

## CABLE TELEPHONY PERFORMANCE OVER DWDM NETWORKS

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### *Abstract*

*In the last two decades, a trend toward metro market clustering under a single operator led to changes in metro market architecture. This trend allowed for significant headend consolidation and for lowering the number of signal processing facilities to the level dictated by local programming requirements and operational issues. A side effect of this benefit was an increase in distances between the processing facilities and the customers. This had not been an issue for traditional broadcast services that did not require two-way communication. However, with the introduction of interactive services with their strict requirements for proper timing and synchronization, the absolute distance from the processing centers and the differential distance between the devices transmitting on the upstream path became critical.*

*Additionally, requirements for increased network availability on long fiber routes made it necessary to deploy optical switching to reduce the network downtime to a minimum. Optical switching activation results in an instantaneous change in distance that causes a change in delay between the terminal devices affected by the switch and the processing facilities. It also affects differential distances between the terminal devices. Therefore, a reliable and timely recovery from these changes became crucial to achieve network availability targets.*

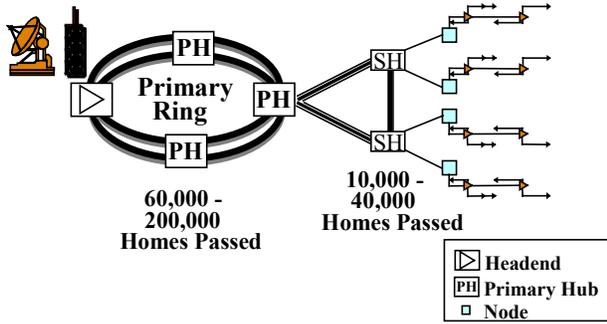
*This paper presents the requirements formulated for all interactive service platforms operating in the HFC network with consolidated signal-processing facilities. It also presents and discusses the results of tests performed on several proprietary digital telephony platforms to verify these requirements.*

### **INTRODUCTION**

The major system clustering and headend consolidation activity occurred between 1990 and 1997. It brought a significant benefit in operational savings, improved signal quality and network reliability. In 1994 and 95, a deployment of highly interactive services began. Initially, for high-speed Internet access services, the segmentation requirements were low enough to allow for a cost-effective use of 1310 nm technology for short distances and 1550 nm externally modulated laser transmitters for longer distances. However, with the deployment of digital telephony services and increased segmentation requirements, expensive 1550 nm externally modulated laser transmitters dedicated to a small number of customers could not be justified.

Additionally, increased requirements for network availability made it necessary to deploy self-healing rings deeper into the network. This goal could be achieved only after a reduction in fiber count in these rings.

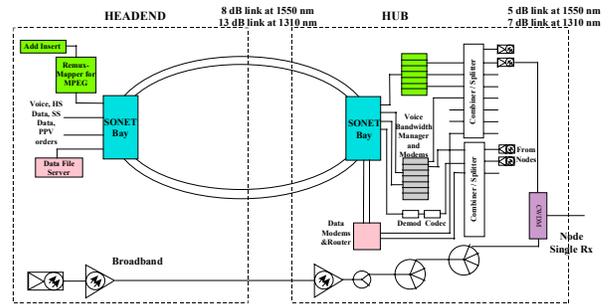
The topology of the network meeting these requirements is presented in Figure 1. This topology has been deployed by virtually all hybrid fiber-coax (HFC) network operators providing telephony services and by many other operators who opted for increased network availability.



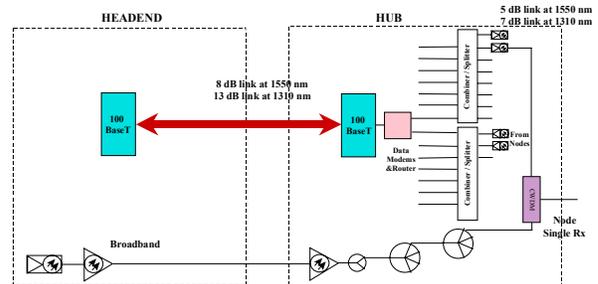
**Figure 1: Generic Configuration of Modern Metro Market HFC Network**

