Transmission Technologies in Secondary Hub Rings — SONET versus FDM Once More

Thomas G. Elliot
Senior Vice President
Engineering & Technical Services
TCI Cable Management Corporation

Terrace Tower II
5619 DTC Parkway
Englewood, CO 80111-3000
(303) 267-5222
FAX (303) 488-3210

Oleh J. Sniezko
Director
Transmission Engineering
TCI Communications, Inc.

Terrace Tower II
5619 DTC Parkway
Englewood, CO 80111-3000
(303) 267-6959
FAX (303) 488-3210

Abstract

The choice of architecture and transmission technology for signal delivery from primary hub rings to clusters of coaxial buses with 125 to 500 homes passed per bus is a subject of an ongoing debate. This paper presents an analysis of the several transmission technologies suitable for these links, and namely:

- *dedicated fiber delivery system (simple FDM technology) from the primary hub ring to the coaxial bus (ring-star-bus);*
- *FDM technology with block conversion for targeted services;*
- *hybrid FDM (for all broadcast signals) and SONET (for targeted services);*
- *hybrid FDM (for analog broadcast signals) and SONET (for all digital signals).*

The impact of the following factors on the results of the analysis are considered:

- *service requirements;*
- *architectural requirements;*
- *capital and operating costs;*
- *future-proof level of the architecture and transmission technology.*

The results of the analysis can be used in selecting a solution suitable to a particular set of requirements and a size of the system. The authors also present their vision of the future and TCI's technology of choice at this point in time.

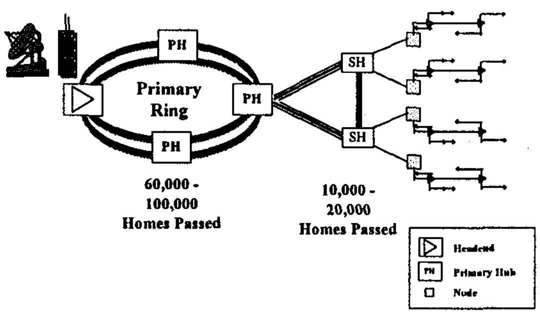
INTRODUCTION

As the world is rushing into the telecommunication age and becoming even more a 'global village' prophesied by McLuhan, we, telecommunications engineers, try anticipate future requirements and design a network that will not become obsolete before it is completed. Of course, we are restricted by the equation diametrically different from the equation used by some of the telecommunications service providers. Ours is that "profitability equals revenue minus expenses". Hence, our effort is full of circumspection. The equation and its implications are described by Dan Pike in his address to the Western Communication Forum[1].

HFC ARCHITECTURE

In most cases, we decided on a transmission technology in major parts of our network. Let us review the HFC network architecture as an example (see Figure 1). This architecture closely resembles CableLabs' Active Coaxial Network Architecture. Other MSO's architectures are similar in many solutions to the CableLabs' network. In the largest metropolitan areas, numerous headends are most likely to be connected in a ring to provide a fully redundant and survivable platform. In many cases, primary hubs are established to maintain signal quality delivered to the distribution network. These hubs serve from 60K to 100K homes passed.

Figure 1: HFC Network — Dual-Ring / Star / Bus



The other end of the HFC network is configured as a bus. To provide all the services anticipated, we have to share limited resources of the bus in our network among a limited number of potential subscribers. The number of customers that can be share the resources will depend on modulation schemes and other technical solutions employed as well as on demand for services The industry estimates this number between 125 and 500 homes passed. Usually, several of these buses are fed from a central location (nodes) to share the resources. These nodes serve clusters of 500 to 2000 homes passed.

The looming question is how to deliver signals from the primary hub ring to the clusters of customers served by the bus. This question encompasses two issues:

1. Architecture, and
2. Transmission technology.

Both issues are interrelated but are treated separately by network engineers for several reasons:

- lack of the optimal transmission technology for the range of services to be delivered;
- unpredictability of the future requirements; and
- the limits set by the equation ruling our industry (profit equals revenue less expenses).

