Evaluation Experiment of the Multicast Communication System

Shin-ichi YAMAMOTO, Kazuyoshi KAWASAKI, and Masaki SATOH

We carried out the multicast communication experiment for mobiles using the Engineering Test Satellite VIII (ETS-VIII). In communication experiment, we measured the transmission characteristics in the case that OFDM signal passed through the satellite link with a non-linear characteristic, and confirmed the effect on the transmission characteristics due to non-linear link of the multi-carrier constituting the OFDM signal.

1 Introduction

We conducted multicast communication experiments using the Engineering Test Satellite VIII (ETS-VIII), and used the orthogonal frequency division multiplexing (OFDM) for the communication method. The OFDM method is a multi-carrier digital modulation method that transmits data using multiple carrier waves. Neighboring carrier waves are orthogonal to each other, even if each overlapping spectrum is transmitted; the data demodulation is possible on the receiving side. Therefore, it enables the spacing between carrier waves narrower than in the case of a normal frequency-division multiplex system, and can efficiently use the transmission frequency bandwidth. Also, in order to disperse the transmit data on multiple carriers and modulate, it can reduce the modulation rate of each carrier and increase the symbol length. Further, by inserting guard interval into each symbol, it is an advantage that it is insusceptible to intersymbol interference even if multipath delay waves are received, and is suitable for reception at mobiles (e.g. cars). However, in cases that the transmission channel has non-linear characteristics, the transmission characteristics are likely to deteriorate to the intermodulation effect between carrier waves that constitute OFDM signals. Moreover, in the satellite links, the high power amplifiers of repeaters are often used in the non-linear region due to the power limit of the onboard satellite equipment. Therefore, in this experiment, we obtained the data about the effects of the transmission characteristics by the transmission channel that has non-linear characteristics when OFDM signals are transmitted using the satellite link, and the data about the effects of the delay waves by multipath from buildings when the experimental vehicle is moving in a suburban and urban area. In addition, we evaluated the reception quality from the obtained data during moving. In this paper, we will describe the experiment overview and results.

2 An overview of the experiment

2.1 OFDM experiment system

The OFDM signal used for this experiment is compliant with the Eureka147 Digital Audio Broadcasting (DAB)[1] which is high- quality DAB standards for mobile objects. The reception quality and other standards of the DAB are set by the ITU-R[2]. In the experiment, we used the MODE III of standards for satellite broadcasting. Table 1 shows the transmission parameters for the MODE III. The modulation method of each carrier wave that constitutes OFDM signals uses $\pi/4$ shift Differential QPSK method, the effective symbol length is 0.125 msec, and the guard interval length of the OFDM symbol is 0.031 msec.

Table 1 OFDM signal type

	MODE III
Modulation Scheme (Subcarriers modulation)	OFDM ($\pi/4$ shift D-QPSK)
Number of OFDM symbols (NULL symbol is excluded)	153
Number of transmitted carriers	192
Carrier spacing	8 kHz
Transmission frame duration	24 ms
NULL symbol duration	0.168 ms
Duration of OFDM symbols	0.156 ms
Inverse of the carrier spacing	0.125 ms
Duration of the time interval called guard interval	0.031 ms
Modulation bandwidth	1536 kHz

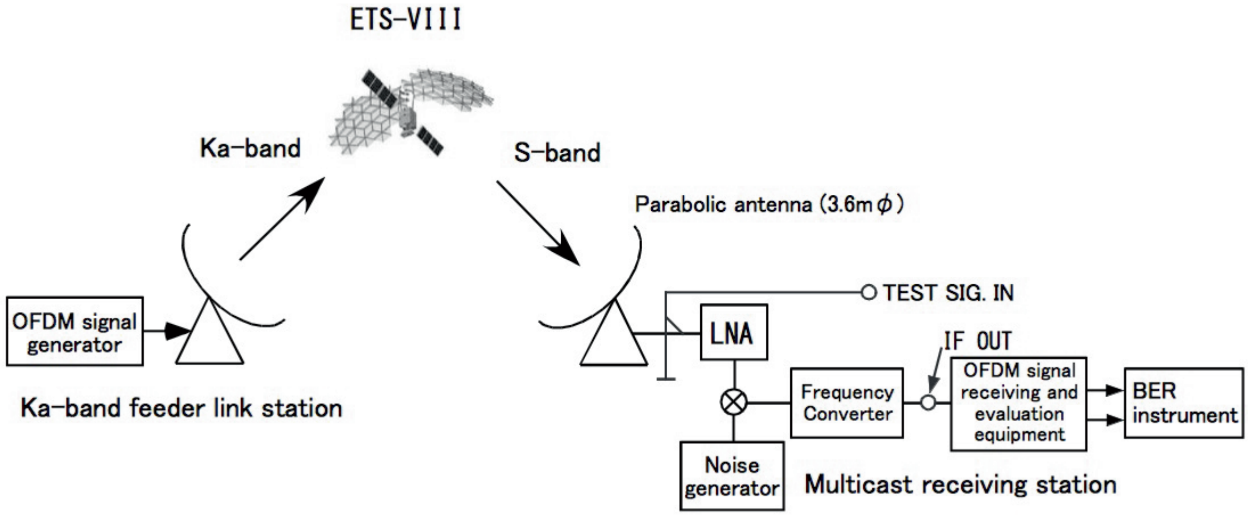


Fig. 1 OFDM experiment configuration

In the DAB standards, the error-correction by convolution coding (code rate=1/3, constraint length=7) is supposed to apply to transmission signals that used in the experiment. The OFDM signal generation equipment used in the experiment can be set not to perform error-correction, and the occurrence of the pseudo noise (PN) codes as test signals is also possible. Then, using these functions in the experiment, we measured the bit error rate (BER) of a basic transmission characteristic of digital communication mainly. Figure 1 shows the configuration of the experiment system. The earth station of the transmission end used the Ka-band feeder-link station that is installed in the Kashima Space Technology Center; one of the receiving end used the S-band reference station that is installed in the same place.

