A Study on the Ka-band Satellite 4K-UHD Broadcasting Service Provisioning in Korea

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***Abstract*—Advances in ubiquitous system and service are recently made thanks to the fruition of hardware and software developments so far achieved. The key elements of the ubiquitous services might be the omnipresence of service equipment and the distribution network to provide information to users everywhere. In this sense, satellite network could be one of the most suitable candidates for ubiquitous services in mobile and fixed environment for bi-directional communication and wideband broadcasting network system, which could be the optimal choice for high quality educational information services. This paper analyzes the feasibility of new satellite UHD broadcasting service scenarios using the Ka frequency band while increasing the service availability in Korea. Some countries have started their service trials, and plan to launch commercial broadcasting through a satellite link. For these services, diverse service scenarios should be evaluated to identify the most efficient way to provide the target service on schedule. For this purpose, a rain attenuation analysis was conducted to recognize the amount of expected attenuation in the Korean territory, and the results were applied to the design of the DVB-S2 satellite link. The service scenarios were then analyzed from a variety of aspects considering as many technologies as possible that are expected to be available in the near future. Some of these service scenarios were evaluated for their service availability within the Korean territory through live experiments, the results of which showed that satellite UHDTV service in the Ka band is possible if the proper technologies are selected. This study will be helpful for determining the most reasonable way for other countries preparing similar services at the initial stage, and can contribute to a stable provisioning of UHDTV services in the consumer market.**

***Index Terms*—Satellite UHD Broadcasting; Immersive Broadcasting; Ka-band; Channel Adaptive Broadcasting.**

I. INTRODUCTION

Since its inception with a 24 hours-a-day single channel service in 2003, digital HDTV satellite broadcasting service in Korea has developed into a large market with more than 100 HDTV channels and about four-million subscribers. Currently, digital satellite broadcasting services are provided through the Ku-band transponder of the KoreaSAT-6 satellite, which was launched in December 2010, and they will be extended for next-generation broadcasting services, such as stereoscopic 3-Dimentional TV (3DTV) and Ultra HDTV (UHDTV). These new broadcasting services will demand frequency capacity more than the current saturated Ku-band, and to resolve such limitations, the 21.4 to 22.0 GHz frequency band was allocated for Broadcasting Satellite Service (BSS) in regions 1 and 3 at the World Administrative Radio Conference-92 (WARC-92) for implementation after April 1, 2007. According to this allocation, many countries in these regions have been competitively requesting frequency registration for this frequency band, and the number of registrations has increased significantly to up to 700 satellite networks. However, since propagation attenuations in this badn may place a heavy restriction on the service availability and system feasibility, mitigation techniques have been studied from diverse perspectives [1]. Many advanced countries have developed various Ultra High Definition (UHD) broadcasting technologies, opening a new horizon for the possibility of commercial UHD broadcasting service. Since it began its R&D activities for UHD broadcasting service in 1995, Japan has established a new concept for next-generation broadcasting service that fully satisfies the human perception capacity in a visual and auditory sense [2]. With overall research results in the every part of broadcasting chain [3], the Japanese government announced the launch of trial broadcasting at 4K resolution for mid-2014 and the start of test broadcasting at 8K resolution for 2016. In the case of Korea, the pay TV operators conducted experiments for UHD broadcasting service and started their trial service from the first quarther of 2014. For this end, satellite transmission tests and terrestrial broadcasting tests for 4K UHD broadcasting service were successfully conducted in 2013. During the initial stage of such service, satellites are expected to be the major medium because of its flexibility and adaptability for new services. However, since the propagation attenuation in the Ka band, particularly from rain, poses a significant challenge in service availability, it is needed to investigate the pertinence and possibility of commercial broadcasting services using this band for immersive media including UHD video. Moreover, since the weather in Korea has been changing to an increase in rainfall in recent years, worsening the conditions for satellite broadcasting [4][5], reasonable service scenarios should be carefully taken into consideration. For this purpose, a simple analysis was conducted to identify what kinds of services are possible [6]. In this paper, an analysis of previous rain attenuation models is conducted to confirm their results, and a link analysis is extended to consider more detailed parameters. Through these analyses, much more diverse service scenarios are envisaged. The remainder of this paper is organized as follows. A rain attenuation analysis for UHD broadcasting using a satellite at the Ka frequency band, to identify how much rain attenuation has to be expected using the regional rain distribution of Korea, is presented in Section II. In addition, an analysis of the link margin for each code rate and the modulation method of DVB-S2 at a certain rain rate are presented to evaluate the service availability in Section III. Next, channel-adaptive UHD satellite broadcasting scenarios based on the combinations of various technical elements are provided in Section IV, and the experimental progress for UHD satellite broadcasting service conducted in Korea is described in Section V. Finally, in Section VI, some concluding remarks are offered.

