Digitized Return Path:

Extending the Applicability of Hybrid-Fiber Coax Architectures for Full-Service Networks

Farr Farhan
Scientific-Atlanta, Inc.

Abstract:

In this paper, the concept of digitizing the Hybrid Fiber Coax Reverse (or Upstream) path is introduced. The Pros and Cons of such a concept are compared against the existing and traditional methods. The cost, performance and evolution potential of this concept are presented, as well as preliminary lab trial data. Some of the concepts are explored further noting some implementation challenges. In closing, some other evolutionary possibilities for the CATV Hybrid-Fiber Coax architectures are discussed.

INTRODUCTION: THE PROBLEM

As cable operators continue their aggressive efforts to upgrade their networks, they are constantly looking for ways to make full use of existing equipment to control costs, while still attempting to increase network capacity. This is especially evident in the implementation of upstream transmission of bandwidth-consuming, interactive multimedia traffic.

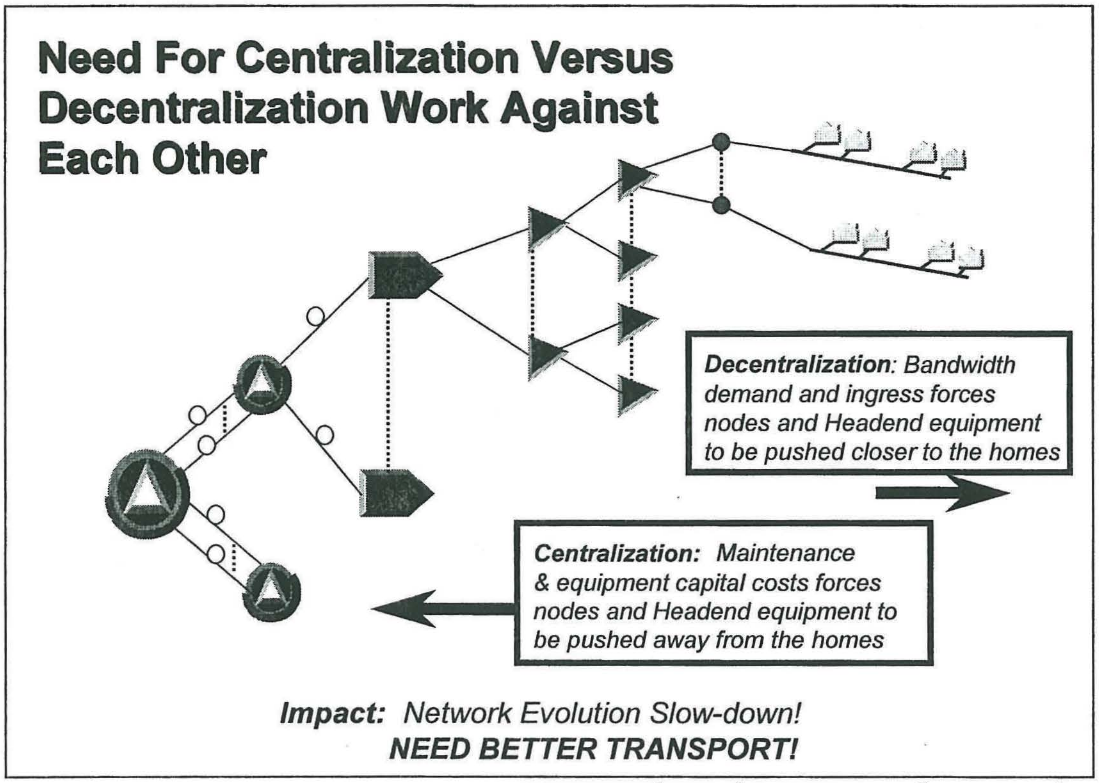
The deployment of the reverse path has brought about several major challenges for cable operators. To deliver new revenue-generating services -- such as multimedia, Internet access and telephony -- and to increase subscriber penetration, operators must dramatically increase their network capacity. They need to allow more traffic over a single fiber while retaining their existing architectures when possible in order to control costs. Operators also need to transmit signals in both directions over longer distances, and allow extra bandwidth for future upgrades -- all while improving network performance and reliability to keep their subscribers satisfied.

