WIRELESS LINKS FOR 8K SUPER HI-VISION PROGRAM PRODUCTION

J. Tsumochi[1], K. Murase[1], Y. Matsusaki[1], F. Ito[1], H. Kamoda[1], N. Iai[1],
K. Imamura[1], H. Hamazumi[1] and K. Shibuya[2]

[1]NHK Science & Technology Research Laboratories, Japan and
[2]NHK Engineering System, Inc., Japan

ABSTRACT

The Super Hi-Vision (8K) regular broadcasting through broadcasting satellite will start in 2018. In light of this, we developed two 8K wireless-links that use microwave and millimetre-wave bands for use in 8K program production. The transmission capacity of the wireless link must be three to five times larger than that of the current High-definition (HD) wireless link to cope with the huge amount of data streams of 8K video and audio signals. Therefore, several approaches, such as dual-polarized multiple-input multiple-output (MIMO), higher-order modulation, wide-band signal processing, were taken to increase the transmission capacity. As a result, the 8K microwave wireless link can transmit more than 300 Mbps over a long distance within the 18-MHz bandwidth. The 8K millimetre-wave wireless link uses the 125-MHz bandwidth in the 42-GHz band and can transmit more than 600 Mbps over a short or middle distance. Field experiments were conducted to prove the feasibility.

INTRODUCTION

Since Super Hi-Vision (8K) (1) regular broadcasting will start in 2018, there is an increasing demand for diversifying 8K content. To diversify such content, outside broadcasting from anywhere at any time, such as electronic news gathering and live feed of sports events, is indispensable, as has been for high-definition (HD) program production. High-definition portable wireless link have been necessary to achieve that (Figure 1). Therefore, portable wireless link for 8K program contribution are necessary as for HD program contribution.

In this paper, we report the development of two portable 8K wireless links that use microwave and millimetre-wave bands, where we took several approaches to increase the transmission capacity required for 8K contribution.

REQUIRED BIT RATE AND FREQUENCY BANDS FOR 8K COTNRIBUTION

The required transmission bit rate for 8K program contribution was evaluated by the Association of Radio Industries and Businesses (ARIB) in Japan in 2016.The subjective evaluation of picture quality after going through the H.265/HEVC (High Efficiency Video

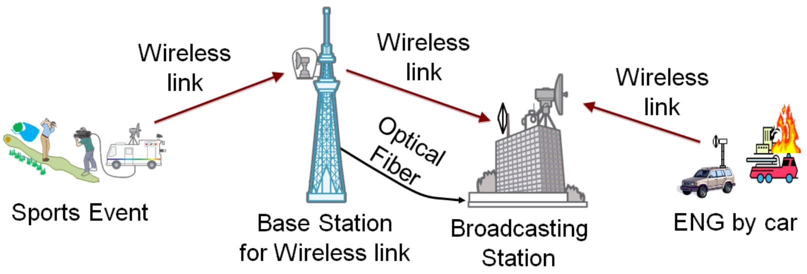

Figure 1 – Scene of wireless-link usage

Coding) codec was conducted to determine the required bit rate satisfying the picture quality for 8K contribution. As a result, the required bit rates (transport stream (TS) rates) were found to be 150, 200, and 300 Mbps depending on the number of codecs connected in tandem.

The HD wireless link currently used in Japan has a capacity of approximately 60 Mbps (2). Therefore, an increase in the transmission capacity by three to five times is necessary to achieve the required bit rate.

We have been considering using both microwave and millimetre-wave bands to achieve 8K wireless link because each band has advantages and disadvantages and they could supplement each other.

Several microwave bands for broadcasting auxiliary services are allocated between 6 and 13 GHz, where the HD microwave wireless link is currently in use. The fact that field engineers operate the current HD microwave links in these bands motivates us to develop 8K wireless links that can operate in the same bands. However, there is a constraint in that the current channel allocation to the operators or broadcasters has to be preserved, meaning that the channel bandwidth is kept to 18 MHz despite the needs for increasing the transmission bit rate. Also, the maximum transmission power must be five watts to avoid new interference problems. However, these constraints enable the smooth transition from HD to 8K or sharing of operation between HD and 8K.

The millimetre-wave band for broadcasting auxiliary services is allocated in the range of 41-42 GHz and is mostly used for HD wireless camera systems in Japan (3). The band is said to be susceptible to rain attenuation, and a solid-state power amplifier in the 42-GHz band has limited amplification performance, therefore, the nominal link distance is shorter than in the microwave band. However, the wide-channel bandwidth is considered suitable for the transmission of high-bit-rate 8K signals. The channel bandwidth of 125 MHz can achieve an even higher bit rate than in the microwave band, enabling higher 8K picture quality.