II. Rain Attenuation Model Analysis in Ka-band

The quality of microwave signals propagating through the atmosphere over the satellite links is affected by complex contributions, such as the absorption and scattering caused by atmospheric gases and water droplets in the precipitation. Among these contributions, attenuation by atmospheric gases may normally be neglected when it comes to Ka band satellite communications. On the other hand, attenuation by precipitation significantly degrades the performance of the transmission link and varies greatly depending on the geographic location and climate [7][8]. It is therefore essential to precisely predict the attenuation by rain on the propagation links for the proper planning of satellite systems and the evaluation of the feasibility for commercial UHD broadcasting services over the Ka frequency band in Korea.

A. Standard rain attenuation model

The rain attenuation can be estimated using the model proposed by Olsen [9], where the rain attenuation for a satellite system can be predicted based on the specific attenuation calculated theoretically according to the scattering properties of hydrometeors, and the effective path length estimated using local rainfall data. The Olsen model and more recent studies for the different microphysical properties of hydrometeors were adopted into the international standards to predict the specific attenuation as a function of the rain rate and target frequency [10]. ITU-R adopted the rain attenuation prediction model for a frequency range of 1 to 400 GHz using the rainfall intensity distribution model for a spherical raindrop shape, and ITU-R P.838 recommended a model for calculating the attenuation from rain based on knowledge of the rain rates, and was revised twice to adopt the type of polarization and the scattering properties for non-spherical raindrops [11]. The estimation model of rain attenuation [12] currently used as the international standard is the DAH model [13]. This model uses an empirical approach for estimating the effective path length, and additionally includes a vertical adjustment factor to consider the combined effect of several propagation impairments. The rainfall rate exceeding 0.01% of an average year with an integration time of 1-min, i.e., $R_{0.01}$, is desirable to take local measurements for an accurate estimation of the rain attenuation whenever possible. Otherwise, an estimate can be used from the Recommendation ITU-R P.837-6. We found that the characteristics of precipitation recommended by the ITU-R model does not correctly represent the local precipitation intensity in Korea these days, and therefore decided to use local measurement data for calculating $R_{0.01}$, based on a conversion of the integration time from 20-min to 1-min. The local rainfall rate will be discussed again in Section II-B. Next, it is necessary to obtain the specific attenuation, γ, at a rainfall rate exceeding 0.01% of an average year, which can be calculated based on the frequency-dependent coefficients given in the recommendation [10] and $R_{0.01}$ determined in the previous step. The ITU-R model adopts adjustment factors in the horizontal and vertical directions to consider the relation between the path length affected by rain and the diameter of rain cell to estimate the effective path length, L_{eff}. Finally, the rain attenuation for 0.01% of a one-year time period, $A_{0.01}$, as well as for the other percentages of an average year, can be predicted.

B. Rainfall rates in Korea

It is necessary to use rainfall statistics that are as accurate as possible in the calculation of the specific attenuation to obtain the proper rain attenuation value for a certain area under consideration. To this end, ITU-R classified Korea and Japan as rain climate zone K, and recommended using 50.6 mm/h for the rainfall rate exceeded for 0.01% of the average year [14], which is an important parameter for predicting rain attenuation. However, the recommended rainfall rate has turned out to be quite different from the measurement data within the Korea territory.

Table I shows the rainfall rate statistics in Korea, which were measured over a ten-year period in several regional areas with a 20-min integration time, and then converted into a 1-min integration time [5]. It has been reported that the climate of Korea is becoming more like subtropical weather in terms of temperature changes, and that the mean rainfall rate for the last ten years has increased by 9.1% compared to the previous 30

TABLE I. Rainfall Rate Distribution in Korea

Time percentage [%]	Rainfall rate [%]				
	Measurements in Korea			ITU-R P.837-1	ITU-R P.837-6
	Seoul	Busan	Daejeon		
0.01	66.4	66.5	62.9	42.0	50.67
0.02	53.6	49.5	50.3	-	37.21
0.03	45.4	40.1	37.5	23.0	30.11
0.05	35.5	31.1	30.0	-	22.33
0.10	23.5	21.4	21.3	12.0	14.23
0.20	14.1	14.7	12.8	-	8.87
0.30	10.5	10.5	8.8	4.2	6.71
0.50	6.5	6.9	5.5	-	4.69
1.00	3.2	3.8	2.6	1.5	2.79

