Internet information as a necessary condition. Therefore, the composition of the large-capacity mobile communication system in which the video transmission of the multi-channel per one radio zone is possible is examined. The necessary transmission rate is regarded 2~10Mbps, and frequency band is as several hundreds MHz as a system.

(2) The mobile continuous communication system for Large capacity information

It is regarded as integrating for the road-vehicle communication, for the large-capacity continuum mobile communication including the communication with the road outside. For the road-vehicle continuum communication, the radio zone system and wire system using leakage coaxial cable or leakage waveguide are examined at present. In these systems, authors consider that the road-vehicle-communication of the radio zone system suits most in the purpose.

(3) Radio frequency

The radio frequencies considered in this study are 2 to 50 GHz with bandwidth of above 100 MHz that many users in various fields can use even for video signal transmission. The concrete frequencies are the 2GHz band for IMT2000(International Mobile Telecommunications-2000), microwave bands (for instance, the 5.8GHz band and the 24.5GHz band), and millimeter-wave bands (for instance, the 37GHz band and the 45GHz band). Tradeoffs between each of these bands are indicated in Table 2. In general, the higher the frequency, the greater the accompanying engineering problems. Particularly in the millimeter-wave band, there are numerous problems to be resolved, including high-speed handoff, high-speed fading fluctuation, BER floor effect due to fading and effect of rainfall and so on. As the results of radio frequency tradeoff in Table 2, we here examine a 45GHz millimeter-wave system that has wide-band to hold out the promise of multiple-channel video transmission.

(4) The communication system

FDMA, TDMA and CDMA are generally known as the multiple access system. Here, the CDMA system in which the technology develops by the IMT2000 system is adopted with the general advantage of spread spectrum communication system, such as interference resistance, multi-path fading resistance, same frequency with adjacent cell, keeping a privacy, jamming resistance, intercepting-proof and so on. And, by adopting the CDMA, it is possible to take in the advantages of the system such as high frequency efficiency, reduction of transmission power and change of transmission rate in up-link and down-link by changing

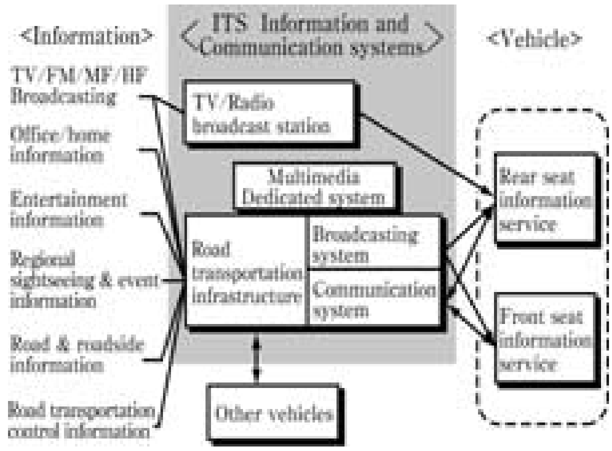


Fig. 2 The role of proposed dedicated communi. system

TABLE 2 Radio frequency tradeoffs

Items \ Frequency bands	2GHz band	5.8GHz band	24.5GH-z band	45GHz band
Bandwidth for multi-channel video Signal transmission *1	△	○	◎	◎
Maximum Doppler frequency *2	333.3Hz	966.7Hz	4.1KHz	7.5KHz
Cell diameter (example)	3 km	1.5 km	500 m	300 m
Propagation loss at distance of diameter of a cell	108.0 dB	111.2dB	114.2 dB	115 dB
Time to traverse cell *2	1 min.	30 sec	10 sec	6 sec
Simplicity of circuit control	○	○	△	△
Simplicity of radio base stations (20dB antenna diameter : mm) *3	○ (675)	○ (233)	◎ (55)	◎ (30)
Availability of existing technology	◎	○	○	△
Influence of rain, snow, ice and Countermeasures	○	○	△	△

*1 Bandwidth at each frequency band assumed to be 0.5% of central frequency for entire system
*2 For a mobile station (train) speed of 180 km/h (50 m/sec)
*3 Equivalent diameter of antenna with efficiency of 50% and indicated gain

