On the Technical Design of Bidirectional Access Networks (Postprint)

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Abstract

This paper discusses the technologies of two-way access networks, drawing on the practical experience of the two-way network transformation at Ezhou Broadcasting Television Station Cable Network Company.

Full Text

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A Brief Discussion on the Technical Design of Bidirectional Access Networks

Abstract: This paper discusses the technology of bidirectional access networks based on the practical experience of the two-way network transformation at the Cable Network Company of Ezhou Radio and Television Station.

Keywords: Bidirectional access network; Optical node; Optical network; Head-end; Terminal
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1. Bidirectional Access Network Technology Modes

The bidirectional access network utilizes the bidirectional transmission capability of EPON to meet the most fundamental needs of network and business development. Key performance indicators include: system carrier-to-noise ratio (C/N) $\geq$ 43 dB, composite second-order distortion (C/CSO) $\geq$ 54 dB, composite triple beat (C/CTB) $\geq$ 54 dB, modulation error ratio (MER) $\geq$ 32 dB, and bit error rate (BER) $\leq$ 1.0E-9. The basic services include: (1) High-speed Internet access: providing high-speed Internet service access to end users; (2) Interactive digital television: leveraging EPON's bidirectional transmission capability and IPQAM to expand multimedia services such as time-shifted TV program viewing; (3) Video telephony and other services.

FTTB (Fiber to the Building) technology is an EPON+LAN-based bidirectional network technology. Its greatest advantages are guaranteed transmission quality, low operational costs, and reduced network maintenance expenses, making it conducive to the evolution toward FTTH and triple-play service integration.

1.2 FTTH (Fiber to the Home) Technology

FTTH (Fiber to the Home) technology is an EPON-based bidirectional network technology. Its characteristics include excellent upgradeability and strong integrated access capabilities, and it has been widely adopted in information infrastructure construction in advanced countries worldwide. FTTH technology is also an inevitable choice for the development of broadcast television network services (Figure 1 [Figure 1: see original paper]).

2.3 Optical Node Indicator Requirements

Optical receiver input indicators: optical power -5 to -1 dBm. Optical receiver output indicators: signal level 101$±$2 dB V; MER $\geq$ 35 dB; BER $\leq$ 1.0E-9.

2.1.1 HFC Network Performance Indicators

System carrier-to-noise ratio C/N $\geq$ 50 dB; composite second-order distortion C/CSO $\geq$ 60 dB; composite triple beat C/CTB $\geq$ 65 dB; modulation error ratio (MER) $\geq$ 37 dB; bit error rate (BER) $\leq$ 1.0E-9.

2.1.2 Data Network Performance Indicators

Transmission delay $\leq$ 150 ms; packet loss rate $\leq 10^{-3}$; jitter $\leq$ 50 ms.

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3. Bidirectional Access Network Design

The EPON system employs a two-level splitting design with even-numbered optical splitters (total splitting ratio of 1:32). As services develop, when the data traffic on each PON port reaches 80% load capacity, splitting becomes necessary, which can be implemented using convergence methods such as 1:2:8 or 1:8. For FTTH fiber-to-the-home, the ratio is 1:32.

3.1 Sub-headend Design

Each sub-headend incorporates primary and backup routes. At the sub-headend, primary and backup cable television signals are selected via optical switching before entering the first-stage optical amplifier for amplification. After the first-stage amplification, the cable television signals are split at a 1:32 ratio, while each user-level optical amplifier at the sub-headend splits at a 1:2 ratio. IP data, video, voice, and other services from the main headend are delivered via OTN ring network to OLT equipment (no splitting occurs within the sub-headend), and then transmitted through the ODN optical network to the ONU.

OLTs are recommended to be centrally deployed at sub-headends or township equipment rooms, with urban coverage distances of 3-5 km and rural network coverage radii of approximately 5-10 km. The limited number of equipment rooms facilitates convenient maintenance, making this approach highly suitable for large-scale FTTx deployment (Figure 2 [Figure 2: see original paper]).

3.2 Optical Network ODN Design

The basic EPON network structure consists of three components: Optical Line Terminal (OLT), Optical Network Unit (ONU), and Optical Distribution Network (ODN). The ODN network includes feeder optical cables, optical cable cross-connect cabinets (splitters), distribution optical cables, fiber distribution boxes (splitters), and drop optical cables (Figure 3 [Figure 3: see original paper]).

3.2.1 Feeder Optical Cable Feeder optical cables are deployed from sub-headends to street curbsides, residential communities, or villages, with optical cable cross-connect cabinets installed at centralized points. Within the cabinets, optical splitters distribute signals to building access points in communities or natural villages. Where conditions permit, the feeder optical cable network should employ ring-type non-decreasing cross-connection for distribution; when conditions are not suitable, chain-type non-decreasing cross-connection may be used to facilitate future ring formation of feeder cables. During design, there should be 4 direct fiber cores between each building and the sub-headend, with 2 cores reserved for future use. Specific designs should incorporate the number of buildings.