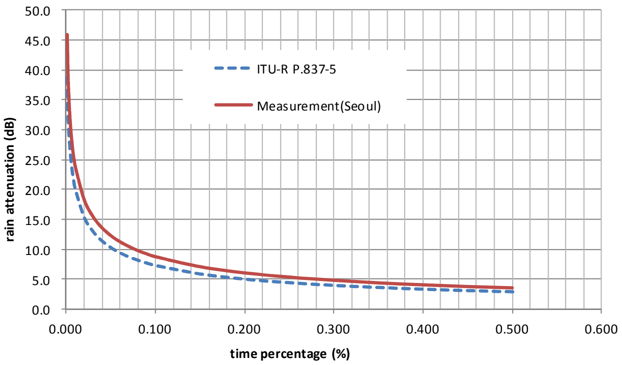

Fig. 1. Predicted rain attenuation distribution in Korea

years [4]. The difference in rainfall rate between ITU-R models and the measurements listed in Table I indicates that the rain rates obtained using the ITU-R P.837-6 model do not fully reflect these changes in Koreas local rainfall characteristics. We therefore use the measured rainfall rates to predict the various propagation parameters in this paper since the ITU-R model may give erroneous rain attenuation values on the radio links in Korea. For calculating the rain attenuation for UHD satellite broadcasting over the Ka band in Korea, the center frequency of channel 3 of the Chollian satellite was used for the operating frequency, and vertical polarization was therefore selected. To take into account domestic rain distribution trends, we take 66.4 mm/h as the rainfall rate for $R_{0.01}$, which is the measured value for Seoul with location data of 126.58E and 37.33N. With these values, the estimated attenuation from rain for the regional use of the Ka-band satellite system is obtained, and the results compared with those from the recommended rainfall rate in ITU-R P.837-5, as shown in Fig. 1. The difference between the two results becomes larger as the rainfall rate increases reaching more than 3.5 dB at 0.01% time rate, which means that the ITU-R model does not fully reflect domestic weather changes, and regional statistics should therefore be used for a better quality service provision.

III. Link Analysis for Ka-band Satellite System

The second version of Digital Video Broadcasting via Satellite (DVB-S2) standard is one of the most popular technologies in satellite broadcasting. We take the DVB-S2 technology into consideration for the transmission system of a UHD satellite broadcasting service since the system has been adopted for Ku band satellite broadcasting in Korea, and this is therefore the best way to launch a new service minimizing the burden of risk in terms of investment and service compatibility. In this section, we describe DVB-S2 system performance characteristics, which was conducted by finding the C/N required to achieve a packet error rate (PER) of less than 10^{-7} for the TS packet for each coding and modulation technique of DVB-S2. The link margin of the DVB-S2 system under the link conditions addressed in Section II is then estimated.

A. DVB-S2 system performance

The DVB-S2 standard has been specified to meet the demands for the best transmission performance, total flexibility, and reasonable receiver complexity. To achieve the best performance-complexity tradeoff, DVB-S2 benefits from more recent developments in channel coding and modulation. Moreover, the system was intended to be used for several applications including interactive point-to-point applications and professional applications, such as IP unicasting, digital TV, news gathering, and data content distribution. The unique features making these diverse applications achievable is the adoption of adaptive coding and modulation (ACM) functionality, which allows an optimization of the transmission parameters for each individual user on a frame-by-frame basis depending on the path conditions under closed-loop control through a return channel. To keep the packet error rate at less than 10^{-7} over an AWGN channel, it is known that the required C/N of the DVB-S2 system varies from -2.4 dB with QPSK 1/4 to 16 dB with 32APSK 9/10. However, since the effects of nonlinearity and synchronization loss and phase noise should be considered along with the ideal performance [15], we take 0.6/1.0/2.0/4.0 dB as an additional power losses for QPSK/8PSK/16APSK/32APSK, as reasonable estimates with typical equipment characteristics, respectively. Therefore, the C/N values required to meet 10^{-7} of PER over an AWGN channel for each modulation and coding (MODCOD) parameter of the DVB-S2 system are calculated as shown in Table II.

