DSRC using OFDM for roadside-vehicle communication system

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I. Abstract - We propose to apply DSRC using OFDM to roadside-vehicle communication system as a means to overcome frequency selective fading, shadowing and high-speed hand-over difficulties. We optimized the transmission rate of a subcarrier which is a transmission parameter of the OFDM system. Our goal is to achieve BER of less than 10^{-5} under the conditions of transmission rate 2.048 Mbps, carrier frequency 5.8GHz, vehicle speed 180km/h, simulcasting of several roadside transmitters, maximum delay of less than 1μsec and utilizing forward error correction (FEC). We developed the transmitter and receiver of DQPSK-OFDM system in 5.8GHz band and measured the BER performance to show that OFDM system was applicable to roadside-vehicle communication system.

II. Introduction

The OFDM system is adopted in European DAB and domestic next generation digital broadcasting because of its robustness against frequency selective fading caused by delayed waves on propagation paths.
This modulation is a multicarrier modulation scheme, where data symbols are transmitted in parallel on multiple subcarriers. This technique narrows the subcarrier bandwidth and achieves tolerance against fading.
This modulation utilizes the orthogonality relation of frequency with frequency spacing of the subcarrier and the transmission rate of a subcarrier equally, and arranges the carrier by minimum frequency spacing. The spectrum efficiency is higher as a result. The guard interval reduces ISI and ICI to utilize this orthogonality relation for the delayed wave in the guard interval.
In this paper, we apply the OFDM system to roadside-vehicle communication system, and optimize the transmission rate of a subcarrier and introduce an estimation method of BER performance. We also measured BER performance with a transmitter and receiver we developed in 5.8GHz band.

III. Transmission rate of subcarrier

We consider these three topics (frequency selective fading, time selective fading, spectrum efficiency) while optimizing the transmission speed of the subcarrier in the OFDM system.
First, to study frequency selective fading, we supposed two paths with some delay between them which induce notches by $1/\tau$ [Hz] spacing in the frequency domain. These notches decrease BER performance. It is known that it is necessary to make the transmission rate of a subcarrier less than $1/(2\pi\tau)$ [Hz] to reduce this effect.
As to time selective fading, the random FM noise caused by the receiver movement induces interference between subcarriers.
It is important to widen the frequency spacing more than a doppler spread between each subcarrier. Because the frequency spacing of the subcarriers and the transmission rate is equal, the transmission rate R [bps] of a subcarrier must satisfy the following relation in order to reduce the effect of the above-mentioned two kinds of fading simultaneously.

$$f_d << R << 1/_{2\pi\tau} \quad (1)$$

fd:maximum doppler frequency

Next, the guard interval duration tg [sec] of the OFDM system must be more than the delay time of the delayed wave to reduce ISI and ICI effects.

$$t_g \geq \tau \quad (2)$$

However, it consequently decreases the effective transmission rate compared with the case of no guard interval. The bandwidth of (ts+tg)/ts times is therefore needed to realize no degradation of the effective transmission rate on condition that ts is FFT symbol duration and equals 1/R. This leads to the deterioration of spectrum efficiency. In this paper, since it should be no less than 80%, the transmission rate of a subcarrier must satisfy the following expression.

$$R < 1/_{4t_g} \quad (3)$$

The parameters of the system model are summarized in table1.

Table1

Modulation	DQPSK-OFDM	
Transmitting frequency	5.8GHz	
Bit rate	2.048Mbps	
Number of subcarriers	12	24
Frequency spacing between subcarriers	93.3kbps	44.7kbps
FFT symbol duration	10.7μsec	22.4μsec
tg/(ts+tg)	3/35	3/67

IV. Multicarrier modulation system

The block diagram of a transmitter and a receiver of the DQPSK-OFDM system is shown in fig.1.
In the transmitter (a) of fig.1, the FEC of the Reed-Solomon encoder is applied to input data and the output of FEC is applied to the interleave, differential encoding. Then inverse discrete Fourier transform is performed. The guard interval is added and orthogonal modulation is performed. The output of this modulation is converted to 5.8GHz by analog block, and it is transmitted from an antenna.
The transmitted signals are expressed as the following.

$$x(t) = \sum_{i=-\infty}^{\infty} \sum_{k=-\infty}^{N-1} \mathrm{Re}\left\{a_{ik} e^{j\, 2\pi f_k (t-iT)}\right\} f(t-iT) \quad (4)$$

where

a_{ik} is the differential encoded.

