NEXT GENERATION CABLE NETWORK ARCHITECTURE

Stephen D. Dukes
Vice President, Advanced Network Development
Cable Television Laboratories, Inc.

ABSTRACT

Today's cable network is migrating from the traditional tree-and-branch topology originally designed for point-to-multipoint video entertainment to a star, tree-and-branch topology with a robust, dynamic capability for a wide range of applications beyond video entertainment. One of the major research efforts at CableLabs is focused on leveraging this newly evolving topology so that it can support applications such as multimedia and personal communication services (PCS).

The cable network is positioned to deliver digital signals that will reside above analog spectrum and to provide analog and digital fiber within the same sheath. This will allow the transparent transport of multimedia and PCS applications.

This paper addresses the concept of the regional hub, which provides connectivity to regional and national networks; the transport and interface requirements for analog and digital video entertainment and new applications; the attributes of interactivity and bi-directionality in cable's network design; and reliability and system performance over cable's infrastructure.

1.0 INTRODUCTION

Technology relative to new applications, like multimedia and PCS, is on a convergent path that has led to the integration of audio, data, video and graphics. Converging technologies make it possible to access a great deal of information through the use of a single system or the integration of a number of systems. Many of these advancements are occurring in parallel with advancements in cable network design.

Cable's broadband capacity will make the transport of these services technically feasible and economical. It is the cable network that is the missing link to myriad multimedia applications now being developed by the computer industry, by the consumer electronics manufacturers, by publishers, and by the motion picture industry. PCS will be economical on cable's infrastructure because of the cable network's robust, dynamic bandwidth. The differences between applications are distinct and the requirements are as unique as the implementation. However, cable's infrastructure can provide a common platform for all these new applications.

2.0 THE REGIONAL HUB

Currently, in any given region, it is likely that there will be more than one cable operator with one or more headends serving a portion of that geographical area. Service is provided independent of other operators, even though the cable operators may obtain some or most of their source material from the same programming providers. Hence, a duplication of satellite feeds, off-the-air equipment, and microwave facilities is required to secure this source. This plant might be shared across several headends in the same region owned by the same cable operator, however, usually not with other adjacent or separate cable operators in the region. This situation is further complicated by the fact that most operators provide functionality that duplicates that of other cable operators for video storage, advertisement insertion, etc. The result is slow implementation of new service opportunities.

A solution is the regional hub. A regional hub is a centralized facility that is tightly coupled to a dual ring network topology to interconnect headends located in a common geographic region. The dual ring topology may interconnect a single cable operator's headends or the headends of any number of MSOs operating in adjacent serving areas. A regional hub could be owned by a predominant cable operator in the region, a third party, or some other arrangement.

Centralization of capital-intensive investments for a range of advanced functionalities at the regional hub allows the cable operators to spread the investments across a wider base. It also provides a platform for offering a common set of functionalities to large and small operators. It allows multiple cable operators to share the additional revenue streams as well as the investments and risks associated with providing the advanced applications. This is particularly important because of re-regulation and the introduction of costly advanced-feature functionality.

In addition to the regional hub, cable's next generation architecture will include fiber nodes. Fiber nodes represent a new addition to the network as fiber is migrated further down in cable's network architecture. (See Figure 1 and Figure 2.) This incremental migration of fiber will minimize the need for a total network rebuild. This architecture was conceived to take into consideration a wide variety of network types so that no operator's network is made obsolete.

2.1 Functions of the Regional Hub

The regional hub is a centralized, shared facility that can serve many functions. It allows cable operators to negotiate programming arrangements in bulk that will potentially reduce programming costs. This is particularly important as a means of minimizing overall operating costs.

The regional hub can serve as the platform for:

- advanced television
- bulk program distribution
- storage facilities for network-distributed video on a regional basis
- mass storage for multi-channel pay per view and multimedia applications
- advertisement insertion facilities
- compression/decompression of video source
- advanced program guide for multi-channel systems
- PCS switching and cross-connecting facilities
- multimedia distribution
- automated network management capabilities

The regional hub also provides cable operators with a centralized platform of advanced systems for performing rapid prototyping of more advanced applications. As these applications are "proven in" and demand and revenue streams grow, advanced systems can be gracefully migrated down from the regional hub down to the headend, then from the headend to the fiber hub and, eventually, from the fiber hub to the fiber node. The regional hub can provide an access point to other networks including:

- local exchange carriers
- inter-exchange carriers
- alternate access carriers
- satellites
- microwave
- cellular
- off-the-air broadcast
- PCS providers

2.2 Applications

A range of multimedia applications is being considered as part of the requirement for interactive services. In order to characterize the transport and interface requirements of these applications, it is necessary to evaluate each application independently. A brief list identifying generalized application categories is provided below:

- education
- cable-commuting
- entertainment
- professional

- home shopping
- customer services
- information services
- wired and wireless telephony

2.3 Ring Interconnection

The regional hub provides an interface to other networks and to the headends in its region for real-time and non-real time programming source and control access. (See Figure 3.) This keeps the interconnection point at a higher hierarchical level and allows the cable industry to utilize protocols that are suited to cable's transport requirements. The interconnection of the regional hub to the headends will be through a dual ring topology.

