On The Design of Hybrid Fiber-Coax Networks

Emil Stoilov

Abstract: *Consumer demand for services, such as high-speed internet access, multiple voice lines, and video on demand has continued to grow in recent years. Hybrid Fiber-Coax (HFC) networks have been recognized as the only singular, proven, residential access networks able to deliver the enormous bandwidth necessary for supplying these services. In this paper, Dense Wavelength Division Multiplexing (DWDM) deep fiber architecture is discussed. The presented schemes allow highly scalable bandwidth delivery and at the same time minimize RF actives from the coax plant. It is demonstrated how the use of DWDM can significantly reduce the expenses by diminishing costly hub real estate and by eliminating SONET transmission systems. Finally, a cost-effective implementation combining digital transmission and DWDM in return path is presented.*

Key words: *Hybrid Fiber-Coaxial Network, DWDM, Deep Fiber Architecture, Hub, Headend.*

The changing economic situation within a number of Eastern European countries is linked to an increasing interest for new ways of entertainment and delivering of information. Especially in big cities, the combination of higher income and access to Internet creates a higher demand for a larger variety of video entertainment channels and higher speed Internet access. The opportunities provided by digital video, Internet, and interactive video services are very attractive to cable operators who are willing to upgrade existing, outdated infrastructures. The question is how to evaluate the available technologies, products and services and how to make the best decision. Choosing suitable technology for the optical track and determining the optimum size of the serving area for every node depend on several factors and must be seriously considered.

It has become generally accepted that when closer to customers and virtually unlimited bandwidth offered by fiber is deployed, there is more capability and flexibility of service. The key architectural issue becomes how to use the last-mile media most effectively, either coax or copper-based. Gigahertz-based coax pipes can be used to offer a wide range of interactive video, data and voice services. Fiber optics has been utilized in cable TV networks since 1991. Figure 1 depicts this type of analog television broadcast based network with upstream capabilities used for set-top controls and network management. The Hybrid Fiber-Coax (HFC) transport network is typically limited to the use of 1550 nm analog transmitters to extend the reach of the cable plant. Usually, each optical node serves 500 to 2000 subscribers. The key network drivers are low-cost and have good performance of the analog video signal in terms of noise and distortion. The user receives up to 78 video channels and has optional control of premium channels and pay-per-view via an analog set-top.

However, what would happen if there were no video signals in these networks? One of the key advantages of the HFC architecture is its ability to carry multiple type of information in multiple formats shared by scalable number of users. If the video was terminated and the pipes were used entirely for data by a spectrally efficient modulation scheme, such a 256 QAM, yielding 7 bits per hertz, the result would be a 5-gigabit pipe. The decline of analog video and the use of the available bandwidth for other purposes, offers an enormous potential for new services to become available. The flexible use of bandwidth for different services in multiple formats is an essential strength of HFC networks. To expand the service set offered by HFC, certain network changes are necessary, in both access and transport.

The key to make this enormous bandwidth available to subscribers is to dedicate narrowcasting services to transmitters and optical nodes to serve small service areas in a scalable fashion.

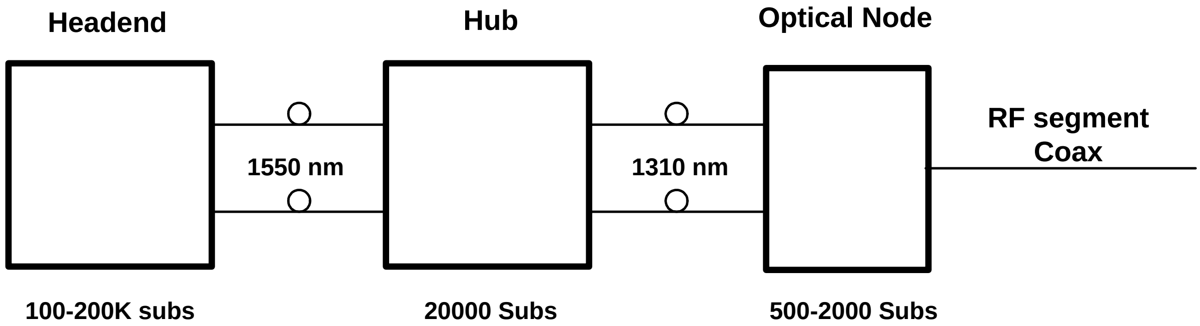

Figure 1: An Analog Television Broadcast-Based Network with Upstream Capabilities

