

Advanced Upstream CATV Access Technologies and Standards

(Invited paper)

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Abstract

Dense-Wavelength-Division-Multiplexed (DWDM) technology has emerged as a viable option for the cable-TV operators to solve their current HFC network architecture design. Performance requirements to increase upstream traffic capacity using time-division-multiplexing (TDM) and frequency stacking methods with directly or externally modulated DFB laser transmitters will be presented. In addition, the advanced upstream physical layer standard for cable modems consisting of frequency-agile TDMA and synchronous code-division multiple-access (S-CDMA) methods will be reviewed.

Introduction

Hybrid fiber/coax (HFC) networks enabled robust transmission of the broadcast AM-VSB video channels via standard single-mode fiber (SMF) to the fiber-node, and thus the significant reduction in the number of cascaded RF amplifiers. The signals from the master headend to the primary and secondary hubs were transmitted over SMF using 1550-nm externally modulated (EM) DFB laser transmitters. The composite signal is a mixture of traditional broadcast analog signals with MPEG compressed digital video. At the hubs, which may house Synchronous Optical Network (SONET) equipment as well as modems, routers, and servers for high-speed data, the optical signals at 1550-nm were converted to RF signals and then back to optical signals for transmission to various fiber nodes using 1310-nm DFB laser transmitters. Thus, cable TV operators were able to cut cost and further improve the quality and availability of the original broadcast services. The development of QAM modulators and digital set-top boxes, which have built-in QAM receivers, MPEG decoder, and RF upstream transmitter, enabled the cable operators to offer many new digital video services with a host of emerging interactive services such as Internet access and Video-On-Demand along with the traditional broadcasted AM-VSB channels.

The problem with this network architecture is that the secondary hubs had grown very rapidly to very large facilities that are expensive to maintain. In addition, upgrade of existing 450-MHz HFC networks can be expensive since it requires additional installations of fiber optics cables for two-way transmission.

Upstream DWDM Network Architecture

The upstream network architecture is also being modified by the DWDM technology¹. Fig. 2 shows for example a simplified block diagram of the upstream DWDM network architecture. It is assumed that each subscriber is connected to the closest fiber node via a coaxial cable plant. At the fiber node, a low cost uncooled DFB laser transmitter operating at either 1310-nm or 1550-nm wavelength band will be used to transmit the high-speed data in the 5-42-MHz band to the secondary hub. These low-cost upstream laser transmitters typically have an optical link loss of 5-dB at 1550-nm or 7-dB at 1310-nm.

At the secondary hub, the upstream data can be aggregated to drive a directly modulated (DM) DWDM laser transmitter using time-division-multiplexing (TDM) and frequency stacking methods. The combination of TDM and frequency stacking significantly increases the upstream traffic capacity. Fig. 3 shows for example the composite RF spectrum of four up-converted return-path frequencies blocks (5-42-MHz) using a commercial Frequency Stacking System (FSS). A reference pilot tone is generated at a frequency of 370-MHz in the FSS in order to synthesize the four-band stack. The pilot tone is transmitted along with the upconverted signal and utilized in the block down-converter unit to synchronize the down-conversion, thus removing any frequency offset errors. The composite RF signal is used to drive each of the DWDM upstream laser transmitters at the secondary hub. The DWDM upstream laser transmitters are operating in 1550-nm wavelength band with optical budget link of 8-dB. Using 1x4 DWDM multiplexer, the optical signal is transmitted through 40-km of standard SMF to the primary hub. At the primary hub, the optical signal is amplified, for example with +13-dBm in-line EDFA, and optically demultiplexed to four different optical receivers. The composite output RF signal from each optical receiver is transmitted to the block down-converter unit, which extracts the four separate 5-42-MHz bands. Then, each of the high-speed data bands can be routed and transmitted to return-path burst receivers or other network control and management equipment. The required output optical power level for each of DWDM upstream transmitters is 7-dBm with spurious output level ≤ -45 dBc. The minimum required C/(N+I) at optical receiver is 40-dB. Other upstream and downstream transmission performance requirements will also be reviewed and presented at the conference.

Joint FA-TDMA/S-CDMA Upstream Standard

An advanced upstream physical layer for cable modems (CMs) is currently under development by IEEE 802.14a working group². It employs burst modulation formats for synchronous and non-synchronous frequency-agile TDMA (FA-TDMA) transmission (mandatory), and synchronous CDMA (S-CDMA) transmission (optional). Simultaneous upstream transmissions at different RF channels are done using frequency-division-multiple-access (FDMA) method. Various new signal processing building blocks and modulation schemes have been added.