The dual ring consists of analog and digital fiber facilities that are broadband, "self-healing," and bi-directional. The fiber cable contains digital and analog fibers in the same sheath. (Microwave may be used where fiber is uneconomical or inexpedient.)

The dual ring topology of choice is a dual ring, with one ring running clockwise and the other counter clockwise. This builds in considerably higher reliability and increases mean time between failure (MTBF) when compared to a star topology with fiber distributed between the regional hub and the headend.

The ring topology interconnects large and small cable operators to a wide variety of advanced applications, such as multimedia, PCS, wired telephony, and cellular radio, over a regional area (e.g., an entire metropolitan area). The ring protocol suite will be discussed in Section 2.12.

Many of the ring transport facilities already exist and can be leased through a competitive access provider (CAP) or a metropolitan area network (MAN) provider. Alternatively, they can be owned by a cable operator or a consortium of cable operators, by other transport providers, such as a local exchange carrier (LEC), an inter-exchange carrier (IXC), or by other private long haul carriers.

2.4 Systems Redundancy

With the centralization of advanced functionality in the regional hub, it is critical to have duplicate copies of systems, such as mass storage, video servers, and switching, since an outage of any system will have an impact on many headends and, subsequently, a large number of subscribers. Because the regional hub will provide service to large regional areas, it is important to provide redundancy not only on advanced systems but on primary and secondary regional hubs on the ring infrastructure. (See Figure 4.)

2.5 Secondary Backup of the Regional Hub

As advanced functionality is moved higher in the network hierarchy, redundant regional hub functionality becomes more important to avoid single points of failure on the ring. This means duplicate copies of each advanced and gateway system are necessary in order to avoid single points of failure. Secondary locations that mirror the functionality in the regional hub are necessary to ensure that if the regional hub is out of service, cable operators can still provide uninterrupted service to the subscriber base. (See Figure 5.)

2.6 Gateway to Other Networks

Since the regional hub facility serves as a gateway to other network types, i.e., the inter-exchange carriers, local exchange carriers, and other public and private networks, the gateway will initially have systems that are compatible with these networks. For example, interoperability with a network using synchronous optical network (SONET) would require SONET equipment with a gateway to the protocol in use on the regional hub ring infrastructure.

Over time, a series of specifications will be developed that identify the interface requirements of the regional hub. The need for systems that directly interface with other networks will be replaced by a need for equipment that complies with the protocols and systems used on the regional hub dual ring infrastructure. (See Figure 6.)

2.7 Tightly Coupled Rings

To cover a larger geographical area and to reduce the price floor of the advanced functionality of the regional hub, rings are coupled. The interconnection of tightly coupled rings to the main ring extends the reach of the regional hub and offers access to the same complement of advanced functionalities. This extended coverage allows for interconnection of many headends in a regional area. Testing will determine what radius the ring can support. For example in the state of Colorado, the main ring could serve an area such as Denver with coupled rings extending north to Boulder and another ring reaching south to Colorado Springs. Along the way, other, smaller systems interconnect the ring. (See Figure 7.)

2.8 Avoiding Single Points of Failure

The coupled rings interconnect with the primary ring in two different locations to avoid single points of failure. This ensures that the same level of performance and reliability exists on the secondary rings as is provided on the main ring. (See Figure 8.)

2.9 Links to Adjacent Headends

An additional point of interconnection is provided through a link to adjacent headends. This link ensures connectivity to the regional hub dual ring infrastructure in the event of a headend outage or other catastrophic circumstances. (See Figure 9.)

2.10 Virtual Ring

The regional hub design lays out a virtual ring to provide physical route diversity between the fiber hubs which are subtended from a single headend on the regional hub ring. (See Figure 2.) The link between the headend and the fiber hub is the primary path. However, a secondary link between adjacent fiber hubs provides an alternate route to ensure connectivity between all fiber hubs and the headend. This capability is possible through the physical connection between the adjacent fiber hubs and a manual or dynamic cross-connect functionality at each fiber hub.