Initially, due to the lack of other cost-effective transport technology choices, signal processing equipment for high-speed Internet access services (cable modem termination systems — CMTSs) and for digital telephony (host digital terminals — HDTs) was deployed in secondary hubs and interconnected with the primary hub rings with SONET and ATM transport systems<sup>1</sup>. In many cases, point-to-point Ethernet transport systems were deployed in place of ATM systems to support high-speed Internet access equipment. This solution is depicted in Figure 2. Although this negated the trend toward, and hence the benefits of, processing facility consolidation, it was the only viable solution at that time. In this arrangement, redundancy switching or routing was taking place on the network side of the processing equipment with well-defined timing performance of the SONET, ATM or Ethernet transport systems. The CMTSs and HDTs were connected over an HFC network to their corresponding cable modems and network interface units (NIUs)

located at customer homes. The HFC network consisted of short fiber links (10-25 km) from the secondary hub (SH) to the optical node (usually unprotected) followed by a tree and branch coaxial cable run of a few miles. This meant a typical distance from HDT to NIU of between 12 km and 30 km



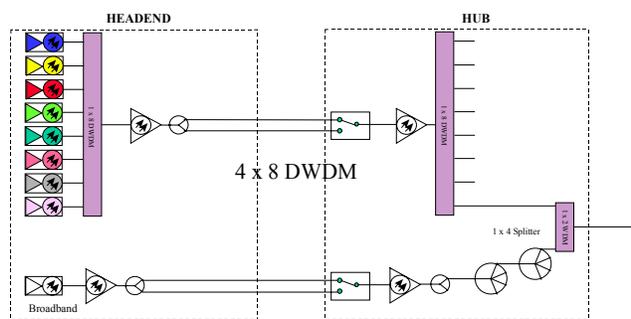
**a) SONET SH Rings**



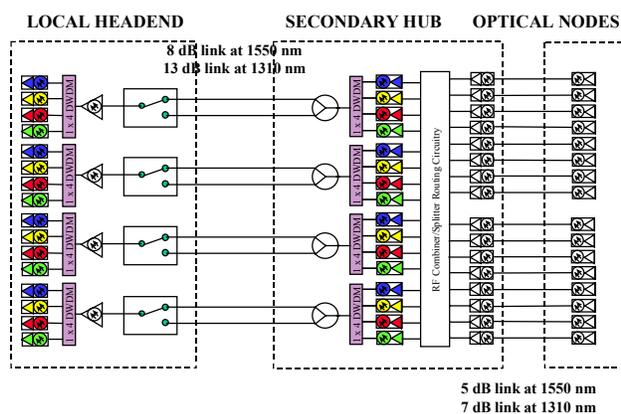
**b) Point-to-Point Fast Ethernet SH Link**

**Figure 2: Hybrid Analog and Digital**

In 1998, dense wavelength division multiplexing (DWDM) technology reached a level of performance adequate for carrying multiple QAM signals over long distances. Moreover, it reached the price points to become a cost effective alternative to the SONET transport system in secondary hub rings<sup>2</sup>. It also eliminated the need for different transport systems dedicated to different services. A DWDM network configuration is presented in Figure 3.



a) Forward



b) Reverse

**Figure 3: DWDM in Secondary Hub Links**

The most important benefit of this technology was the fact that the operators could continue the consolidation of signal processing facilities. The CMTSS and HDTs could again be concentrated in a few primary hubs (PHs) and headends. This resulted in cost savings in hub buildings, improved reliability due to faster mean time to repair (MTTR), and operational efficiencies due to having highly sophisticated and environmentally sensitive equipment placed in fewer, well-designed locations.

This desirable change increased the distances to the cable modems and NIUs from the typical 12-30 km to much greater distances of 70-100 km and, in a few extreme cases in backup routes in secondary hub rings, to 150 km. Due to these

increased distances, it also became necessary to introduce diverse fiber path routing between CMTSSs and HDTs and their respective cable modems and NIUs, both in the forward (FWD) and reverse (REV) paths. The DWDM optical links between PH and SHs were configured as self-healing rings. Each SH was connected with its respective PH via automatic optical protection switches (AOPSs) selecting between principal and backup fiber routes, often significantly different in length (and hence in transit delay). These differences could result in instantaneous changes in delay and/or optical power levels as a result of the switchover. The latter can be addressed by a judicious use of optical amplifier and attenuators for level equalization in principal and backup paths after redundancy switching. However, the instantaneous changes in delay caused by AOPS activation require cable modems and NIUs to adapt to such changes with minimal loss in service availability.

