# Co-existence generation of XG-PON and single carrier XLG-PON for ultra-high definition TV transmission with entirely passive optical plant

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International telecommunication union (ITU) recently has standardized ultra-high definition television (UHD-TV) with a resolution which is 16 times more than that of current high definition TV. Increasing the efficiency of video source coding or the capacity of transmission channels will be needed to deliver such programs by passive optical network (PON). In this paper, a complete passive co-existence of 10 Gbit-PON (XG-PON) and single carrier 40 Gbit-PON (XLG-PON) for overlay of UHD-TV distribution to 32 optical network units (ONUs) on broadcast basis is presented. The results show error free transmission performance with negligible power penalty over a 20 km bidirectional fiber.

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Service providers and telecom operators are concentrating to offer triple-play service on single common broadband passive optical network (PON) infrastructure. They now mainly provide voice services and broadband internet access services over internet protocol (IP) networks, because video content delivery services require more bandwidths[1,2]. IPTV is becoming a common service for many IP service providers, especially for live television and for video on demand (VOD). But next challenge for IPTV providers is to enhance the bandwidth capacity to deliver contents in stereoscopic video, which has gained popularity for three dimensional (3D) vision films[3]. At present, another problem with the IPTV service is the delay in channel selection for live broadcast TV. The channel change response time (CCRT) is affected by network operations at network elements (e.g., admission control, multicast distribution at routers and switches, and video processing, such as decoding and buffering). Network delay is the time interval that the first video frame of a requested channel arrives after completing the internet group management protocol (IGMP) leave/join process[4]. This delay problem for live TV channels is primarily due to multicast nature of IPTV delivery and decoding process at the set top box. Whereas, encoding is applied to reduce the size of TV channel, and normal high-definition television application is compressed at a constant bit rate of 12 Mbit/s[5]. In near future, ultra-high definition television (UHD-TV) is expected to become available, and 8K UHD-TV systems are expected to start in 2017−2020 in Korea and Japan. Increasing the efficiency of video source coding and the capacity of transmission channels will be needed to deliver such programs by PON[6]. A very efficient source encoder will be required to reduce 3 Gbit/s data rate of UHD-TV, which can involve either the complex processing on set top box or the compromise on some quality features of UHD-TV. Due to complex processing at set top box, the delay time in channel selection will be added and the cost of box also will be raised. A high bandwidth system is required to simplify the work of source encoding, so that 50−100 MB/channel will easily be supported by future PON networks. Furthermore, high bandwidth will allow all live TV channels to broadcast at the same time for reducing the channel latency problem of multicast propagation. IPTV over gigabit-capable PON (GPON) and gigabit ethernet PON (GEPON) is proposed[2,4], but it is based on multicasting and legacy TV transmission. In this paper, a co-existence of 10 Gbit-PON (XG-PON) and single carrier 40 Gbit-PON (XLG-PON) with entirely passive and optical plant is demonstrated to achieve high bandwidth for overlay of UHD-IPTV.

A typical optical transport network layout for the delivery of IPTV services is presented in Fig.1. Live television contents from sources, such as satellite, analog with off-the-air or direct feeds from broadcasters, are aggregated at the head-end. Many content related processing

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and administrative tasks are carried out at middleware[7]. This content is then distributed over the core transport network to metropolitans/cities central offices which are further connected with optical line terminals (OLTs) through metro area fibers. To achieve very high bandwidth for delivery of UHD-IPTV, a proposed schematic architecture of co-existent XG-PON and single carrier XLG-PON is shown in Fig.2.