N is the number of carriers.

$$f(t) = \begin{cases} 1 & (-t_g \le t \le t_s) \\ 0 & (t < -t_g,\ t > t_s) \end{cases} \quad (5)$$

$$f_k = \frac{2\pi k}{t_s} \quad (0 < k < N-1) \quad (6)$$

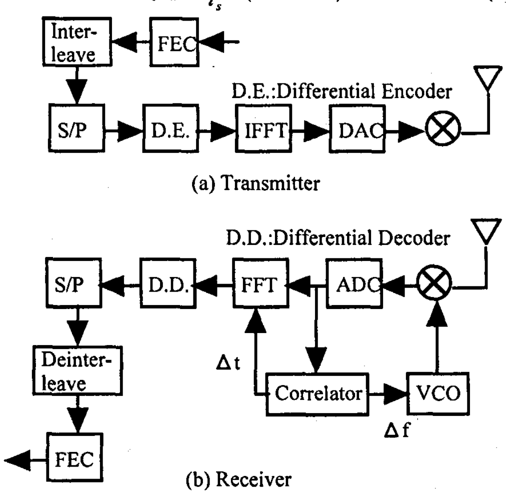


Figure 1. Block diagrams of transmitter / receiver

The transmitted signal is propagated through the channel h(τ ; t), and additive white Gaussian noise n(t) is added at analog front-end, and the orthogonal demodulation is done after frequency down-conversion.
This received signal is given in the next expression.

$$y(t) = \int_0^t h(\tau;t)\, x(\tau) d\tau + n(t) \quad (7)$$

By calculating the correlation of the guard interval portion with this received signal, the correlator detects a carrier frequency error betweent the transmitter and the receiver and the FFT symbol timing, and the FFT and the VCO blocks work on the basis of the calculation result.
As for the received signal y(t), FFT, differential decoding, deinterleaving, Reed-Solomon decoding are performed.
We next introduce an estimation method of BER performance on the basis of fig.1 with the exception of interleaving and FEC.
This estimation method requires the probability density function pdf(SINR,power) of the instantaneous power and the averaged signal to interference plus noise ratio (SINR) considering interference between subcarriers, and calculates the BER performance from eq.(8).

$$BER\,(SNR) = \int_0^{\infty} pdf\,(SINR, p) \exp(-p)\, dp \quad (8)$$

We next derive SINR to estimate the BER performance where the channel fluctuation can not be neglected, and propagation delay can be neglected. Under these assumptions, the propagation path is expressed in the next equation.

$$h(\tau;t) = g(t)\delta(t) \quad (9)$$

where g(t) is a complex Gaussian random process with a zero mean and has an autocorrelation function of the next equation.

$$R(\tau) = \tfrac{1}{2} E\left[g(t-\tau) g^*(t)\right] \quad (10)$$

Substituting eq. (4),(9) into (7), and performing FFT, the following equation is provided.

$$z_{im} = \frac{1}{t_s} \sum_{k=0}^{N-1} a_{ik} \int^{t_s} g(t) \exp\left(-\frac{2\pi(m-k)}{t_s}\right) dt + n_{im} \quad (11)$$

The next equation is provided from correlation of zim and z(i-1)m under a_{ij} is equal to $a_{(i-1)j}$.

$$\rho = \frac{E\left[z_{im} z^*_{(i-1)m}\right]}{E\left[z_{im} z^*_{im}\right]} \quad (12)$$

Interference between subcarriers is given with the equation.[1]

$$I = \frac{1}{t_s} \sum_{\substack{k=0 \\ k \ne m}}^{N-1} \int_0^{t_s} \int_0^{t_s} R(u-v-t_s-t_g) \exp\left(-\frac{2\pi(m-k)(u-v)}{t_s}\right) du dv \quad (13)$$

Assuming the directivity of the receiving antenna is isotropic, the mean received power s, and autocorrelation function R (τ) if (fd τ <<1) satisfies the following equation.

$$R(\tau) = J_0(2\pi f_d \tau) \doteqdot 1 - (\pi f_d \tau)^2 \quad (14)$$

Substituting eq. (14) into eq. (13), and simplifying the equation.

$$I = (f_d t_s)^2 \sum_{\substack{k=0 \\ k \ne m}}^{N-1} \frac{1}{(k-m)^2} \quad (15)$$

It can be rewritten as eq.(16) when we utilize the relationship that FFT symbol duration and the transmission rate of a subcarrier is equal.

$$I=\left(f_d/f_R\right)^{2}\sum_{\substack{k=0\\k\neq m}}^{2N-1}\frac{1}{\left(k-m\right)^{2}} \tag{16}$$

This equation represents the interference between subcarriers shown by the ratio of the transmission rate of a subcarrier to a doppler spread.
This relation has been described considering the time selective fading.
This interference increases with the number of subcarriers, but is almost saturated with 10 or more subcarriers as shown in fig.2.