BASIC TRANSMISSION SCHEME TO INCREASE TRANMISSION CAPACITY

Figure 2 illustrates the transmission scheme of the 8K wireless links. Both links use dual-polarized MIMO (Multiple-Input Multiple-Output)-OFDM (Orthogonal Frequency Division Multiplexing) as one of the approaches to increase transmission capacity.

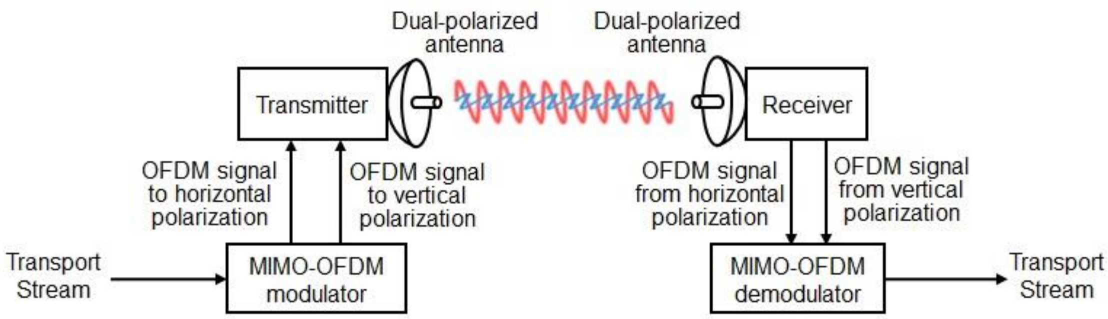

Figure 2 – Transmission scheme of 8K signals using 8K wireless link

In the dual-polarized MIMO scheme, horizontal and vertical polarizations are used to double the transmission capacity by transmitting different data streams on the two polarizations. Interference between the two polarizations may occur during the propagation, but it can be cancelled by MIMO detection using the pilot carriers arranged for MIMO.

Based on the assumption that the wireless links are used in a fixed and line-of-sight environment, the degradation of the cross polarization discrimination can be ignored. Therefore, the MIMO-detection method at the receiver can be a simple linear process, such as zero forcing, making hardware implementation easy. Moreover, a parabolic antenna, which has been used for the HD wireless link, make it easier to transmit or receive both polarizations with a single reflector, avoiding the large space required for installing two antennas.

8K MICROWAVE WIRELESS LINK

Increasing Transmission Capacity

Apart from the dual-polarized MIMO scheme, other approaches to increase the transmission capacity are required to attain the transmission bit rate of up to 300 Mbps. Because the channel bandwidth must not be expanded from the current 18 MHz in the microwave bands, the spectrum efficiency needs to be further enhanced. Therefore, higher-order modulation schemes have been introduced, such as 1024 Quadrature Amplitude Modulation (QAM) and 4096QAM. The current HD microwave wireless link uses 64QAM, which carries six bits per carrier-symbol, while 1024QAM and 4096QAM carry 10 bits and 12 bits, respectively, approximately doubling the transmission capacity.

Another approach is adopting a large fast Fourier transform (FFT) for the OFDM scheme. The larger FFT size allows reducing the guard interval ratio (while keeping the absolute guard interval length constant) and decimating the pilot carrier insertion in the frequency dimension, resulting in enhanced transmission efficiency. The FFT size of the HD microwave wireless link is 2048, while we use 8192 for the 8K microwave wireless link, meaning an increase in capacity of 23%.

As a result of combining the above approaches, the transmission capacity of the 8K microwave wireless link becomes five times larger than that of the HD wireless link.

Parameter		HD microwave link	8K microwave link
Frequency		6-13 GHz	
Occupied bandwidth		17.2 MHz	
FFT size		2048	8192
FFT sampling clock		20.460743 MHz	
Subcarrier spacing		9.99 kHz	2.5 kHz
Number of data carriers		1344	6426
Transmission scheme		OFDM	Dual-polarized MIMO-OFDM
Subcarrier modulation		BPSK, QPSK, 16QAM, 32QAM, 64QAM	64QAM, 256QAM, 1024QAM, 4096QAM
Effective symbol length		100.14 μs	400.57 μs
Guard interval length		12.52 μs	
Forward error correction	Inner code (code rate)	Convolutional code (1/2, 2/3, 3/4, 5/6)	LDPC (1/2, 2/3, 3/4, 5/6)
	Outer code	Reed-Solomon	BCH

Table 1 – System parameters of HD and 8K microwave wireless links

Meanwhile, to reduce the high required carrier-to-noise ratio (CNR) due to the higher-order modulation, a low-density parity-check (LDPC) code is used. The LDPC code has much better performance than the conventional convolutional code. We adopted the LDPC code defined in the standard; ARIB STD-B44 − Transmission System for Advanced Wide Band Digital Satellite Broadcasting (4).