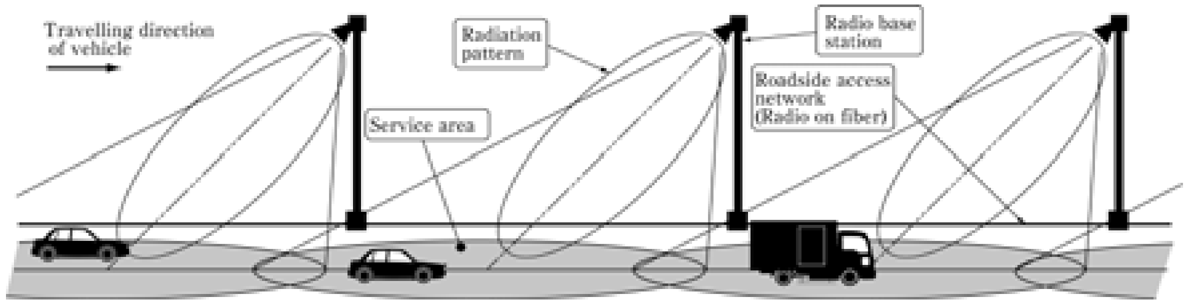
the spreading ratio at the base-band.

(5) The cell size (Interval between radio base stations)

When millimeter wave is used at RF, the propagation loss increases and the propagation condition is largely affected by weather and circumference environment. Therefore, it is necessary that the propagation distance during transmission and reception is within about several hundred meters in the line-of-sight.

(6) Antennas

@About 115dB propagation loss is generated at 300m propagated distance, when it is 45GHz millimeter-wave. And, the requirement reception level has the necessity including the sufficient margin, since the propagation condition is largely affected by weather and circumference environment. It is possible to use the transmission and receiving antenna of the desirable directionality with the high gain of 20~30dB, because the relationship between the transmission and reception may be considered on the line along the road in this system, unlike usual



@ @ @ **Fig. 3** The composition of the radio zone using directional antennas

portable telephone.

(7) The composition of the radio zone @

As a result of the examination, the composition shown in Fig. 3 is adopted here because of the requirement that the delay of the signal in hand-off does not become complicated, even in the case of the multi-path propagation.

4. Proposal of RVC System for the Future ITS

From the result of the above examination, authors propose a road-vehicle communication sys-tem using the millimeter wave as a integration mobile communication system of the ITS in the next generation. And, aims of this system are as high-quality continuous communica-tion, two-way interactive communication between multiple vehicles and ground facilities, and optimization of information service and control.

Outlines of the proposed road-vehicle-communication system are as follows.

1) In various information, the news, sport, movie and the other immediate video image that correspond to rear seat information are received from satellite broadcasting with multi-channel TV by the antenna mounted on the roof of the vehicle. In mountainous area and road in the tunnel, the satellite broadcast is received and boosted in reception facility equipped the region of the problem, and retransmitted to the vehicles.

2) For the information transmission of other than 1) including video image, a new road-vehicle-communication network is constituted, which uses the DS spread spectrum communication system by millimeter wave for radio link, and radio on fiber optical communication system[4] by optical fiber for the feeder link which constitutes the roadside network. Then, voice and video signal are continuously transmitted in radio link, and the data signal of which bit error is severe is transmitted in burst near the RBS.

3) The CS is placed in the wayside of the road every 20 ‘30km, and it is connected by roadside network by the optical fiber in the interval with RBS placed in the roadside every several hundred meter. Up-link radio signal by the roadside network is transmitted as a sub carrier, after it is converted into the lower frequency.

4) The CS is composed of control switches, modulators, demodulators, E/O converters, O/E converters and so on. And, the radio base station is composed of the transmission reception dual use antenna, duplexer, and O/E converter, up Converter, SS transmitter for down-link, and of SS receiver, down converter, E/O converter for the up-link. By installing the control switches in the lump together which controls the network in the control station, the composition of the RBS is supposed to be very simple.