At the time of the experiment under the moving environment, we measured the data using the evaluation equipment of OFDM signal (a demodulator of OFDM signals) and the BER measuring instrument which was equipped in the test vehicle. The antenna of the receiving station is a single-element microstrip antenna which is small and lightweight and was installed on the test vehicle roof.

2.2 Measurement of transmission characteristics

2.2.1 Measurement of non-linear characteristics of the transmission channel

In the measurement of transmission characteristics, we first obtained the data on input-output characteristics of the transmission channel in order to confirm the transmission channel's non-linearity.

Figure 2 shows the measurement results of input-output characteristics. The horizontal axis represents the transmission power that is the output power of the high power amplifier of the Ka-band feeder-link station, and the vertical axis represents the output power of the down converter at the S-band side, that is the input power of the receiving and evaluation equipment of the OFDM signal. We used the OFDM signal for measurement, and used a spectrum analyzer for reception power measurement. In addition, the Signal/Noise (S/N) ratio at the time of reception is 20 dB or more, and its noise effects during measurement are negligible.

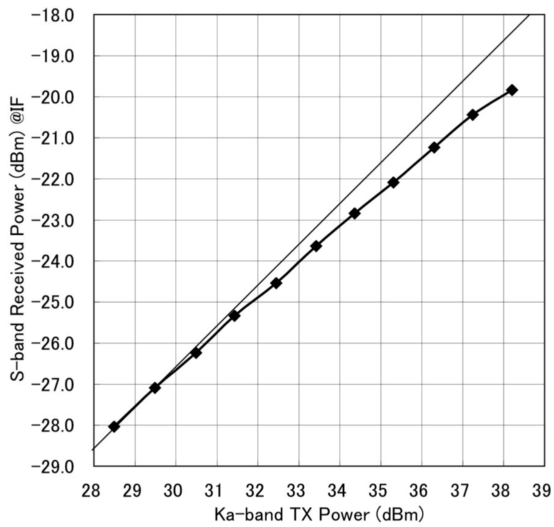


Fig. 2 Input-output characteristics of the transmission channel

A straight line in Fig. 2 represents linear characteristics, and if the transmission power of the Ka-band feeder-link station exceeds +30 dBm, the transmission channel becomes non-linear characteristics, which can be seen from the measurement results. Also, the point of the input-output characteristics of the transmission channel, which is compressed 1dB from the linear characteristics, that is the output power of the Ka-band feeder-link station in the so-called 1dBcompression point is a +36.6 dBm.

2.2.2 Measurement of transmission characteristics

We measured the BER characteristics of the OFDM signals transmitted on the transmission channel with non-linear characteristics, and examined the effects of the transmission characteristics by non-linear characteristics of the transmission channel.

In order to measure the effects of the transmission channel's non-linear characteristics, we first transmitted OFDM signals with +36.6 dBm of the Ka-band feeder-link station's transmission power that is the 1dB compression point mentioned above. At the reception side, we measured the characteristics in carrier-power-to-noise-density ratio (C/No) vs. BER by changing the C/No of the signals to be input into the receiving and evaluation equipment of OFDM signals. The C/No was varied by adding the noise of the noise generator to the OFDM signal outputted from the low noise amplifier (LNA) to adjust the noise level. We also measured the data on the characteristics of C/No vs. BER for the respective values of output power at the Ka-band feeder-link station by adjusting +2 dB, −4 dB, and −8 dB to the reference value of +36.6 dBm, and as in the above experiment, the C/No value of reception end was adjusted by the added noise power from the noise generator. Figure 3 shows the measurement results. The reference value at the 1 dB compression point is shown as 0 dB, and shows the measurement results of +2 dB, −4 dB,

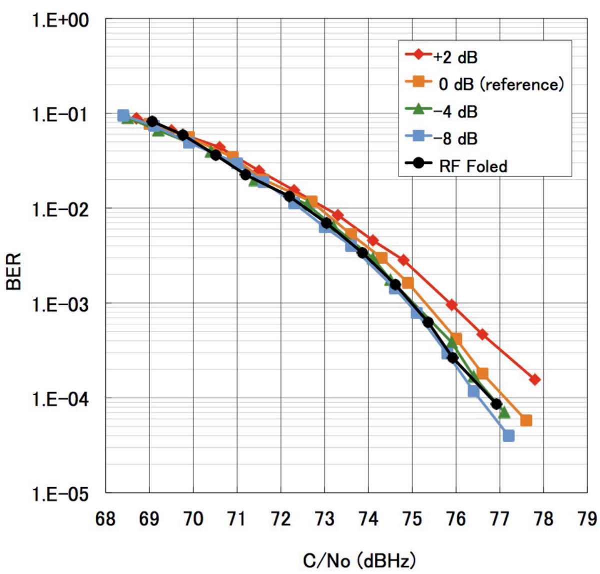


Fig. 3 BER characteristic

and −8 dB that are relative values from the reference value respectively. The RF folded characteristics in Fig. 3 are the data obtained in laboratory experiment; the signal does not via the satellite link. The frequency of the output signals of the OFDM signal generation equipment shown in Fig.1 converted to 2.5 GHz band signal, and then it inputs the test signal input terminal (TEST SIG. IN) of the multicast receiving station, and is input to the LNA through the directional coupler, then measure the BER using the OFDM signal receiving and evaluation equipment when the transmission channel is linear characteristics.

