TECHNOLOGY TO THE RESCUE – OPTICAL ARCHITECTURES FOR INCREASED BANDWIDTH PER USER

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Abstract

The requirements for segmentation levels (or segmentation granularity) have been continuously evolving and have changed significantly since the first HFC networks were deployed. At that time, the main reasons for building HFC networks were amplifier cascade reduction for improved reliability, better EOL performance and improved network level stability. In the second half of the 1990s, a majority of HFC networks were upgraded to 550 MHz and higher badnwdith. However, after the first fiber deployments, the demand for increased interactive bandwdith per user grew significantly due the success of high-bandwidth interactive services.

This paper describes recent progress in some areas of optical and digital technologies that allow a significant increase in interactive bandwidth per user. These technologies enrich the toolbox available to HFC network engineers to increase available bandwidth per user by providing several segmentation alternatives that eliminate the need for additional optical cable construction while reusing existing fibers. Further, we describe some of the optical components that permit significant reduction in the cost of segmentation, the components having been developed for these applications with emphasis on their robustness and flexibility.

This paper also presents segmentation alternatives that take advantage of these new technologies. Several scenarios are possible. Nodes in areas previously upgraded can be segmented to allow independent forward and upstream paths without the need for upgrade in the fiber and RF coax part of the network. Hence, the capacity per user can be increased without significant capital expenditures. In areas where nodes with a large number of homes per node were deployed earlier, or in new communities growing outside of the existing boundaries, the capacity per user can be readily increased by adding new nodes without adding new fibers on the existing fiber routes and without costly bandwidth upgrades in the RF coax part of the network. Yet in other areas when the network is newly built or rebuilt for the reasons of inadequate cable, bandwidth or components, and in some areas of extensive upgrades, a node architecture with superior capacity per user can be deployed.

This paper presents capital cost savings realized by deploying these solutions with real life examples. Finally, we describe some feedback from field deployments of the segmentation alternatives and the enabling features of the node technology that allow easy alignment and maintenance.

INTRODUCTION

HFC Network Status

Most older tree and branch networks have been upgraded to HFC networks with 550 MHz and higher bandwidth, with this upgrade process having accelerated over the last decade. The upper limit of bandwidth upgrades has been limited to 870 MHz. There is currently no pressure on or trend toward expanding RF technology beyond 870

MHz. HFC networks have proved their ability to support a multitude of services ranging from traditional broadcast entertainment to telephony services that successfully compete with the services provided by traditional voice service providers.

Traditional Broadcast Entertainment Services

After initial fiber deployments, however, the demand for increased capacity per user accelerated as well. Because the HFC networks were upgraded over a period of at least 10 years, the node sizes in the networks upgraded in the mid-nineties were significantly larger (on the order of 3,000 to 5,000 households per node) than the node sizes in the networks upgraded in more recent years (on the order of 500 and fewer households per node). Moreover, many communities grew within their boundaries or outside of their original boundaries. In many cases, for today's segmentation requirements, additional optical nodes would have to be added to the existing nodes. In outlying areas, additional nodes would have to be added to serve new communities. And in many situations, fibers on the existing optical cable routes have been depleted to serve the existing nodes or for other services.

All these segmentation levels have proven adequate to support broadcast services. Even after the introduction of digital TV, 550 MHz RF bandwidth (even in 5,000 HP nodes) was sufficient to support hundreds of video services. Moreover, even following initial deployments of high speed Internet access services, the node sizes and forward and upstream bandwidth per user could support highly assymetrical high speed data services (given very low P2P traffic and typical customers' behavior and applications characteristic to dial-up Internet connections).

New Services and Increased Bandwidth per User Needs

With a change in behavior of high speed Internet access service subscribers, P2P traffic explosion, introduction of VOD and other one demand services (including the possibility of high definition video-on-demand), as well as additional symmetrical telecommunication services (voice), nodes larger than 1000 homes became a liability. Even very coarse calculation shows that VOD with 5% contention (in the number of households served) would result in 50 digital streams in a 1000 HP node (five 64QAM channels for SDTV with 10 streams per channel). After accounting for other interactive services, 6-8 QAM channels may be needed for such a 1000 HP node. Similarly, upstream bandwidth was not sufficient to support the myriad services, especially when shared by more than 500 homes.

All these factors contribute to continous segmentation activities, especially in those HFC areas that were upgraded in the beginning of the HFC upgrade cycle with large size nodes. Moreover, population growth within the covered area as well as outside its boundaries also requires continous addition of bandwidth capacity per user.

EMBRACING THE TECHNOLOGY

Fortunately, progress in several optical and digital technologies supported development of optical architecture design tools that result in lowering the capital cost of upgrades to the optical part of the HFC network while taking advantage of the vast bandwidth provided by the RF coax segment of recently upgraded HFC networks.

Optical Passive Components

To fully utilize the optical fiber bandwidth capacity, many independent streams are being transported over fiber deep into the plant. New passive optical modules enable selection of narrowcast information to be forwarded to a dedicated node. These components are located as close as possible to the final node location in order to preserve fiber between their location and the signal origination (hub or headend) point. Only recently, a wide range components from:

- DWDM filters
- CWDM filters
- Dual-window optical passives

have become available for outdoor applications. The following environmental specification of these components permit their application in the most demanding environments.

Table 1: Environmental Specification of Field-deployable Optical Components

Parameter	Specification
Operating Temperature Range	-40°C to +85°C
Vibration	Strand Mount Nodes Wind Load
Humidity	Up to 95% of relative humidity

The importance of selecting and maintaining the required quality for these components cannot be underestimated. The plots in Figure 1 show how some components, not properly specified and screened, can behave in the field over the required temperature range.