Table II can be used to select feasible transmission schemes for a certain service availability by comparing the required signal level with the link performance as in Table III. Moreover, this can be used to design service composition meaing how many channels and what kind of channels could be transmitted within the dedicated bandwidth because total data rate is simply calculated when the transmission schemes used are determined.

B. Link analysis of Ka band satellite broadcasting system

To recognize the possible transmittion configuration for 4K UHD satellite broadcasting over the Ka band, it is necessary

TABLE II. Required C/N of DVB-S2 system

Code rate	QPSK	8PSK	16APSK	32APSK
1/4	-2.59	-	-	-
1/3	-1.39	-	-	-
2/5	-0.19	-	-	-
1/2	0.81	-	-	-
3/5	2.11	5.71	-	-
2/3	2.91	6.81	10.21	-
3/4	3.81	8.11	11.41	15.91
4/5	4.51	-	12.21	16.81
5/6	5.01	9.61	12.81	17.61
8/9	6.11	10.91	14.11	18.91
9/10	6.61	11.21	14.31	19.31

to evaluate the link margin of the Chollian satellite and the available bitrates that can be transmitted through its corresponding bandwidth for each MODCOD parameter of the DVB-S2 system under a certain rain attenuation condition. The link margins of the Chollian satellite downlink, which can be used to define the possible transmission method to be used for a certain rainfall rate, are given in Table III. For a more realistic analysis, the required C/N contains non-linear power loss under the assumption of using a pre-distortion technique at an earth station, as discussed in Section III-A.

TABLE III. DOWN-LINK PERFORMANCE OF CHOLLIAN SATELLITE

D/L (20.13GHz)	Clear	Rain (0.07%)	Rain (0.1%)	Rain (0.3%)	Rain (0.5%)
Saturated EIRP	60	60	60	60	60
Free Space Loss	209.9	209.9	209.9	209.9	209.9
Rain Attenuation	0	10.44	8.73	4.78	3.5
ES G/T	15.51	13.30	13.38	13.79	14.04
Channel Bandwidth	80	80	80	80	80
C/Nd	13.2	0.55	2.35	6.7	8.23
D/L C/N[dB]	13.2	0.55	2.35	6.70	8.23

*Above listed figures are assumed that antenna diameter = 45cm(38dBi), antenna Noise Temperature = 92K, Noise Bandwidth = 100MHz and all the carrier to interference ratios (C/I) = 60 dB.

For the simple design of the uplink from the transmitter station to satellite, it is assumed that no rain loss is considered thanks to the perfect uplink power control, and the total transponder bandwidth is occupied with the minimum input and output backoff. The earth station antenna gain is calculated under the assumption that a 70 cm antenna diameter would be proper for the Ka band satellite link. As shown in Table III, it turns out that the link margin for clear sky conditions is around 13 dB, and the broadcasting link is unable to maintain its connection with the receivers at rain conditions of higher than 0.07% of the time percentage because the only possible tramission schemes are lower than QPSK 1/2 code rate which could be usable but very impractical choices.

IV. KA-BAND UHD SATELLITE BROADCASTING SCENARIOS

Based on the above link analysis of the DVB-S2 satellite UHD broadcasting system using the Chollian satellite, several satellite UHD broadcasting scenarios are considered, and their service performances are analyzed. As candidate technologies to be used for the service scenario establishment, diverse technologies available at present or expected to be available in the near future are taken into account. Special regard is paid to the backward compatibility with the current HDTV services and the adaptability to channel variation for extending service availability. Channel adaptability is a technology being introduced to mitigate rain attenuation, which is a critical issue in Ka band satellite services. The related technologies in terms of transmission are being widely developed in many countries [1]. To discuss the backward compatibility, it is necessary to identify the legacy HDTV receiver and new UHDTV receiver in terms of the element technologies. Legacy HDTV receivers are defined to have the capability to deal with H.264/AVC HP@4.1 for the video codec, and DVB-S2 constant coding and modulation (CCM) mode for the transmission. On the other hand, the new UHDTV receivers have the capability to support H.264/AVC with higher than HP@5.1 and HEVC for the video codec, and DVB-S2 variable coding and modulation (VCM) mode for the transmission. Therefore, new UHDTV receivers are able to receive the frame resolution of UHD video as well as HD video and a satellite signal with multiple protection levels, which makes it possible to design much more flexible service scenarios. The service scenarios for satellite UHD broadcasting are categorized according to the perspective on the video codec, transmission mode and frequency band. In the first step, service scenarios are classified into single layered and multiple layered services according to whether the service is composed of multiple layers in terms of video quality. Single-layered service is the simplest scenario and can be applied for dedicated channel service, which only covers new subscribers for UHDTV services. However, in multiple-layered service scenarios, several combinations of technologies are considered to find a way to provide backward compatibility and mitigate the channel deterioration from rain attenuation. To meet these requirements, scalable video coding (SVC) and simulcasting schemes are considered in the scenario as well.