This paper deals with the second issue — transmission technology to be used. However, to deal with this issue, we have to analyze possible architectures for the links between the primary hub ring and the clusters. The analysis is conducted for two geographical areas with 20K homes passed each, fed from a primary hub ring. The areas are located so that they can be connected into a ring to provide backup feeds. Each area can be logically arranged into twenty-two 900-home passed nodes. Each node feeds three buses of 300 homes passed. Several solutions are analyzed in a historical order as they were considered and championed by TCI.

These solutions are included within the wide range of architectural choices. One side of this range is the physical star architecture in which all nodes (in the extreme cases, all homes) are fed via a dedicated link. This architecture is deployed by telephone companies (switched star).

On the other side of this range is the bus structure or a ring structure feeding the nodes directly from the primary hub ring.

Most of the evolving HFC architectures deploy some intermediate solutions — redundant secondary hub rings to deliver signals and services over optical fiber from primary hubs (central offices) to the neighborhood of 5,000 to 40,000 potential customers. From this point on, the signals are distributed either over fiber or coaxial cable to clusters of 500 to 2,000 customers to allow for segmentation and targeted services delivery.

The HFC network in its completeness described above would be implemented only in large metropolitan areas. It will be scaled down in areas with fewer than 100K homes passed. In areas with fewer than 20K homes passed, the choice of architecture will be different (probably direct feed to the nodes) than in areas with 60K to 100K homes passed.

TRANSMISSION TECHNOLOGIES DEPLOYED

Primary Hub Ring

The primary hub rings utilize technologies suited the best for long distances and introducing the lowest level of impairments. The most common deployed so far are listed in Table 1.

The choice of the transmission technology in the past was based mostly on the requirements for the quality of signals and on availability of the technology (including its cost). For these reasons, no standard technology has been selected by the industry. Several studies by major MSOs and the industry[2 3 4] concluded that, in large metropolitan areas with high demand for wide array of services, it is cost effective and beneficial now to deploy SONET-based systems. It is the authors opinion that, as the quality of the video codecs improves[5] and the prices fall further, this technology will prevail in competition with proprietary technologies in primary hub rings, even for video distribution. This will probably happen in the next several years. There will be a niche for analog technologies (1550 nm optical links for example) in small markets with limited demand for competitive access provisioning for obvious reason of better cost-effectiveness.

Table 1: Transmission Technologies in Primary Hub Rings

Technology	Description	Comments	
		Pros	Cons
Analog FM	Baseband video signals FM modulated	• good overall signal quality	• problems with different analog scrambling systems • proprietary systems • non-standard network management elements • limited cascading • not suitable for system interconnects • high cost of interfacing to RF
Analog AM 1550 nm window	RF signals with higher-power, externally modulated lasers with optical amplification.	• transparent to any technology • low cost of interfacing to RF	• ring length is limited due to cascading noise of amplifiers (repeaters) • less reliable than 1310 nm lasers • network management proprietary • few vendors for analog video quality systems
Linear PCM	Baseband or IF video signals digitized and transmitted for long distances	• very good video quality • SONET-like features • numerous interfaces available (DS3 and subsets) • 16 to 32 high quality channels per wavelength • 8 to 16 IF channels per wavelength • QAM and VSB signals at IF can be digitized and only up-converters are required • drop/add capability • good reliability record	• non-standard, proprietary systems • limited number of vendors (two major vendors only) • non-standard network management system • high cost of interfacing to RF
SONET	Digital TDM optical hierarchy system	• reasonable video quality • potentially interfacing with any digital service • standard systems • standard network management • limited number of fibers • survivability • perfect for system interconnects • many vendors • drop/add capability • good reliability record • system prices lowering	• high cost of interfacing to RF

Optical and RF Coaxial Bus

Signals distributed over the final part of the distribution network must be compatible with terminal devices or network interface units, and must be suitable for bus type architecture and shared coaxial cable distribution network. These requirements practically define the type of transmission technology that can be deployed between secondary hubs and customers. This must be FDM with the type of modulation compatible with the terminal devices: AM modulated NTSC signals of EIA channel assignment; FM radio; QPR Sega channels, QPR digital radio services, QPSK telephony, QAM MPEG video channels, QAM and QPSK high speed two-way data, QPSK voice, etc. The alternative to this technology would require a placement of expensive signal conversion centers shared by few users.