In this situation, two main forces are competing against each other (Figure 1). The need for additional bandwidth forces nodes and headend equipment to be pushed closer to the homes. In the meantime, the need to control maintenance costs and capital investments force the equipment away from homes, so a larger number of subscribers can share the same capital investment. The answer to this dilemma is: Better Transport. This means transmission equipment that is lower in cost, better in performance and more importantly, more efficient.

Reverse Optics Issue 1:

Within traditional analog optical network architectures, the performance of upstream signals are usually unpredictable, suffering from the effects of optical noise as well as temperature fluctuations at the node and at the hub (See Figure 2). The fiber-optic portion of return path HFC is still considered the weakest link. This transmission is often handled by Fabry-Perot lasers, which are relatively inexpensive but unable to

Figure 1: Two Forces Working Against Each Other



effectively handle large volumes of multimedia traffic. Uncooled distributed feedback (DFB) lasers, offer better dynamic range performance but at a higher cost. These lasers also exhibit a variation in slope efficiency and noise floor as a function of temperature.

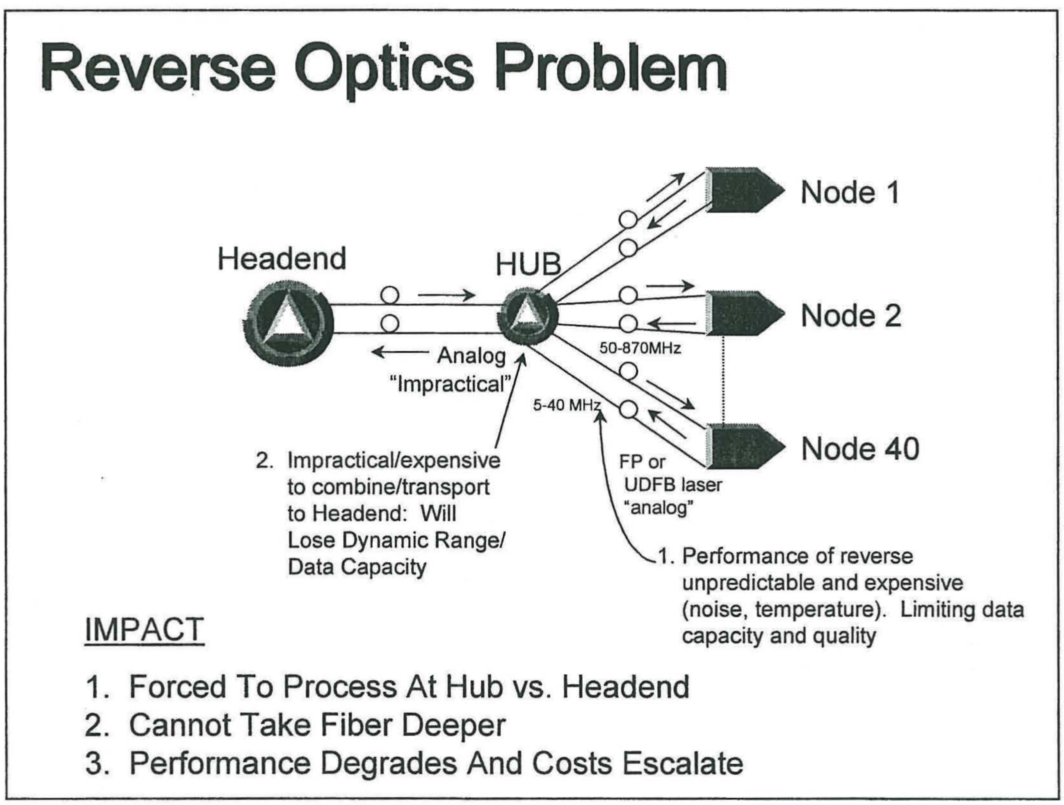


Figure 2: Reverse Optics Problem

Although many vendors have done a great job adding circuitry to reduce the dependency of Carrier to Noise Ratio (CNR) on temperature variation, there is still a measurable dependency and, of course, unpredictability.

Reverse Optics Issue 2:

With so many signals to handle, and because the analog signal cannot be sent over long distances without signal degradation (CNR degrades as a function of distance), many operators have been forced to configure their networks to process the upstream traffic at the hub (Figure 2). These hubs have by necessity become larger than desired buildings that require additional right-of-way, staff, power, etc., making them expensive facilities to operate.