The DOCSIS standard addressed the long absolute and differential distances likely to exist between CMTSSs and cable modems, and DOCSIS-compliant high-speed Internet access platforms can operate at these long distances (transit delay from headend to most distant customer can be  $\leq 0.800$  ms). However, the proprietary digital telephony platforms could not initially meet similar requirements for absolute and differential distances. Moreover, neither DOCSIS standards nor proprietary digital telephony platform specifications directly addressed the recovery issues related to the instantaneous changes in these distances.

This situation necessitated the definition of new requirements for the interactive service platform capabilities for both distance requirements and recovery

requirements in case of the instantaneous change in these distances.

## **REQUIREMENTS FOR INTERACTIVE SERVICE PLATFORMS**

### AT&T Broadband Requirements

Based on the considerations presented above, AT&T Broadband defined the following architectural requirements for the interactive service platforms:

1. Absolute maximal distance between signal processing equipment and terminal equipment at which the terminal equipment can range and register shall be as specified below. All terminal devices must register automatically for the entire absolute range without reconfiguration of the headend/primary hub equipment.

- **Requirement: 70 miles,**
- Objective: 90 miles.

(**Note:** DOCSIS requirement approximates to 110 miles of optical fiber)

2. Differential distance between the closest and the furthest terminal devices served by a single headend modem (i.e., on the same forward and upstream carrier path):

- **Requirement: Half of the maximal absolute distance,**
- Objective: Maximal absolute distance.

3. Change in the distance due to the optical path redundancy switch activation — all terminal devices at the maximal unit load per carrier path, calculated based on traffic modeling and equipment limitations, must re-range and re-register after a change in the distance for either or both carrier paths (forward or reverse) equal to the maximal absolute distance

in either direction (i.e., from the maximal distance to zero distance and from zero distance to the maximal distance):

- **Requirement: Within 4 minutes,**
- Objective: Within 2 minutes.

(**Note:** The additional objective is not to terminate a call in progress upon the change in distance described above).

4. Terminal units operating on the same modem as the units subjected to the change in distance (optical path redundancy switch activation) shall not require re-ranging or re-registration or be affected in any way.

### Statistical Analysis of PH to Home Distances – Requirement 1

Approximately 500 SHs are designed or scheduled for design and construction in AT&T Broadband markets with interactive services. Approximately 5% of these hubs (25 locations) are located far from a primary hub and either a principal or backup route or both would result in exceeding a distance of 50 miles between the primary hub and the terminal equipment (cable modem or NIU). Some of the older versions of the digital telephony platforms would not operate at these distances and would require placement of HDTs in secondary hubs. This would result in a significant capital cost and an increased cost of operations. This consideration led to the requirement for longer operational distances. Several secondary hubs are located further than 70 miles away from their respective primary hubs. The distance from any primary hub to the furthest customer in the existing AT&T Broadband markets does not exceed 90 miles.

## Clustering – Requirement 2

In extreme cases where some terminal devices fed via home run nodes (nodes fed directly from primary hubs) are attached to the same modem as the terminal devices fed via secondary hubs, the differential distance between the devices and the signal processing equipment may approach the absolute distance to the furthest customer. Although the network designers and service operators try to avoid these situations, an efficient use of the signal processing equipment dictates the need for this requirement.

### Network Availability – System Recovery: Requirements 3 and 4

The optical fiber links stemming from primary hubs can reach lengths approaching 90 miles. Based on the data collected over the years<sup>3</sup>, this length of unprotected fiber link could result in 107 minutes of downtime a year. Hence, the redundancy switching in these and any other optical fiber runs, except for the direct runs from primary and secondary hubs to the nodes (usually shorter than 16 miles, and typically only several miles), is required to meet the network availability goals. Since the SONET or ATM rings to the SHs would prevent any downtime caused by fiber cuts, the downtime allocations for fiber-cut redundancy switching in these links was equal to zero. Therefore, AT&T Broadband attempted to reduce to a minimum the redundancy switching downtime caused by re-ranging and re-registration. It was assumed that there would be one redundancy switching event (i.e., two switchovers per event) a year due to maintenance activity in addition to the redundancy switching caused by fiber cuts. Based on the statistical data on fiber cut events, there is a 40% likelihood

of a cut per year in a 90-mile optical cable run. The 4-minute requirement was selected as a reasonable and achievable compromise based on discussions with several vendors of proprietary and DOCSIS-compliant systems. However, it does not fully satisfy AT&T Broadband's needs. It would still result in an 11.2-minute downtime in longest runs versus the zero downtime for SONET rings. The objective of a 2-minute downtime with the additional objective of not dropping calls in progress would be more satisfactory.