Primary-to-Secondary Hub Links

Primary-to-secondary hub link engineers exercise a significantly higher degree of freedom while selecting a transmission technology for this part of the HFC network. Beside the paradigm of the signal compatibility with the remaining elements of the HFC plant, the following factors must be considered:

Service Needs

1. Cable television needs:
    - broadcast services,
    - NVOD services,
    - VOD services;
2. Telecommunications services.

Architectural Considerations

1. reliability:
    - redundancy,
    - network management;
2. quality;
3. interoperability and level of standardization:
    - comfortability of the potential end users with the technology selected;
4. cost of the final network per home passed and per active customer;
    - lay-out cost in light of time value of money,
    - operating cost;
5. technology availability; and
6. cost of becoming obsolete.

All these factors are dynamic in nature and change continuously with the progress in technology and declining prices of yesterday's novelties.

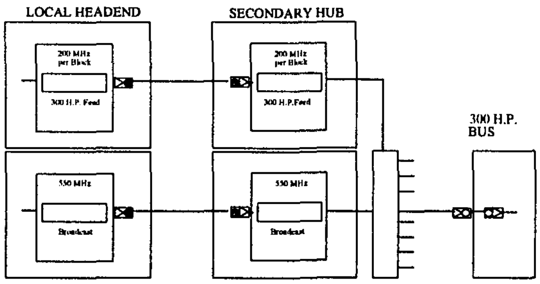
AVAILABLE CHOICES

The following technologies for connecting the primary hub ring with the nodes are the most popular among HFC network engineers:

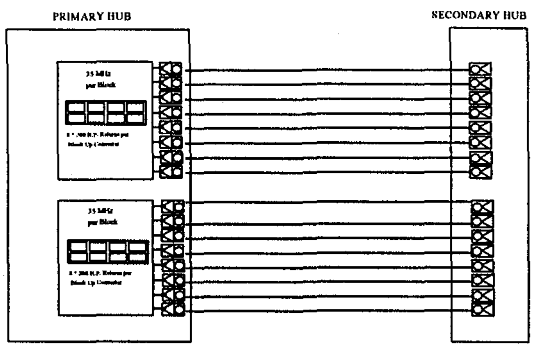
- dedicated fiber delivery system (simple FDM technology) from the primary hub ring to the coaxial bus (ring-star-bus);
- FDM technology with block conversion for targeted services;
- hybrid FDM (for all broadcast signals) and SONET (for targeted services);

These choices are presented in Figures 2 through 4.

