16APSK/16QAM-OFDM 3.2Gbps RF Signal Direct-Processing Transmitter and Receiver Communication Experiments Using WINDS Satellite

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Abstract The National Institute of Information and Communications Technology (NICT) has experimented using a 1,244 Mbps high-speed burst modem with single carrier QPSK modulation through a bandwidth of 1.1 GHz transponder on the Wideband InterNetworking Engineering Test and Demonstration Satellite (WINDS). We developed a 16APSK/16QAM-OFDM 3.2 Gbps RF Signal Direct-Processing Transmitter and Receiver system for even greater broadband transmission. This paper shows that a 4K UHDTV transmission experiment using WINDS satellite connection through a 10GbE interface was successfully performed by this system.

Keywords Reconfigurable, WINDS, 16APSK/16QAM-OFDM, Uncompressed 4K UHDTV

1. Introduction

NICT is conducting research and development of high-speed satellite communication using WINDS (Wideband InterNetworking engineering test and Demonstration Satellite, also known as “Kizuna”), launched in 2008. In 2010, NICT succeeded in achieving a single carrier transmission rate of 1.2 Gbps by maximizing the 1.1 GHz bandwidth of WINDS’s K_a band bent-pipe relay mode [1]. Also, we are developing engineering flight model (EFM) for reconfigurable communication equipment (RCE: software defined radio) [2] using SRAM-based FPGA (Fig.1). This is a satellite-equipped transponder whose circuits can be configured by uploaded circuit information from earth after the satellite has been launched into orbit. To make reconfigurable communication equipment more compact and lightweight, we developed a 16APSK/16QAM RF signal direct-processing transmitter and receiver [3]. We sought to expand on this and achieve broadband transmission using WINDS. We developed a 16 APSK-OFDM (16-ary amplitude and phase-shift keying, orthogonal frequency-division multiplexing) 3.2 Gbps RF signal direct-processing transmitter and receiver with multi-level modulation, orthogonal frequency-division multiplexing (OFDM) and achieved $6.12 \times 10^{-3}$ bit error rate on the WINDS circuit. We added LDPC error correction to this system and succeeded in broadband transmission with a data transfer rate of 3.2 Gbps. Furthermore, we added a 10 GbE interface, connected a multi-channel video codec system, and succeeded in UDP/IP transmission of uncompressed 4K UHDTV[4].

Fig.1 RCE Onboard Software Defined Radio (EFM)
2. 16APSK/QAM-OFDM 3.2Gbps transmitter and receiver

The circuit diagram of the 16 APSK/16QAM-OFDM 3.2 Gbps transmitter and receiver system is shown in Fig.2. Its specifications are shown in Table 1. Fig.3 Shows modulator print wired board and demodulator print wired boards. Fig.4-1,2 shows the 16APSK/16QAM signal mapping. As shown in Fig.5, the 16APSK/16QAM signal is multiplexed into 16 frequencies(f01-f16) and a data transfer rate of 3.2 Gbps was realized. To reduce the effects of inter symbol interference, which causes distortion in the transmission line, we set 57.14MHz as the frequency interval and the entire bandwidth (equivalent noise bandwidth) as 920MHz. With a single carrier 16APSK 750 Mbps signal, the bandwidth of the frequency is expanded. To cancel the effects of group delay due to the characteristics of earth station’s communication equipment, satellite circuit, and satellite’s transponder, adjustment of the equalizer coefficient is required. However, because the frequency bandwidth for each frequency can be narrowed with OFDM, these effects can be reduced.

![Fig.2 16APSK/16QAM-OFDM 3.2Gbps RF Signal Direct-Processing Transmitter and Receiver Circuit Configuration](image)

![Fig.3 16APSK/16QAM-OFDM 3.2Gbps RF Signal Direct-Processing Modulator/Demodulator Print wired boards](image)

![Fig.4-1 16APSK Signal Mapping](image)

![Fig.4-2 16QAM Signal Mapping](image)

**Table 1 Major Specifications of 16APSK/16QAM-OFDM3.2GbpsRF Signal Direct-Processing Transmitter and Receiver**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
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<tbody>
<tr>
<td>Modulation:</td>
<td>16APSK-OFDM, GI=2.5ns (radius ratio $\gamma=R2/R1=2.73205$), 16QAM-OFDM</td>
</tr>
<tr>
<td>Signal Mapping:</td>
<td>DVB-S2 conformity, Gray code(16QAM)</td>
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<tr>
<td>Data Rate:</td>
<td>3200Mbps =50Mmps x 4bit/symbol x 16ch</td>
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<tr>
<td>Error Correcting Code:</td>
<td>LDPC code</td>
</tr>
<tr>
<td>Interleave:</td>
<td>Interleave between subcarriers (every eight subcarriers)</td>
</tr>
<tr>
<td>Randomizer:</td>
<td>Generating polynomial $h(x)=x^8+x^7+x^5+x^3+1$ (CCSDS)</td>
</tr>
<tr>
<td>$10\text{GbE}$ external interface:</td>
<td>10GbE SFP+ interface, Internet Protocol: UDP/IP, Bit Rate: 3200Mbps (after adding error correction)</td>
</tr>
</tbody>
</table>
3. WINDS satellite communication experiment:

Uncompressed 4K UHDTV

Fig.6 shows an overview diagram of the WINDS satellite communication experiment. A satellite communication experiment was conducted using a large-scale in-vehicle earth station with a 2.4 m antenna in the earth station. Fig.7 shows the received signal frequency spectrum through the WINDS satellite. Fig.8 shows the I/Q constellation of each of the 16 frequencies when demodulating. Because of differences in the Es/No for each wavelength due to the effects of the transponder’s amplitude-frequency characteristics, differences in demodulation characteristics were observed. However, all 16 frequencies were demodulated normally. The bit error rate before correction was $6.12 \times 10^{-3}$. Quasi error free (BER < $1.0 \times 10^{-11}$) line was achieved by applying LDPC error correction. Fig.9 shows 16APSK and 16QAM I/Q constellation(f12). 16QAM confirmed that BER before error correction is improved compared with 16APSK. The improvement which is about 0.3 dB by a BER theoretical value.

For the uncompressed 4K UHDTV’s codec system, the “multi-channel video codec system” developed by NICT [5] (Fig.10) was used. This codec is entirely software-based, and is realized with ultra-high-speed, multi-channel parallel processing on a multi-core PC. The amount of information was made 4/9 (YUV611) using the method for thinning out chrominance components while leaving the pixel count as-is, yielding a transfer rate about 2.65 Gbps. Four-channel video (4 high-definition images) were synchronously transmitted. With these achievements we confirmed that UDP/IP transmission of uncompressed 4K UHDTV took place without packet loss. Example of a transmitted 4K UHDTV picture is shown on a fig. 11.
4. Conclusion

We achieved 3.2 Gbps satellite transmission. Anticipated applications include the field of telemedicine, in which medical information can be accurately transmitted to specialist physicians in remote locations by large-scale in-vehicle earth stations. Also possible is, if a disaster occurs, the transmission of high-resolution images of injured victims in the disaster area to disaster response units in 4K UHDTV (Fig.12).

Finally, we wish to express our thanks to JAXA and other parties involved in the WINDS satellite for their assistance with this research.

References