The system parameters and the transmission capacities of the 8K microwave wireless link are summarized in Tables 1 and 2, respectively.

Subcarrier modulation	LDPC code rate	Transmission capacity (Mbps)
1024QAM	1/2	156.4
	2/3	208.5
	3/4	229.4
	5/6	260.7
4096QAM	1/2	187.7
	2/3	250.2
	3/4	275.2
	5/6	312.8

Table 2 – Transmission capacity for 8K microwave wireless link (Capacities for 64QAM and 256QAM are omitted)

Long-haul Transmission Experiment

We conducted a field experiment to confirm the feasibility of the 8K microwave wireless link. As this experiment was conducted half way through the development of the wireless link, we used a proof-of-concept prototype, the system parameters of which are slightly different from those in Table 1. The transmission distance was 59 km, transmitting from Dodaira Observatory (Tokigawa town, Saitama) and receiving at NHK Broadcasting Centre (Shibuya ward, Tokyo). Table 3 summarizes the link budget for the field experiment when using 0.6-m-diameter antennas for the transmitter and receiver.

The measured received power was −65 dBm, which agrees well with the estimated received power of −63.8 dBm.

The bit error rate (BER) versus received power was measured using variable attenuators. The results are plotted in Figure 3 together with those from a laboratory experiment

Parameter	Value
Transmission power	200 mW (100 mW per polarization)
Frequency	7.026 GHz
Antenna gain (diameter)	31 dBi (60 cm)
Feeder loss	1 dB
Effective isotropic radiated power	50.5 dBm
Transmission distance	59.2 km
Free space propagation loss	144.8 dB
Received power	−63.8 dBm
Noise figure	3.0 dB
Thermal noise power	−98.5 dBm
Required CNR	30.2 dB (1024QAM, code rate 5/6)
Margin	4.5 dB

Table 3 – The link budget for field experiment of 8K microwave wireless link

conducted beforehand. Only the results for the parameters that achieved an approximately 200-Mbps transmission bit rate are plotted for brevity. The BER curves closely agree with those from the laboratory experiment. The difference between the two can be attributed to the propagation, antenna characteristics, and systematic errors due to the difference in the measurement systems. Therefore, we confirmed that the approaches are practical and can increase the transmission capacity in the microwave band.

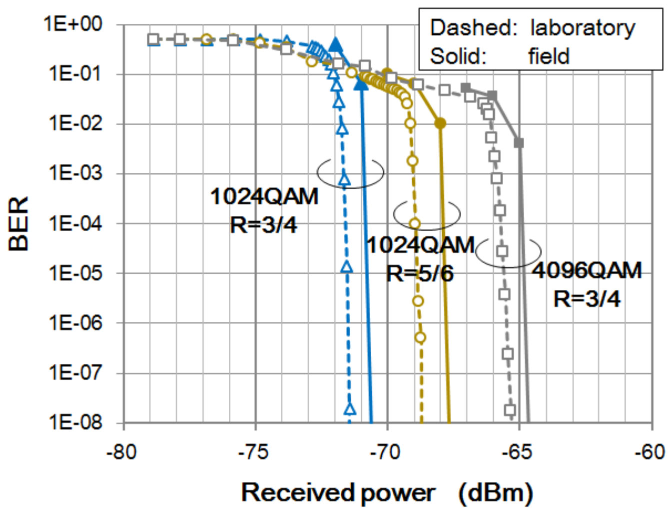

Figure 3 – BER versus received power in field experiment

In addition to the above experiments, we tested the transmission of compressed 8K signals at the TS rate of 180 Mbps through the prototype. The 8K video was flawlessly decoded and displayed at the receiving site, proving the functionality of the 8K microwave wireless link.