Figure 2: Ring/Star/Bus Architecture

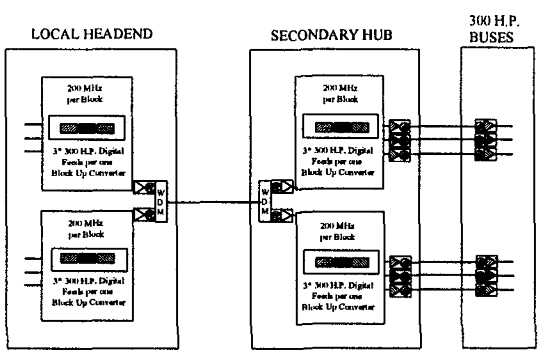


TSD LINK SERVES 300 HOMES PASSED
COMBINED WITH BROADCAST

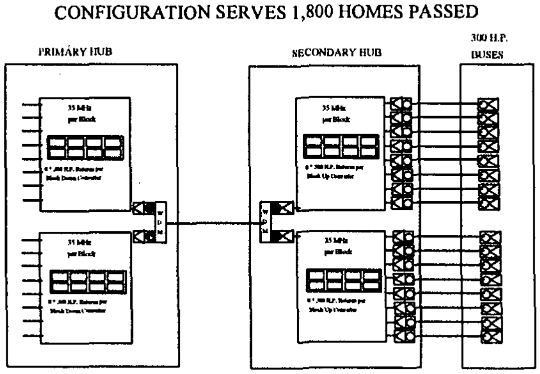


SECONDARY TO PRIMARY HUB REVERSE LINKS

Figure 3: Ring/Ring/Star/Bus Architecture with FDM Transmission

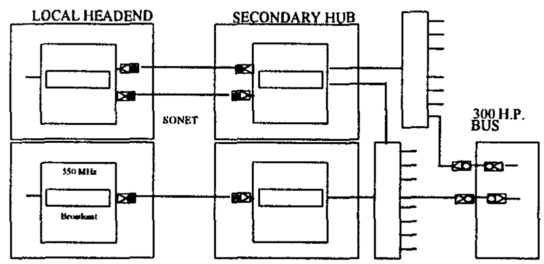


TSD BLOCK CONVERSION AT THE HEADEND
CONFIGURATION SERVES 1,800 HOMES PASSED



RETURN PATH BLOCK CONVERSION AT THE OTN
CONFIGURATION SERVES 4,800 HOMES PASSED

Figure 4: Ring-Ring-Star-Bus Architecture with Hybrid FDM/SONET Transmission



SONET DROP/ADD FETAURE PROVIDES
OUPTUT/INPUT PAIR FOR EACH 300 HP BUS

All three solutions are analyzed below.

ARCHITECTURAL CONSIDERATIONS

Ring/Star/Bus

This architecture provides the highest level of flexibility in the selection of the transmission technology. In this case, the FDM technology is deployed throughout all the network between the primary hub ring and the customer. The FDM technology can work in combination with a digital or analog transmission technology (and multiple access protocols or schemes) compatible with the terminal devices. There is, however, a major drawback to this technology: the number of fibers required to facilitate this architecture for two secondary hubs with twenty-two nodes, each feeding three 300-home passed buses (see Figure 1) would reach 154 without redundancy or 308 with redundancy. For rings with more secondary hubs, the number would be higher. If better quality were required in the forward direction, the number of fibers would have to be increased further. Moreover, to provide protection against single point of failure to the level of 4,000 homes passed, a significant number of optical switches or repeaters with RF switches would have to be deployed at the secondary hub. The cost of such an arrangement and the manageability problems are prohibitive.

Ring/Ring/Star/Bus

To limit the number of fibers in the links between primary and secondary hubs, some way of sharing the fibers had to be developed. We were considering two options:

- using FDM technology with frequency block conversion, and
- using dense WDM technology.

Since WDM technology was not mature at the time (and is not widely deployed in cable TV today), we concentrated on the FDM arrangement with block conversion. This approach limited the number of fibers in our reference secondary hub links to 27 fibers without redundancy or 54 fibers with redundancy. This is a big gain in fiber network simplicity traded off for more complex electronics.

In recent months we reviewed our experience from Hartford where we dealt with this problem somewhat differently. We applied SONET technology in links between primary and secondary hubs. This allowed for limiting the number of fibers even further. For our test area, the number of fibers would equal 7. This number would include forward analog (and digital) broadcast signal fibers (two fibers for dual-fiber configuration plus one back-up fiber), two fibers for SONET ring (OC3 for both forward and reverse voice an data signals), and two fibers (principal and backup) for reverse signals that cannot be easily interfaced to SONET at this time.

The only remaining issue is whether to use SONET for transmission of all digital signals or only targeted digital signals. This issue will be analyzed later.

Let us qualitatively compare the FDM block conversion technique with SONET technology (Table 2).

Table 2: Qualitative Comparison between FDM Block Conversion and SONET

Desirable Feature	Block Conversion	SONET
Low cost interface to RF	✓	
Many vendors		✓
Standard system		✓
Standard network management		✓
Limited number of fibers required	✓	✓✓
Interfaces with digital systems	✓	✓
Good reliability record		✓
Survivability	✓	✓✓
Same system for forward and reverse		✓
Drop/add capability		✓

Undesirable Feature	Block Conversion	SONET
Possible problems of instability	✓	
Potential of becoming obsolete	✓	
Potential of becoming single-vendor product	✓	
Fixed system frequency bandwidth split between broadcast and targeted services	✓	
High cost of RF interfaces		✓

Table 2 clearly shows that the SONET solution is technically superior to the FDM Block Conversion. Moreover, many of our partners on the manufacturing side are uneasy about possible unknown impairments that block-conversion technology can introduce (frequency instability, jitter, etc.). How do the two technologies compare based on cost? To judge this issue, we had to analyze requirements for different services.