A. *Single layered scenarios*

Single layered scenarios only aim to provide UHD broadcasting service itself, and thus do not consider subscribers with legacy HDTV receivers. Since they are not configured to have multiple layers in the UHD program, a single-frequency band and DVB-S2 CCM mode are used in the scenarios. Therefore, these scenarios do not support backward compatibility because they require video coding technology higher than H.264/AVC HP@5.1 profile to deal with the 4K frame resolution of the video. These scenarios include two types of scenarios, which are classified according to which video codec is used for the UHD program compression. The single layered scenario system is expected to be the most appropriate system for the initial UHD satellite test broadcasting because it does not affect the current on-air services if the frequency band is properly selected.

B. *Multiple layered scenarios*

In multiple layered scenarios, each program is transmitted at different layers with different protection levels to provide adaptive service in a channel variation environment. To this end, the base layer stream and enhancement layer stream are constructed from one program. For the sake of convenience, in this paper a low-quality video stream is called a base layer stream, and a high-quality video stream is called an enhancement layer stream. The base layer stream and enhancement layer stream can be generated by either way of SVC or simulcasting scheme. In addition, each layered stream can be transmitted in diverse ways depending on the transmission mode and target frequency band.

In the first step, multiple layered scenarios are classified depending on their backward compatibility possibility. To

TABLE IV. Classification of Multiple Layered Service Scenarios

	Multiple layered Service Scenarios							
	Non-Backward Compatibility Supported				Backward Compatibility Supported			
	SVC		Simulcasting		SVC		Simulcasting	
	Single Codec	Multi Codec	Single Codec	Multi Codec	Single Codec	Multi Codec	Single Codec	Multi Codec
Single Band	[B]HEVC,Ka [E]HEVC,Ka [T]VCM	[B]AVC,Ka [E]HEVC,Ka [T]VCM	[B]AVC,Ka [E]AVC,Ka [T]VCM [B]HEVC,Ka [E]HEVC,Ka [T]VCM	[B]AVC,Ka [E]HEVC,Ka [T]VCM	N/A	N/A	N/A	N/A
Multiple Band	[B]HEVC,Ku [E]HEVC,Ka [T]CCM	N/A	[B]HEVC,Ku [E]HEVC,Ka [T]CCM	N/A	N/A	[B]AVC,Ku [E]HEVC,Ka [T]CCM	[B]AVC,Ku [E]AVC,Ka [T]CCM	[B]AVC,Ku [E]HEVC,Ka [T]CCM

*[B]: Base layer of UHD service, which means it is for an HD program, [E]: Enhancement layer of the UHD service, which means it is used for reproducing a UHD program, and could be an enhancement layer for SVC coding and the UHD program signal itself in a simulcasting scheme, and [T]: Transmission mode of DVB-S2 technology, where N/A denotes that the service scenario is not able to meet the corresponding conditions.

*It is assumed that SVC coding with H.264 would not support UHD resolution, and thus the enhanced layer of SVC in the scenarios is generated by only HEVC video coding. It is also assumed that the SVC with HEVC supports both H.264 and HEVC for its base layer stream.

support backward compatibility to the current HDTV service in Korea, the scenario should involve H.264/AVC and DVB-S2 CCM mode for the base layer stream. Providing backward compatibility with DVB-S2 CCM mode in a single band is not considered in the paper because of its inefficiency. Therefore, there are three scenarios that can provide backward compatibility, as shown in Table IV. The base layer stream used for HDTV service should be coded with the H.264/AVC scheme of HP@4.1, and transmitted through the Ku band frequency. In addition, the enhancement layer stream is transmitted through the Ka band frequency using either H.264/AVC of HP@5.1 or the HEVC coding schemes. Since these service scenarios use dual-band transmission, each layer stream is transmitted with DVB-S2 CCM mode, and the new UHDTV receiver requires to have Ku/Ka dual-band signal reception capability when the SVC scheme is considered. As for the non-backward compatibility scenarios, the HEVC coding scheme for the base layer stream and DVB-S2 VCM mode can be considered for the scenario analysis. Both single-band transmission and multiple-band transmission can be possible because they can utilize DVB-S2 VCM mode to transmit each layer stream with differentiating its protection level even in single-band transmission. For the single-band transmission scenarios, every combination of technology is technically possible, while multiple codec scenarios for multiple band transmission are not available because they are involved in the backward compatibility scenario. As shown in Table IV, it is assumed that only HEVC SVC usage is considered because SVC in H.264 is hard to be practically applied. H.264 SVC is currently not supported by most commercial products, and HEVC SVC technology will be used later if such functionality is thought to be needed. However, since HEVC SVC technology is under standardization, it will take time to appear on the market, and more importantly, it is not clear at the moment whether the business market will demand scalable video coding applications. Therefore, simulcasting scenarios will be more reasonable for satellite broadcasting in the near future if channel adaptability is required for the target service, even though it is necessary to submit to a sacrifice in bandwidth.