## **TEST RESULTS**

### Requirement 1

To preserve the clarity of the test result analysis, the test setup and test conditions are detailed in the addendum at the end of this paper. The table below illustrates the results for each cable telephony platform.

**Table 1: Test results for the Absolute Distance**

**Absolute Maximal distance at which NIUs can Register**

	<b>70-mile (112 km) Requirement</b>	<b>90-mile (144 km) Objective</b>
<b>Platform A</b>	<b>Yes</b>	<b>Yes</b>
<b>Platform B</b>	<b>Yes</b>	<b>Yes</b>
<b>Platform C</b>	<b>Yes</b>	<b>Yes</b>

The results indicate that all three platforms performed the normal provisioning, registration, diagnostic and operations functions at the maximal required distance of 70 miles (112 km), and also at the objective distance of 90 miles (144 km) at high call volumes without problems, thus satisfying Requirement 1.

## Requirement 2

The test setup and test conditions are detailed in the addendum at the end of this paper. The test results are shown below in Table 2.

**Table 2: Test Results for Differential Distance**

	<b>Requirement: 1/2 Max absolute distance (35 miles, 56 km)</b>	<b>Objective: Max absolute distance (70 miles, 112 km)</b>
<b>Platform A</b>	<b>Yes</b>	<b>Yes</b>
<b>Platform B</b>	<b>Yes</b>	<b>Yes</b>
<b>Platform C</b>	<b>No</b>	<b>No</b>

Platform C did not meet this requirement at the time of the test. This platform was also tested to make sure that it did not work *outside* of its specified differential range. An attempt to register units at distances outside of the specified differential distance range after registering units at 70 miles or other distances could result in interference and service disruption for the units already registered. These tests were performed during normal operations under a call load and showed that there was no interference and the platform did not attempt to register the units placed outside of the specified differential range.

The differential distance tests were also performed at 90 miles for all platforms with the results being identical to those in Table 2.

## Requirements 3 and 4

When an optical fiber protection switch activates in the FWD or REV paths, NIUs experience an instantaneous change in delay offset from the HDT since the fiber path being switched-to is usually of a different length than the original path. Frame alignment in the FWD and REV

becomes offset in time and the NIUs no longer transmit or receive at the expected time intervals. The system detects this condition and acts to correct it. As a result, most NIUs will un-register from the HDT modem (i.e., lose communication). Usually, most of the calls in progress are lost as well. The system will then attempt to re-register the NIUs returning them to full operation within a certain amount of time. Depending on the amount of delay change, some platforms can preserve the active calls, and some or all units may not un-register but, in general, there is always a fiber delay change value for which all units un-register and all calls in progress are lost. If NIUs un-register, they are unavailable for calls until fully re-registered. This situation constitutes a real service outage. Detection “audits” exist within each system platform to detect that a loss of communication has occurred, and recovery mechanisms are triggered as a result of the audits to re-register the NIUs. Each vendor has a different implementation of these mechanisms and audits. Therefore, testing of the AT&T Broadband requirement necessitates a thorough understanding of the particular implementation to create the appropriate test conditions to verify its effectiveness.

The time to re-register depends on different factors for different platforms. The most important factors are: the number of NIUs registered on the HDT modem, the amount of delay change, the amount of traffic being handled by the HDT modem under test during the switching event, and whether delay was increased or decreased as a result of switch activation. Also, audit and recovery mechanisms are triggered by different situations in each platform. For example, one platform is more sensitive to small changes in delay and another is more sensitive if the delay is decreased rather than increased.

The test setup and test conditions are detailed in the addendum at the end of this

paper. Table 3 summarizes the test results.

