Digital Baseband Signal Broadcasting of Ultra-High Definition Video over Analog/Digital Hybrid Network

WDM Overlay of 10G digital broadcast signal on FM conversion based Analog optical network

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***Abstract*— This paper describes the concept of the digital baseband signal broadcasting of ultra-high definition (UHD) video over an analog/digital hybrid network. It also provides, as an exemplary feasibility study, system designs for WDM (Wavelength Division Multiplexing) overlay of 10 Gbps digital baseband signal on an analog optical network based on frequency modulation conversion.**

Keywords—Broadcasting; Video distribution; Ultra-high definition; Access network; PON; WDM; Analog/Digital Hybrid

I. INTRODUCTION

One of the killer network service applications must be video distribution. In particular, the multi-channel broadcast-type service over the FTTH (Fiber-To-The-Home) network, which exploits the broadband characteristic of optical fiber, is very attractive and competitive, and a force driving the demand for greater network bandwidth. Advances in ultra-high definition (UHD) video, such as 4K/8K, have been significant [1], with the development of efficient video compression techniques and high definition displays. In the future when high definition displays will be common in most homes, the multi-channel video broadcasting service, consisting of several tens to one hundred UHD channels, will be needed. Such a UHD video broadcasting service will be considered to have a bandwidth of up to 10 Gbps or higher. This makes the fiber-based network a promising candidate, since radio-wave and CATV (Cable television) [2] face spectrum resource limitations.

In this paper, we describe the concept of the digital broadcasting of UHD videos with analog/digital hybrid network. An important feasibility study is provided that examines system designs for WDM (Wavelength Division Multiplexing) overlay of a 10 Gbps digital baseband signal on an analog optical network based on frequency modulation conversion [3].

II. DIGITAL BASEBAND SIGNAL BROADCASTING OF UHD VIDEO WITH ANALOG/DIGITAL HYBRID NETWORK

A. *Digital Baseband Signal Broadcasting of Ultra-High Definition Video*

In the conventional scheme, video broadcast service that uses FTTH employs analog transmission methods, such as frequency modulation conversion [3] or subcarrier multiplexing [4], in which the video signal of the radio wave or the CATV can be transmitted transparently. Baseband digital broadcasting has also been studied, and it is expected to realize lower equipment cost than analog methods [5]. The digital baseband method multiplexes multi-channel video signals in the time domain, i.e., TDM (Time Division Multiplexing), whereas analog transmission methods employ FDM (Frequency Division Multiplexing).

Since UHD videos (4K/8K) have bandwidths of up to 40Mbps(4K)/100Mbps(8K) per channel, even with highly efficient compression techniques [6], transmission bandwidth of up to 10 Gbps will be needed to realize multi-channel video distribution. With conventional analog transmission systems, the usable spectrum is limited to 1-2 GHz, making it difficult to convey several tens to one hundred UHD channels. For the multi-channel UHD video broadcasting service, the digital baseband scheme will be a promising candidate, since the high capacity transmission can be realized with low equipment cost, as reported in [5]. Moreover, video distribution over long distances with high splitting ratios can be expected since sensitivity is higher than that possible with analog transmission methods.

B. *WDM Overlay of Digital Baseband Signal on Analog Optical Network*

To implement a UHD video broadcasting service with short lead time and low cost, it is essential to exploit the configuration of the existing video distribution network and minimize equipment investment. The solution shown in Fig. 1, the WDM overlay of digital baseband signals on an FTTH-based CATV system, is promising. The conventional analog optical network uses analog modulation methods and a single wavelength optical signal to convey multi-channel HD videos with FDM. The signal is distributed using optical amplifiers and signal branch components (i.e. optical splitters). In the WDM overlay scheme, a digital baseband optical signal based on the NRZ-OOK (Non-Return-to-Zero On-Off-Keying) format conveys multi-channel UHD videos with TDM. The signal is transmitted using a wavelength different from that of the existing analog signal. Since the optical amplifiers, the signal branch components and the optical fibers already installed for existing video distribution network can be utilized, the UHD video broadcasting service can be implemented with

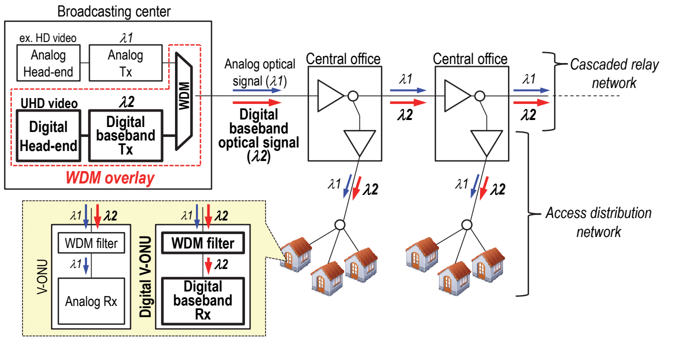


Fig. 1 WDM overlay of digital baseband optical signal on analog optical network

short lead time and minimal investment. End users can enjoy the two video broadcasting services individually or simultaneously by selecting the appropriate wavelengths.

