New Architectural Solutions to Improve the CATV System Performances

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Abstract – **In this paper several conceptions for building the architecture of CATV systems with improved parameters are presented. They are based on the application of technologies DWDM, frequency stacking, PON, FTTH in order to increase the bandwidth efficiency of both the downstream and upstream paths, to reduce the existing asymmetry between them and to improve the quality of services. Criteria to choose the appropriate components (such as laser transmitters, DWDM multiplexers, optic amplifiers etc.) are given for each of the suggested architectures.**

Keywords – **HFC CATV, broadcast and targeted services, DWDM, upstream path, CWDM, PON, FTTH.**

I. Introduction

The new generation of CATV systems are the hybrid fiber/coax (HFC) distribution systems that consist of optical rings with additional hubs included along the rings. The signals are conveyed from the hubs to the optical nodes over the optical fibers. In the optical nodes the optical signals are transformed into electrical ones. After that the signals are distributed to the subscribers by a coaxial distribution system. Hence, previously built coaxial distribution systems were combined through the usage of optical rings and in this way the subscriber service was localized in one headend .

Cable distribution networks are bi-directional: that makes it possible for additional services (such as Internet access, VoD, VoIP etc.) to be provided to the subscribers. Two-way transmission of high-speed interactive services is performed by Cable Modem Terminal System (CMTS) that is located in the headend or the hub. Cable Modem or Set-Top-Box is used in order to receive the data packets addressed to the subscriber and to transmit the data to the CMTS.

Signals transmission over the cable network of a CATV system worsens the quality of service (QoS) due to noise and distortions inherent to the active devices in the HFC system such as laser transmitters, optical receivers, optical and RF amplifiers. The level of both noise and unwanted spurious signals depends on the parameters of the HFC network components, the dynamic range of RF signals, number of channels, optical modulation depth etc. Noise and distortions are mainly due to RF amplifiers used to compensate attenuation in the coaxial network. Hence, designers should aim at shortening the coaxial part of HFC networks.

The extension of the territorial range of CATV systems and the services package available, and the increasing of the number of their users demands new architectural solutions for building the cable distribution network. The aim is to increase the system's throughput and to improve the quality of the provided multimedia information.

Today, DWDM systems are being deployed to provide network segmentation and increased bandwidth. Additionally multiplexing in the RF domain is also being used in the upstream passband to increase bandwidth efficiency [1-3]. The best solution for reducing noise and signal distortion in the amplifiers used to compensate the attenuation in the cable is to move towards a fully passive cable distribution networks such as fiber to the curb (FTTC) and fiber to the home (FTTH) [4-6]. This paper presents architectures of CATV systems, based on the combination of these technologies.

II. Application of DWDM for Building the Downstream Path of HFC CATV System

CATV systems differ by using RF carriers to transmit the information signals. Two frequency bands are provided for signal transmission from the headend to the subscribers: 112 MHz to 550 MHz (for analog video broadcasting) and 550 MHz to 862 MHz (for narrow casting services – data, voice and digital video). Analog video signals are transmitted by using VSB-AM while QAM methods (usually 256-QAM) are mainly used to transmit digital video programs and data. The system reverse paths make use of the 5 MHz to 65 MHz frequency band and subscribers' signals are transmitted by using QPSK or 16-QAM methods.

The RF signals are transferred over the optic fiber by means of optic carriers whose wavelength may be 1310 nm or 1550 nm while with DWDM the wavelengths can be chosen from the wave range recommended by ITU (from 1530 to 1565 nm). The step of the ITU grid is 0.8 nm but in the CATV systems it is selected greater (usually 1.6 nm). This is done to avoid the appearance of nonlinear distortions due to four-wave mixing (FWM).