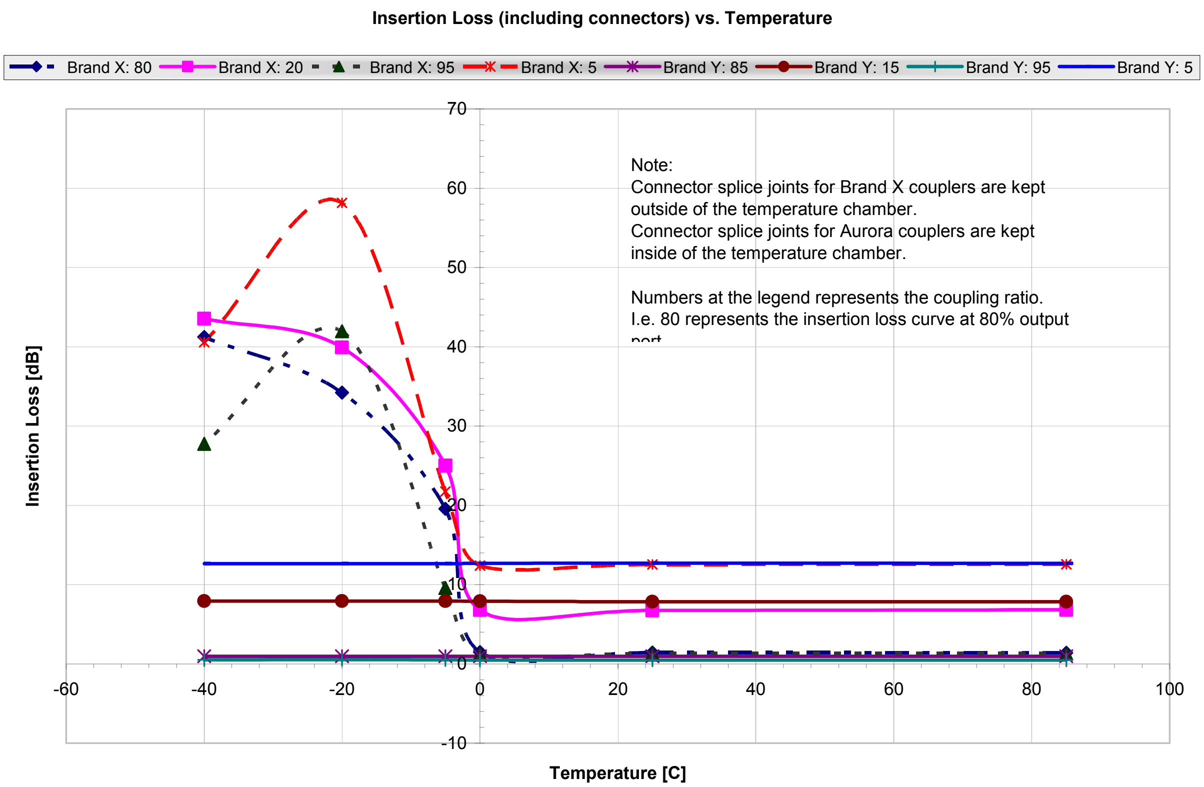


Figure 1: Thermal Behavior of Optical Passives of Two Different Brands

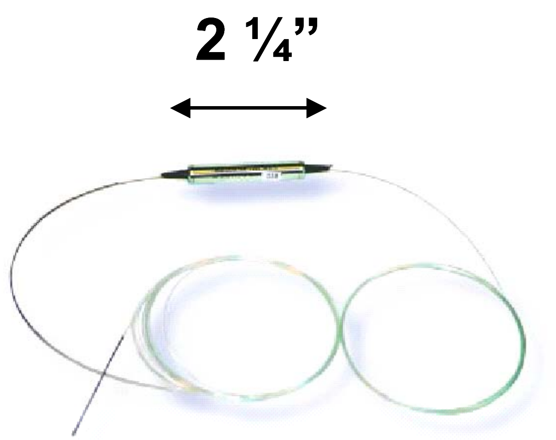


Figure 2: CWDM Wavelength Filters and 1310/CWDM Filters

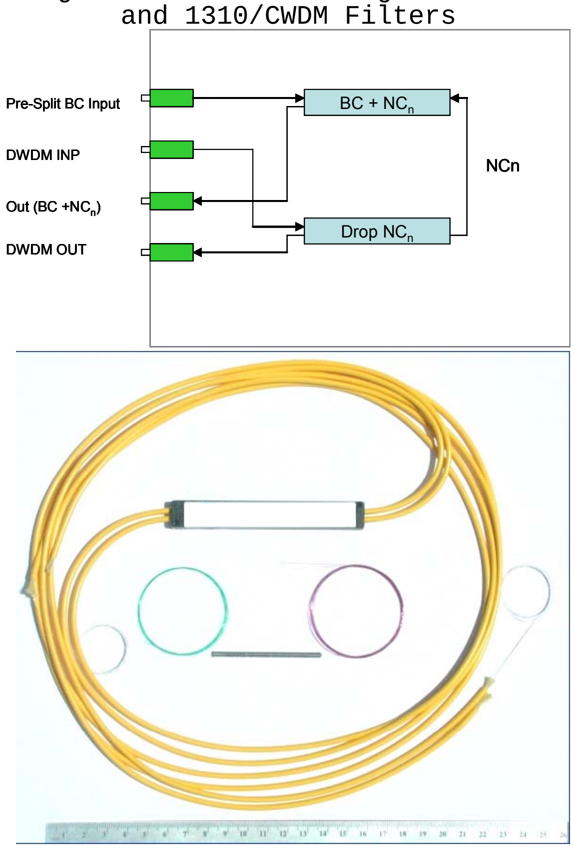


Figure 3: Dual Filtering NC Wavelength Separator/BC-NC Combiner

In parallel to the increased robustness of components, innovative packaging allowed their miniaturization. Figure 2 shows the size of some CWDM filters and 1310/CWDM combining or separating filters, while Figure 3 shows a functional diagram and the relative sizes of some integrated dual DWDM filters used to separate (or combine) discrete DWDM wavelengths with a shared wavelength carrying a broadcast signal (with dual filtration to eliminate ASE components and to achieve increased wavelength isolation).

<u>Digital Technology</u>

Digitization of the upstream bandwidth has allowed significant performance improvement in link CNR, dynamic range, thermal stability (refer to Figure 4), loss budget and link length (up to 200 km fiber length). Practically, digital links allow for constant level and performance over the entire operational link loss budget and fiber length. This significantly simplifies the link alignment process.

Digital technology also allows for significant signal processing capability. Two or more independent signals, whether local or remote, can be digitized and time division multiplexed to utilize fiber bandwidth more efficiently and to share transport components (1310 nm and 1550 CWDM or DWDM lasers). Similarly, several digitized signals can be simply added together in a digital domain, thus simulating RF combining (or RF amplifier cascading). Moreoevr, manipulation of the bit stream allows for selective attenuation of the upstream path, thus improving problem troubleshooting granularity and enabling level-fine ingress mitigation without the intrusion of “wink-switches”. These are examples of only the simplest types of signal processing capabilities that can be implemented within digitized upstream bandwidth. Additional benefits include the capabilities of dedicating a communication channel for equipment monitoring and of adding traffic other than the legacy RF upstream (*e.g.*, native Ethernet).

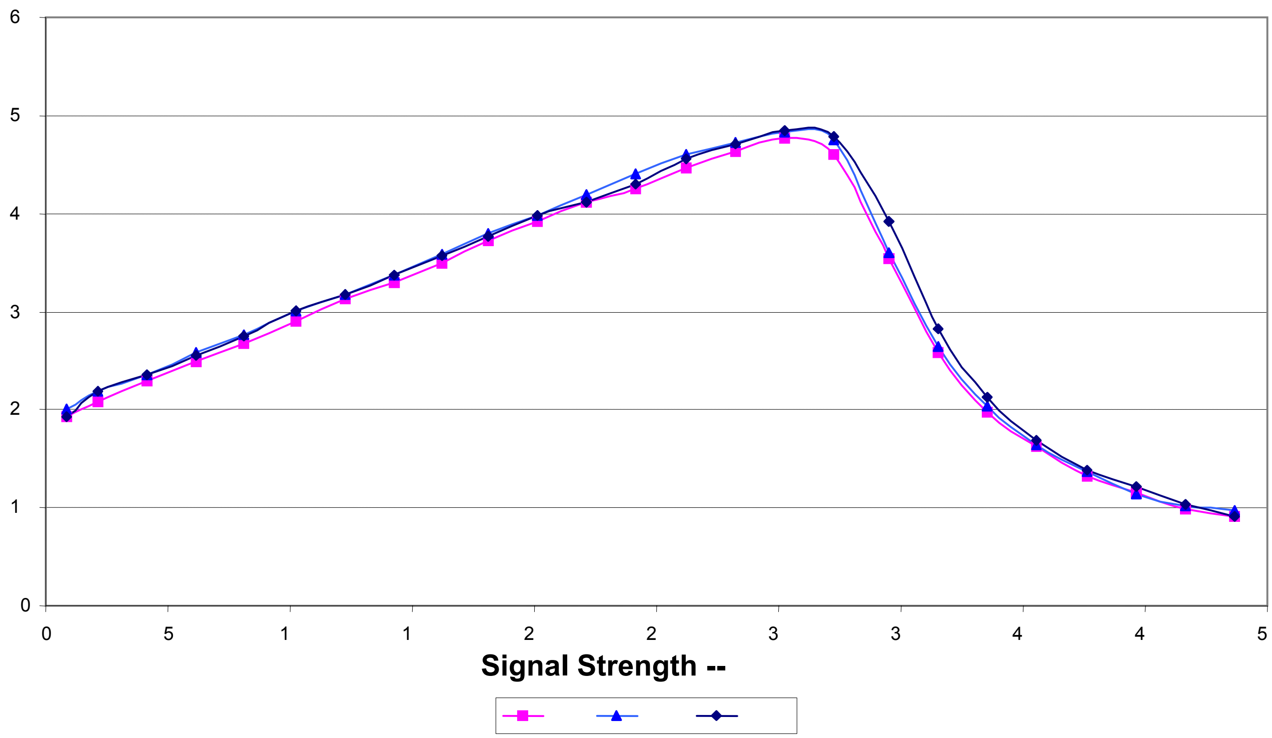


Figure 4: Thermal NPR Performance Stability of Cascaded Digital Links

(8 Links Cascaded)