The typical bandwidth range necessary for a number of video, data, advertising, telephony, and multimedia services, assuming a node size of 500 subscribers and a reasonable penetration rate is given in [1]. Expected total forward and reverse bandwidth ranges are respectively 650-1000 MHz and 35-45 MHz. It is quite clear that 500-subs node will not be sufficient in the end, assuming that analog broadcast cannot be abolished the next few years. Therefore, the goal is to find ways to drive more efficiently the fiber deeper into access network.

NODE SEGMENTATION

The number of subscribers to an optical node for a typical HFC system has steadily decreased over the last decade. Previously, the norm was between 1000 and 2000 home nodes, but nowadays new builds and upgrades are more likely to be between 100 and 500 homes per node range. Introducing fiber deeper into networks results in improved bandwidth, performance and reliability, particularly due to the reduction of RF active components from the coax plant. Removing RF amplifiers from the system is an excellent goal, since the system would have a 33-50% less active components resulting in greater reliability and reduced power consumption. Completely passive coax networks are possible in cases of very high subscriber density, for example in a block of flats. If the density is not high enough, it is necessary to segment down to approximately to 35 homes per optical node in order to create a completely passive coax network. This assumes a four-output node with 51-53 dBmV outputs. Unfortunately, for the most cable plants, it is very difficult or even impossible to use effectively all four outputs from the node, without a tremendous difference in the cost of nodes utilizing two, three or four ports. In general, it is better to push fiber as deep as possible, however, 35 homes per node is probably not a cost-effective alternative at this point. A practical solution is to employ a segmentable four-output node passing 100 subscribers [2]. During the initial system design, it is essential to ensure that the optical node size is small enough and will allow sufficient bandwidth for each subscriber to take full advantage of all future one-way and interactive services.

DEEP FIBER ARCHITECTURES

A traditional HFC architecture is shown on Figure 2. Broadcast analog video is transmitted by an externally modulated 1550 nm transmitter from the headend to the hub. A redundant transmitter and a path are included for signal protection. Narrowcasting services, such as data, voice, and optional digital video, are typically transmitted via a SONET link. Other options including ATM, IP or proprietary baseband digital transport are also available. At the hub, the digital narrowcast signals are processed for transmission over the HFC network by the appropriate interface unit. A cable modem termination system (CMTS) converts the downstream data signal to QAM, and QPSK demodulates the upstream signal, and supplies the media access control. It is assumed that any CMTS/Cable modems deployed in the future will be based on the DOCSIS standard. The host digital terminal (HDT) performs the same tasks for cable telephony. Video servers are situated at the headend, but could also be located in the hub to provide digital video and video-on demand (VOD) service. After processing and QAM modulation, the 550-860 MHz narrowcast signals are combined with the 50-550 MHz broadcast analog signal and fed into 1310 nm transmitters, which in turn feed multiple or individual optical nodes.