In Fig. 1 and Fig. 2 two concepts for building the forward path of the CATV system are given. A specific feature of these architectures is that they implement DWDM technology to transmit interactive downstream channels from headend to hub over one optical fiber. To transmit 256-QAM signals for the interactive subscribers' service *n* wavelengths ($\lambda_1 \dots \lambda_n$) selected from the ITU grid are used. The RF signals of the analog TV programs (VSB-AM signals) are transmitted over a separate fiber and to this end they modulate an optical carrier of wavelength λ_0 = 1550 nm.

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The analog transmitter and the ITU transmitters in the headend can be regarded as externally modulated sources that comprise a distributed-feedback (DFB) laser coupled to a Mach-Zehnder modulator. Outputs from the ITU transmitters are multiplexed and transported to the hub. To compensate for the loss within the optical channel erbium-doped fiber amplifier (EDFA) is used.

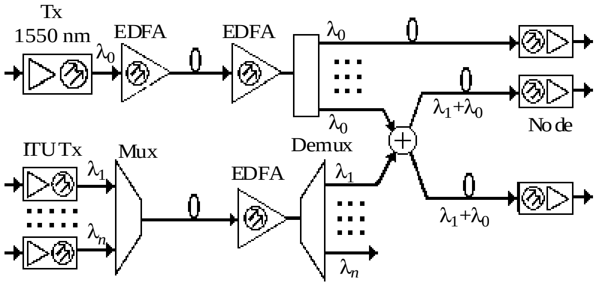

Fig. 1. Forward path configuration 1

The first DWDM architecture has been developed for the 1550-nm range where signals coming over the common-access and the interactive channels are combined at the hub in the optic range. The analog transmitter output is optically amplified to a saturated level of about 17 dBm and transmitted through a shared fiber to the hub, amplified again and split into a number of outputs that matches the number of targeted-services wavelengths. After splitting, the analog signal is combined with the QAM wavelengths and that combination is again split to serve the number of optical nodes for which the given wavelength is targeted. There may be multiple nodes targeted per wavelength, especially in the early deployment stages when subscriber take rates are low corresponding to a low bandwidth requirement per node.

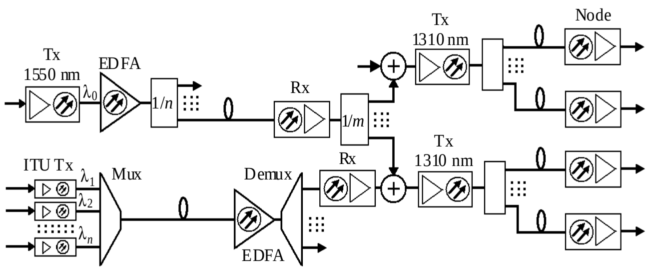

Fig. 2. Forward path configuration 2

The second DWDM architecture refers to cases when an infrastructure of a conventional HFC CATV system in the range of 1310 nm already exists. At the hub, the signals are returned to RF by means of optical receivers. Combined at RF, both broadcast and narrowcast signals drive the 1310 nm lasers. At the optical node (ON) a single detector converts optical signals to RF for distribution into the CATV plant.

Essential to the shared use of fibers is a means by which to combine incoming signals at the transmit end and to separate them at the receiving end. It is possible to use simple wideband splitter/combiners or directional couplers to combine optical signals at the transmit end. The trade-off is that a broadband optical combiner (e.g., an RF combiner), has a insertion loss of about 3.5 – 4 dB per two-way splitting level, whereas a 2-wavelength multiplexer may have a loss of under 2 dB, and a 20-wavelength multiplexer a loss of under 4 dB. At the current state of technology, the retail cost of a broadband combiner is about 10 to 15% of the cost of a 200-GHz-spaced DWDM multiplexer with an equivalent number of ports. Thus, the decision as to whether to use wavelength-specific or broadband combining at the transmit end of a WDM link must be driven by the consideration of the overall link design. At the receiving end, however, there is no alternative to using wavelengthspecific demultiplexers if the signals are to be detected separately.