8K MILLIMETRE-WAVE WIRELESS LINK

Specifications

For the millimetre-wave wireless link, another approach to increase the transmission capacity besides the dual-polarized MIMO is introduction of a wideband signal processing, making use of the available wide channel bandwidth of 125 MHz. It was achieved by

Parameter		Value
Frequency		41-42 GHz
Occupied bandwidth		109.2 MHz
FFT size		2048
FFT sampling clock		130 MHz
Subcarrier spacing		63.5 kHz
Number of data carrier		1344
Transmission scheme		Dual-polarized MIMO-OFDM
Subcarrier modulation		QPSK, 16QAM, 32QAM
Effective symbol length		15.75 μs
Guard interval length		0.98 μs
Forward error correction	Inner code (Code rate)	Convolutional code (1/2, 2/3, 3/4)
	Outer code	Reed-Solomon

Table 4 – System parameters of 8K millimetre-wave wireless link

making digital circuits, such as an FFT and a forward error correction (FEC) coding and decoding, operate on a high-speed clock and in a parallel manner.

Table 4 lists the system parameters and Figure 4 shows the required CNR versus transmission capacities of the 8K millimetre-wave wireless link. Signal distortion due to a power amplifier tends to be large in the millimetre-wave band and may impede a use of higher-order modulation, therefore, the subcarrier modulation was set to 32QAM or lower.

In accordance with the system parameters, a prototype of the 8K millimetre-wave wireless link was built (Figure 5). It consists of a MIMO-OFDM modulator and demodulator, transmitter, receiver, and dual-polarized antennas.

BER Characteristics

We measured the basic BER characteristics in radio-frequency (RF) loopback by connecting the transmitter and receiver with waveguides. The transmission power of each

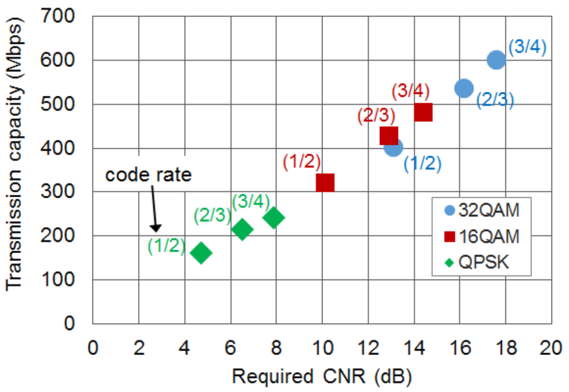

Figure 4 – Required CNR versus transmission capacities

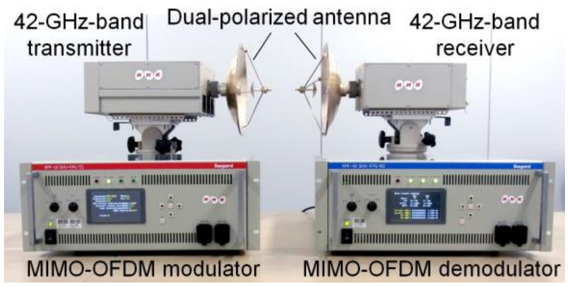

Figure 5 – The prototype of 8K millimetre-wave wireless link

polarization was 250 mW (500 mW in total) and the subcarrier modulation was 32QAM.

The results are plotted in Figure 6 with and without FEC (Viterbi decoding), the code rates of which are 1/2, 2/3 and 3/4. The BER without Viterbi decoding showed an error floor due to signal distortion caused by the power amplifier in the transmitter.

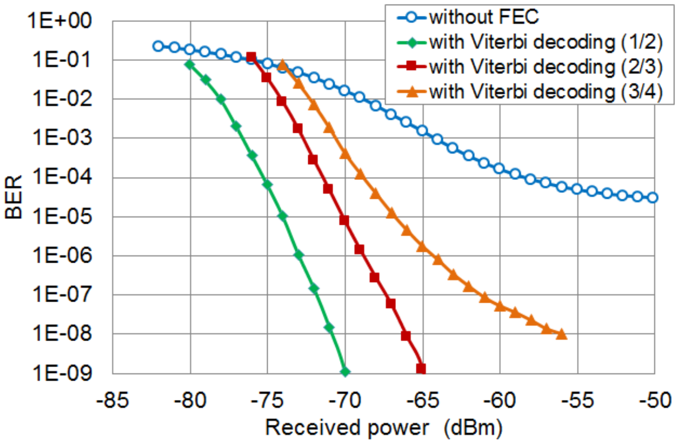

Figure 6 – BER versus received power in RF-loopback test

Here, the quasi error free (QEF) is defined as a state where the BER after Viterbi decoding is less than 1×10^{-4}. Therefore, the required received power achieving the QEF was −75.2 dBm and −68.8 dBm with the code rate of 1/2 and 3/4, respectively. These values revealed 0.2 and 2.1-dB degradation for the code rate of 1/2 and 3/4 respectively from the required received powers in the intermediate-frequency loopback, which can be calculated from the required CNRs shown in Figure 4. The degradation was caused by the power amplifier. Therefore, a high-power and low-distortion millimetre-wave band solid-state power amplifier is desired especially when trying to extend the transmission distance or to increase the transmission margin.