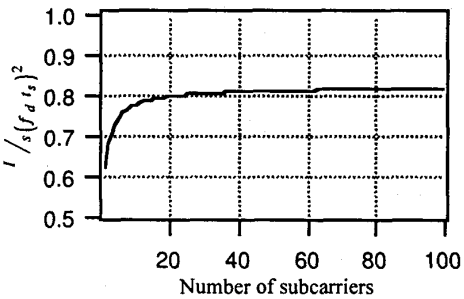


Figure 2. The normalized interference vs number of subcarriers

Considering this, the interference of more than 10 subcarriers is expressed as:

$$I \doteqdot 1.6425 * \left(f_d t_s\right)^2 \tag{17}$$

SINR is given from eq. (17) as follows.

$$SINR=\frac{1}{\frac{1}{SNR}+1.6425 * \left(f_d t_s\right)^2} \tag{18}$$

V. BER Performance

In this section, we show the results which include the BER performances of the suggested computation model and actual measurement results of the developed DQPSK-OFDM system. In simulation, we used rician fading channel, and substituting its probability density function of power[2] into eq.(8), and eq.(19) is provided.

$$BER(SNR)=\frac{\left(1+k\right)}{2\left(1+k+SINR\right)}\exp\left(\pm\frac{k\,SINR}{1+k+SINR}\right) \tag{19}$$

where k is rician factor.

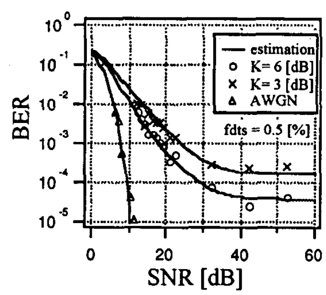
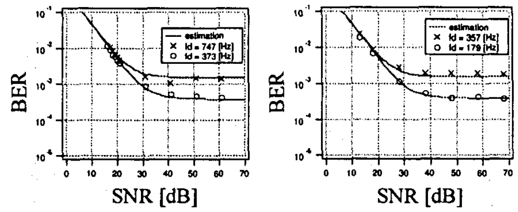


Figure 3. BER vs SNR under rician channel

From fig.3, it can be seen that the computation model agrees very well with actual measurement results with rician factor K= 3,6 [dB]. Fig.3 includes BER performance of AWGN which corresponds to k=infinity.



(a)12 subcarriers (b)24 subcarriers

Figure 4. Comparing the BER performance of 12 subcarriers with the BER performance of 24 subcarriers under the same fdts (fdts = 0.4, 0.8 [%])

Figure 4 shows that the BER performance of 12, 24 subcarriers under rayleigh channel when fdts is 0.4,0.8[%].
Figure 4 indicates that the BER is saturated when SINR is large. This means that BER(IBER) is the irreducible which is caused by the interference between subcarriers. And from (a) and (b) of fig.4, we confirmed that IBER is almost the same when fdts is equal, although a quantity of the interference between the subcarriers changes by the number of 12, 24 subcarriers. This indicates that the assumption in derivation of SINR is valid.
Figure 5 shows IBER against fdts. The computation model agrees very well with actual measurement results when AFC of the receiver does not operate and the transmitter and receiver uses a common local oscillator. But in the case when AFC of receiver operates, there is a gap between the computation model and actual measurement results. Therefore, we could confirm that a gap occurs when the AFC does not operate well. Consequently, it was necessary to improve AFC.

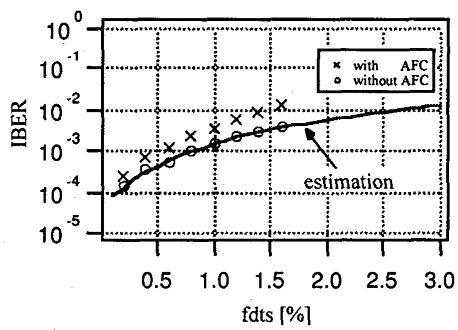


Figure 5. IBER vs fdts

From fig.5 IBER becomes 10^{-2} when fdts is equal to 0.025. Using an appropriate error correction code, one can improve the bit error rate sufficiently if the input bit error rate to the error correction decoder is less than 10^{-2}. So, we need that fdts is less than 0.025.
Figure 6 shows the IBER performance as a parameter with level difference D/U and delay time τ between two paths to investigate the effect of delayed wave under two paths rayleigh channel. We assume that two paths are transmitted by two roadside transmitters.