III. SPLITTING THE OPTICAL NODE IN THE UPSTREAM DIRECTION

The demand for upstream bandwidth is increasing rapidly, driven primarily by the needs of DOCSIS modems. Each voice call requires about 128 kb/s in the upstream direction, while with 50 simultaneous conversations the necessary channel capacity increases up to 6.4 Mb/s. Peer-to-peer applications consume a lot of upstream bandwidth. Furthermore, the large picture, audio, and video files being uploaded today demand higher speeds. This pressure on upstream bandwidth has generated several technologies for splitting the node in the upstream direction, without using more fibers to get data back to the hub or headend. Splitting the node also helps with noise-funneling issues.

The return channel capacity may be increased by using a block conversion system, which takes several return paths and converts all except one to a unique block of frequencies. The blocks are combined and transmitted to the headend using one return optical transmitter. Single conversion is used for economy. For other applications, double conversion might be used if it is necessary to put many blocks close together, but the cost is higher.

Figure 3 illustrates block conversion in a common configuration that uses a 240-MHz return optical transmitter. Up to four return paths may be accommodated. The first is coupled directly to the optical transmitter. The other three are up-converted to other frequencies up to about 240 MHz and combined with the unconverted spectrum to supply signals to a return transmitter. At the headend, the process is reversed, developing four individual 5 to 65-MHz spectra to be supplied individually to receivers. Alternatively, it is possible to build return receivers that tune to 240 MHz, eliminating the need for down-conversion in the headend.

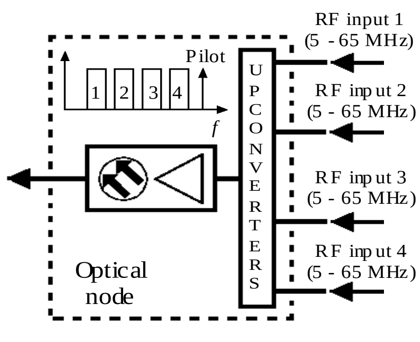

Fig. 3. Block conversion at an optical node

An alternative to block conversion is dense wave division multiplexing (DWDM). Each branch coming back to the node is supplied to a different optical transmitter operating on a different wavelength. A DWDM is used to combine the wavelengths on a single fiber for transmission to the headend or hub. A second DWDM is used at the headend or hub to separate the individual wavelengths before they are supplied to individual optical receivers.

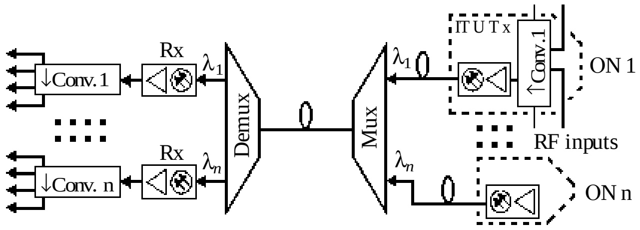

Fig. 4. DWDM reverse path configuration 1

Combining both DWDM and block up-conversion at an optical node it is possible to have 4*n* return bands on a single fiber. There are two configurations currently being investigated to combine these two technologies. The difference is the location of the ITU grid transmitters. In the first configuration these transmitters are located at the hub. In the second configuration, illustrated by Fig. 4, DWDM transmitters are located in the node. Fed by the RF spectrum from the upconverter the individual wavelengths are transmitted back to the hub.

A third technology for combining reverse path signals has also been developed: digitize the return band at the node and transport the digitized signals to the headend. At the headend, the digitized signals are converted again to RF in order to allow interface with legacy headend systems.