III. SYSTEM DESIGN FOR WDM OVERLAY OF 10G DIGITAL BASEBAND SIGNAL ON ANALOG OPTICAL NETWORK

Since the existing video distribution network is optimized to transmit the analog optical signal at a specific wavelength, and was not designed for multiple wavelength transmission, there are some technical issues to realize the WDM overlay scheme. The following sections focus on the FM (Frequency Modulation) conversion [3] based analog optical network. We discuss system designs for the WDM overlay of a 10G digital baseband signal in the cascaded relay network and the access distribution network.

A. System Design for Cascaded Relay Network

Technical issues in the cascaded relay network are the feasible level diagram of the digital baseband optical signal and the non-linear interaction between the analog optical signal and the digital baseband optical signal. Since the gain of the optical amplifiers and the pass-band of the optical filter installed to suppress the out-of-band ASE (Amplified Spontaneous Emission) noise, are optimized for the analog wavelength, if the digital wavelength is greatly different, the digital baseband optical signal cannot maintain sufficient power during transmission. On the other hand, if the wavelength spacing of the two signals is small, the non-linear interaction will be large and degrade signal quality. We need to determine the optimum system parameters, such as the wavelength spacing, the power ratio and so on, by taking account of these issues.

Figure 2 shows the setup for a proof-of-concept experiment. The analog optical signal was yielded by the FM conversion [7] of a 96-channel FDM video signal consisting of 72-channel 64QAM/256QAM (Quadrature Amplitude Modulation) signal (90-770 MHz) and 24-channel TC8PSK (Trellis Coded 8-Phase Shift Keying)/QPSK (Quadrature Phase Shift Keying) signal (1-2.1 GHz). And, the digital baseband optical signal was modulated with 10 Gbps PRBS (Pseudo Random Bit Sequence) data in NRZ-OOK format. The wavelength lay in the 1.55 μm band, permitting efficient EDFA (Erbium Doped Fiber Amplifier) operation; the

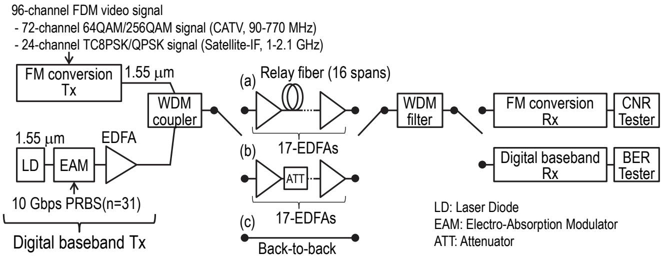


Fig. 2 Setup for proof-of-concept experiment of WDM overlay in cascaded relay network

wavelength of the FM converted optical signal was 100 GHz longer than that of the digital baseband signal. The power of the 10 Gbps digital baseband signal was set 6 dB lower than that of the FM converted optical signal. The cascaded relay network was emulated by 16 spans of optical fibers with 17-EDFAs; the total transmission length was 400 km. And, the setup (a) also used dispersion compensation fibers to suppress the chromatic dispersion effect.

Figure 3 shows the CNR (Carrier-to-Noise Ratio) of the 1049.48 MHz channel of the FM converted optical signal after relay fiber transmission. In the figure, measured results for case (b) attenuators instead of the relay fibers, (c) back-to-back (5 m fiber patch cord), are also plotted. From a comparison of these results, we expect that the CNR was degraded by relay transmission due to the non-linear effect of the fiber. However, we can also see that the CNR exceeded 14dB, which is the Japanese technical criterion for the passed through satellite-IF (Intermediate Frequency) signal (1-1.5 GHz, TC8PSK). Figure 4 shows the BER (Bit Error Rate) of the digital baseband optical signal. While we can see the penalty due to the non-linear effect after relay transmission, there was no significant degradation in receiver sensitivity. These results confirm the feasibility of the WDM overlay scheme in a 400 km cascaded relay network with the system parameters examined.

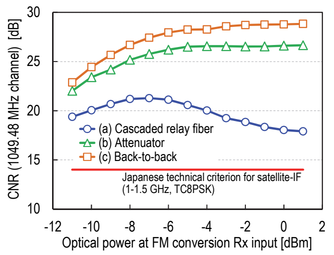


Fig. 3 CNR (1049.48 MHz channel) versus optical power at FM conversion Rx input

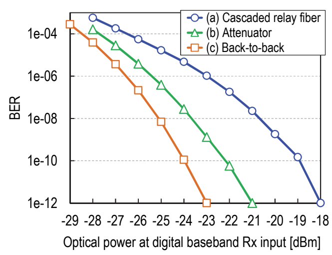


Fig. 4 BER versus optical power at digital baseband Rx input

B. System Design for Access Distribution Network

In the access distribution network, the major technical issue is the linear crosstalk from the digital baseband optical signal to the analog optical signal. The access network generally employs the PON (Passive Optical Network) configuration. Thus the V-ONUs (Video-Optical Network Units), which receive the analog optical signals, will also receive the digital baseband optical signal, as shown in Fig. 1.