V. Ka-Band 4K-UHD Satellite Experimental Broadcasting Demonstration

4K UHD satellite experimental broadcasting services through the Ka band satellite have been conducted in past years. In this experiments, only two service scenarios with single band and single codecs with one of AVC and HEVC schemes are applied, as shown in Fig. 2. The experiments were conducted to evaluate the multi-channel service provisioning with channel adaptibility for 4K UHD satellite broadcasting. To meet the requirement, a high-speed DVB-S2 modem was developed using VCM mode support. Most of the legacy DVB-S2 modems are developed to support Ku band transponders of around 30MHz providing 80Mbps of maximum capacity. Our new modem extends this capacity upto around 300Mbps to support wideband Ka band transponders, which are required to provide multiple UHDTV channel services. In addition, this modem supports all the MODCOD listed in the DVB-S2 standard with multiple TS interfaces functionality for VCM transmission, and implemented with 0.3 dB margin in average comparing to the ideal required C/N of each MODCOD. For the channel adaptive service verification, several combinations of two MODCODs are selected that each combination can serve more than 99.7% of their service availibilty.

According to the link budget analysis in Section III and the experiment results, it turned out that this channel adaptive

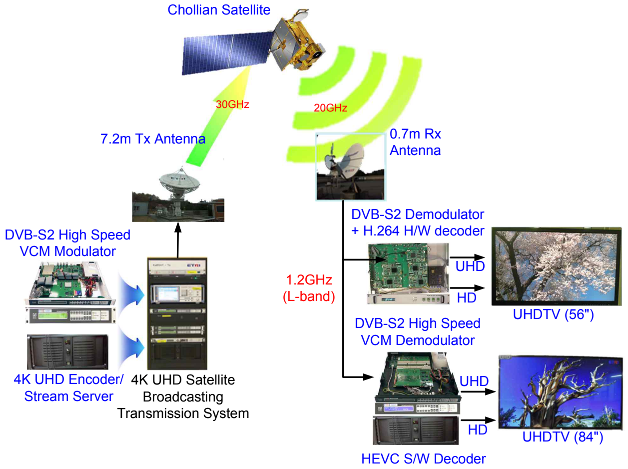

Fig. 2. Ka-band Satellite UHD Broadcasting Demonstration

functionality can be able to increase the service availability by more than 7 hours per year. It is clear that the channel adaptability is worthy of attention, especially in regions of heavy rainfall. Moreover, it would be much more important in applications in which the link should always be connected between earth stations, such as for public protection and disaster relief.

VI. Conclusion

This paper presented a variety of analyses on Ka band satellite broadcasting service for immersive media, providing the technological background for a verification of satellite UHD service commercialization. Rain attenuation modeling was performed first through the international standard method with the domestic rainfall rate statistics, since the rain attenuation is the most critical factor for satellite broadcasting in the Ka band. Next, the satellite link performance was analyzed to determine the most suitable transmission method for the service under the local environment, and it turned out that the channel adaptive functionality should be seriously considered for more stable service continuation. The paper presents diverse feasible service scenarios with the combinations of technologies which are currently available and expected to be available in the near future as well. Some of these combinations are open to discuss in terms of economics. However, most of them are worth taking into consideration since it is still vague about what will be the correct answer in every element for UHD service. Since technology developments will make rapid progress, it will reduce the cost and make it possible to bring about much more complicated scenarios in reality. Along with the service scenarios, the result of satellite experiments which were conducted for the preparation of satellite UHD broadcasting service in Korea was presented. Thanks to these gradual developments of service technologies, plans for satellite UHD broadcasting service will materialize in the very near future as announced by certain countries.

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