5) Radio link between RBS and vehicles adopts the micro celluler communication system which arranged a series of elliptical cell along the road, and the DS spread spectrum system using millimeter wave for the communication system. 45GHz band is considered for example as the frequency of millimeter wave, where the very wide frequency band has been allocated for mobile communication. Owing to place the RBS every several hundred meter, communication is fundamentally done in the line-of-sight. And also, two waves of direct wave and road surface reflected wave are dominant, and non-direct wave except road surface reflected wave becomes relatively a very small environment in the propagation condition. @ @

6) Transmitted power from RBS is controlled in order to be proportional to the square of the distance to mobile station (MS) from RBS, so that the reception level in MS may not become minute at the cell edge and near the station. For the same purpose, in RBS, the directional antenna of the ellipse beam with gain of 20~ 30dB and F/B ratio of over 30dB is used and is installed with the beam tilt for the radiation direction. The ellipse beam antenna is adopted for reducing the leakage of the radio wave to the road outside, and it is placed so that the major axis of ellipse beam may parallel the road. And, on the antenna of the MS, the fan beam antenna with a half-power width of 3~5 degrees in vertical plane and a half-power width of about 20 degrees in horizontal plane is used for reducing the reception of the reflected wave by the ground. It is installed so that both antennas may face each other and approach with the advance of the vehicle to each other, as shown in Fig.3. By such antenna configuration, reception level of the non-direct wave is reduced, and the stabilized reception level is also ensured even in winding road.

5. Evaluation on Radio Link of the Proposed System

Here, we discuss the characteristic on radio link of the proposed system, such as the vehicular interval for the line-of-sight communication, the propagation characteristics with the diversity of equal gain combining and attenuation caused by rain which are clarify the possibility of a realization of this system.

5.1 The vehicular interval for the line-of-sight communication

Figure 4 shows the vehicular interval d_x for the line-of-sight communication in showing the parameter as the height of forward vehicle; 3.8m, the height of receiving antenna; 0.5m, distance from edge of the cell; x and the height of transmitter antenna; h_t d_0 : diameter of the cell (refer to Fig. 5).

5.2 The propagation characteristics

It is reported that propagation of millimeter wave in the line of sight agrees well with analysis of two-wave model [5]. So, we evaluate the received level characteristics on the model shown in Fig. 5. Mobile antennas are installed at the front of the vehicle with a diversity of the vertical direction. Here, we suppose that upper antenna and lower antenna receive direct wave and reflected one by the earth plane, respectively. And, the selection combining diversity scheme is applied between these antennas. The objective is to reduce the effect of excessively deep fades in the received levels.

Electrical field intensity E of direct wave at the receiving antenna is generally calculated as equation (1).

$$E = E_0 \exp(-jkr_0) \cdot D_T(\theta_0) \cdot D_R(\theta_0) \quad (1)$$

$$E_0 = C \cdot \sqrt{P_t \cdot G_t \cdot L_S} \quad (2)$$

$$k = 2\pi / \lambda \quad (\lambda : \text{wavelength}) \quad (3)$$

Here, r_0 is the path length of the direct wave; θ_0 is an angle between the direction of a direct wave and the antenna main beam axis, C is constant, P_t is transmitted power controlled in proportion to the square of the distance, as shown here in equation (4);

$$P_t = P_0 \cdot \left((d_0 + 50. - x)/d_0\right)^2 \quad (4)$$

where, P_0 : transmitter output power, d_0 : diameter of the cell, x : distance from far edge of the cell.

L_s is transmission loss shown as equation (5).

$$L_S = \left(\frac{\lambda}{4\pi d}\right)^2 \quad (5)$$

And, D_T and D_R, which are directivities of the transmitting antenna and the receiving antenna, are shown as equation (6).

$$20 \cdot \log D_{T,R}(\theta) = 20 \cdot \log \cos^x \theta \quad \text{(in main lobe)}$$

$$= 32 - 20 \cdot \log \theta - G_{t,r} \quad \text{(in side lobe)} \quad (6)$$

where, x is the coefficient which shows the half beam width corresponding to antenna gain $G_{t,r}$, and is 30 at $G_{t,r} = 20$ dB, here.

