Transmission Techniques for Broadcast Satellites in the 21-GHz Band aiming for "Super Hi-Vision" Broadcasting

1. Introduction

Existing high-definition technologies, referred to as "hi-vision" in Japan, are expected to be replaced by "super hi-vision" technologies with more than 4,000 scanning lines. In addition to extremely high-definition images, super hi-vision will offer viewers an overwhelming sense of realism and a feeling of being totally engulfed in the content. Broad bandwidths and high-volume transmission channels are required to transmit this super hi-vision content. NHK is currently studying satellite broadcasting system in the 21-GHz band as a strong candidate for these new transmission channels.

In this paper, we provide an overview of satellite transmission in the 21-GHz band to be used for Super Hi-Vision broadcasting, and some of the issues involved. Satellite transmission in the 21-GHz band is highly susceptible to rain attenuation, but the long-period interleaving technology and variable e.i.r.p satellite systems are effective technology for dealing with this problem. In this paper, fundamental studies are shown to aim transmitting power control for variable beam patterns using rainfall forecast from the Meteorological Agency.

2. The Potential of Satellite Broadcasting in the 21-GHz Band for Super Hi-vision Transmissions

When uncompressed super hi-vision signals are transmitted, transmission speeds of about 50 Gbps are required, but with digital compression and encoding technologies, it is expected that these transmission speeds can be reduced to between 200 and 400 Mbps. In the 12-GHz band that is used in today's satellite digital broadcasting, the maximum transmission speed per channel is about 52 Mbps, which does not offer enough bandwidth for super-hi-vision broadcasting. For this reason, it must be necessary to open up new transmission channels in order to achieve super hi-vision broadcasting.

Based on a decision by the International Telecommunication Union (ITU), a specialized organization affiliated with the United Nations, Japan can use a frequency bandwidth of totaling 600 MHz – from 21.4 GHz to 22.0 GHz – for satellite broadcasting in the 21-GHz band. This band can be one strong candidate for the transmission channels to be used in super hi-vision broadcasting because there is still no planning for the allocation of channels in this frequency band and it will be possible to secure broadband channels.

Figure 1 shows the relationship between modulation schemes, transmission speeds, and the number of channels in the case of super hi-vision satellite broadcasting in the 21-GHz band. In satellite transmissions, because satellite transponders are operated at a saturation point, it is common to use various types of PSK modulation as the modulation scheme. From this figure, if the super hi-vision data can be compressed and its transmission speed can be reduced to between 200 and 400 Mbps, it will be possible to transmit three super hi-vision programs using the TC-8PSK modulation scheme, or to transmit two or three channels using the QPSK modulation scheme with a convolutional code at coding rate of 3/4(QPSK (r = 3/4)). When using the QPSK modulation scheme with a convolutional code at coding rate of 1/2(QPSK (r = 1/2)), it will be possible to transmit two super hi-vision channels.

Figure 2 shows the signal flow from the broadcasting station when super hi-vision programs are broadcasted to households using a satellite. Digital super hi-vision program produced in the studio of broadcasting station is converted into compressed and sent to the transmitting facility. After multiplexing and the addition of designated error correction codes, the data is modulated digitally, and
transmitted to the satellite. In the satellite, the transmission waves are amplified to the specified output power by the transponder, and they are transmitted to the service area from the satellite transmission antenna. The transmission waves from the satellite are received in the households, and after digital demodulation and error correction, the original audio and video data is extracted from the multiplexed digital data for viewing.

Table 1 is a summary of the issues that must be examined in order to achieve super hi-vision satellite broadcasting. To enable satellite transmission of high-speed super hi-vision signals in the 21-GHz band, it is necessary to consider appropriate satellite link budget – for example, the required transmitting power to counter rain attenuation – and to effectively increase broadcasting service availability. At the same time, some new transmission schemes should be applied to the system with using large-volume memory devices.

Table 2: Signal flow of satellite super hi-vision broadcasting

Rain attenuation in the 21-GHz band is about three times larger in dB unit than that in the 12-GHz band, and the frequency of large rain attenuation is much higher. When very large rain attenuation occurs, it becomes impossible for the satellite broadcast receiver to receive the broadcasting program correctly.

In current BS digital broadcasting, when using a 45-cm reception antenna (the standard sized antenna used for households), if the rain attenuation exceeds about 5 dB in the 12-GHz band, the high-vision broadcasting reception is interrupted. Using the rain attenuation prediction method described in P.618-8 of the ITU-R recommendations, if we assume one-minute-rain rate of 52.5 mm/h for 0.01 % of the annual time percentage, it is predicted that outage time of high-vision reception is about three hours in a year in the 12-GHz band but in the case of the 21-GHz band, the outage time is predicted 10 times longer, or about 35 hours. It is thus essential to implement rain attenuation countermeasures in order to achieve stable satellite broadcasting, when using a 45-cm reception antenna (the standard sized antenna used for households), if the rain attenuation exceeds about 5 dB in the 12-GHz band, the high-vision broadcasting reception is interrupted.
broadcasting in the 21-GHz band. In this paper, a long-period interleaving transmission scheme and a variable e.i.r.p. broadcast satellite system as candidate technologies to compensate for rain attenuation in the 21-GHz band. Vigorous studies regarding these technologies are being conducted at NHK Science and Technical Research Laboratories (NHK STRL).