**Table 3: The Platform Behavior after Optical Redundancy Switch Activation (Separately for FWD and REV)**

<b>FWD Switching</b>		<b>0 km (no change in delay)</b>	<b>1km to 4 km</b>	<b>20 km, 25 km, 50 km, 75 km, 100 km, 112 km (70 miles), 125 km, 144 km (90 miles).</b>	<b>Notes</b>
<b>Platform A</b>	Add Delay	No change, no un-registration	2 min 57 sec. to 4 min 53 sec.	2 min 49 sec. to 3 min 33 sec.	Fully loaded HDT modem. Most units unregistered during a switch event except for those at 0 km. Times are to full recovery.
	Reduce Delay	No change, no un-registration	3 min 17 sec. to 6 min 15sec.	2 min 45 sec. to 3 min 53 sec.	
<b>Platform B</b>	Add Delay	No change, no un-registration	Not tested	10 sec. to 3 min 33 sec.	Only 8 NIUs per HDT modem. Majority of units unregistered and re-registered, including ones at 0 km.
	Reduce Delay	No change, no un-registration	Not tested	3 min 17 sec. to 4 min.	
<b>Platform C</b>	Add Delay	No change, no un-registration	No un-registration	No un-registration (20, 25 km) to 5 min 22 sec.	Fully loaded HDT modem. If un-registration occurred, all units un-registered, but never those at 0 km.
	Reduce Delay	No change, no un-registration	No un-registration to 6 min 23 sec.	3 min 48 sec. To 5 min 47 sec.	
<b>REV Switching</b>		<b>0 km</b>	<b>1km to 4 km</b>	<b>20 km, 25 km, 50 km, 75 km, 144 km (90 miles).</b>	
<b>Platform A</b>	Add Delay	No change, no un-registration	Not tested	3 min 12 sec. to 3 min 17 sec.	Fully loaded HDT modem.
	Reduce Delay	No change, no un-registration	Not tested	2 min 45 sec. to 3 min 56 sec.	
<b>Platform B</b>	Add Delay	No change, no un-registration	Not tested	10 sec to 3 min 30 sec.	Only 8 NIUs per HDT modem, far below the full load. Also units at 0 km un-register at times.
	Reduce Delay	No change, no un-registration	Not tested	2 min 18 sec. To 3 min 43 sec.	
<b>Platform C</b>	Add Delay	No change, no un-registration	No un-registration	No un-registration (20, 25 km) to 5 min 5 sec.	Fully loaded HDT modem. Higher sensitivity to delay reduction than to delay increase.
	Reduce Delay	No change, no un-registration	No un-registration to 5 min 43 sec.	3 min 48 sec. to 5 min 47 sec.	

The results indicate that Platform A met the 4-minute requirement for fiber deltas of 20 km and greater. In contrast, it did not meet the requirement for fiber deltas of 1 to 4 km. This platform was the only one that had a specific system mechanism to detect and correct changes in delay caused by the fiber switchover. The other two platforms had not developed specific methods to deal with this at the time of this writing. They relied on mechanisms that were optimal for recovery from outage situations and not specifically from changes

in transit delays. The improvements to fiber switching for Platform A are implemented in software and do not require new hardware. Platforms B and C did require new hardware and new types of units to meet some of the new requirements.

Platform B showed that re-registration times were just at or below four minutes. However, this platform was loaded with only eight units per modem, far below its maximal capacity. It is reasonable to extrapolate that this time will most likely

exceed the 4-minute requirement for fully loaded modems. Other tests performed by the vendor have confirmed this extrapolation. During some of the fiber switchovers, the units at 0 km un-registered and re-registered even though their delays were not affected by the switching event. This behavior did not occur in the other two platforms. The vendor is working to implement a mechanism that specifically detects fiber delay changes and responds to them in less than four minutes, without affecting the units not subjected to the delay change (i.e., not subjected to the fiber switchover) on the same modem.

Platform C was very robust when fiber switchovers resulted in the addition of a delay caused by up to 25 km of additional fiber. In these situations, units did not un-register and calls were not dropped. However, reductions of delay by more than

1 km equivalent fiber caused complete un-registration and subsequent re-registration. In both situations (negative delay changes and positive delay change in excess of 25 km of fiber), the recovery times were often above the 4-minute requirement. This platform also relied on the use of mechanisms developed for detection and correction of outages and not on algorithms optimized for handling fiber delay changes. The vendor of this platform has developed an optimized algorithm that will detect a fiber delay change and very quickly correct all units for it with minimal un-registration. This solution has already been tested by the vendor and is scheduled for implementation in the next system software release.