From the input-output characteristics of the transmission channel shown in Fig. 2, the transmission channel has almost the linear characteristics in the case of 8 dB less transmission power than the reference value, but becomes the non-linear characteristics while increasing the transmission power than that. In Figure 3, there is a trend that the BER deteriorates when the transmission power becomes larger. Comparing the C/No values where the BER is 2×10^{-4}, there is about 1.5 dB deterioration of the C/No in +2 dB from the reference value to that of −8 dB from the reference value, this shows the effect of the non-linear characteristics of the transmission channel.

The OFDM signals used for the experiment are composed of 192 carrier waves which are 8 kHz intervals each. For this reason, when the transmission channel has non-linear characteristics, the spurious will occur due to intermodulation between carrier waves and be overlapped with these waves. Consequently, as shown in the results, there appears a tendency for BER characteristics to deteriorate in the non-linear range.

2.3 Evaluation of reception quality under the moving environment

2.3.1 Experimental overview

We obtained the data to evaluate the reception quality in the moving environment used the test vehicle (hereinafter referred to the mobile receiving station) that was installed the OFDM signal receiving and evaluation equipment and the BER instrument.

We consider that, in receiving S-band downlink signals from the satellite in the mobile receiving station, fluctuations of signal level and bit errors occur from shadowing and blocking by buildings and trees, the fading due to interference by reflected waves from buildings and others around the road and from the movement of the vehicle.

In the experiment, by moving the mobile receiving

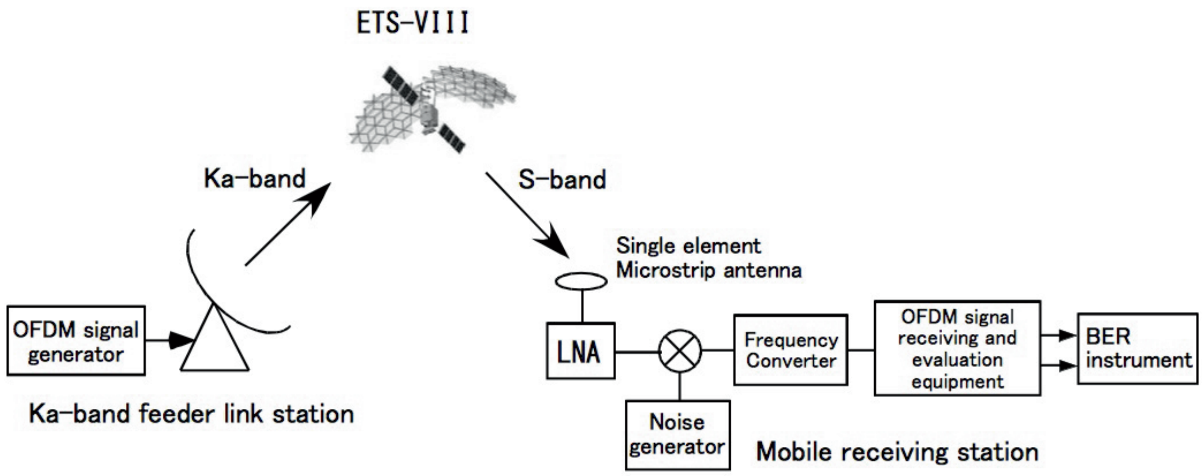


Fig. 4 Configuration of the moving experiments

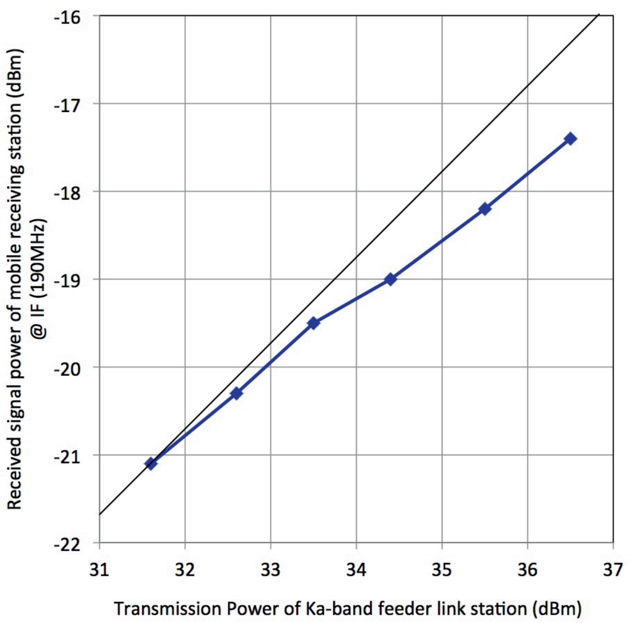


Fig. 5 Input-output characteristics when using the mobile receiving station

station under the different moving environments, we measured the received power and the bit error of the S-band downlink signals from the satellite.

Figure 4 shows the configuration of the moving experiments. The OFDM signals were transmitted by the Ka-band feeder-link station, and then S-band downlink signals were received in the mobile receiving station via the ETS-VIII. Figure 5 shows the input-output characteristics of the transmission channel when using the mobile receiving station.