3.2.2 Optical Handover Point (Cross-Connect Cabinet) The design of optical handover points must consider multiple factors, such as equipment room location and size, and should preferably be installed at indoor locations convenient for maintenance and management. The number of cascaded cross-connect cabinets between the headend and optical nodes should not exceed 3 levels in principle, meaning a first-level cabinet is established in functional areas, with the actual optical cable distance from sub-headend to optical node controlled within 5 km. The actual cable distance from sub-headend to first-level cabinet should be within 2 km; from first-level to community cabinet within 2 km; and from community cabinet to optical nodes within 1 km. First-level cabinets should cover 1,800-2,500 users, while community cabinets should cover 250-300 users, with two 1:8 optical splitters installed inside (one for cable television and one for EPON network). Active equipment is not recommended at cross-connect cabinet locations. First-level cabinet capacity can be selected based on network conditions or city size, with options of 144D, 288D, or 576D specifications. Community cabinet capacity should be 48 cores based on 8 optical nodes, with excess capacity reserved for future use.

3.2.3 Distribution Optical Cable Distribution optical cables connect optical handover points with optical distribution points. Distribution cables may employ either star or tree network structures. Considering the evolution of cable access networks, shared fiber cores should be minimized, generally not exceeding 12 cores. Design should also consider resource utilization, such as duct occupancy, and should generally not be less than 24 cores.

3.2.4 Optical Splitter Splitting methods include uniform splitting and cascaded splitting (not exceeding 2 levels). In digital transformation engineering design (FTTB to FTTH), user bandwidth must be guaranteed as the prerequisite, with the number of users per splitter carefully controlled. Splitter quantity should be determined based on the total number of users within the coverage area, generally controlled at approximately 30% of the user count, with consideration for future expansion as users increase. For high-end residential areas, high-rise buildings, or relatively mature communities, complete splitter deployment can be considered during FTTH construction.

3.2.5 Optical Distribution Point (FTTH Fiber Distribution Box) The design of FTTH fiber distribution boxes primarily considers regional pipeline resources, surrounding environment, and safe operation and maintenance costs. For mature communities or densely populated urban areas with concentrated users, dedicated distribution boxes should be considered. Each optical distribution point should cover a radius of 200$±$50 meters and should preferably be located at equipment rooms or outdoor optical cross-connect cabinets. Optical distribution point cross-connect cabinets are recommended to use 48 to 288 cores.

3.2.6 Drop Optical Cable Drop optical cables, also known as indoor fibers, primarily refer to the optical cable lines between optical distribution points and user terminal facilities. Indoor optical cables are deployed based on actual installation conditions within user premises. Cabling from optical distribution points to user terminal facilities includes vertical and horizontal distribution. Vertical distribution may employ star or tree structures, while horizontal distribution should be implemented according to user requirements while ensuring installation quality, with fiber core counts determined by the number of users. In practice, for floors with many users (such as small hotels and office buildings), deployment typically uses a tree-star structure with additional distribution boxes. For users requiring fiber-to-the-desktop (such as commercial office buildings, computer rooms, and government offices), higher-capacity optical cables can be deployed directly from cross-connect cabinets to optical distribution points serving concentrated users, with individual user terminal facilities then connected via drop cables.

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4. Conclusion

This paper analyzes and designs bidirectional network access based on practical two-way network transformation experience and relevant standards. The discussion inevitably has certain limitations and one-sidedness that require continuous improvement through practical application.

Design Basis and Referenced Standards: - GB/T 17768-1999 Frequency Allocation for Cable Television - GB/T 20030-2005 Specifications for HFC Network Equipment Management Systems - GY/T 121-1995 Measurement Methods for Cable Television Systems - GY/T 106-1999 Technical Specifications for Cable Television Broadcasting Systems - GY/T 180-2001 Technical Specifications for Upstream Transmission Physical Channels in HFC Networks - GY/T 221-2006 Technical Requirements and Measurement Methods for Digital Cable Television Systems - GY5073-2005 Construction and Acceptance Specifications for Cable Television Network Engineering - GY5075-2005 Design Specifications for Urban Cable Radio and Television Networks - IEEE802.3ah (Ethernet in First Mile) Ethernet-based PON - SARFT "Guidelines for Bidirectional Transformation of Cable Television Networks" - China Telecom "Guidelines for China Telecom Broadband Access Development"

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Note: Figure translations are in progress. See original paper for figures.