By adding the field intensity of reflected wave got in the same way to equation (1), synthesized reception field intensity E transmitted by beam tilt antenna is obtained as the following equation (7),(8).

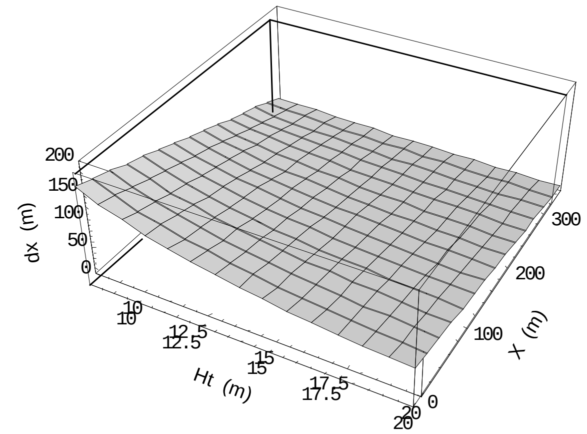


Fig.4 The vehicular interval for the line-of-sight communi.

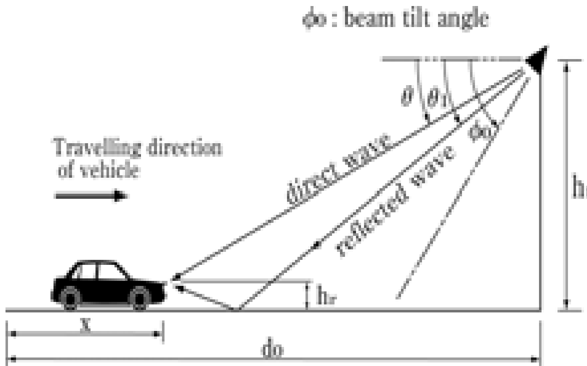


Fig. .5 Analytical model for the received level

$$E = E_0 \exp(-jkr_0) \cdot [D_0 + D_1 \cdot R_V \cdot \exp\{-jk(r_1 - r_0)\}] \quad (7)$$

$$D_0 = D_T(\theta_0 - \phi_0) \cdot D_R(\theta_0),\ D_1 = D_T(\theta_1 - \phi_0) \cdot D_R(\theta_1) \quad (8)$$

Here, transmission loss of reflected wave is assumed being nearly equal to direct wave one. r_1 is the path length of a reflected one. θ_1 is angle between the direction of a reflected wave and horizontal axis. ϕ_0 is a tilt angle of the transmitting antenna. And, R_V is the Fresnel reflection coefficient for vertical polarization with equal permeability in the boundary of two media, given as equation (9).

$$R_V = \frac{n^2 \cos\varphi - \sqrt{n^2 - \sin^2\varphi}}{n^2 \cos\varphi + \sqrt{n^2 - \sin^2\varphi}} \quad (9)$$

n : complex index of refraction (here, $n = 2.0 - j0.05$), φ : incidence angle.

Therefore, received field intensity $|E|$ is obtained in the following equation (10).

$$|E| = E_0 \cdot \sqrt{(D_0 + D_1 R_V \cos\delta)^2 + (D_1 R_V \sin\delta)^2} \quad (10)$$

$$\delta = k \cdot (r_1 - r_0) \quad (11)$$

Figure 6 shows the calculated results of the received level with transmitting power control and the diversity

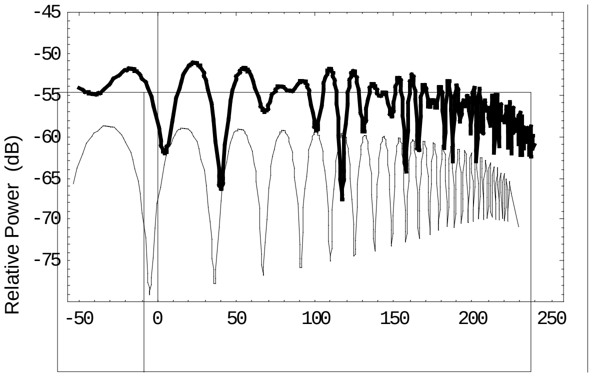


Fig. 6 Relative received level with the diversity

of equal gain combining (bold line), compared with the received one without diversity (fine line), in the condition of f =45GHz, P_0 =17dBm, d_0 =300m, the height of transmitter antenna; h_t = 15m, $\phi_0 = 4h_t / d_0$ = 0.16 and the heights of lower and higher receiving antennas; h_{rl} =0.5m, h_{rh} =0.65m, respectively. Fig.6 shows the received power level that is down of about 15db by fading, but this level is improved about 8dB by diversity in this case.