To transmit the signal from the hub to the headend, some operators have implemented some form of multiplexing or combining scheme such as, RF combining, block conversion or reverse dense wave division multiplexing (DWDM). In all these schemes noise is added to the signal in addition to other specific artifacts. Reverse DWDM has provided the best choice for preserving signal quality, however still at a significant price increase.

THE PROPOSED SOLUTION: APPLYING DIGITAL TECHNOLOGY

The proposed solution to the dilemma facing operators is the application of digital technology in the reverse path. Specifically, by digitzing the link between the node and the hub, and the link between the hub and the headend (Figure 3). While the use of digital has been technically possible for some time, it only recently has developed to the level of feasibility needed by cable operators in performance and to some extent in cost.

The solution involves digitizing the upstream spectrum at the node, utilizing an Analog to Digital Converter (A/D) followed by a serializer (Figure 4) and lastly a digital laser to transmit the digital stream. At the Hub (or even at the node), a number of these digital streams can be combined using Time Division Multiplexing (TDM) techniques (Figure 3 and 6) to create a higher speed digital signal. This higher speed digital signal is then transported to the final destination for O/E conversion, followed by demultiplexing and de-serialization and lastly by a Digital to Analog Converter (D/A) for reconstruction of the original upstream spectrum. Figure 6 shows that the signal can remain in the digital format, from the node all the way to the headend, while providing the added flexibility of TDM for trunk reduction.

By use of digital techniques including TDM, the cable operator can now greatly improve reverse bandwidth and consequently improve subscriber penetration. In effect this proposal solves both of the issues raised previously with today's reverse optics as follows:

1) By keeping the signal in the digital domain, there is no longer a penalty in signal quality due to distance or combining. As a matter of fact, as long as the converted signal is maintained in its digital format, the degradation remains zero. Because of the lower power requirements and in general the resilience of digital transmission, the return path payload can be transmitted from the node all