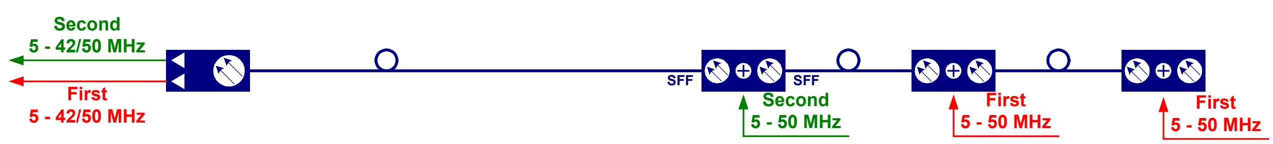


Figure 5: An Example of Signal Processing Capability Inherent to Digitized Upstream Signals

Integration and Miniaturization

Packaging progress and equipment integration also contribute to the capability of unorthodox expansion of bandwidth capacity per user. Two examples of higher packaging density and integration are presented in Figures 6 and 7.

Figure 7 depicts a module that integrates several modules previously available only as discrete parts. Moreover, it adds a significant functionality for level monitoring and level management for remote single-person level alignment and DWDM balancing. This integration eliminates the need for at least three modules of significantly lower functionality, six optical jumpers and 12 optical connectors, thus lowering the cost and increasing the reliability of the system. All of this is achieved under the assumption that level monitoring and level management components are also eliminated from the setup with discrete modules. To match completely the functionality of the integrated module (including dual-filtering adavantages discussed previously), significantly higher numbers of discrete modules, jumpers and connetors would be needed.

Miniaturization and integration trends, as well as progress in optical components (environmemtal robustness), obviate costly OTN installations by integrating entire OTN functionality inside a single node enclosure. The OTN-on-the-Strand shown in Figure 7 is capable of feeding 16 nodes with dedicated narrowcast signals while amplifying other signals for more distant locations.

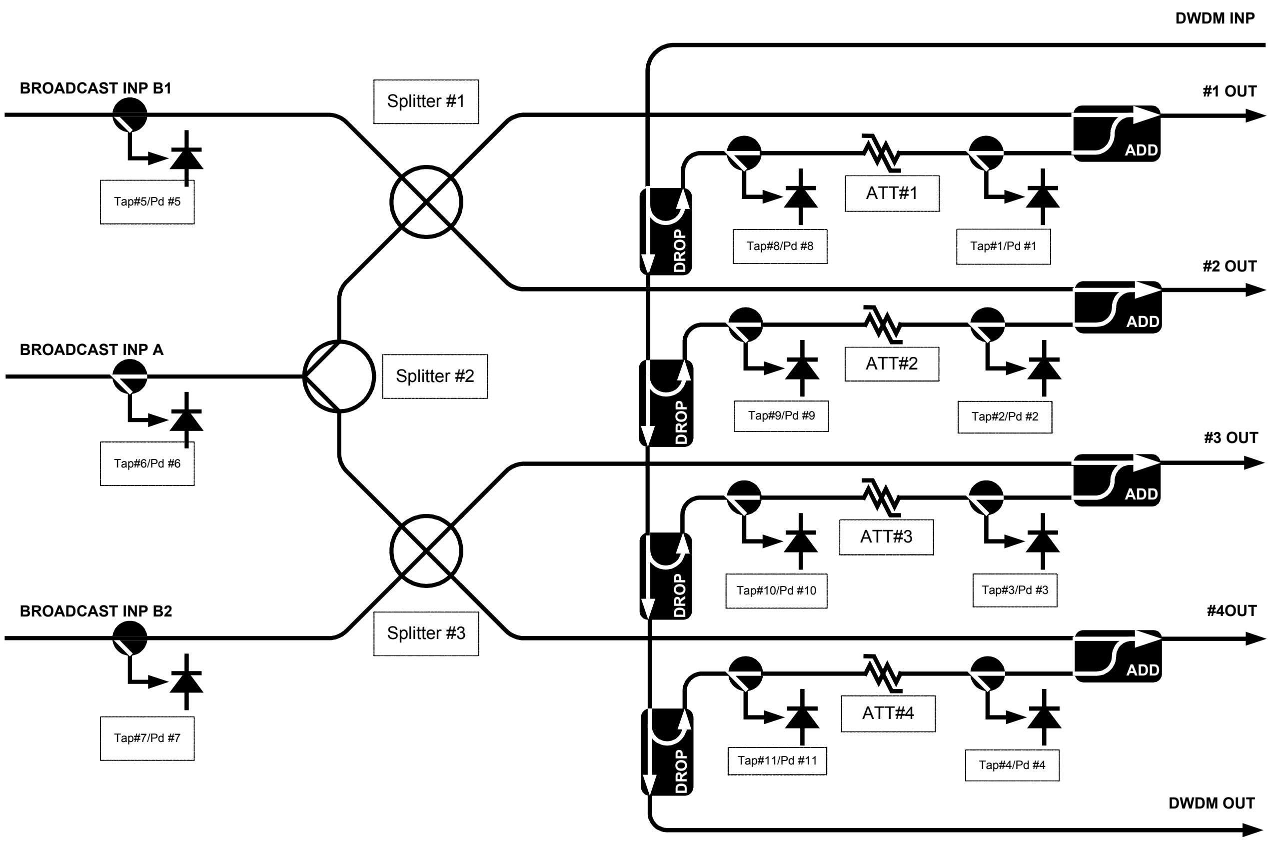


Figure 6: Integrated BC Splitting, DWDM Filtering and BC-NC Combining Module with Level Monitoring and Level Management Capabilities