It is necessary to measure the receiving signal power and BER in a short time, since the reception environment is constantly changed by buildings and trees which are around the road while the vehicle is moving. Therefore, the measurement time per data was set to 240 msec (time for 10 frames of OFDM signal). The number of data bits that can be received in 240 msec is 30,720 bits; and if there is an error in one bit of the data, the bit error rate becomes 3.25×10^{-5}.

In the power measurement, the average value was measured at about 240 msec of the modulated wave power of the received OFDM signals using a spectrum analyzer. Also, the test vehicle was equipped with a distance-pulse generator, that is generates a pulse per moving certain distance. In the moving experiments, we obtained the data on the vehicle's travelled distance by setting the pulse-generation interval to 3 mm and counting the number of pulses during the time of measurement. In order to compare with the reception characteristics of OFDM, we carried out the transmission experiment that used the QPSK signals that is a single career. The QPSK signals which used for the experiment, the symbol rate and occupied bandwidth of modulated wave were 1,200 ksps and 1,525 kHz, respectively.

2.3.2 Reception quality while the vehicle is stationary

In the evaluation test while the vehicle is stationary, the mobile receiving station was parked at the place where the satellite link is without obstruction and there is almost no obstacles such as buildings around, in the Kashima City (Ibaraki Prefecture), and obtained the data about the characteristics of C/No vs. BER by received S-band downlink signals from the satellite. The results are shown in Fig. 6.

The transmission power of the Ka-band feeder-link station was set about +36 dBm that becomes roughly the

1 dB compression point, from the input-output characteristics when using the mobile receiving station shown in Fig. 5.

Figure 7 shows the cumulative probability distribution of the C/No which was calculated from the received power which was measured in the mobile receiving station, and shows the cumulative probability distribution of the BER (without error correction) which was measured at the same time. In Figure 7 (1), the horizontal axis represents the C/No, while the vertical axis represents the probability that the C/No value of received signals becomes less the value of the horizontal axis. In Figure 7 (2), the horizontal axis represents the BER, while the vertical axis represents the probability that the BER value exceeds the value of the horizontal axis. As a result of the measurement, the average value of the C/No of the received signals within the measurement time was 72.7 dBHz, while the fluctuation range of 1–99 percent in the cumulative probability distribution was about 1 dB. On the other hand, the average BER was 1.1×10^{-2}, and the BER was fluctuated between 7.2×10^{-3} and 1.8×10^{-2}. The reception antenna used for measurement was the single-element microstrip antenna which has a gain of about 5 dBi, and which has the omnidirectional characteristics in the azimuth angle direction, and a gain half-width of about 80 degrees in the elevation direction. Since this planar antenna was installed on the roof of the vehicle, it is considered that the reflected waves from the ground were not received. Also, since there was no obstacle around the planar antenna, the received signals are estimated to be only the direct waves from the satellite. However, in the power measurement, the C/N of the received signals was about 11 dB, which the sufficient value could not be ensured for the measurement system because the power of broadband modulated wave of OFDM signals was measured. Consequently, as shown in Fig. 7, the fluctuation band of received power is about 1 dB which was relatively large value under the influence of noise.

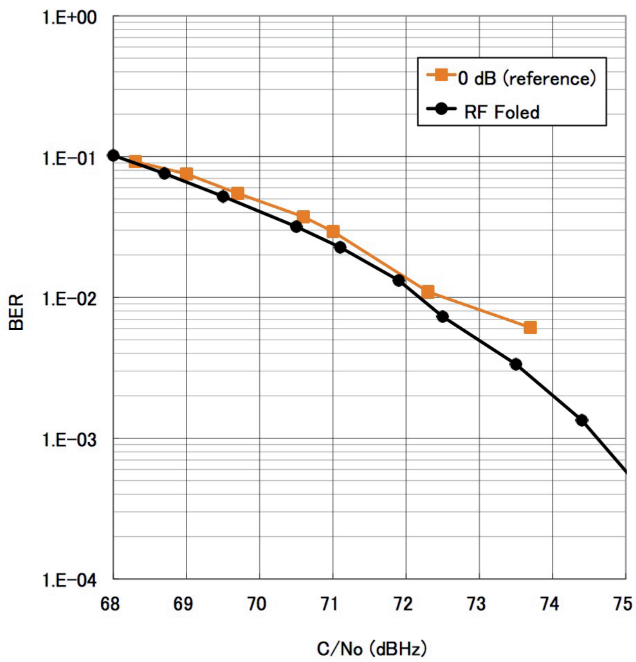
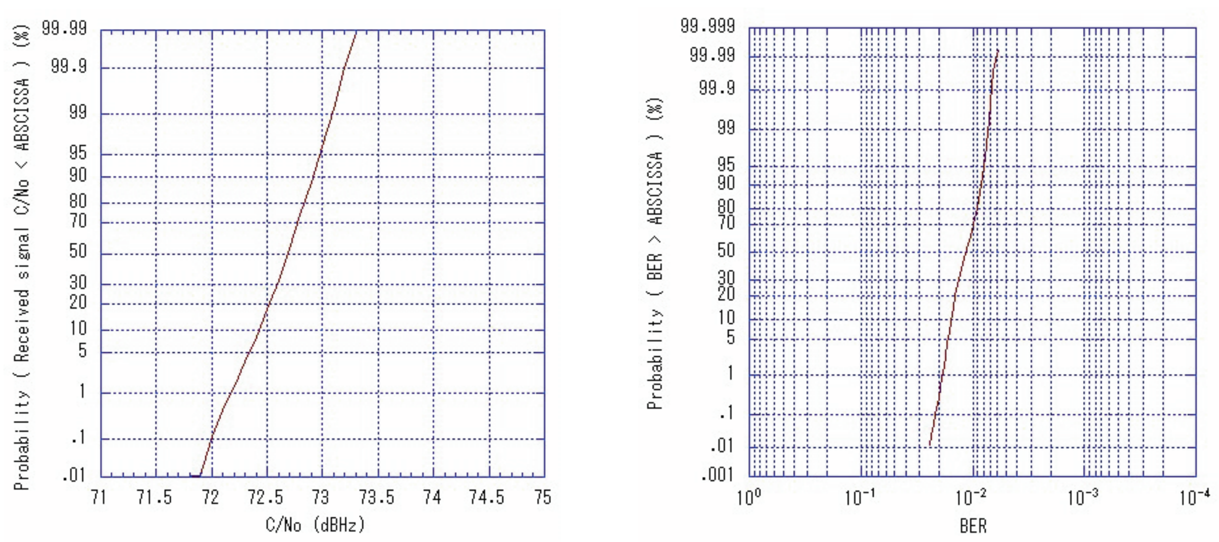