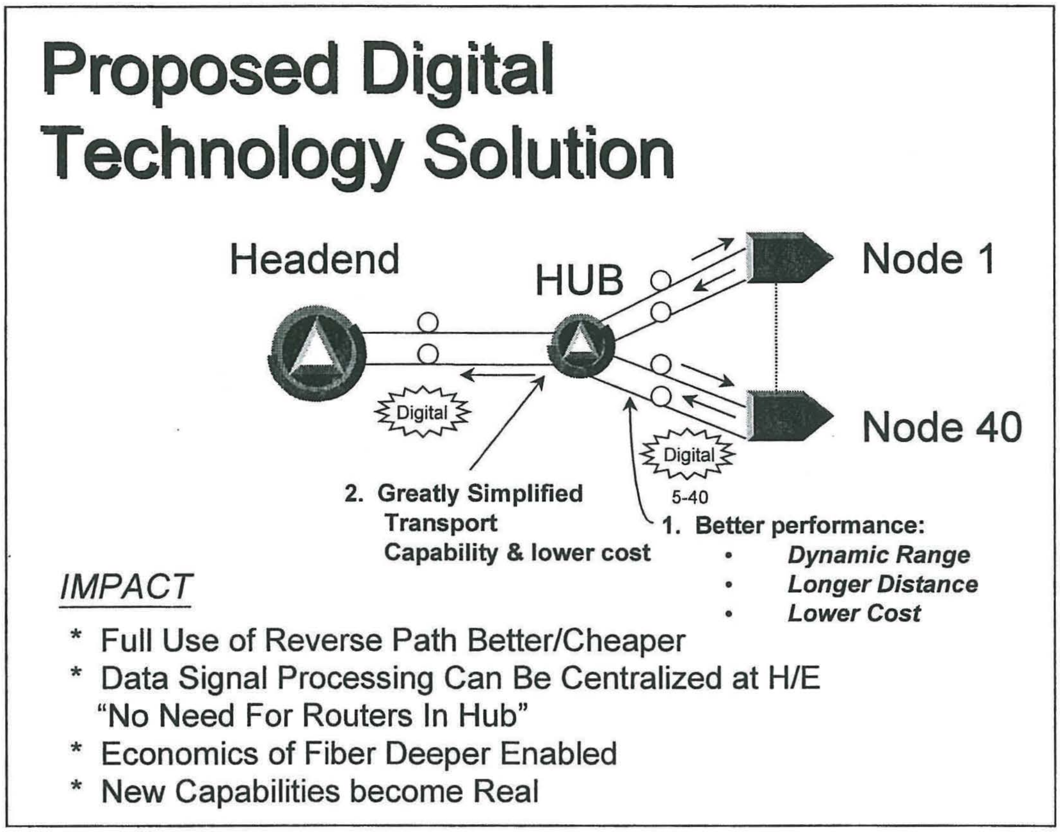


Figure 3: The Proposed Solution

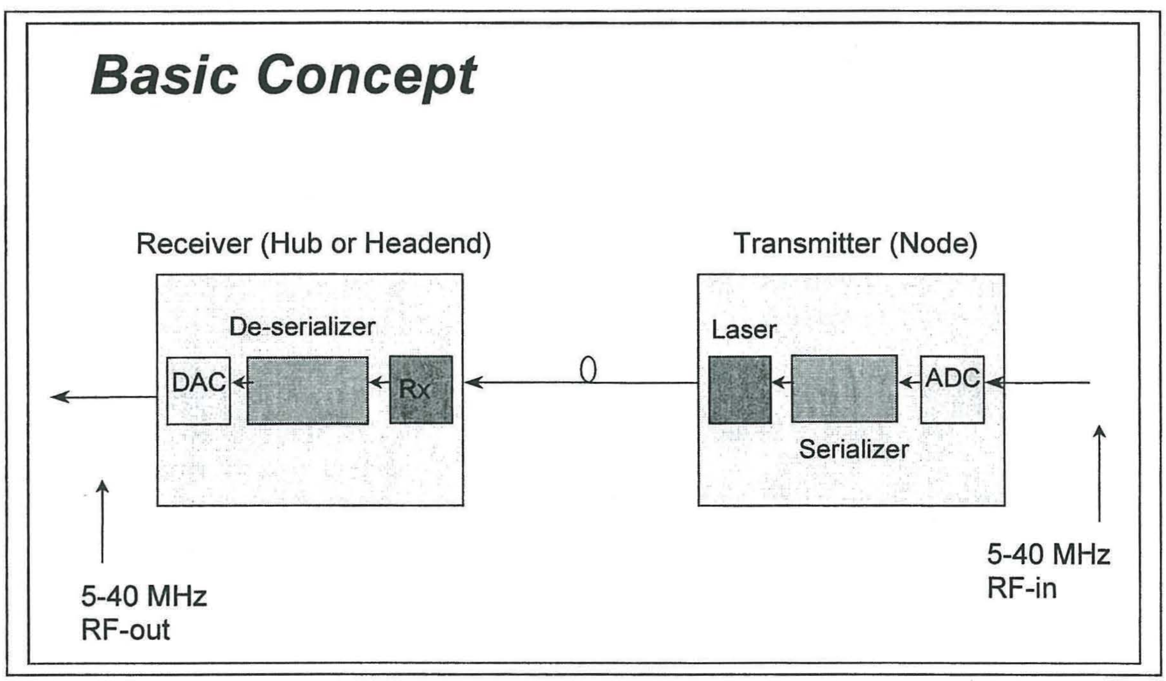


Figure 4: The Basic Concept

the way to the headend, creating the option of a passive hub (See Figure 7)

2) The use of TDM creates a new dimension in multiplexing capability. TDM augments Wave Division Multiplexing (WDM). Both TDM and WDM can coexist in perfect harmony. As a matter of fact, this is exactly what is happening in the world of telecommunication outside cable.

Some operators prefer to use their existing hub architectures, while others choose to build networks without hubs. Digital technology has the flexibility to meet both their needs allowing them to select where they want to process the information. Operators can often retain much of their current architecture by simply plugging in digital instead of analog transmitters or receivers.

COMPARISON WITH ANALOG SOLUTIONS

1) Performance

Because digital transmission is more robust than analog transmission, the susceptibility of the upstream signal to optical noise and temperature variation of the network is greatly reduced. As mentioned previously, once the return band is converted to digital format and retained, its quality is preserved. Recent lab trials have shown that with existing conversion technology, Fabry-Perot performance can be exceeded (See Figure 5). Using digital methods, it can be proven that the performance of Uncooled DFBs can be met or even exceeded. Furthermore, we have demonstrated that the susceptibility of system gain to temperature variation in the plant was literally removed. We also found that CNR was also significantly less susceptible to temperature variations in the plant. It is interesting to note that all these improvements in signal quality are achieved without any dependency on the quality of the optical components used. This latter benefit has a very significant implication: The cost of an optical link is no longer determined by the quality of the optics used. When this benefit is combined with the independence of signal quality over distance (as long as the payload is kept in digital format), the future promise becomes even greater.