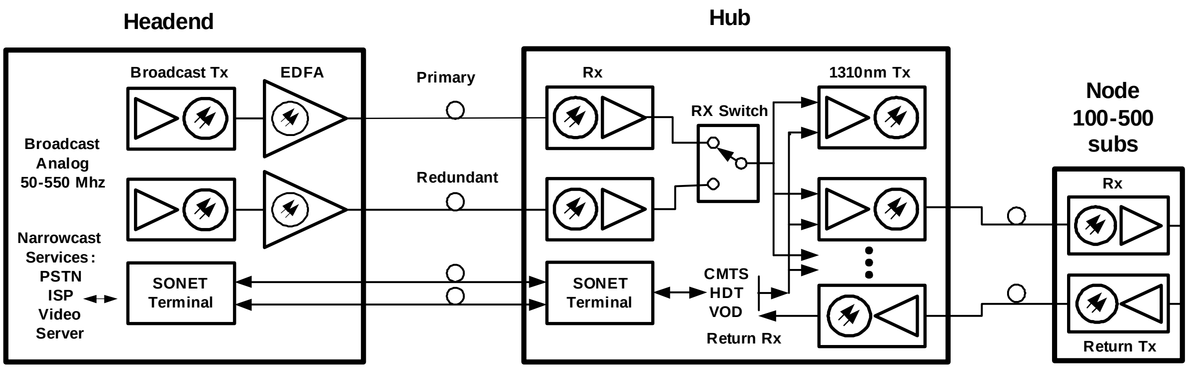

Figure 2: Traditional HFC Architecture

Each optical node could serve anywhere between 100 and 1000 subscribers; for the deep fiber architecture, 100 subs/node will be assumed. Since each hub serves 50,000 subscribers, the hubs must be relatively large buildings in order to store all the equipment and fiber connections, and hence very costly. There are several obstacles for operators deploying traditional double-hop architectures to serve today's bandwidth-hungry subscribers. Aside from the expense, difficulty to locate and build a large hub site, there are some functional problems of redundancy and great number of fibers necessary to feed about 500 nodes from each hub. For services such as telephony, most operators need both equipment and fiber path redundancy down to at least the 500-1000 home level. This is difficult to achieve in the double-hop architecture and is definitely expensive.

An additional disadvantage of the double-hop architecture is the high cost of the SONET or proprietary digital transport as bandwidth demand increases beyond 1 Mbps per home. For a hub, serving 50,000 subscribers and providing just 2 Mbps to each of them 100 Gbps from the headend to the hub are required. This corresponds to 10 OC-192 terminals in both the headend and the hub, a great expense of both equipment and space.

Dense Wavelength Division Multiplexing (DWDM) deep fiber architecture is shown on Figure 3. As previously, the broadcast analog video is redundantly transmitted via an externally modulated 1550 nm transmitter from the headend to the hub. At the hub, the broadcast signal is amplified and split to feed optically scaleable nodes (OSN's). The signal at the OSN is further split to feed 100 home mini-nodes. The narrowcast signals are transmitted via directly modulated DWDM transmitters, whose wavelengths correspond to those of the ITU grid. The wavelengths are multiplexed together at the headend, optically amplified by an erbium doped fiber amplifier (EDFA), pass through the hub site, and are demultiplexed at the OSN. In this ultimate configuration, each wavelength serves a single mini-node, providing 300 MHz of narrowcasting QAM channels (about 2 Gbps or 20 Mbps per subscriber). However, the system can be scaled so that initially each wavelength is shared amongst eight mini-nodes. A simple optical splitter is deployed in the OSN instead of a DWDM demultiplexer. As the bandwidth demand increases, additional DWDM transmitters are added at the headend, and DWDM demultiplexers replace the optical splitters in the OSN. In the configuration shown on Figure 3, each OSN serves eight mini-nodes. That limitation exists at present due to the temperature dependence of DWDM demultiplexers. The implementation of a new generation DWDM couplers will enable each OSN to serve 16 mini-nodes, making the system more cost-effective.