3. Rain Attenuation Compensation Technologies

3.1 Long-period interleaving transmission using the large-volume storage device

By the fact that heavy rainfalls tend to occur sporadically for short periods of time, the long-period interleaving transmission scheme can be one promising technology to compensate for rain attenuation, which diffuses program data over time and transmits it and stores the data in the receiver. Errors in the received data are corrected afterwards. Due to storage operations in the receiver, broadcasting programs cannot be viewed in real time.

Figure 3 shows the effects of improvements in annual broadcasting service availability obtained by using long-period interleaving transmissions. This evaluation is conducted by using rain attenuation data for Tokyo over past 3 years. From this figure, it is found that there is a suitable combination of interleaving time, modulation scheme and error correction method for the annual broadcasting service availability to be achieved. For example, in the case of QPSK modulation scheme with a convolutional code at coding rate of 5/6 (QPSK (r = 5/6)) and a Reed-Solomon code where the code byte length is 200 byte and information byte length is 120 (RS (200,120)), it is found that an annual broadcasting service availability of 99.99 % can be achieved. This is higher service availability than that for the current BS digital broadcasting in the 12-GHz band. In order to apply this technology efficiently, it is necessary to analyze rain attenuation time series in the 21-GHz band in detail and to understand the characteristics such as duration of rain attenuation exceeding a certain threshold level and its occurrence probability.

3.2 Variable e.i.r.p system

Conventional broadcast satellites have been designed to cover the whole service area uniformly. It is uneconomical to boost transmitting power uniformly to compensate for rain attenuation because the scale of the satellite system (including transponders) would increase prohibitively. NHK STRL has been conducting research on technologies that effectively compensates for rain attenuation for satellite broadcasting in the 21-GHz band. The new broadcast satellite system incorporates
variable e.i.r.p system using a phased-array-fed reflector antenna to effectively boost signal strength in areas with heavy rain attenuation. Figure 4 shows an example of the satellite system that employs variable e.i.r.p system using a large phased-array-fed reflector antenna. The antenna has a large reflector and multiple small traveling wave tubes (TWT) on a feed array. The output phase and the amplitude of RF signal from the each small TWT is adjusted and synthesized in space. The emitted power to heavy rainy area can be boosted by the variable e.i.r.p. system with covering uniformly other broadcasting service area under clear sky.

Figure 5 shows the areal percentage for which rain attenuation compensation is needed and its annual average occurrence time. This result is estimated by using AMeDAS 1-hour-rainfall data for past 20-year period between 1979 and 1998. To conduct the survey, a Japan island is divided into 112 square blocks. Compensated areas are determined by the rainfall detected in each block and then the compensated areal percentage is calculated. It is assumed that the rain attenuation compensation is required when 1-hour rain fall data exceeds 3 mm. For 1-hour rainfall of 3 mm, the average rain attenuation of 3.5 dB in the 21-GHz band is estimated. For a region with less than 1-hour rainfall of 3 mm, the area is assumed to be covered using the transmitting power margin for clear sky. The figure shows that rain attenuation compensated area is less than only 10 % of whole service area for 80 % of compensation time. This means that boosting transmitting power only for heavy rain attenuation areas can be an effective measure.

4. Estimation of Rain Attenuation using Rainfall Forecast

Assuming the operation of a variable e.i.r.p. broadcast satellite, an effective rain attenuation compensation method is studied. This method determines the transmitting power required for rain attenuation compensation by using short-term rainfall forecasts by the Japan Meteorological Agency. The short-term rainfall forecasts are predictions of the 1-hour rainfall for 5 km square areas. In order to determine the transmitting power required to compensate for rain attenuation using these predicted 1-hour rainfall, it is needed to know the characteristics of rain attenuation occurring during these hourly rainfalls. As a preliminary study of rain attenuation characteristics in the hourly rainfalls, the statistical characteristics of the maximum 10-minute rainfall in total six 10-minute rainfalls that make up a given 1-hour rainfall.