Therefore, the parameters of the digital broadcasting system have to be set so as not to interfere with the analog optical signal.

Figure 5 shows the setup to investigate the impact of the 10.3125 Gbps digital baseband optical signal on the FM converted optical signal. The CNR of the FM converted optical signal versus the power ratio, S/X (S: FM converted optical signal, X: Digital baseband optical signal), which was adjusted by attenuators, is shown in Fig. 6 (a). The ER (Extinction Ratio) of the 10.3125 Gbps signal was 8 dB. Fig. 6 (b) plots CNR degradation versus ER. These results indicate that the S/X after the WDM filter inside the V-ONU has to be higher than 25 dB to suppress the CNR degradation to less than 1 dB.

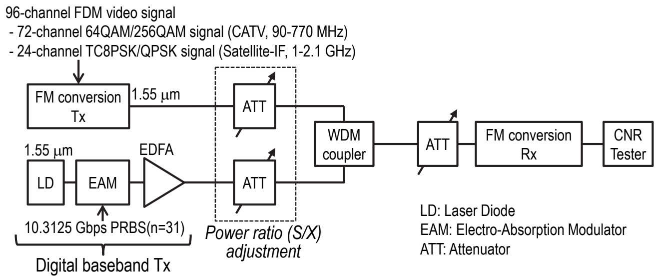
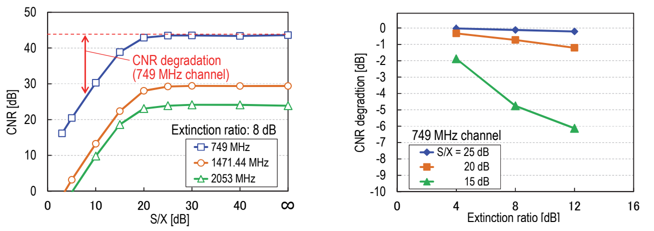


Fig. 5 Setup to investigate impact of 10.3125 Gbps digital baseband optical signal on FM converted optical signal



(a) CNR versus power ratio S/X (Extinction ratio = 8 dB)

(b) CNR degradation versus extinction ratio (749 MHz channel)

Fig. 6 CNR of FM converted optical signal versus power ratio S/X and extinction ratio (S: FM converted optical signal, X: Digital baseband optical signal)

As another technical issue, the SBS (Stimulated Brillouin Scattering) induced limitation of the launch power to fibers must be considered. The essential features of the access distribution network are the long distance transmission and the high split ratio by exploiting the high output power of optical amplifiers, therefore, a transmitter configuration to suppress the SBS effect and maximize the transmit power will be significant.

One solution is additional phase modulation to induce the spectrum spread effect. Fig. 7 shows the setup used to confirm the SBS suppression effect. The fiber transmission loss versus the optical power at SMF (Single Mode Fiber) input is shown in Fig. 8. Without the additional phase modulation, the fiber transmission loss increased when the input power was higher than 10 dBm, where SBS was thought to occur. On the other hand, when the signal was phase-modulated, we could increase the input power to 19 dBm with no significant SBS-induced transmission loss. This means that, with this

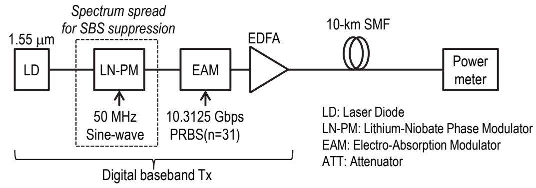


Fig. 7 Setup to confirm SBS suppression effect with additional phase modulation

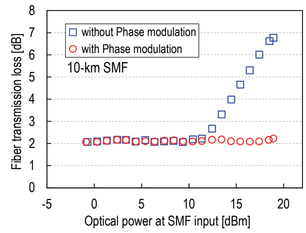


Fig. 8 Fiber transmission loss versus optical power at SMF input

configuration, when we assume that the 10 Gbps signal receiver sensitivity is -28.5 dBm as specified in the 10G-EPON standard [8] for example, a large power budget such as 47.5 dB can be achieved for the digital baseband optical signal. This indicates the possibility that even when the power budget of the analog optical signal conveying multi-channel HD video broadcasting services is 20-30 dB, for example, we can extend the delivery area of the multi-channel UHD video broadcasting service using the excess budget possible with the digital baseband optical signal to increase fiber distance and/or splitting ratio.

IV. SUMMARY

To implement the multi-channel UHD video broadcasting service, we described the concept of the digital baseband signal broadcasting of UHD videos over analog/digital hybrid networks. In addition, we provided the system designs for WDM overlay of a 10 Gbps digital baseband signal on an analog optical network based on FM conversion. Experiments confirmed the feasibility of the WDM overlay scheme in the cascaded relay network with the system parameters we set. We also investigated the tolerance of the FM conversion receiver to crosstalk created by the additional digital baseband signal and the SBS suppression effect in the access distribution network.

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