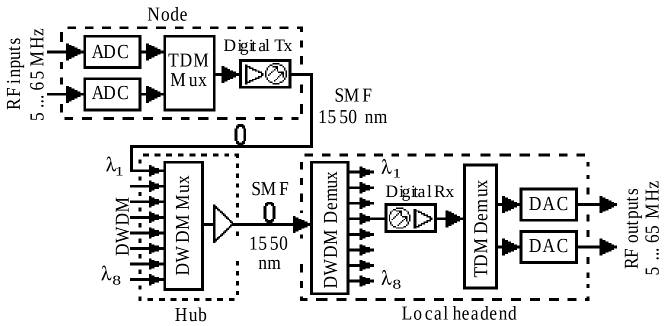

Fig. 5. DWDM digital return system

The implementation principle of a DWDM digital return system is shown in Fig. 5. In such a system, the outputs of the two diplexer low-pass sections are individually digitized in the two analog-to-digital converters (ADC), and then applied to a TDM multiplexer, which alternately passes data from one ADC and then from the other. The data are serialized and supplied to a digital transmitter for transport to the headend. At the headend, the data is demultiplexed into two signal streams, which are converted to RF in digital-to-analog converters (DAC). The RF signals can then be supplied to the normal headend upstream receiving equipment, such as DOCSIS CMTSs for data.

IV. Fiber-deep architectures

Several architectures are being used to drive fiber deep into the network, even as far as the home. Most involve a passive optical network (PON), which runs one feeder fiber from the central office to a passive terminal, then distributes the transmitted signals over distribution fibers to each of typically 16 to 32 optical nodes. Fiber-deep architectures, such as FTTC and FTTH, are driven by the improved quality of signals delivered over fiber-optic plant as compared to those delivered over coaxial plant, by improved reliability due to fewer devices in the network, and by improved bandwidth. Because the multiple services (analog and digital video, cable modem-based Internet access) are multiplexed using separate RF subcarriers, the delivered signals are compatible with existing consumer appliances, and demultiplexing the desired information from the full data stream is very simple. Furthermore, this RF subcarrier multiplexing gives the network operator the ability to gracefully evolve the service mix over time if, for example, the operator wishes to replace some or all of the analog channels with digital services.

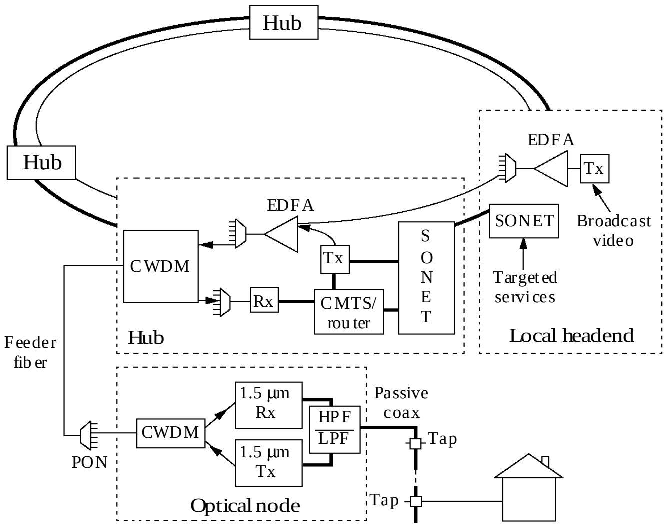

Fig. 6. Fiber-deep architecture

In Fig. 6 a concept for building a CATV system based on the FTTC/FTTH technology is presented. The local headend typically receives video signals in baseband format from a central primary headend, which receives them from a satellite or from local broadcasters. At the local headend, these signals are converted to AM-VSB format for analog video and to QAM format for broadcast digital video and transported to hubs, each serving roughly 20 000 subscribers, via a path-redundant supertrunking ring (that is, each output of the local headend optical splitter connects to a different hub on the ring via a dedicated fiber, and two connections per hub are made – one clockwise around the ring and one counterclockwise for redundancy). IP data and narrowcast video channels are typically carried together from local headend to hub over separate fibers using synchronous optical network (SONET).