All platforms were also tested for Requirements 3 and 4 if both switches, FWD and REV, activated simultaneously. The results are listed in Table 4.

**Table 4: The Platform Behavior after Optical Redundancy Switch Activation (FWD and REV Simultaneously)**

Double Switches		25 km FWD, 25 km REV	50 km FWD, 50 km REV	125 km FWD, 125 km REV	145 km FWD, 145 km REV	Notes
Platform A	Add Delay	3 min 17 sec.	Not tested	Not tested	6 min 45 sec.	Fully loaded HDT modem, no un-reg. of units placed at 0 km
	Reduce Delay	2 min 23 sec.	Not tested	Not tested	7 min 41 sec.	
Platform B	Add Delay	2 min 31 sec.	4 min 8 sec.	3 min 37 sec.	Not tested	No of NIUs was only 8, un-reg. occurred for units at 0 km
	Reduce Delay	2 min 40 sec.	3 min 30 sec.	3 min 23 sec.	Not tested	
Platform C	Add Delay	4 min 13 sec.	4 min 49 sec.	Not tested	Not tested	Fully loaded HDT modem, no un-reg. of units placed at 0 km
	Reduce Delay	4 min 37 sec.	3 min 57 sec.	Not tested	Not tested	

The behavior of the platforms for double protection switching was similar to the behavior when the switchover occurred in one path only. This was expected as the round trip delay change is the parameter of importance. Recovery time for Platform A noticeably exceeded the 4-minute requirement if protection switching added and subtracted 145 km (90 miles) of fiber in both paths. If the switching added or subtracted 25 km of fiber in both paths

simultaneously, the recovery time met the requirement. Platform B performed within the 4-minute recovery requirement, but the tests were again performed with only eight NIUs per modem. As previously, the units at 0 km from HDT (not subjected to switching) un-registered. Platform C also exceeded the 4 minute requirement.

At this time, all three cable telephony platforms do not fully meet

Requirement 3 and Platform B does not meet Requirement 4. All have particular problems in handling certain fiber switch delay differentials. All platform vendors have been encouraged to move from less than optimal detection and correction mechanisms, which were created to deal with specific loss of communication outages, to more robust mechanisms of detection and correction of fiber delay changes. This should result in achieving better recovery results and increased service availability.

#### Optical Power Changes Accompanying Fiber Protection Switches

During all the tests described, protection switch action was *not* accompanied by a corresponding change in optical power at the input to the receiver. Real networks should be designed to equalize the received optical levels at the AOPS to within  $\pm 1$  dB for principal and backup routes. This design consideration is important. If there is an optical amplifier in front of the receiver (after the switch), then power changes will be absorbed by the amplifier and will result only in a slight change in CNR at the receive end. Alternatively, the path losses can be equalized with optical attenuators or couplers. If the level equalization is not achieved, an instantaneous change in RF power from the receiver (and at the input to the HDT modem) will occur. To account for this possibility, all three platforms were tested for the instantaneous level change. All of them showed fast recovery from such changes without affecting service, as long as the changes were within 4-6 dB in RF level (2-3 dB optical change). The call BER was not affected significantly.

This special design requirement for level equalization is not relevant in digital

reverse links (either digitized analog or baseband digital signals). In this case, the changes in optical power levels do not affect receiver RF output levels as long as the optical levels are well within the receive window of the digital receiver.