Fig. 6 BER characteristics of when using the mobile station

2.3.3 Reception quality while moving

We carried out the moving experiments in Kashima City (Ibaraki Prefecture), and Route 51 (between Kashima City and Mito City), and Makuhari area of Chiba City.



(1) C/No of received signal

(2) BER (without FEC)

Fig. 7 Cumulative probability distribution of BER and C/No of the received signals while the vehicle is stationary

Kashima City is a suburban area which has places that attenuation or a blocking to S-band downlink signals from the satellite occur mainly due to low-rise buildings and trees are dotted. The received power of the OFDM signal and the BER (without error correction) were obtained after moving about 6 km on general roads in the city. Figure 8 shows an example of the C/No of received signal and BER measured in moving. A drastic fall of the received level on the left side of the graph is due to the blocking or shadowing by obstacles. The fluctuation range of level was about 3 dB when the satellite link is without obstruction. Figure 9 shows the cumulative probability distribution of C/No and BER of the received signals. Probability shows the probability of a relative to the total distance traveled (about 6 km).

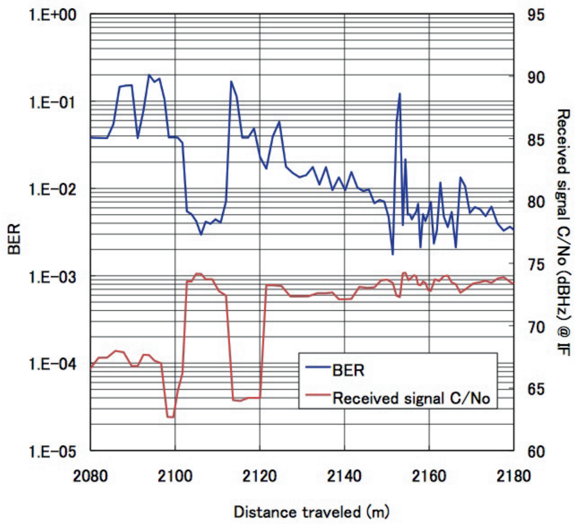
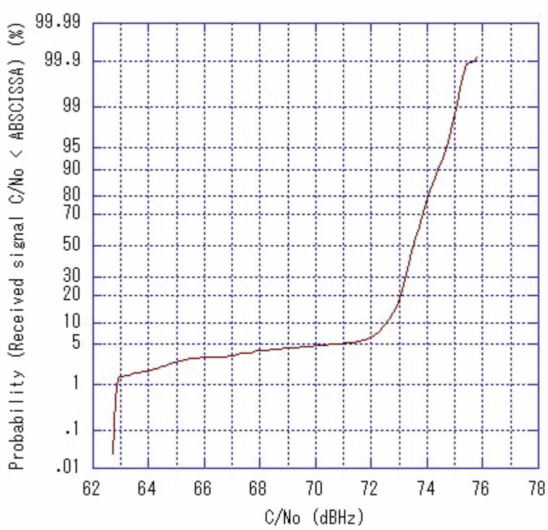


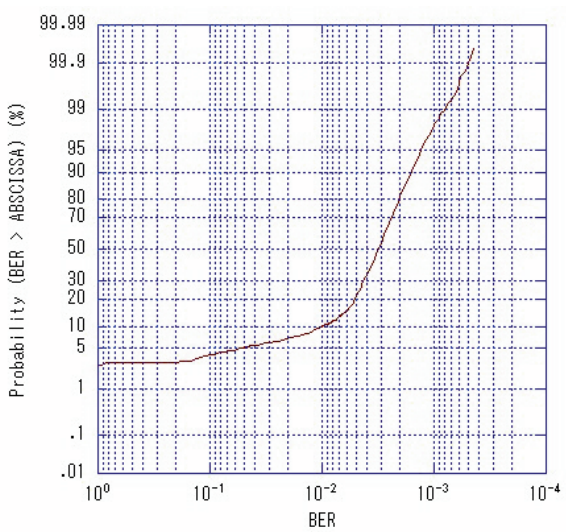
Fig. 8 Variation of the BER of when performed the moving experiment in Kashima (OFDM)

In Figure 9 (1), a slope in the graph indicates a change where the C/No is about 72.5 dBHz, it is considered that the satellite link is without obstruction when the C/No is 72.5 dBHz or higher, and the received signal is attenuated in vehicle's moving situation by shadowing or other factors when the C/No is lower. On the other hand, under conditions where the satellite link is without obstruction, the fluctuation range of C/No values is about 3 dB (between 72.5 dBHz and 75.5 dBHz) that is larger than 1 dB which is the fluctuation range when the test vehicle was stationary. That is, the statistical values suggest that fluctuations in the signal reception level are caused by movement of the vehicle. As for the cumulative probability distribution of BER as shown in Fig. 9 (2), the horizontal axis represents the BER, the vertical axis represents the probability at which the obtained BER exceeds the value on the horizontal axis.