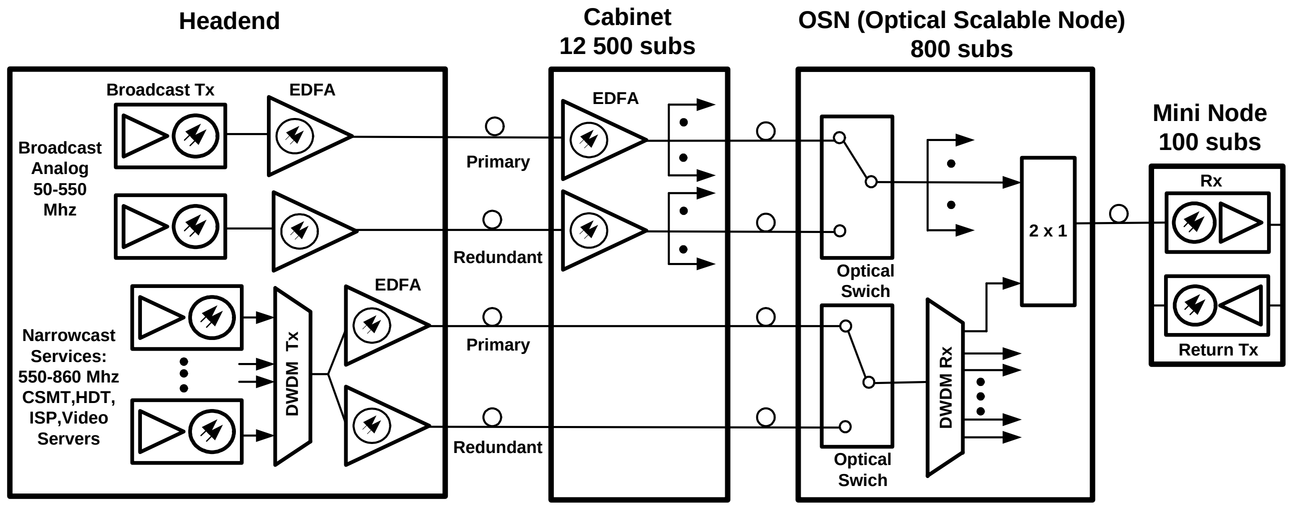

Figure 3: DWDM Deep Fiber HFC Architecture – Forward Path

The broadcast and the demultiplexed narrowcast signals are combined at the OSN and transmitted over the same fiber to a single receiver in the mini-node. The signals can be combined via a simple 2x1 optical coupler, or by a 2x1 DWDM multiplexer, depending on the available resources. Another option is the broadcast and the narrowcast signals to remain separate, and to be transmitted over individual fibers to separate receivers in the mini-node.

The DWDM deep fiber system shown on Figure 3 does not require an expensive SONET or any other digital transport systems. When combined with use of cabinets, rather than expensive Hubs, there are very significant savings as the narrowcast bandwidth demand to the home increases at the range of the several Mbps. The cost of the traditional architecture rises rapidly with the increase of bandwidth demand, but the DWDM architecture only requires additional DWDM transmitters, which are relatively cheap. Similar to the SONET, the DWDM architecture also provides path and equipment protection via redundant optical amplifiers and optical switches. However, for certain high-priority services, such as telephony, many operators are more comfortable with the extensive protection and monitoring capabilities of SONET. For these operators, a hybrid approach is possible. The low bandwidth, high-priority services like telephony can be transmitted to the hub/cabinet via SONET, while the high bandwidth, non-lifeline services such as VOD can be transmitted via DWDM.

Traditionally, multiple-return paths are simply combined, so that the upstream signal from thousands of subscribers is fed into a single CMTS or HDT. This results in very high noise levels, and limits the number of subscribers who can access the service. As the service penetration increases, operators must be able to segment the upstream and to serve much smaller numbers of subscribers. There are several existing methods for segmenting the return path, and thus providing dedicated upstream bandwidth to customers. Figure 4 illustrates the pure DWDM option, which is basically the mirror image of the DWDM downstream. The ITU return path transmitters in the mini-node transmit back to the OSN, where the signal is DWDM multiplexed with the signals from the other mini-nodes served by the OSN. Since the signals are 5-40 MHz analog, it is necessary to amplify with an EDFA before transmitting them back to the headend in order to maintain acceptable performance. At the headend, the signals are demultiplexed and fed into individual return path receivers. The DWDM upstream option provides excellent segmentation, but it is not scalable. The required ITU laser in every mini-node and the EDFAs in the cabinet make the initial system deployment relatively expensive. The system does provide excellent return path bandwidth of up to approximately 100 Mbps, assuming 16-QAM modulation. This corresponds to 1 Mbps peak rate per subscriber, which may be more than the necessary at the early stages of deployment.