Figure 6 indicates that the IBER is independent of τ / ts when the level difference D/U between the two paths is greater than 25dB, and IBER converges the near value with 1 path rayleigh channel. This indicates that two paths rayleigh can be interpretd as one path rayleigh channel when D/U becomes greater than 25dB.

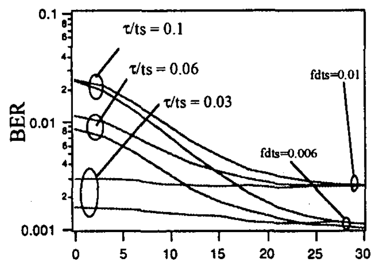


Figure 6. IBER vs D/U as parameter with fdts, τ / ts

And the curves where τ / ts equals 0.03 of fig.6 indicates that IBER is independent of D/U. This indicates that we can interpret the case as one path rayleigh channel.
We can permit τ / ts < 0.06 and D/U = 0 [dB] if we use forward error correction which improves the bit error rate from 10^{-2} to 10^{-5} which is our goal, and of course, τ / ts of more than 0.06 is possible when D/U is larger than 0 [dB].
As summary, we find that fdts < 0.025 and τ / ts < 0.06 is satisfied to reduce the effect of time selective fading and frequency selective fading simultaneously.
The next expression was concluded when we substituted fd and τ into transmission rate 2.048 Mbps, carrier frequency 5.8GHz, vehicle speed 180km/h, simulcasting, maximum delay < 1μsec

$$17\mu\text{sec} \le t_s \le 26\mu\text{sec} \qquad (20)$$

when we utilized the relationship between FFT symbol duration and the transmission rate of a subcarrier, the transmission rate of a subcarrier satisfying the following inequality.

$$38kbps \le R \le 60kbps \qquad (21)$$

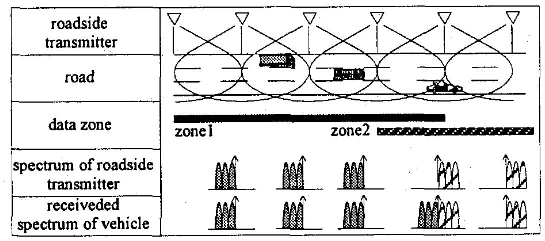
The expression satisfied spectrum efficiency eq.(3) simultaneously.

VI. DSRC/SR-DSC

We propose the DSRC/SR-DSC (Dedicated Short Range Communication/Single Radio frequency-Dividing Sub-Carrier) as a way to realize the high speed hand-over systems. We divide the OFDM signal into subcarrier groups, and change the subcarrier groups at the hand-over.
This DSRC/SR-DSC is shown in fig.7. This system is that the roadside transmitter transmits a subcarrier group and these groups in using FDMA are arranged. A group represents a data zone along a road and all roadside transmitters are synchronized. The roadside transmitters of the same data zone simulcast the same data to reduce shadowing effects. The receiver has the equivalence of several receivers on the basis of Post-detection because FFT operation of the receiver can demodulate several subcarrier groups simultaneously.

When a vehicle runs in a data zone, the receiver on the vehicle demodulates the signal which has several delayed paths within the guard interval (1μsec duration) that are transmitted by roadside transmitters in a data zone, and extracts suitable subcarrier groups.
When a vehicle passes a boundary between data zones, receivers demodulate the signal of the two data zones, and perform selective diversity in accordance with RSSI or the number of corrected symbols by FEC. Since the hand-over signal in DSRC/SR-DSC is gathered from analog front-end to the baseband part, we can realize high-speed hand-over without changing the frequency of the local oscillator.

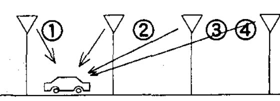
Figure 7. The system model of the DSRC/SR-DSC



VII. IBER performance in a data zone

This section evaluates the IBER performance in a data zone when using DSRC/SR-DSC, we show the results which was measured using a fading simulator.
Table.3 shows the measurement results in the edge of the data zone using number of 12 subcarriers in the table 1 with propagation channel on table 2.