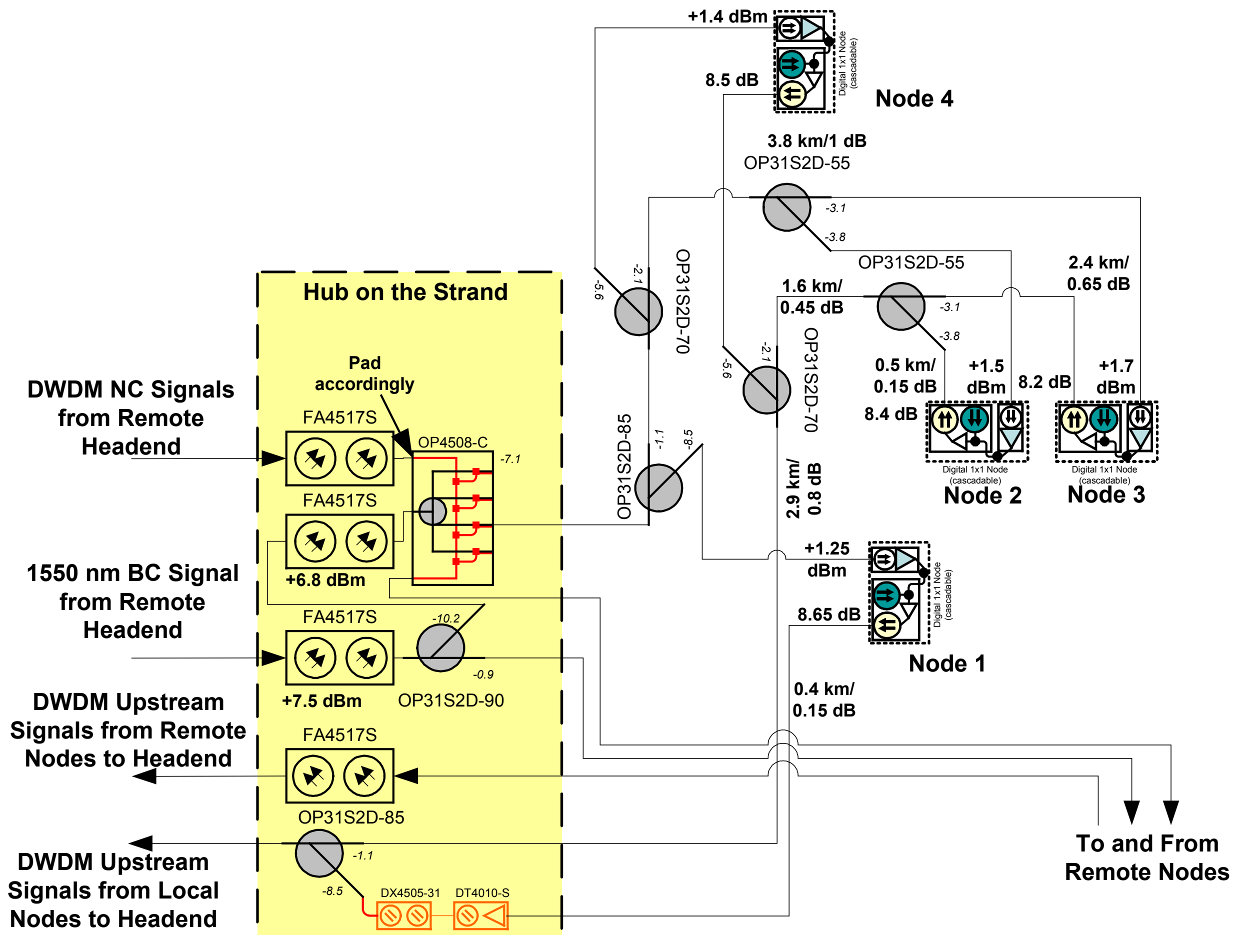


Figure 7: An Example of a Hub-on-the-Strand Configuration

TECHNOLOGY FACILITATES INCREASED CAPACITY PER USER

The technology capabilities so far described translate into capability for increasing bandwidth per user at significant capital and/or operational savings. The architectural implementations described below confirmed the saving estimates.

Upstream Bandwidth Segmentation

In areas of large nodes with reasonably balanced buses, the simplest segmentation option is to segment the upstream bandwidth. Digital technology supports two- to up to four-play segmentation without the need for additional fiber or wavelength as long as the node platform can be provisioned for separate upstream paths. If the platform does not allow this, one alternative could be to replace the platform while preserving the investment in optical cable and RF coax network. This translates easily into significant capital savings. Figure 8 shows a conceptual diagram of node segmentation with application of digital technology. This segmentation option becomes more complicated when node buses are not balanced. In such cases, a different approach must be applied. One option is to segment the buses with express coaxial cable. Another option is to push fiber deeper and add a node.

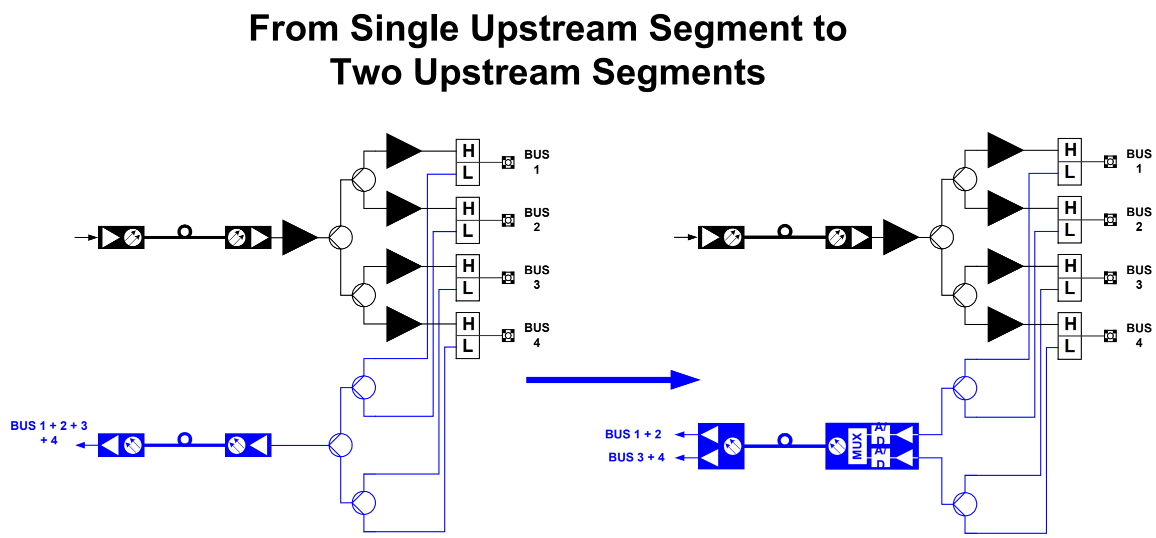


Figure 8: Upstream Segmentation with Digital Technology

From Fiber Scarcity to Fiber Plentiful

One of the node segmentation options would require a separate node. However, with a separate node, additional fibers are needed between the node and the hub or headend if a traditional 1310 nm technology is used. Most of the operators' HFC design guidelines include rules on the permitted number of fibers per node and per household count. While fiber availability may not be a problem if only few nodes are to be added, in an area previously upgraded with large nodes or in areas growing rapidly within or outside their boundaries, the additional node count for interactive services may easily double the existing node count and so put excessive requirements on fiber count. An example of such a system is presented in Figure 9.

The statistics for the example of Figure 9 are presented in Table 2. With this number of new nodes added and provisioned for future growth of services, the number of fibers required in the main route with the existing optical cable significantly exceeded the number of available fibers when designed with a traditional HFC architecture based on 1310 nm laser technology. Two areas (the one depicted in Figure 9 and a second adjacent area extending on the same cable route) were redesigned with "fiber-save" architecture (distributed DWDM, or "D^2WDM" architecture). The required number of fibers on any of the routes dropped to between 3 to 5 with full planned segmentation. The fibers used to feed the existing nodes were actually recovered and available for other services.