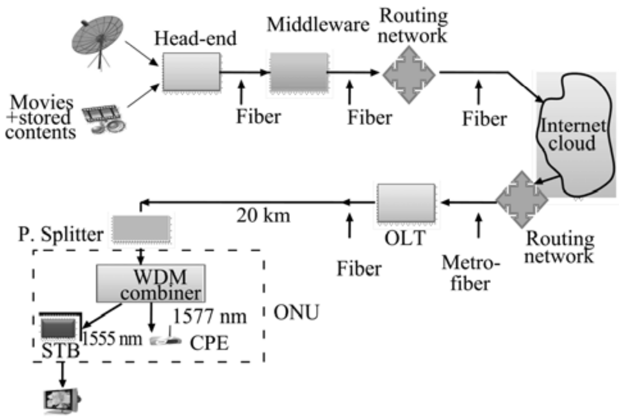



**Fig.1 The principle diagram of typical setup of IPTV distribution**

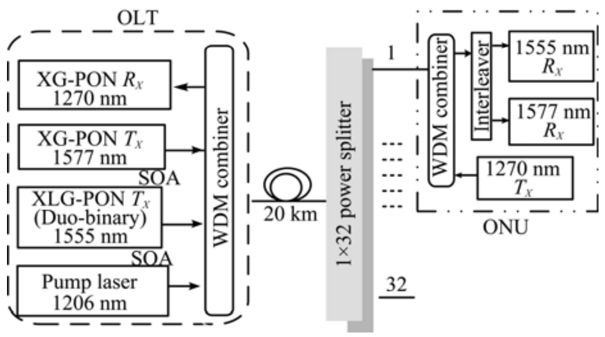
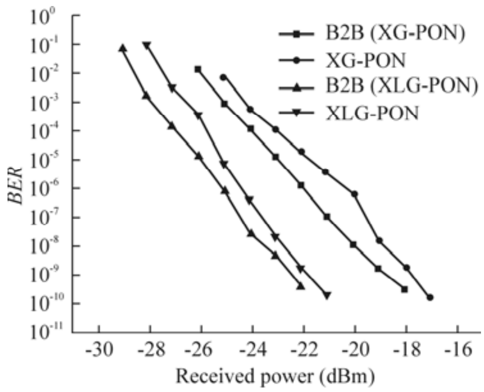


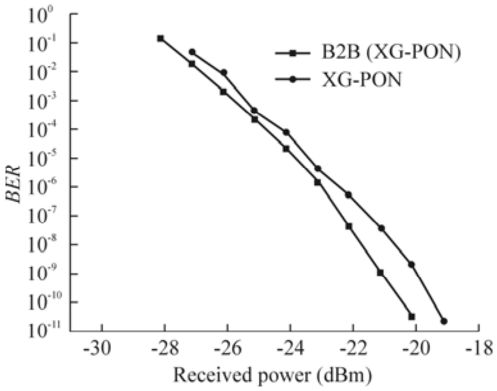

**Fig.2 Schematic diagram used for co-existence generation and transmission of XG-PON and XLG-PON**

In this scheme, an OLT is connected to the remote node (RN) by 20 km of standard single mode fiber (SSMF) to deliver multimedia services to 32 ONUs. The OLT consists of an optical duo-binary XLG-PON downstream (DS) transmitter at 1555 nm, an electro-absorption modulated laser (EML) at 1577 nm as XG-PON DS transmitter and an avalanche photo diode (APD) as XG-PON upstream (US) receiver. A pump laser is also added at OLT to boost XG-PON US signal to avoid the insertion of amplifier at subscriber end. The pump laser is coupled into the feeder fiber to provide the distributed Raman gain for upstream XG-PON signal band (1260−1280 nm) at 1206 nm. Furthermore, for high-speed optical 40 Gbit/s XLG-PON link, chromatic dispersion (CD) limits the transmission distance to a few kilometers without dispersion compensation[8]. In this setup, a three-level intensity duo-binary modulation is applied to reduce the impacts of chromatic dispersion on XLG-PON, instead of dispersion compensation modules in access network. The power spectral density of duo-binary signals is more concentrated around the optical carrier resulting in the reduced bandwidth requirements for the system, which helps to increase CD tolerance about three times compared with NRZ[9]. The duo-binary data can be generated at the transmitter by sending NRZ data through a "delay and add" filter, which has a $z$-transform of $1+z$-1, and can be approximated by a low-pass filter[10]. A 10 GHz low-pass filter is used to generate 40 Gbit/s duo-binary signal in this simulation setup. The distributed feedback (DFB) LD is modulated at 10 Gbit/s ($2^{31}$-1) pseudo random bit sequence (PRBS) using pattern generator (PG) to operate at 1577 nm as the XG-PON DS transmitter. To compensate losses at high data rates, two low-cost SOAs for XG-PON and XLG-PON are integrated with DS transmitters at the OLT into the feeder fiber to boost down signal power respectively. An arrayed waveguide grating (AWG) combiner is employed to combine the XG-PON/XLG-PON DS signals and Raman pump laser. Since only passive splitter is used in RN, the outside fiber plant is entirely passive. At ONU, XLG-PON signal is separated from XG-PON signal by applying two first-order Bessel filters with bandwidth of 10 GHz at central wavelengths of 1555 nm and 1577 nm, respectively. After photo detection, XLG-PON signal is sent to set top box to further convert IP packets into TV contents. While, wavelength pair of 1577/1270 nm DFB LD and APD receiver is used to receive and transmit XG-PON signal. The US EML is also modulated at 10 Gbit/s ($2^{31}$-1) PRBS using a PG with output power of 0 dBm at 1270 nm. A 10 G APD with a bandpass filter is used as XG-PON US receiver at OLT to receive US signal.