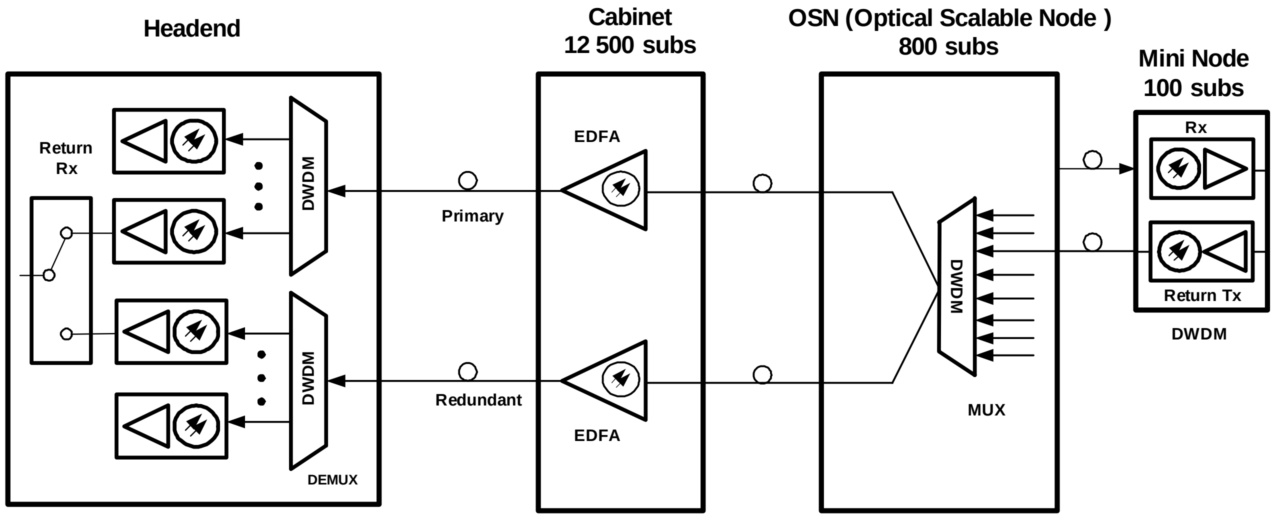

Figure 4: Deep Fiber HFC Architecture – Pure DWDM Return Path

A more scalable and less expensive return path option is to combine digital transmission with DWDM. As shown on Figure 5, the 5-40 MHz upstream signal is transmitted by a 1310 nm laser from the mini-node to the OSN. The laser could be either a relatively low-expense distributed feedback (DFB) laser or a very low-cost Fabry-Perot (FP) laser. The choice between the two depends on how much combining the operator plans to do. FP lasers are noisier, particularly in the cases when no signal is driving them. Therefore, DFB lasers may be necessary for combining many return path segments, and when high priority services like telephony are offered.