The probability is about 10% when the C/No of the received signal is 72.5 dBHz or lower, the value of BER is about 1×10^{-2} when the cumulative probability of BER is 10%. This corresponds well to the BER characteristics at the mobile receiving station as shown in Fig. 6. In addition, the probability is about 80% when the C/No is 74 dBHz or lower, the value of BER is about 2×10^{-3} when the cumulative probability of BER is 80%. This also corresponds well to the BER characteristics at the mobile receiving station as shown in Fig. 6. On the other hand, if the C/No was 72.5 dBHz or less, the decrease of the signal level was mainly caused by shadowing. For this reason, the measured signal level becomes near the noise level of the



(1) C/No of received signal



(2) BER (without error correction)

Fig. 9 Cumulative probability distribution of the BER and the C/No of the received signal in traveling (at Kashima-city) measurement system, most of the value of the BER is accounted for 0.1 or more. Consequently, it was confirmed that, under the conditions where the satellite link is without obstruction, the reception performance when the vehicle is moving is almost the same performance as while the vehicle is stationary.

Figure 10 shows the transmission characteristics of QPSK which was measured in the moving experiment on the same road as in the case of Fig. 8. In terms of BER fluctuations in the graph, many bit errors occurred in the areas indicated in red circles. However, there is no large fluctuation in the C/No of the received signal. In the corresponding location of road that the vehicle traveled, the medium-rise building stands on the right side of the vehicle, on the other hand, since a downlink signal from the satellite is coming from the direction of about 50 degrees elevation on the left side of the vehicle, it is considered to be effects of delay waves reflected by buildings. Moreover, since there is no large fluctuation in the received C/No value, the frequency selective fading which only a portion of the signal level of signal band changes is estimated to have occurred.

On the other hand, in the case of OFDM signals that shows in Fig. 8, there is no rapid deterioration in the BER. Because the OFDM signal is the multi-carrier, is not susceptible to frequency selective fading that occurs when receiving delay waves, and a guard interval is provided in the OFDM symbol, it is considered less susceptible of inter-symbol interferences as well.

We carried out the moving experiment and obtained the data in Makuhari area of Chiba City where has many high-rise buildings, because it is difficult to observe the effects of reflected waves from the road conditions in Kashima City.

We carried out the moving experiment in Makuhari New City Center that has a driving environment where about 10 relatively-high buildings (about 30 stories) are scattered in a narrow area adjacent to Kaihin-Makuhari Station of JR Keiyo Line. Relatively-wide roads which have 2–3 lanes in one side, and narrow one-way roads are mixed, and there are areas which downlink signals from the satellite are blocked often by footbridges and railway viaducts. Figure 11 is a photo of Makuhari New City Center where we carried out the experiment.

In the moving experiment in Makuhari area, we measured the spectrum of reception signals at a point where direct waves from the satellite and the reflected waves from high-rise buildings can be received at the same time. Figure 12 shows the spectrum of received OFDM signals. As shown in Fig. 12, occurrence of the frequency-selective fading which was decreased of the level of received signal in the low-frequency range of the occupied frequency band can be seen.

In consideration of the driving environment, since the possibility that the vehicle has been received a direct wave and one reflected wave at the same time is high, we estimated the parameters of the direct wave and the reflected wave using a fading simulator. Figure 13 shows the OFDM signal spectrum which was reproduced by the

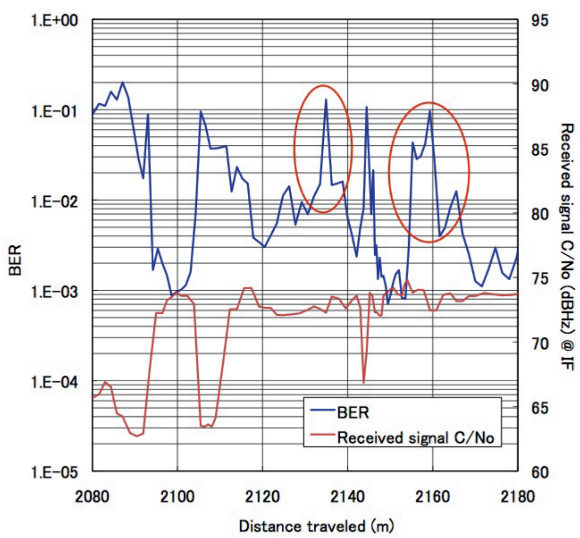


Fig. 10 Variation of the BER of when performed the run experiment in Kashima (QPSK)