2) Capacity

The added capacity, enabled through TDM, allows a much greater number of subscribers to be served by one fiber. It also makes the network much easier to manage.

If propagation delay is not a concern, the use of digital transmission also enables many components, such as demodulators and routers, to be moved upstream to the headend, creating economies of scale at the headend as well as simplifying maintenance. It also lowers costs by eliminating the need for large and expensive hub facilities.

3) Cost

While the performance capability of digital technology has ever been increasing, its cost has been continually decreasing. The prices are expected to continue to fall in the coming future. While the performance of the key components for building a digital optical link capable of carrying digitized cable return spectrum has been increasing, overall, their price has been decreasing.

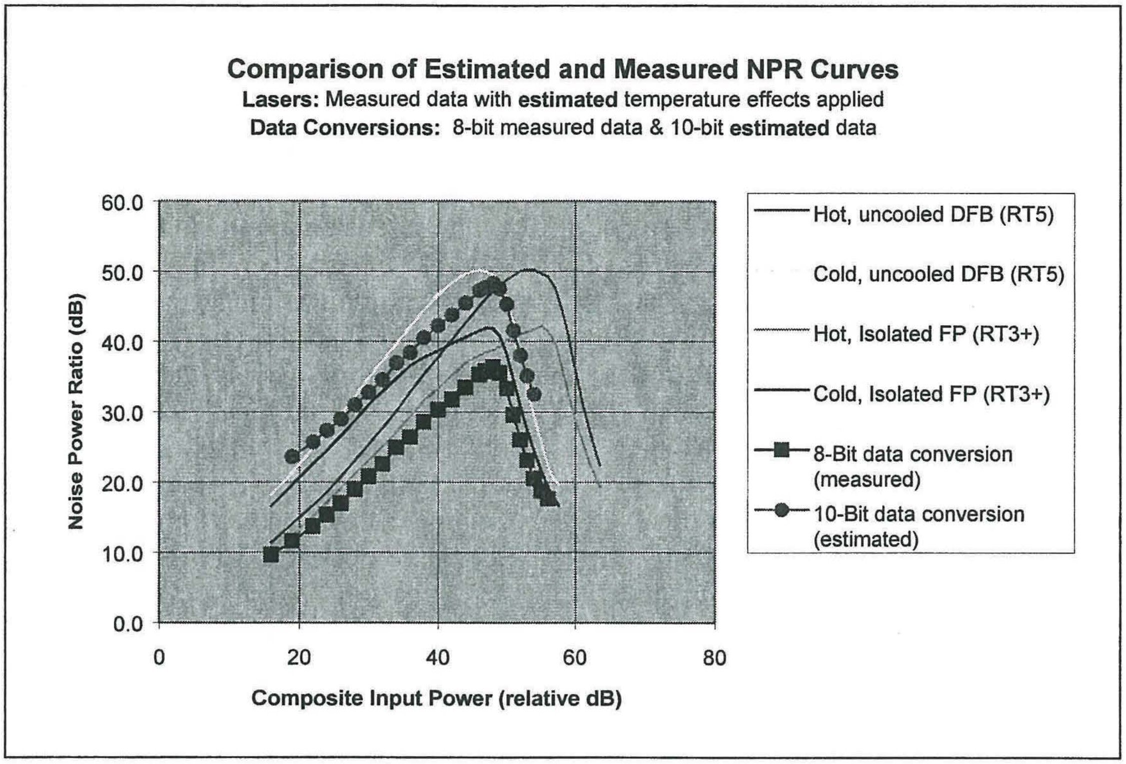


Figure 5: Preliminary Lab Results

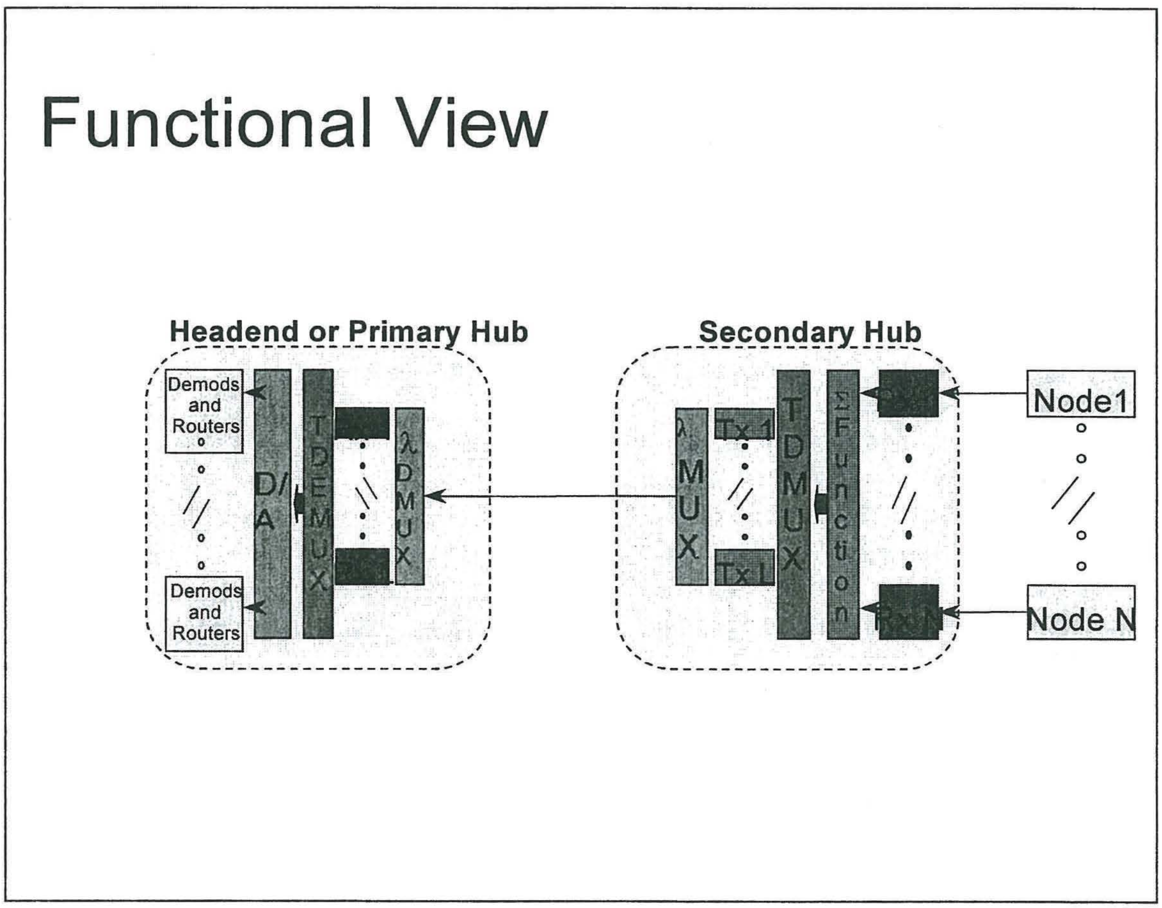


Figure 6: Functional View

The key cost advantage behind a digital reverse link is the fact that it will rely on the technological advancements of digital components, while enjoying their declining cost curves. Everyone would agree that the global deployment of digital components will continue to outweigh that of analog components. Hence it is logical to conclude that digital implementations will always have a cost advantage over analog implementations.

Implementation Challenges

While there are always challenges with the introduction of new concepts, we expect that the challenges with the introduction of this technology to be far less than those experienced recently with other key technologies. We have learned that the quality of clock is extremely important. Any noise introduced in the time domain or in the voltage domain can lead to degradation of signal to noise ratio. The reason is that uncertainty introduced in the clock sampling instant, translates to uncertainty in the converted signal, hence to noise. Though this noise is bounded, the signal to noise ratio will be impacted. Of course there is still a lot more to be learned in this area, however so far, experimental results have closely matched the underlying theory.