Targeted services (TS) are passively combined with broadcast services at the hub and then the downstream signal

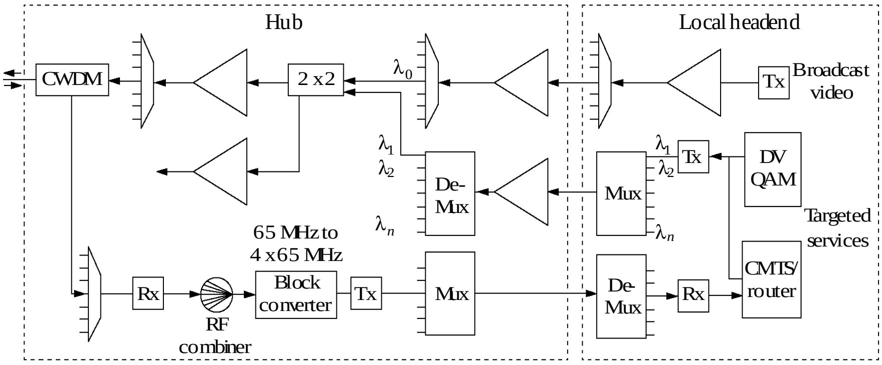

Fig. 7. DWDM-based fiber-deep architecture

is amplified and split multiple times. Amplifiers with up to +30 dBm are now commercially available and these high powers permit extensive optical splitting so that the amplifier cost and, indeed, the cost of all components from the splitter back can be shared over a large number of users. Inserting the TS channels at the hub reduces the sharing of the available TS bandwidth. Moving the TS insertion point toward the output of the hub reduces bandwidth sharing.

Unlike HFC, which uses dedicated downstream and upstream feeder fibers to connect the hub to remote optical nodes, this architecture employs PONs that branch out from each hub and terminate at ONs. Each PON carries bidirectional signals via 1.5 μm/1.3 μm coarse wavelength division multiplexing (CWDM). The FTTH ON operates from its location on the side of a house, while the FTTC ON serves a plurality of houses via one or more coax buses. Coax drops to subscriber homes connect directly to existing in-house coax so that existing customer premises equipment (cable-ready TVs, STBs, cable modems, and IP telephones) can be connected to the network.

In order to increase the system's capacity DWDM can be used to deliver targeted services. DWDM allows to move the TS interfaces (CMTSs, video modulators, video servers, telephony bandwidth managers, and advertisement-insertion equipment) back to the headend, thereby centralizing the operation and maintenance of the network and saving valuable floor space in hubs. Additionally, the use of DWDM between the local headend and the hub eliminates the need for the SONET ring.

The fiber-deep architecture with DWDM is shown in Fig. 7. Typical for this architecture is that the TS transmitters are located in the local headend and each is fixed at a controlled wavelength. These sources are multiplexed onto one or more fibers and transported to the hub. At the hub, the wavelengths are separated and each one is inserted onto a different branch of the network. Thus, by putting a channel on a specific wavelength or a set of wavelengths, it can be targeted to a specific segment of the network. In this case the TS insertion is done optically with a 2 x 2 combiner in the hub.

V. Conclusion

The concepts to build up the downstream and upstream paths of a DWDM-based HFC CATV system, suggested in this paper, allow delivery of independent signals to various end users, and the cost-effective collection of return signals from those users. These independent signals, or targeted services, include internet data streams, telephony, requests for and delivery of video-on-demand, near-video-on-demand, and analog channels reserved by franchise requirements for public, education, and government use.

The presented fiber-deep CATV architectures are superior to HFC in that they offer more total bandwidth, both upstream and downstream, which can be shared among fewer homes. By limiting the coax plant to a small passive run in FTTC, or eliminating it altogether in FTTH, minimizing of noises and nonlinear distortions is achieved, which leads to improvement of QoS. High-power EDFAs, CWDM, and PONs-technologies make the extension of fiber deeper into the network practical.

Optical signals on separate wavelengths interact as they travel through the fiber, and those interactions generate various levels of crosstalk. Depending on the parameters of a given link, these mechanisms can have a serious effect on recovered RF signal quality. As our analysis shows, the quality of discrete components in general, and of the wavelength demultiplexer in particular, is typically the limiting factor in achieving acceptable low levels of crosstalk interference.

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