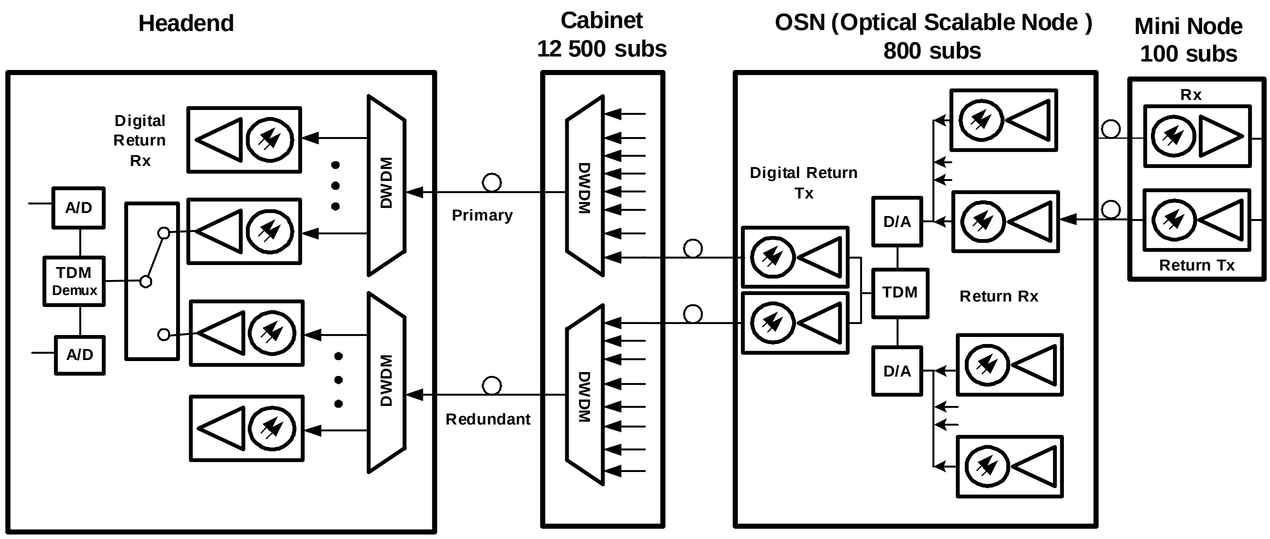

Figure 5: Deep Fiber HFC Architecture – Digital/DWDM Return Path

At the OSN, the signal is received and combined with three other upstream signals. A 10-bit sampling A/D converter then digitizes the combined 5-40 MHz signals. This results in a baseband digital signal of approximately 1 Gbps. At this point the signal is time division multiplexed (TDM) with the digitized signal from four other combined receivers and transmitted back to the cabinet via a 2.5 Gbps ITU transmitter. At the cabinet, the signals are DWDM multiplexed with other return path wavelengths and transmitted to the headend. No EDFA is necessary because the signals are in a digital format. At the headend, the signals are demultiplexed, converted back into an analog format, and fed into the appropriate CMTS, HDT or VOD controller. This system uses fewer ITU lasers than the pure DWDM return option, and no EDFAs; therefore, it is more cost-effective.

A final return path option is to employ a more efficient form of digitization of the QPSK and the 16-QAM signals in the 5-40 MHz return band. Digital sampling of the return path signal is impressive, but very inefficient. The 5-40 MHz waveform is digitized to produce a 1 Gbps signal, despite the fact that the maximum useful information carried by the signal, assuming 16-QAM modulation, is only 100 Mbps. A possible solution to the discussed digital upstream efficiency problem is to remotely demodulate the DOCSIS QPSK or 16-QAM upstream signal by transferring some of the functionality of the CMTS from the headend to the OSN or mini-node. Using such a technique makes the return path more scalable.

CONCLUSIONS

The present paper discusses mainly the practices and opportunities of cable TV operators and computer network designers. The cable operators are updating their HFC networks under pressure for delivery of a variety of new services. Moreover, not provided with sufficient information, they still must choose what new technologies to adopt, and to compare unfamiliar technical solutions, taking into consideration the available budget. At this moment, it is very important for them to receive supporting background information about the advantages and disadvantages of the developed architectures for data transmission.

Computer network designers, in general, are not well familiar with modern telecommunication technologies. They seem to prefer standard solutions and to distrust HFC networks for data transmission. The present state of HFC networks, however, enables these networks to be used as a basis for setting up of Virtual Private Networks (VPN) [3] and effective business applications. In Sofia, Bulgaria, for example, the cable TV operator Evrotur SAT has a HFC network, that covers the city. By using Scientific Atlanta DPC2100 cable modems (DOCSIS 2.0) this company ensures a stable, sufficient and two-way traffic. Therefore, VPN can be set up between the offices of different companies. Furthermore, the prices are symbolic and the clients can choose from several Internet providers.

REFERENCES

[1] Hybrid/Fiber Coax (HFC) and Dense Wavelength Division Multiplexing (DWDM) Networks, International Engineering Consortium, www.eic.org

[2] David Slim. Optical Node Configuration for HFC Networks, Scientific Atlanta Inc. White Paper.

[3] Deploying Prisma IP for Delivering Commercial Services in Cable Networks, Prisma IP Product Management Team, Scientific Atlanta, www.scientificatlanta.com

ABOUT THE AUTHOR

Assoc. Prof. Emil Stoilov, PhD, Department of Informatics, New Bulgarian University, Phone: +359 2 8260385, E-mail: emil.stoilov@gmail.com