#### CONCLUSIONS

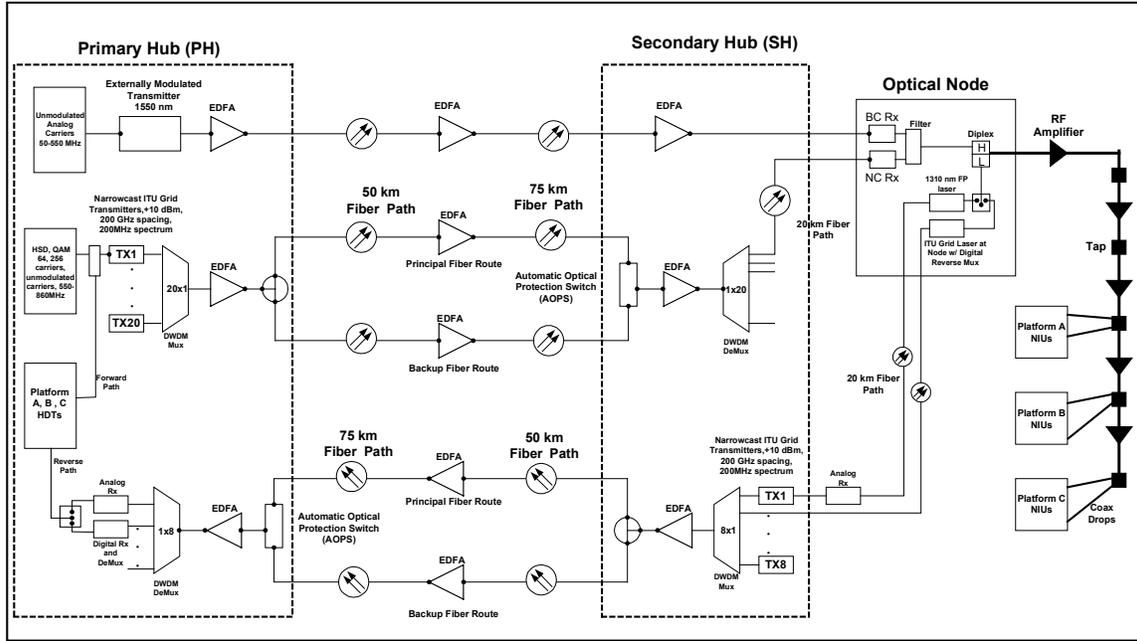
New requirements for interactive service platforms with respect to fiber protection switches and increased distances between signal processing equipment (e.g., CMTSS and HDTs) and terminal equipment (e.g., cable modems and NIUs) have been presented and explained. These requirements are partially reflected in DOCSIS standards (absolute and differential distance requirements) but have not been adequately addressed in digital cable telephony platforms. The most current hardware and software releases of the three proprietary platforms deployed in AT&T Broadband markets were tested and analyzed to verify if these requirements were met. The results indicate that all the platforms have problems meeting the recovery requirements after fiber protection switch activation. All of the platforms can accommodate the increased HDT to NIU distance requirements. However, in the test for differential distance requirements, that being the distance between the farthest and closest NIU to the same HDT modem, one of the platforms failed. The vendors anticipate that by the end of this year or in Q1 of 2002 all four requirements will be met. AT&T Broadband will retest these platforms once the upgrades are implemented.

It is critical that similar requirements are extrapolated to DOCSIS-compliant IP platforms, especially the ones supporting voice over IP services, and to PacketCable-compliant platforms.

## ADDENDUM – TEST SETUP AND TEST CONDITIONS

To test performance of all digital cable telephony platforms, a full DWDM network was set up in AT&T Broadband

Lab facilities in Westminster, CO, as shown below in Figure 4. Additional testing was performed at vendor locations to simulate more complex situations such as full loading of HDT modems with NIUs.



**Figure 4: Test Setup in AT&T Broadband Lab**

The test architecture consisted of a DWDM system with 20 narrowcast ITU wavelengths (200 GHz spacing) in the FWD path and eight in the REV path. An analog broadcast system carrying 550 MHz of unmodulated carriers on a separate fiber link was also used. The narrowcast signal consisted of 200 MHz of bandwidth carrying the cable telephony signals, as well as some 64 and 256 QAM carriers, HSD signals and several unmodulated analog carriers to fill the band from 550-860MHz. This signal was modulating only one of the narrowcast forward lasers. The narrowcast and broadcast signals were received on separate receivers at a node and combined before RF transport over a simulated coax plant with five amplifiers in cascade. At the end of the cascade, 30 NIUs (for each tested platform) were connected to the network. In the REV

path, both analog and digital return systems were used to carry NIU signals back to their respective HDTs. RF switches were used to select either transport technology in the REV and the platform performance was tested with both technologies. The total distance between HDTs and NIUs was 90 miles (144 km) of real fiber in each direction. This length could be changed to create lower values of total distance by removing fiber spools from the backup fiber routes. The same approach was used to create the differential delays between principal and backup routes. Tests for double (simultaneous) protection switching were also performed. Both AOPSs were activated simultaneously in the FWD and REV paths to reflect real-life situation where the principal fibers for FWD and REV paths are usually in the same fiber sheath and are

usually cut or damaged at the same time. Double switches were also used to attain long round trip delay changes and to simulate situations where switchover results in zero net change in delay.