Table 2: Upgrade Area Statistics

Summary Statistics for the Implementation Area					
	Number of Nodes	Number of Segments		Shortest distance / lowest loss (1550) from Keswick	Longest distance / highest loss (1550) from Keswick
		Near	Future		
BC from area Headend	22	30	34	0.4 km (0.1 dB)	19.4 km (5.8 dB)

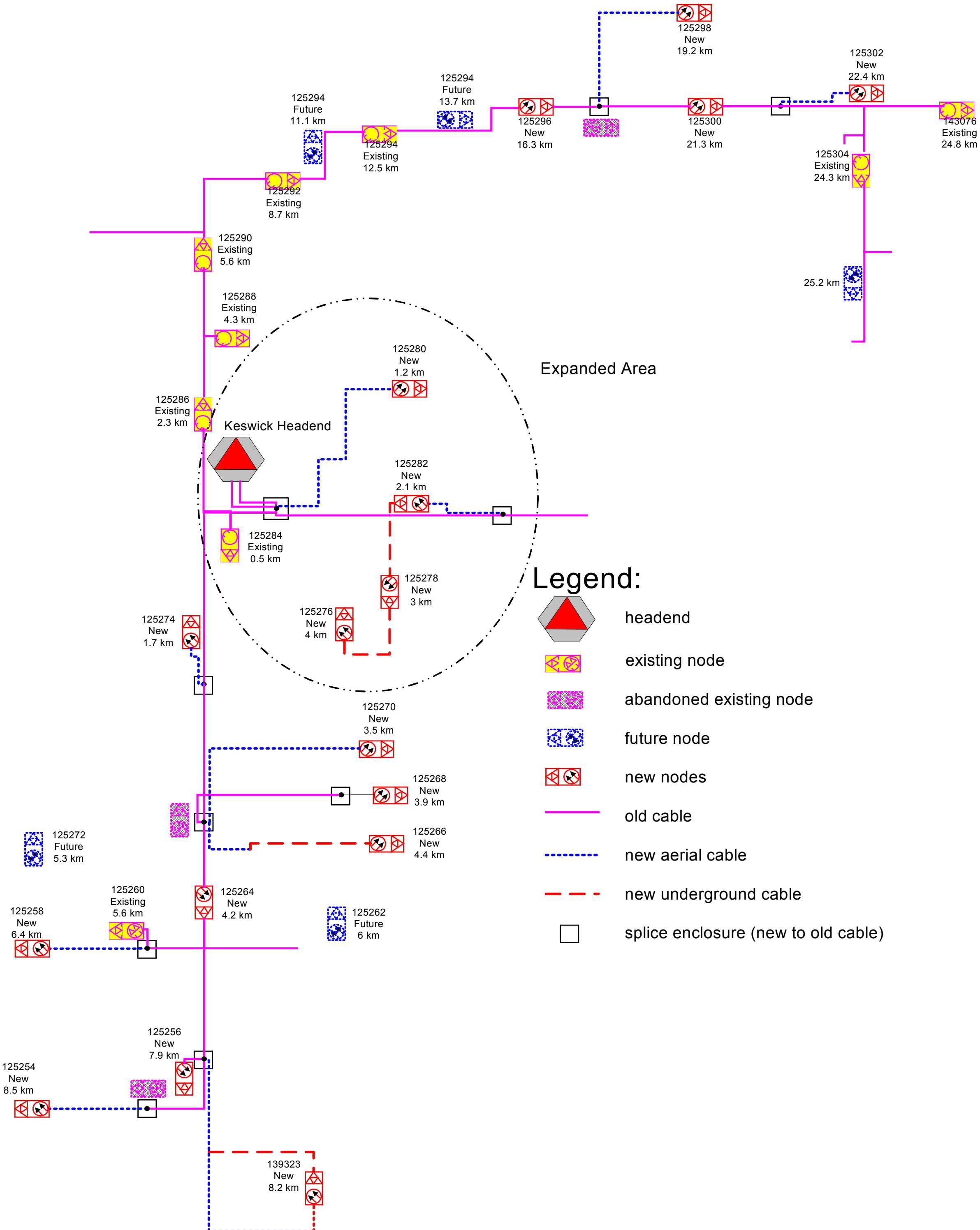


Figure 9: Upgrade Area Node and Fiber Route Configuration

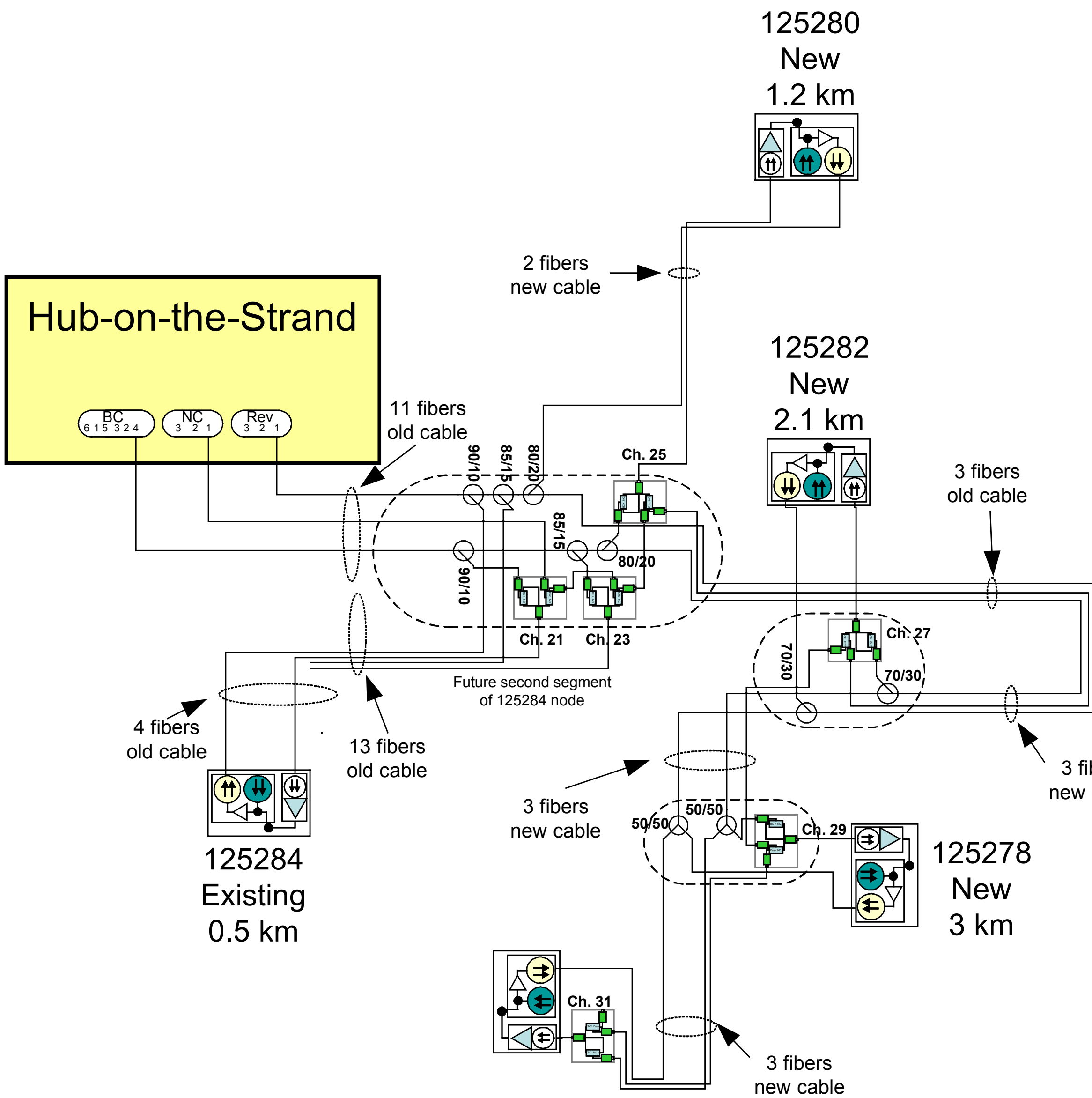


Figure 10: Detailed Area Segment Configuration

The robust optical passive components already described in this paper have been successfully deployed in the field for over a year. The technology and configuration is illustrated in Figure 10, where a segment of the upgraded area (encircled in Figure 9) is detailed. Moreover, with the miniaturization achieved for a Hub-on-the-Strand configuration, the area hub could be replaced with a strand mount enclosure to feed the upgraded area from a distant consolidated headend. Upon the completion of the project, substantial capital savings were realized. This project, initially budgetted at $1.2 million (for two adjacent communities), was completed for approximately $600 thousand, thus achieving a 50% capital cost reduction.