Table 2. Propagation model



model	channel	speed [km/h]	rician factor [dB]	Loss [dB]	delay [usec]
I	①rayleigh	100		0	0
II	②rayleigh	100		0	0
III	①rician	100	13	0	0
IV	②rician	100	13	0	0
V	③rician	100	13	5	0.6
VI	④rician	100	13	10	0.9

	model	IBER
A	I	3.00e-3
B	I + II	3.00e-3
C	III+IV(anti-phase)	1.50e-3
D	III+IV(anti-phase) + V	2.00e-3
E	III+IV(anti-phase) + VI	1.50e-3

Table 3. IBER under model

Table 3 indicates IBER Performance is almost same among A, B, C, D and E.
For example A,B, what they indicate almost same IBER performance is thought that it is interpreted two paths rayleigh fading to one path rayleigh fading because there was no delay time between two paths of B. And, in example of C,D,E, they have almost the same performance although they do not satisfy $\tau / ts < 0.06$. It is thought that the effect of time selective fading by delayed wave is relaxed because there is level difference, and we use the anti-phase in C,D,E to assume the worst case of simulcasting.

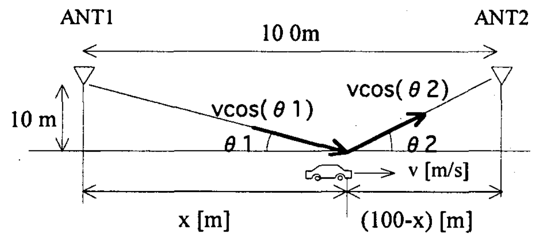


Figure 8. The channel model between two transmitters and receiver.

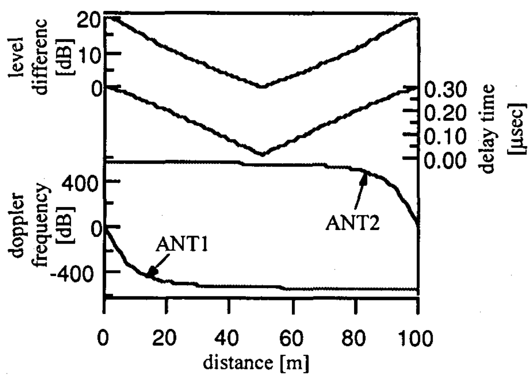


Figure 9. Doppler frequencies, level differnece and the delay time between the two paths transmitted from two transmitters.

We considered only two roadside transmitters nearest to vehicle and measured the IBER using a fading simulator. We supposed the delay time, the level differnece and the doppler spread which considered elevation angle of an observed vehicle. Figure 9 shows the level difference and delay time between two paths which are transmitted by two roadside transmitters.
Fig.10 shows IBER performance when using 2 path rayleigh and rician channel with rician factor of 6 [dB]. From this graph, we found that IBER performance became almost 10^{-3}. And when we used error correcting code of RS(63,40), we confirmed that the IBER performance improves from 10^{-3} to less than 10^{-7} under both the rayleigh channel and the rician channel.

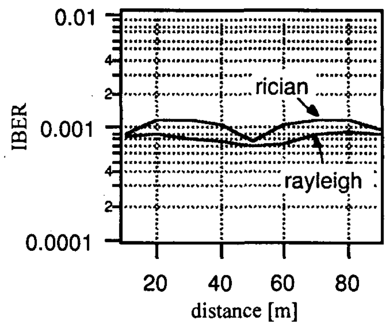


Figure 10. IBER is the dependent on the distance under rayleigh channel and rician channel.

VIII. Summary

In this paper, we applied DSRC using OFDM to roadside-vehicle communication system as a means to overcome frequency selective fading, shadowing and high-speed hand-over. We optimized the transmission rate R of a subcarrier, and we found that R must satisfy that $38kbps \le R \le 60kbps$ where $\tau = 1$ [µsec], fd = 966 [Hz] which corresponds to the vehicle speed of 180 [km/h].
We proposed the DSRC/SR-DSC(Dedicated Short Range Communication/Single Radio frequency-Dividing Sub-Carrier) as means to realize a roadside-vehicle communication system, and the IBER performance in a data zone is shown, which is 10^{-3} without forward error correction and less than 10^{-7} with RS(63,40) under both 2 paths rayleigh and rician channels, vehicle speed of 100 [km/h].
In future, we will conduct an outdoor experiment to measure the IBER performance at the vehicle speed of less than 180 [km/h].

Reference

[1] Okada, M., Hara, S.and Morinaga, N.,"Bit Error Rate Performances of Orthogonal Multicarrier Modulation Radio Transmission Systems," *IEICE Trans. Commun.*, Vol. E76-B, No2, pp.113-119, Feb. 1993.

[2] Inoue, T., Karasawa, Y. ,"Theoretical Analysis on Level Variation of Wideband Signals under Multipath Fading Environments," *IEICE Technical Report,* A • P98-40,Aug. 1998.