#### Details of Test Setup for Requirement 1

Requirement 1 for each platform was tested with NIUs of all types used by AT&T Broadband (e.g., 2-line, 4-line, 12-line, 16-line, locally and network powered and all different hardware types). The NIUs and HDTs were equipped with the currently deployed software releases. The units were connected and powered up in the coax plant at the end of the 90-mile network, one at a time, as they would be under real-life conditions in the field, following the recommended turn-up procedure. Other units were pre-provisioned when possible. The time taken for first-time registration was verified for compliance with the specification. The NIUs were provisioned with dialtone using an Element Manager (EM) or equivalent system interface, and checked for proper operation and RF levels at this maximal distance. They were then subjected to call loads close to the maximal specified calls per hour (cph) for each platform using analog bulk call generators (BCG) to verify call completion rates (CCR) of 99.99% during several overnight/weekend load runs. In parallel, additional tests were performed on individual units to check that all their attributes worked properly at this new distance. Most of the basic and critical features were tested together with those system attributes to verify whether their operation was affected (e.g., turning forward error correction (FEC) on/off, concentration on/off). The tests were performed for many distances to allow for extrapolation of the results over the entire range of distances from 0 to 90 miles.

#### Details of Test Setup for Requirement 2

To test Requirement 2, several NIUs (of all types) from each platform were connected directly (0 km) to the HDT modems so that their delay from the HDT was negligible, while the other units remained at 70 miles (or 90 miles during testing the objective performance), on the *same* HDT modem. Additional tests were performed with the units closer to the HDTs placed at 600m, 1.1 km, 2.3 km, 4.0 km, 25 km, 50 km, 75km, 112 km (70 miles), 125 km and 144 km (90 miles). Load runs were performed with the bulk call generators (BCGs) to test for 99.99% CCR. Provisioning, maintenance and operations functions were performed on the units in parallel to testing for normal operation at 0 miles and 70 miles simultaneously. Further opportunity to test different distances from closest to furthest NIUs from the HDT occurred during testing for Requirement 3 where fiber distance to farthest NIU was changed as a result of the fiber protection switching.

#### Details of Test Setup and Test Conditions for Requirements 3 and 4

In order to test these two requirements, the lengths of backup paths in the FWD and REV directions were changed by adding and taking away fiber reels in multiples of 25 km. Shorter fiber lengths (1 to 10 km) were used around the critical length change points within each vendor's platform to increase the test resolution. The maximal distance never exceeded the maximal absolute HDT to NIU distance of 144 km (90 miles) of fiber tested before for all three platforms. The optical protection switches were manually activated to cause the determined delay change. HDT modems for platforms A and C were loaded with the maximal number of NIUs. It was not possible to simulate the maximal NIU load for Platform B due to test set up constraints.

This platform was tested with eight NIUs per modem, far below its full load. However, the results were still very meaningful. The NIUs were exercised during the fiber switchovers with bulk call generators at call loads of 6000 to 9000 cph but below the maximal stress specification of the particular platform. Before each protection switch activation, a period of 15-30 minutes of bulk call activity was allowed to establish the CCR. Similarly, a period of 15-30 minutes was allowed to elapse after the switchover to monitor recovery to the previous CCR level and to detect any longer-term anomalies that arose from the switchover. Recovery times were measured from the fiber switch instant to the point at which all units were registered back in the system and the BCGs recovered the CCR levels established prior to the test. The optical power applied to the optical switch from principal or backup fiber paths in FWD and REV was always equalized irrespective of the length differences except when the platform behavior at the instantaneous RF level changes was tested. All platforms had units registered at 0 km on the same HDT modem as units at the longer distances. These were not subject to fiber delay changes.

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<sup>1</sup> Thomas G. Elliot and Oleh J. Sniezko, "Transmission Technologies in Secondary Hub Rings — SONET versus FDM Once More", *1996 NCTA Technical Papers*: 382.

<sup>2</sup> Oleh J. Sniezko & Tony E. Werner, "Invisible Hub or End-to-End Transparency", *1998 NCTA Technical Papers*: 247.

<sup>3</sup> Tony E. Werner & Oleh Sniezko, "Network Availability, Requirements and Capabilities of HFC Networks", *1996 Conference on Emerging Technologies*: 123.