Fig. 11 Driving environment in Makuhari area

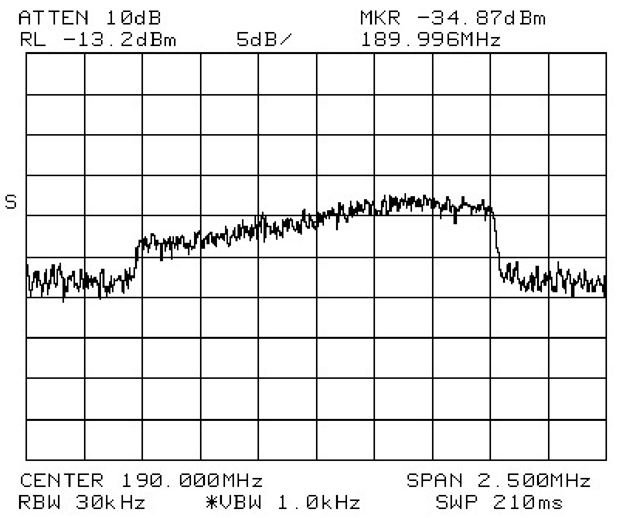
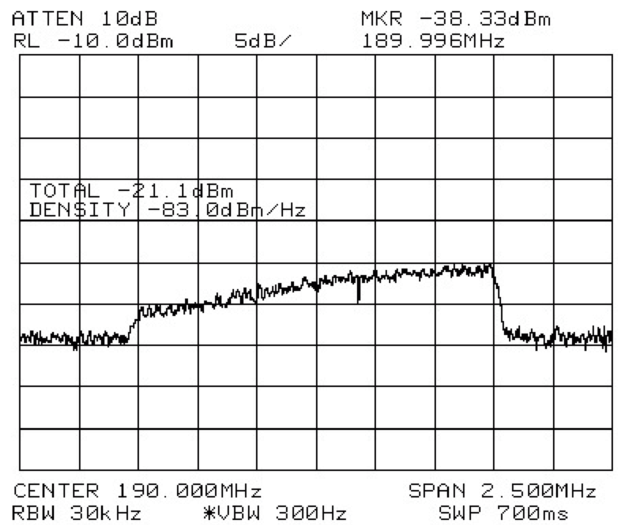


Fig. 12 Spectrum distortion of received signals caused by delay wave



OFDM (D/U=6dB delay=0.3μsec)

Fig. 13 Spectrum distortion of received signals caused by delay wave (A simulation)

simulator. The D/U which is the power ratio of the direct waves to the reflected waves was 6 dB, and also the delay time of reflected waves to the direct waves was 0.3 μsec. The delay time can be calculated geometrically from the incoming direction of the radio wave from the satellite and the positional relationship between the high-rise buildings and the traveled vehicle.

As a result of calculation in terms of a 100-meter-high building, it obtained the delay time of about 0.08–0.32 μsec. Furthermore, we calculated the rate of reflection from the building wall based on the Fresnel reflection coefficient formula that is shown below.

$$r_H = \frac{\cos\theta_i - (\varepsilon_r - \sin^2\theta_i)^{1/2}}{\cos\theta_i + (\varepsilon_r - \sin^2\theta_i)^{1/2}}$$

$$r_V = \frac{\varepsilon_r\cos\theta_i - (\varepsilon_r - \sin^2\theta_i)^{1/2}}{\varepsilon_r\cos\theta_i + (\varepsilon_r - \sin^2\theta_i)^{1/2}}$$

Here, r_H represents the reflection coefficient of the horizontal polarization to the plane of incidence, while r_V represents the reflection coefficient of the vertical polarization to the plane of incidence. Also, ε_r represents relative permittivity of the wall material, while θ_i represents the incidence angle to the wall surface.

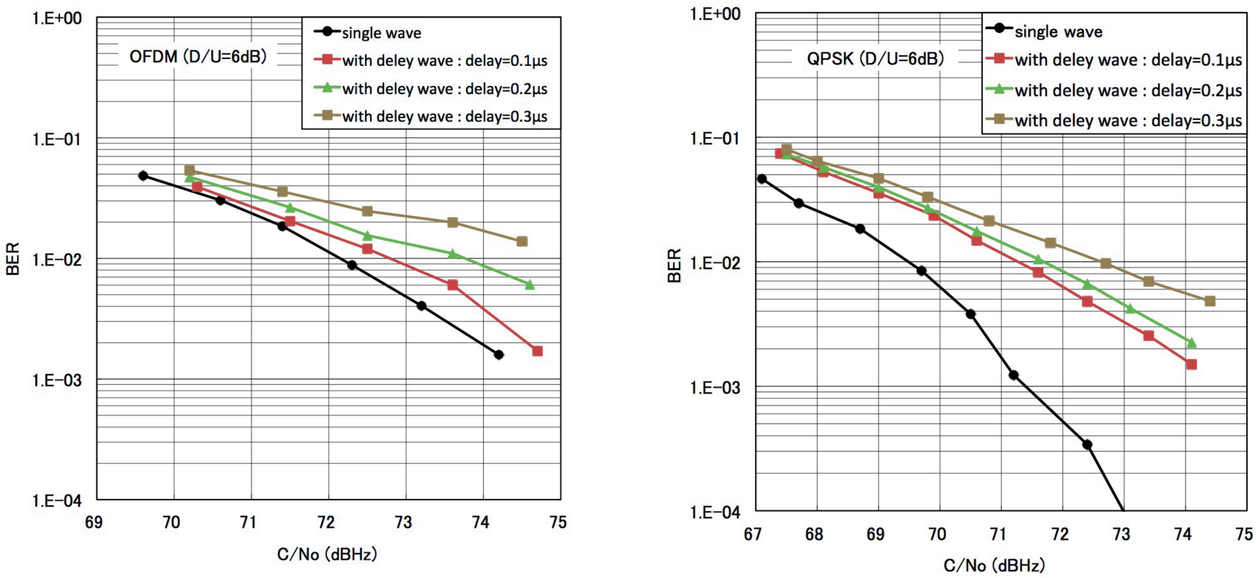
When the wall material is concrete, ε_r is 6.7. Also, the incidence angle of radio waves on the wall surface of the building is about 61.7°, that was calculated when the elevation angle of the satellite is 48° and the angular difference between the normal direction of the wall surface of the building and the azimuth direction of the satellite referred to the map information is about 45°.