SERVICE NEEDS

Let us start with the traditional cable TV services: broadcast entertainment, common at least for a single community. These services can be characterized by common collection points (signal importation, direct feeds, and local origination), centralized switching, and delivery of regional specialty services. Our old architecture (tree & branch) was perfectly suited for this type of service. However, with the advancement of more precisely targeted services and transactional services, this topology outlived itself. Beside such services as VOD, targeted to an individual customer, there is advertising targeted to a neighborhood (possibly as limited as single node or bus). Some may argue whether VOD will become a successful service and whether so narrowly targeted advertising will bring the revenue expected but we, engineers, consider these services as potentially viable and design the network with their delivery in mind. It does not mean that we provision for these service today (remember the equation under which we operate), but we try to make choices that are future- and service-proof.

Although VOD viability is questionable at present, no one questions the fact that the telecommunications services and other transactional services (for example, voice and videophony) will be targeted to an individual customer and that these services have the potential of bringing a sizable revenue to offset the expenses and be profitable. Signals for these services are usually distributed in a digital form. More importantly, they require two-way communication and significant bandwidth availability per customer in forward and reverse directions to be successful.

Interface Equipment Requirements

Both the architecture and the transmission technology selected must accommodate the distinguishable characteristics of the broadcast services and targeted services. In our analysis, we assumed that the analog broadcast signals will be transmitted using existing FDM technology. We also decided that all digital broadcast signals will be transmitted the same way for the foreseeable future. Any local (community or optical node specific) advertising will be injected to a dedicated channel in the set-top boxes. At this point, we did not account for these services. Table 3 lists the interface requirements for the two technologies analyzed for a series of services considered.

Table 3: Interface Equipment Requirements for SONET Based Transmission Network

Service	Existing Multiple Access Protocol (most common) or Interface	Existing Interfaces	Preferable Interfaces	Preferable Multiple Access Protocol	Additional Interface (Existing multiple access protocol or format and RF network)
Voice	TR303 or TR08 interface, DS0 or DS1	Direct to DS1 VT	NA	ATM	Bandwidth Manager
High Speed Data	10BT, 100BT, or FDDI	Router or Protocol Translator from LAN protocols to DS3 or OC3	Direct from a modem or bandwidth manager to DS3 or OC3	ATM	Fast Ethernet Switch, Servers, Bandwidth Manager, Frequency Translators
VOD	MPEG2	Mappers or Groomers into DS3 or STS1	NA	ATM	QAM or VSB Modulators, Demappers, Degroomers

The table indicates the equipment needed at the secondary hub to interface with the SONET ring. This equipment, together with SONET equipment for secondary hubs, replaces equipment required for FDM/Block Conversion scheme. The list of the replaced equipment would include the same interface equipment in primary hubs (lower quantity by 1:3 ratio in TCI), optical transmitters and receivers for forward and reverse (of 1,000 MHz bandwidth), and block converters. This assumes that the primary hub ring is SONET based.

Quick table analysis indicates that the voice and data services transmission over SONET may be already viable from the cost point of view, or viable in the near future. Unfortunately. VOD distribution over SONET would increase the number of QAM or VSB modulators significantly and at the current cost estimate ($3,500 per 6 MHz channel) would not make it viable. At this point in time we have to conclude that VOD services must be delivered in a broadcast mode with sufficient bandwidth dedicated to meet 20K homes passed area demand. Alternatively, separate fibers (saved by deploying SONET) will have to be redeployed with some additional transmitter for forward (some forward transmitters of higher quality and all reverse links will be saved). To avoid the confusion in costing, we excluded VOD services from costing analysis.