Bandwidth Wealth

The same technological wonders can be applied to new builds, rebuilds and extensive upgrades areas when the upgrade activity is driven by the need to upgrade the coaxial part of the network from sub-450 MHz to 600+ MHz bandwidth. In this case, the digital and optical technologies permit driving fiber-to-the-last-active (FTLA) at lower cost than or at cost parity with traditional HFC new-build, rebuild or upgrade, and several areas have been built with this approach in mind. An example of the optical design for FTLA architecture is presented in Figure 11.

Several implementations in North America and abroad have confirmed the model numbers and expectations. An example of a system upgraded with this architecture is presented in Figure 12, with a detail design of a selected area presented in Figure 13. Table 3 details cost comparison between the deployed architecture and the HFC architecture after project completion. The final cost was within a few percent of the cost estimates.

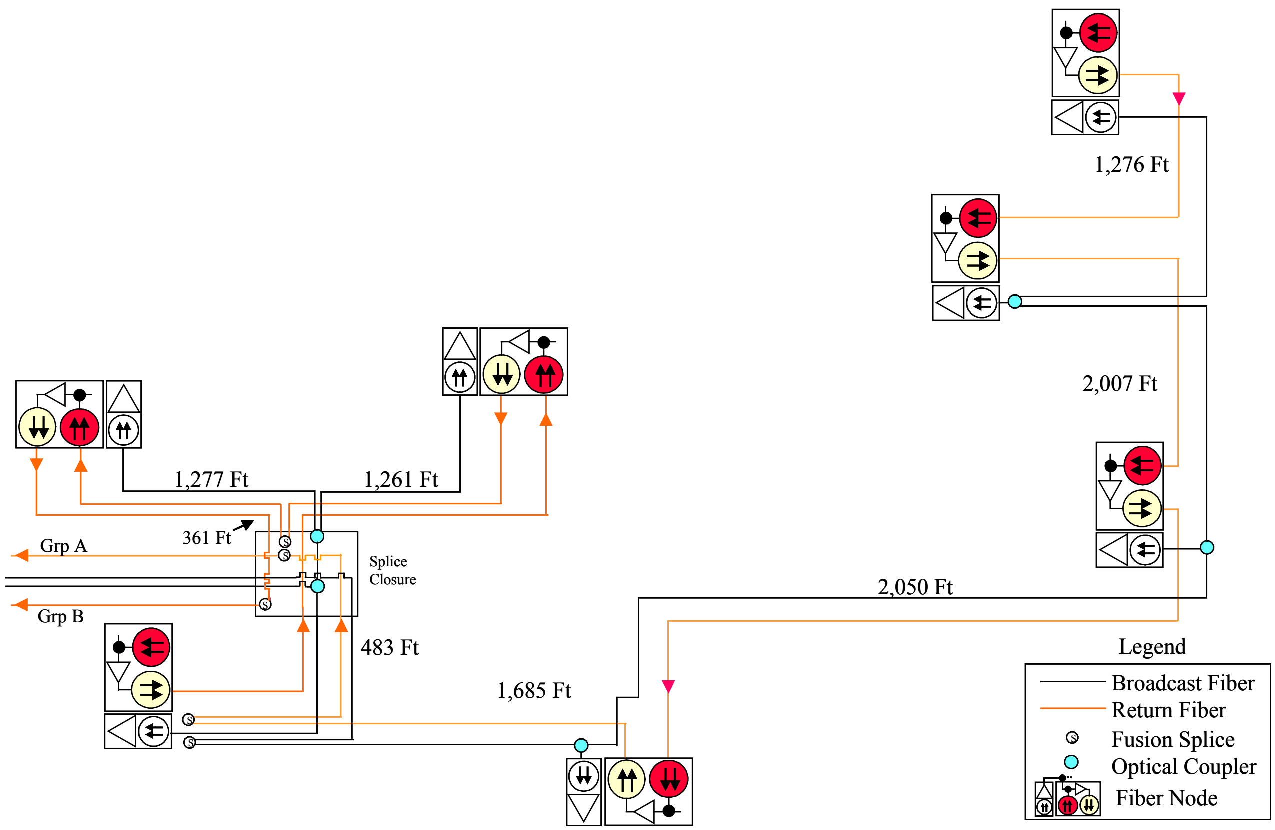


Figure 11: An Example of Optical Design for Fiber-Deep or FTLA Architecture

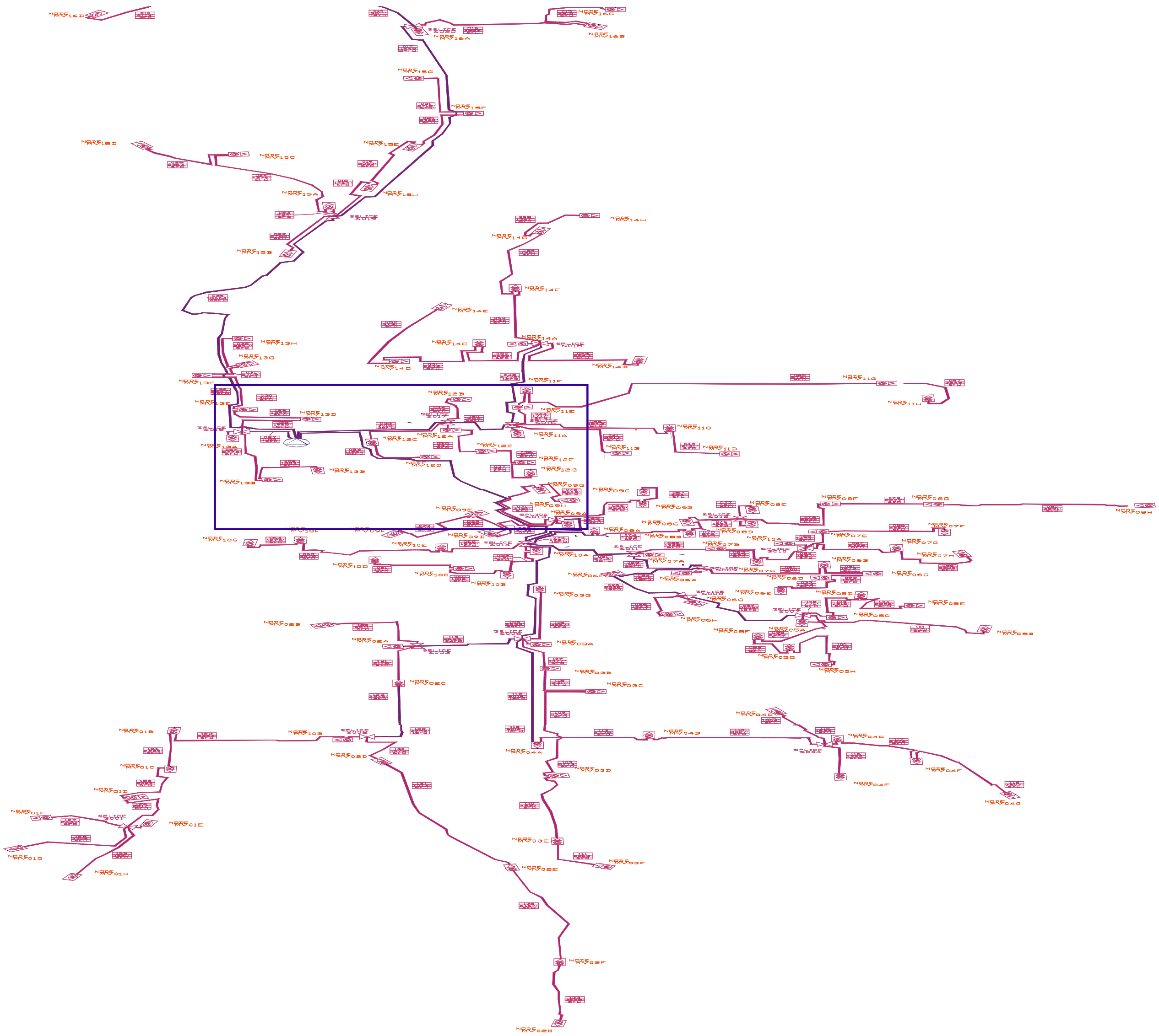


Figure 12: An Area Upgraded with FTLA Architecture

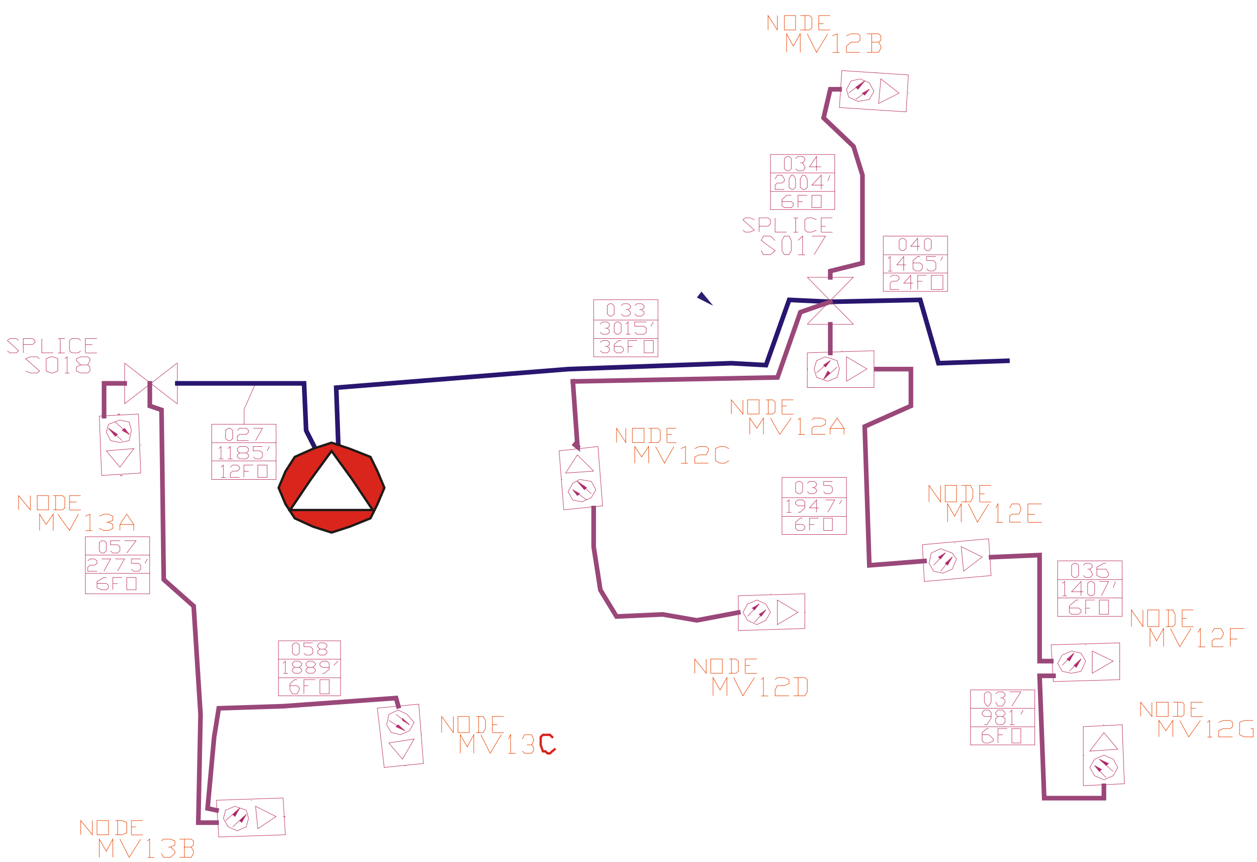


Figure 13: Detail Design of the Framed Segment

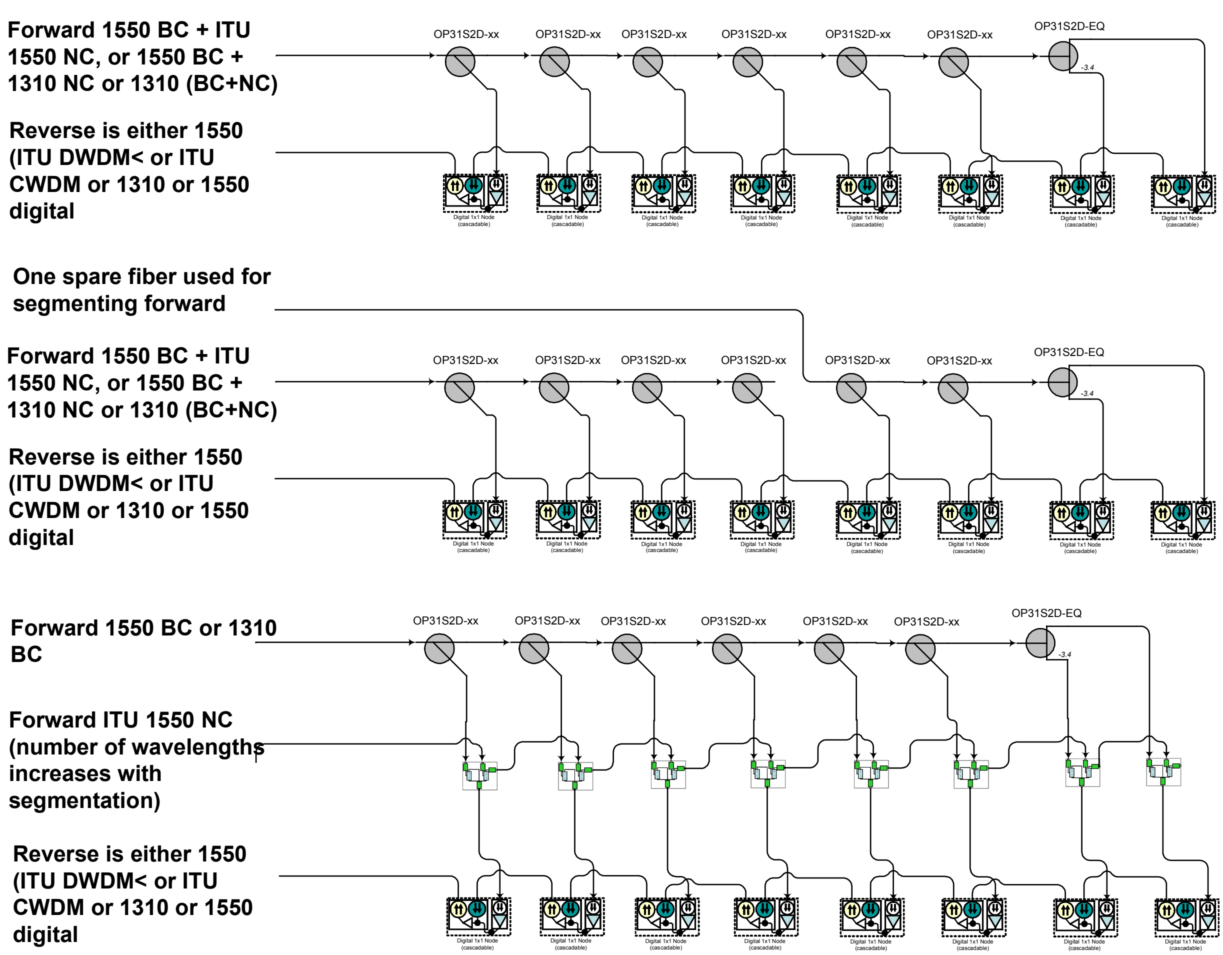
Table 3: Cost Comparison after Impelemntation