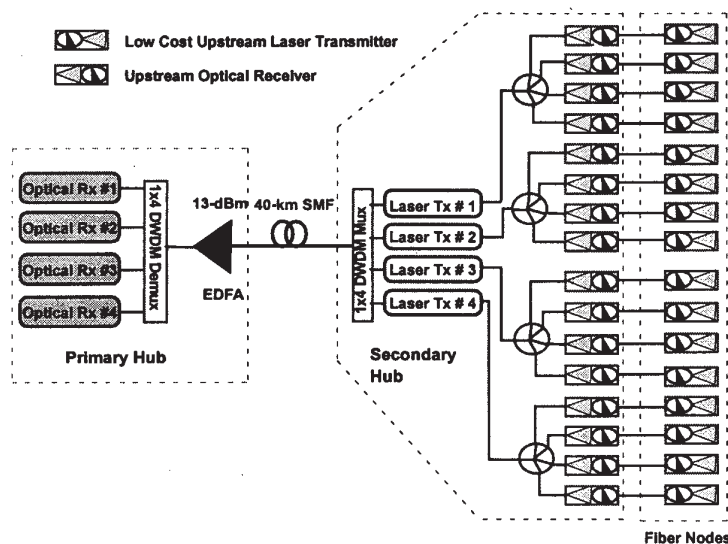


Fig. 1 The Upstream DWDM network architecture

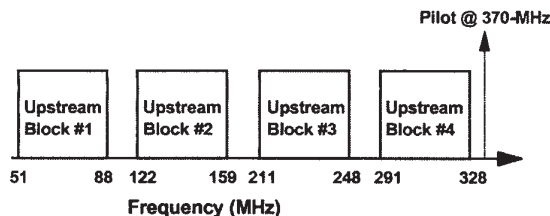


Fig. 2 The composite RF frequency spectrum of four upconverted frequency blocks used to drive each of laser transmitters at the secondary hubs.

Adaptive constellation formats from QPSK up to 128-QAM (TCM only) can be transmitted to maximize data rates when the channel conditions permit. When 8-state trellis-coded-modulation (TCM) scheme is used, 8-PSK and 32-QAM modulation formats provide an efficient way of achieving coding gain compared to QPSK and 16-QAM without sacrificing the bandwidth. TCM coded sub-symbols are interleaved after the TCM encoder to randomize the effect of burst noise in the channel. Alternatively, Bit-Interleaved-Coded-Modulation (BICM) can be used for two-dimensional symbols. The BICM encoding consists of a rate 1/2 convolutional encoder with constraint length $K=7$, bit puncturing unit, and bit interleaver. In addition, there is block interleaving of the Reed-Solomon (R-S) symbols,

which are concatenated with the TCM symbols. Each transmit packet should include a guard time to compensate for ranging errors and ramp up/down time. A variable-length preamble field is also prepended to the transmitted data after it has randomized and FEC encoded.

TDMA with dynamic channel allocation in carrier frequency, symbol rates, and constellation formats are used based on on-going channel quality monitoring. An upstream symbol-spaced transmitter pre-equalizer with 8 feed-forward taps and 16 feedback taps is used to handle multipath micro-reflections on the coaxial plant and allow adaptive ingress cancellation at the headend receiver.

Tomlinson-Harashima precoder with modulo operation is enabled. The pre-equalizer coefficients are being updated during the ranging process.

With S-CDMA, $N=128$ modulation symbols are transmitted simultaneously at modulation rate $(1/N \cdot T_s)$ by using N orthogonal spreading codes. Simultaneous transmission by different CMs in the same channel is based on a combination of burst mode transmission and the use of different spreading codes. To transmit upstream, the CM requests and the CMTS grants programmable number of symbols called min-slots. The mini-slot size is defined by the media-access control (MAC) downstream message for a given FDMA channel, and remains in effect for all upstream transmissions in this channel until it may be redefined by another MAC message.

References

1. O. Snieszko, "Video and data transmission in evolving HFC network", *OFC '98 Technical Digest*, Invited Paper WE4.
2. IEEE 802.14a High-Capacity Physical Layer Specification, Draft 1 (1999).