Transmission Experiment

The field experiment was conducted using the 8K millimetre-wave wireless link at a transmission distance of 8 km from NHK Broadcasting Centre (Shibuya ward, Tokyo) to

Parameter	Value
Transmission power	500 mW (250 mW per polarization)
Frequency	41.0625 GHz
Antenna gain (diameter)	40 dBi (30 cm)
Feeder loss	1 dB
Effective isotropic radiated power	63.5 dBm
Transmission distance	8 km
Free space propagation loss	143 dB
Rain attenuation	0 dB
Atmospheric absorption loss	1.6 dB
Received power	−41.6 dBm
Noise figure	5 dB
Thermal noise power	−88.5 dBm
Required CNR	17.6 dB (32QAM, code rate 3/4)
Margin	29.3 dB

Table 5 – Link budget for field experiment of 8K millimetre-wave wireless link

NHK-STRL (Setagaya ward, Tokyo). The transmission bit rate was 602.2 Mbps containing 213-Mbps 8K signals (TS) compressed with H.265/HEVC.

We confirmed that the 8K millimeter-wave wireless link transmitted clear 8K video without any block noise. The received power was −44 dBm at the horizontal polarization and −45 dBm at the vertical polarization and was lower than the calculated received power shown in Table 5. This is thought due to the angular alignments of the transmitter and receiver antennas not being perfect.

We calculated the transmittable distance of the 8K signal using the 8K millimetre-wave wireless link from the link budget. The transmittable distance under fine weather conditions was calculated to be around 50 km. However, the millimeter-wave band is susceptible to rainfall. According to ITU-R Recommendation (5), the rain attenuation of the 42-GHz radio wave under conditions of 20 mm/h rainfall is about 5.8 dB/km. Therefore, the transmittable distance under such conditions was calculated to be 5 km. We consider the millimeter-wave wireless link suitable for a short or middle-haul large-capacity transmission.

CONCLUSION

We developed two 8K wireless-link systems that use microwave and millimetre-wave bands to achieve 8K outside broadcasting. The transmission capacity needed to be increased by three to five times from that of the HD wireless link. We took several approaches, such as dual-polarized MIMO, higher-order modulation, and wide-band signal processing, to increase the transmission capacity. The 8K microwave wireless link can transmit more than 300 Mbps over a long distance within the 18-MHz bandwidth. The 8K millimetre-wave wireless link uses a 125-MHz bandwidth and can transmit more than 600 Mbps over a short or middle distance. The two 8K wireless-link systems will be used depending on conditions such as transmission distance and required bit rate. We will develop practical models of these 8K wireless link systems to be used at the upcoming Tokyo 2020 Olympic and Paralympic Games. Needless to say, these wireless links can also be used for 4K contribution.

REFERENCES

1. T. Yamashita, M. Kanazawa, K. Oyamada, K. Hamasaki, Y. Shishikui, K. Shogen, K. Arai, M. Sugawara and K. Mitani, 2010. Progress report on the development of Super Hi-Vision. Motion Imaging Journal. September, 2010. pp. 77 to 84.

2. ARIB Standard STD-B33 Ver. 1.1, 2005. PORTABLE OFDM DIGITAL TRANSMISSION SYSTEM FOR TELEVISION PROGRAM CONTRIBUTION.

3. S. Suzuki, T. Nakagawa and T. Ikeda, 2010. Development of Millimeter-Wave Mobile Camera and Performance Improvement in Outdoor LOS Environment. IEICE Trans. Fundamentals. November, 2010. pp. 2099 to 2107.

4. ARIB Standard STD-B44 Ver. 2.0, 2014. TRANSMISSION SYSTEM FOR ADVANCED WIDE BAND DIGITAL SATELLITE BROADCASTING.

5. Recommendation ITU-R P.838-3, 2005. Specific attenuation model for rain for use in prediction methods. March, 2005.