5.3 Attenuation caused by rain

In the millimeter wave region, radio wave attenuation by rain is considerable, and circuits may be interrupted in times of heavy rains. The amount of attenuation Z_0 resulting when rain falls uniformly in the propagation path can be In the millimeter wave region, radio wave attenuation by rain is considerable, and circuits may be interrupted in times of heavy rains. The amount of attenuation Z_0 resulting when rain falls uniformly in the propagation path can be approximated as follows ;

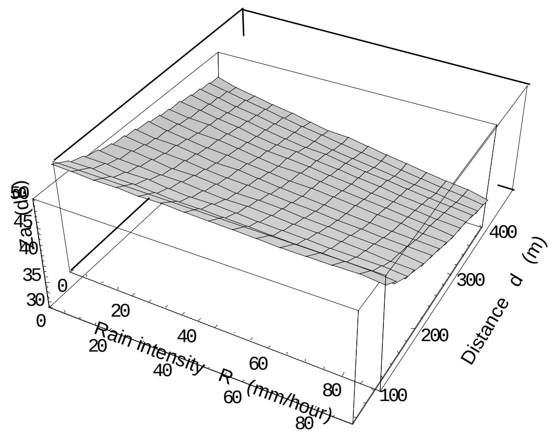
$$Z_0 = \kappa \cdot R^n \quad \text{(dB/km)} \qquad (12)$$

Here R is the rain intensity (mm/min), and κ and n are constants with the values of κ =17.2 and n =0.87 for 45GHz transmissions. Hence when R =1.2 mm/min, the attenuation over a distance of 400 m is calculated to be 8.1 dB.

The C/I ratio taking also the attenuation Z due to rain into account may be calculated, in dB, as follows.

$$C/I = P_0 + Gt + Gr - Ls - Z - KTBF \qquad (13)$$

where, P_0 is the transmitted power, Gt is the transmitter antenna gain, Gr is the receiver antenna gain, Ls is free-space transmission loss and $KTBF$ is the thermal noise of the receiver, K ; the Boltzmann constant, T ; the absolute temperature, B ; the bandwidth, and F the noise figure. Fig. 7 shows attenuation margin $Z_a (= Z - Z_0)$ for attenuation due to rain in the relation with R and distance d. Hence, when spread spectrum modulation are used, C/I required to achieve the necessary transmission quality, that is a signal BER P_e can be obtained by using a following equation.



$$P_e = \frac{1}{2} \cdot \mathrm{erfc}\left(\sqrt{\frac{C}{I} \cdot \frac{W}{R_b}} \right) \qquad (14)$$

For example, when a signal BER P_e is 1×10^{-5}, W is 50 MHz, and R_b is 384Kbps, C/I is –11.6dB by eq.(14)

And so when parameters are given as $Gt + Gr$ =40 dB, Ls =117.5dB (frequency f =45GHz, distance d =400 m), $KTBF$ =-90 dB and p_0 is given as eq. (4), the attenuation Z due to rain is 41.1 dB. Hence a margin of about 33 dB with Z_0 = 8.1 dB above is anticipated.

6. CONCLUSION

In this paper, we propose a road-vehicle communication system using 45GHz band millimeter-wave and CDMA communication system for the future ITS. As an evaluation of the proposed system, propagation characteristics of the radio link are examined. From the results of the examination on the vehicular interval for the line-of-sight communication, the received power level at the mobile station in adopting the transmitting power control and the diversity and attenuation caused by rain, it is considered that the proposed system has the feasibility to realization.

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