The simulation is performed to testify the co-existence generation and transmission of XG-PON and XLG-PON signals. The power for 1206 nm pump laser is fixed at 500 mW that is optimized to ensure 10 Gbit-PON error-free US operation. The bit error rate (BER) as a function of received optical power for DS transmission of XG-PON and XLG-PON signals is shown in Fig.3. For 1577 nm DS, there is about 1.5 dB power penalty after 20 km transmission with total link loss of 34 dBm. While, XLG-PON shows the power penalty of 1 dB with link loss remained at 37 dBm. In US, a power penalty of 1 dB for XG-PON relative to back to back (B2B) is experienced at BER of $10^9$ after propagating for a distance of 20 km as shown in Fig.3(b). Whereas clear eye diagrams for downstream XG-PON and XLG-PON and upstream XG-PON after 20 km transmission are shown in Fig.4. Therefore, it is evident from the above results that an error free transmission has been achieved for both downstream and upstream directions. In this scheme, 1555 nm 40-G signal propagates only in downstream with enough bandwidth to support live broadcast of many hundreds of UHD-IPTV channels without the need of reducing compression ratios. To accommodate other IPTV services, like VOD, community TV, and channel repeat in back time, which are unicast or multicast in nature, some channels can be reserved within 1555 nm 40 Gbit/s DS signal. For backward communication with network operator and service provider, the services like selection VOD, channel reversal request in time and other commands can be communicated through 1577 nm US signal. All this processing can be handled by routing system and set top box.

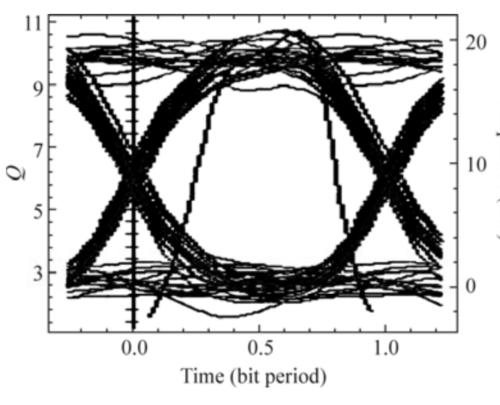



(a)

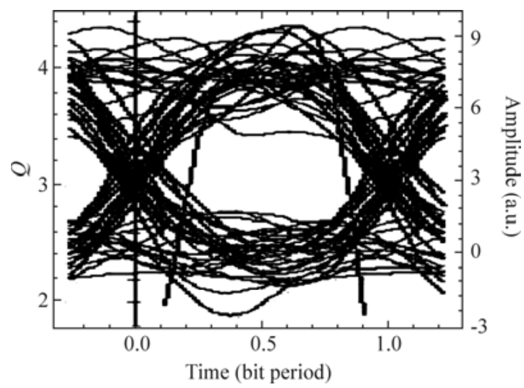



(b)

**Fig.3 (a) DS BER as a function of received power for XG-PON and XLG-PON; (b) US BER versus received power for XG-PON**




(a)

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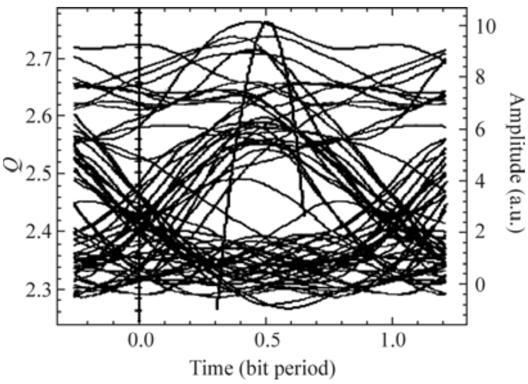


(c)

**Fig.4 Simulated eye diagrams of the data demodulated for (a) DS XG-PON, (b) US XG-PON and (c) XLG-PON signals after 20 km transmission**

The co-existence propagation of XLG-PON at 1555 nm with XG-PON is achieved, which can be used for overlay of UHD-IPTV and is able to transmit all channels simultaneously with minimum delay and processing involved at set top box. There is a bright opportunity to provide the live UHD-TV service with no latency and with all the existing and future auxiliary services of IPTV at minimum cost involved at ONU side for this scheme.

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