As a result of calculation, the reflection coefficient of the horizontal polarization to the plane of incidence of radio waves is about −0.65 and the vertical polarization is +0.15. Therefore, the intensity of reflected wave decreases about 4 dB from the direct wave. Although the reflection coefficient of horizontal polarization is indicated with a minus sign, it indicates that the phase of amplitude is changed by 180°. Therefore, the reflected waves from buildings become the reverse circular polarization to the left handed circular polarization waves of direct waves. When reproduced the spectrum obtained by the moving experiment using these parameter values, if the intensity of reflected waves is −6 dB to the direct wave, the magnitude of fluctuations in the signal level within the signal band is matched better.

Figure 14 shows the BER characteristics when used the delay time as a parameter in the D/U = 6 dB.

Figure 14 (1) is the case of OFDM signals, (2) shows the characteristics measured for QPSK signals in the same way for comparison.

Figure 14 (1) shows deteriorations of the BER to become 0.2 dB (1.5 dB) when overlapped with the delay waves of 0.1 μsec (0.3 μsec), compared with the case of the BER of single wave at 2.5×10^{-2}. BER characteristics change depending on the delay time, since wavelengths of carrier wave frequencies differ in the upper or lower side of signal band, when the delay time is longer (i.e. when the transmission channel of the delay wave is longer), change in the phase of the delay wave becomes differently larger in the upper and lower side of signal band. Because of this,



(1) OFDM (D/U=6dB)   (2) QPSK (D/U=6dB)

Fig. 14 BER characteristics of when superimposed the delay wave (Simulation, without FEC)

the change of the signal level in the signal band becomes larger by the frequency selective fading.

Also, in the case of QPSK, it indicates that deteriorations of the BER to become 1.7 dB (2.5 dB) when overlapped with the delay waves of 0.1 μsec (0.3 μsec), compared with the case of the BER of the single wave at 2.5×10^{-2}, that is greater in the QPSK than the OFDM one.

3 Conclusion

We conducted multicast communication experiments on the ETS-VIII using OFDM signals.

On the subject of the influence on the transmission characteristics of the case where the transmission channel has a non-linear characteristics including the satellite link, we confirmed that the BER characteristics are degraded by the non-linear characteristics from the measured results of the BER characteristics in the area of non-linear from linear.

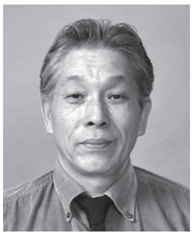
We obtained the data on the received signal level and BER in the moving experiment in which drove the vehicle in the small suburban built-up areas, suburban roads, high-rise building areas and highways. We confirmed that high quality data can be received in small suburban built-up areas and suburban roads which less occurrence of signal decay caused by buildings and shadowing. The quality of received signals which are the C/No of 73 dBHz and the BER of 1×10^{-2} can be ensured if the satellite link can be without obstruction. Also, we compared the data of the state of occurrence of bit errors in the built-up areas which obtained by OFDM and QPSK, and confirmed that the bit errors which influenced by delay waves that reflected from buildings are less likely to occur in OFDM.

Although we consider that high-rise building areas are the driving environment in which a lot of delay waves which reflected from buildings are received, there was no much difference between OFDM and QPSK in the cumulative probability distribution of C/No and BER obtained by the moving experiment. However, we observed the spectrum distortions in received signals caused by the interference of delayed waves which reflected from buildings, thereby confirming that high-rise building areas are the driving environment in which frequency selective fading is likely to occur. About the influence of this delay waves, we measured the BER characteristics that superimposed the delay waves that are 0.3 μsec from 0.1 μsec to the direct wave which were parameters of delay time of the spectrum distortions using a simulator, the BER degraded about 1.5 dB in OFDM and about 2.5 dB in QPSK at 2.5×10^{-2}, compared with the single wave. It showed that the OFDM is less susceptible by the delay waves from these results.

From the above results, the OFDM is less susceptible to the effect of delay waves, and enables the reception of high quality data if the satellite link is without obstruction, that it is suitable for the multicast communication in the mobile environment compared to QPSK, was demonstrated by communication experiment using the satellite.

References

1 European Telecommunication Standard ETS 300 401 Second Edition, May 1997.
2 Rec. BS.1114-5, "Systems for terrestrial digital sound broadcasting to vehicular, portable and fixed receivers in the frequency range 30–3000 MHz," April 2002.



Shin-ichi YAMAMOTO
Senior Researcher, Space Communication Systems Laboratory, Wireless Network Research Institute
Mobile Satellite Commnication

Kazuyoshi KAWASAKI
Senior Researcher, Space Communication Systems Laboratory, Wireless Network Research Instiitute
Satellite Communication

Masaki SATOH
Manager, Collaborative Research Depertment
Space Communication, Antenna