Cost Comparison

The tables indicate that the SONET solution may be already viable. The cost of the SONET option does not include the cost of SONET-RF interfaces (except for the network management signals and reverse video - codecs). For the required interface equipment, refer to Table 3. The cost does not include the cost of interface equipment between different protocols and SONET either. These cost are of very dynamic nature. Moreover, the level of interface will depend on each service business case and rate of success. The availability, cost, size, and power consumption issues of the interface equipment poses the greatest opportunity for progress.

Table 4: Reference System Characteristics

a) Block Conversion

	Service Area	Unit Numbers	Block Converter	He-SH Fiber #
Headend	100,000	1		110
Secondary Hub (SH)	20,000	4		34
Fiber Nodes (FN) per SH	900	22		
Broadcast Services (50-550 MHz)	300	67		2
TSD services (550-750 MHz)	300	67	3 TO 1	22
Reverse Services (5-40 MHz)	300	67	16 TO 1	4
Number of Fibers per Node	9	255		

b) SONET

	Service Area	Unit Numbers	Block Converter	He-SH Fiber #
Headend	100,000	1		8
Secondary Hub (SH)	20,000	4		12
Fiber Nodes (FN) per SH	900	22	DFB	
Broadcast Services (50-550 MHz)	300	67	DFB	2
TSD services (550-750 MHz)	300	67	DFB/SONET	5
Reverse Services (5-40 MHz)	300	67	SONET	incl. in TSD
Number of Fibers per Node	9	205		

Table 5: Total Cost for Secondary Hubs

	Headend		Secondary Hub	
	Space (RU)	$	Space (RU)	$
FDM / Block		$1,819,358	912	$2,920,003
Conversion			**TOTAL**	**$4,739,361**

Hybrid: FDM for Broadcast,		$178,910	1,314	$2,338,530
SONET for Transactional			**TOTAL**	**$2,517,440**

OTHER CHOICES

Only one choice at present can challenge the SONET solution from the point of view of features and advantages, and most likely cost. This is a high density WDM technology. When applied in 1550 nm wavelength window, this technology can results in a completely passive network between the primary hub rings and optical node. Only WDM equipment (passive) would be located at the secondary hub level (if required) to maintain network redundancy. It would certainly require high density WDM techniques to stay within the reasonable limits for fiber count. The biggest disadvantage of this technology is the fact that it is not commercially available. Combination of this technology and some reverse block conversion in optical nodes can lower requirements for the density of wavelength-division multiplexing.

INDUSTRY CHALLENGE — SUMMARY

To make the SONET solution in secondary hub ring a viable option, the industry must move towards developing standardized interfaces between SONET and other digital transmission techniques. A preferable solution would be to select a multiple access protocol capable of supporting most of, if not all, the services we want to provide over coaxial RF network (ATM) and develop interfaces with an ATM protocol on both sides and with SONET and RF interfaces respectively. Of coarse , this standardization should aim at lowering the prices. TCI will work with the potential vendors on target prices.

Equally important is lowering power consumption and size of the interfaces (and other equipment such as modems, routers, servers) to lower our power and real estate requirements for secondary hubs. Current anticipation of 200 square ft and 400 square ft huts for secondary hub significantly increases our problems with site acquisitions.

We think that, given we make progress on the issues outlined above, SONET technology can be successfully applied in secondary hub rings and the same driven deeper into our network.

ACKNOWLEDGMENT

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Hoguta of TCI, Jeff Tokar of ANTEC, and Milo Medina, Jamie Howard, and other members of the engineering staff at @Home for their help in data gathering and their discussion about different matters expressed in this paper.

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[1] Dan Pike, Cable TV Strategies, Western Communication Forum. The other equation described in the paper states that "revenue equals expense plus a profit guaranteed by law".
[2] Rogers Engineering, A Comparison of Transport Technologies for the Rogers Intercity Network, Internal Rogers Report
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[4] James Farmer, Issues in Handling Cable Signals within Digital Optical Interconnect Networks, 1994 NCTA Technical Papers
[5] As in [3]