Figure 6 shows a histogram for the maximum 10-minute rainfall during an hourly rainfall of 5 mm observed in Owase, Mie prefecture, and a line curve approximating the histogram using a log-normal distribution. In this survey, 10-minute rainfall data for the past 8 years from the AMeDAS of Japan Meteorological Agency is used. It is found that even the hourly rainfall is the same and the maximum 10-minute rainfall is distributed with a certain probability. The shape of the histogram has been closely approximated using a log-normal distribution. Figure 7 shows the exceedance probability for the maximum 10-minute rainfall during hourly rainfalls of 5 mm, 10 mm, 15 mm, and 20 mm, plotted on a logarithmic-normal probability paper. From
Figure 7, the exceedance probability for the maximum 10-minute rainfall can be plotted well on a straight line on the logarithmic-normal probability paper, and that the distribution of the maximum 10-minute rainfalls within the hourly rainfall can be approximated using a log-normal distribution. Formulas 1 and 2 below describe the probability density function \( f(R) \) and the distribution function \( F(R) \) for log-normal distribution respectively.

\[
f(R) = \frac{K}{\sqrt{2\pi}\sigma R} \exp\left\{-\frac{(\log_{10}(R) - \mu)^2}{2\sigma^2}\right\} \quad (1)
\]

\[
F(R) = \frac{1}{2} \left[ 1 + \text{erf}\left(\frac{\log_{10}(R) - \mu}{\sqrt{2}\sigma}\right)\right] \quad (2)
\]

\[K = \log_{10}e = 0.4343\]

\[R: \text{10-min. rainfall value}\]

\[\mu: \text{mean of } \log_{10}(R)\]

\[\sigma: \text{Standard deviation of } \log_{10}(R)\]

Figure 7 shows the exceedance probability for the maximum 10-minute rainfall in an hourly rainfall of 5 mm in Sapporo, Tokyo, Osaka, Miyazaki, and Naha. From this graph, it is found that exceedance probability for the maximum 10-minute rainfall is distributed well on a straight line on the logarithmic-normal probability paper at any measurement point. This means that the maximum 10-minute rainfall distribution can be approximated using a log-normal distribution for any region in Japan. In a comparison of the same exceedance probability values, it can be seen that the maximum 10-minute rainfall increases in the order of the locations of these cities from north to south (Sapporo, Tokyo, Osaka, Miyazaki, and Naha). This means that even with the same hourly rainfall, the rainfall characteristic is different among regions, and that the tendency for heavy rainfall over a short period of time becomes higher for southern regions in Japan. This suggests that even with the same hourly rainfall, the degree of rain attenuation may differ depending on the region. More detailed studies on the characteristics of rain attenuation for hourly rainfalls should be needed. Some studies are now being conducted by NHK STRL to estimate the transmitting power to keep outage of broadcasting by rain attenuation below a certain period of time with using 1-hour rainfall forecasts throughout Japan.

Figure 8 shows the exceedance probability for the maximum 10-minute rainfall during 1-hour rainfall of 5 mm in various regions of Japan. From this graph, it is found that exceedance probability for the maximum 10-minute rainfall is distributed well on a straight line on the logarithmic-normal probability paper at any measurement point. This means that the maximum 10-minute rainfall distribution can be approximated using a log-normal distribution for any region in Japan. In a comparison of the same exceedance probability values, it can be seen that the maximum 10-minute rainfall increases in the order of the locations of these cities from north to south (Sapporo, Tokyo, Osaka, Miyazaki, and Naha). This means that even with the same hourly rainfall, the rainfall characteristic is different among regions, and that the tendency for heavy rainfall over a short period of time becomes higher for southern regions in Japan. This suggests that even with the same hourly rainfall, the degree of rain attenuation may differ depending on the region. More detailed studies on the characteristics of rain attenuation for hourly rainfalls should be needed. Some studies are now being conducted by NHK STRL to estimate the transmitting power to keep outage of broadcasting by rain attenuation below a certain period of time with using 1-hour rainfall forecasts throughout Japan.

5. Conclusion

In this paper, satellite broadcasting in the 21-GHz band is introduced. This satellite broadcasting can be expected to enable super hi-vision broadcasting that requires broadband satellite channels. It is also shown that up to about 3 channels of super hi-vision transmission can be compressed to about 200 Mbps. It is also shown that rain attenuation countermeasure is an important issue to achieve stable satellite broadcast in the 21-GHz band. The long-period interleaving transmission scheme and a variable e.i.r.p broadcast satellite system using a phased array fed-reflector antenna are introduced as two potential ways of resolving the problem of rain.
attenuation. We presented the results of research on rain attenuation. In order to determine the transmitting power to compensate for rain attenuation for heavy rainfall regions, which is essential to the operation of the variable e.i.r.p. broadcast satellite system, a basic study of the distribution of the maximum 10-minute rainfall within hourly rainfall is conducted. From this study, it is shown that even when the hourly rainfall is the same, it should be considered to change the satellite transmitting power to compensate for rain attenuation in each region separately.

We are now going to examine methods to accurately estimate rain attenuation distribution occurring during hourly rainfalls, and conduct further studies of methods for estimating transmitting power to compensate for rain attenuation as required for the variable e.i.r.p. broadcast satellite systems using short-term rainfall forecast by the Japan Meteorological Agency and other available data. We also plan to conduct studies of rain attenuation time series models, which are required to evaluate the long-period interleaving transmission method in more detail.

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