Architectural Implications

The flexibility and power of digital technology make it suitable for a variety of situations. In existing networks, receivers can be installed at the hub or headend, depending on the operator's

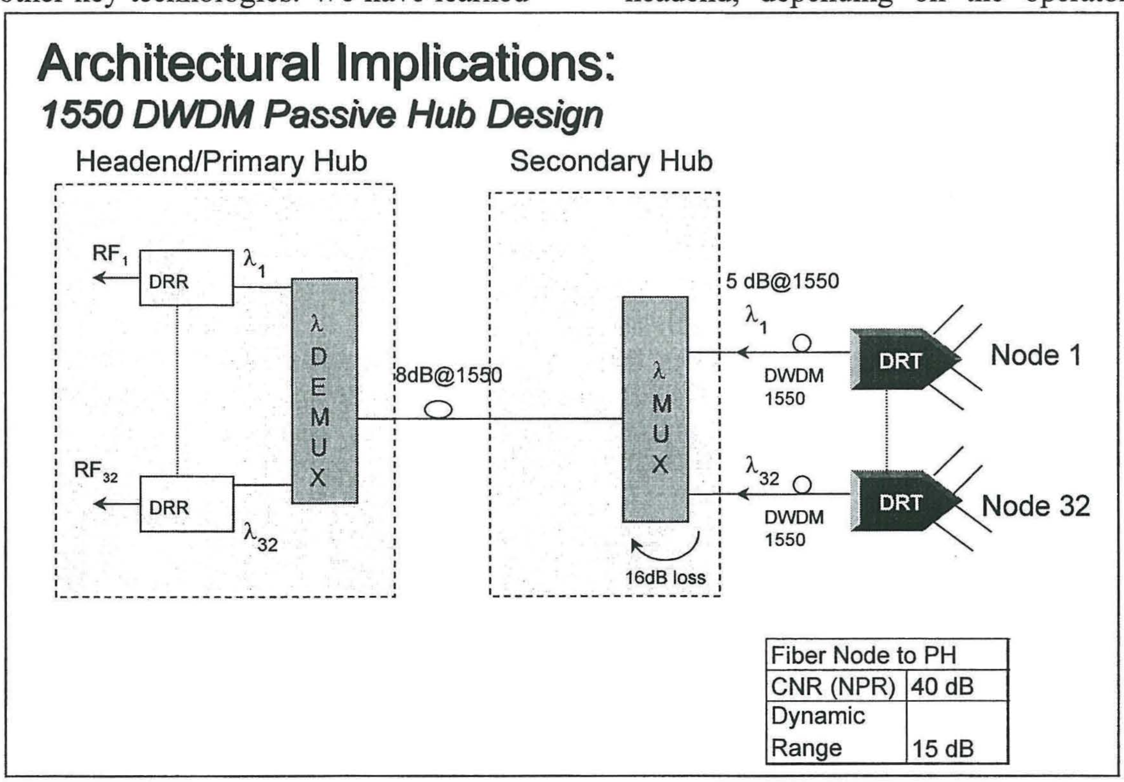


Figure 7: Architectural Implication

preference for where the information is processed.

During the construction of a new network, the operator can choose to dramatically lower hub costs by designing the network for transmission directly from the node to the headend, ultimately eliminating the need for processing equipment at the hub (Figure 7).

Evolution Potential

This new technology allows much more information to be placed on a fiber, increase signal quality, increase network reliability and at the same time reduce network cost. The high bandwidth capacity provides the ability to transmit a range of services in the reverse path, including cable modem traffic, telephone service and other interactive content. It also offers the extra bandwidth necessary for future network expansions including digital payload transport. As a matter of fact, the latter application will convert HFC to the only network capable of simultaneously transporting analog and digital payloads.

By applying digital techniques to reverse signals, it is expected that the effects of undesirable plant noise and ingress will be significantly mitigated. The latter schemes have the potential to erase the negative criticism of cable's "noisy" return plant.

CONCLUSION

Virtually every industry is realizing the advantages of digital solutions, and in the coming years almost any solution that can be converted to digital, will. With the introduction of an array of new, interactive services and ever-expanding channel line-ups, the cable industry is even in more need of an advanced and long lasting transport solution for the upstream path. Digital technology can solve this issue. It is the long awaited solution for the legacy issues of the cable return path.

While preliminary results show that the performance of traditional Fabry-Perot lasers has been exceeded, we claim that the technology is capable of providing the performance of uncooled DFB at the cost of Fabry Perot. Furthermore digital reverse can serve up to four times as many subscribers on a single fiber, compared to traditional cable networks. All this combined with a simplified network architecture with fewer components, means more reliability, less operational and capital cost with better signal quality. This technology has the potential of lifting the cable industry, as fiber did to trunk and feeder plants. We are about to witness the beginning of a significant turning point for the cable industry!