Category	HFC700	FD50	HFC$/Mi	FD$/Mi	HFC$/HP	FD$/HP
Headend Optics	$45,385	$135,773	$319	$955	$7	$21
Field Optics	$39,050	$425,818	$275	$2,996	$6	$65
Fiber Cable	$197,314	$410,813	$1,388	$2,890	$30	$62
Power Supplies	$105,000	$89,554	$739	$630	$15	$14
RF Electronics	$492,358	$14,450	$3,464	$102	$74	$2
Passives	$93,323	$84,853	$657	$597	$14	$13
Coax	$842,737	$864,260	$5,929	$6,080	$127	$131
Hardware	$469,331	$422,770	$3,302	$2,974	$71	$64
Labor	$418,410	$329,638	$2,944	$2,319	$63	$50
Subtotal:	$2,702,908	$2,777,938	$19,015	$19,543	$407	$421
Variance		$75,031		$528		$15

The following list summarizes the experience of the local crew during the first year of operation:

- capital expenses at or close to cost parity with traditional HFC-1000 network
- remote monitoring from all nodes at no additional cost
- higher B/W per home passed than in HFC-700 network
- lower power consumption results in lower operating cost
- lower number of actives results in increased reliability
- remote ingress mitigation on all individual nodes (approximately 100 homes granularity)
- digital return from all nodes.

In this architecture, segmentation steps are practically limited only by the bus size of tens of homes. Figure 14 shows the segmentation steps that allow segmentation of the node cluster down to the individual node, thus increasing the already expanded bandwidth per user by a factor of 5 to 8. Again, the technological advances presented earlier in this paper are applicable. The segementation can be staged in any order (downstream or upstream separately or in parallel) and with any granularity, and can be implemented on an as needed basis without any intrusion into the coaxial part of the network or network powering.



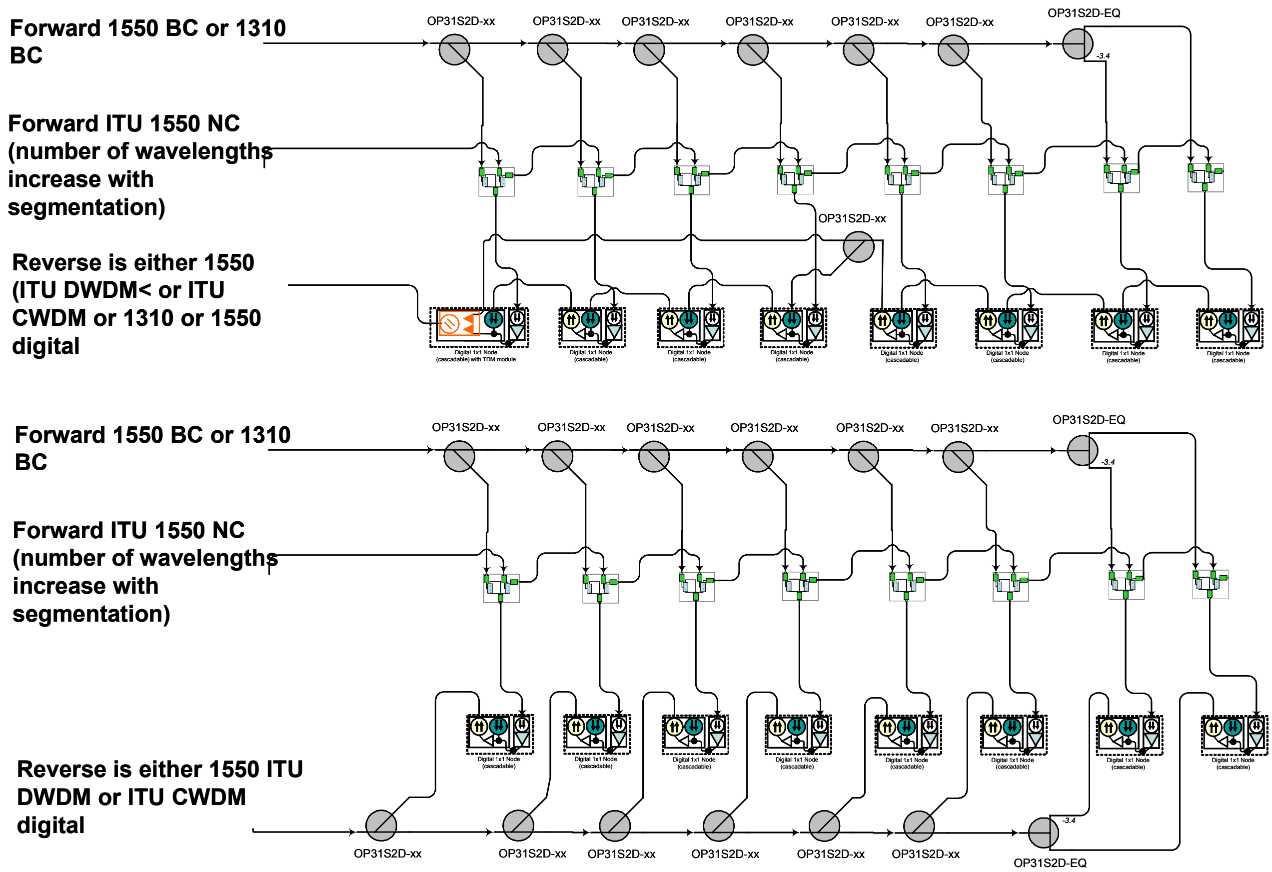


Figure 14: Staged Segmentation of Fiber Deep (FTLA) Node Cluster from Single Downstream and Upstream Segments to 8x8 Downstream and Upstream Segments

CONCLUSIONS

The optical and HFC designer toolbox is full of wonder tools. Although these tools certainly amuse us, they have very practical applications in broadband HFC networks where the need for increased bandwidth per user is looming. Whether for significant capital expenditure avoidance or for significant operational benefit, these tools can be used by the designer to the benefit of broadband service customers and hence to the benefit of service providers. This paper described but a few examples of how today's optical and digital technology can help in increasing bandwidth per user (resulting in increased customer satisfaction and the continuing competitive advantage of HFC network operators) while lowering capital and operational expenses and taking full advantage of the investment borne during bandwith upgrades of the RF coaxial part of HFC networks.