In the event of a fiber cut or an outage on the link between the headend and the fiber hub, an alternative path is provided through an adjacent fiber hub with active linkage to the headend. This linkage allows for continuity of service during a cable cut or link failure. The transfer from the primary fiber system to the alternate route can be provided through manual or automated systems, such as a cross-connect.

Virtual ring capability is not extended below the fiber hub because of the cost and the limited number of subscribers served by the fiber node, i.e., 200 homes passed.

2.11 Capacity on the Regional Hub Ring

The capacity of the ring infrastructure is determined by the fiber count, the bit rate, and the ratio of digital compression. The number of fibers in the fiber sheath is determined by the types of traffic and applications.

2.12 Transport Protocols

CableLabs is currently assessing various protocols to develop a matrix mapping their various parameters. This will provide CableLabs with the tools needed to select the appropriate protocols and interfaces that are well suited to cable's requirements.

Protocols that show promise include IEEE 802.6, known as distributed queue dual bus (DQDB); IEEE 802.6, distributed queue random access protocol (DQRAP); frame relay; SONET; IBM

PARIS; and fiber distributed data interface (FDDI) with some form of layer two, asynchronous-transfer-mode- (ATM) like, fast-packet functionality. It is possible to use attributes from each protocol to facilitate the most efficient delivery from the regional hub to the home, either from an end-to-end basis or within the ring itself. The need to minimize cost and complexity will determine the selection of an appropriate suite of protocols.

An area of concern with the use of ATM is the fact it discards lost packets. If a particular ATM packet is critical, such as in digital video compression, this may result in the loss or degradation of the picture at the subscriber's display. On the other hand, the loss of cells should be negligible in a fiber-based ring system and in the hybrid fiber/coax distribution. ATM may be a good transport mechanism in the ring and on the fiber portion of the cable distribution plant, but its use all the way to the home requires further analysis.

While economics will play a major role in determining when or if ATM will become feasible for transport on the ring or in the local distribution, another determining factor is the type of traffic being carried. A determinant in this transition is likely to be when some unknown threshold is achieved in which traffic on the network migrates from a constant bit rate (CBR), fixed bandwidth to a variable bit rate (VBR), bursty data characteristic. Until that threshold occurs, it is likely that synchronous transport of traffic on the regional hub ring and the local distribution will suffice.

2.13 Business Access

The original research and development of the regional hub architecture focused on providing service to the residential subscriber. However, recent interest in serving the business customer has stimulated CableLabs research to focus on the best approach to meet this potential opportunity while continuing to evolve the network for residential applications and services.

While a virtual ring serves to provide physical route diversity, a virtual private ring network functions as a physical overlay for business applications. The virtual private ring network may reside in the same fiber sheath as the virtual ring, but the virtual private ring network will provide transport solely to business traffic. (See Figure 10.) A virtual private ring network uses a ring topology that interconnects the business customer at specific points of access through a separate transmission facility. Physically this links the business traffic to the regional hub ring through the headend. This approach provides the business customer with connectivity to areas served by the regional hub and with access to the public switched telephone network (PSTN) and private networks.

A different scenario has fiber hubs or fiber nodes as points of access for business traffic to cable's infrastructure, instead of a dedicated virtual private ring network. In this set up, the fiber hub or node is deployed at the business customer's facility and linked to the regional hub ring through a virtual network to the headend. These fiber hubs and fiber nodes are dedicated facilities in the sense that no residential services are provided from the fiber hub or node through the transport facility supporting this traffic. (See Figure 11.)

2.14 Regional Hub Serves as Gateway to National Infrastructure

Because the regional hub is centrally located within given geographic regions, it is a logical gateway for state and national network interconnections. The interconnection of regional hubs in a statewide configuration is already underway in one state (Pennsylvania) and other states are considering this type of infrastructure. The regional hub can also serve as a gateway to local regions for the national infrastructure.

2.15 Regional Hub Implementation

The initial deployment of the ring is likely to take the form of back-to-back multiplexing at each of the headends subtended from the regional hub. Functionality will be provided in early implementation through the sharing of resources already deployed in one or more locations, i.e., one headend may provide advanced television signals to multiple headends through the ring topology, while another headend may offer advertisement insertion to the same group of headends owned either solely or through several cable operators. (See Figure 3.) As the regionalized concept evolves, a single location will be identified as the regional hub with the collective functionality centralized for efficient utilization and operation.

Implementation may occur more rapidly if a single cable operator is considering linkage of many headends to the ring and centralizing functionality, as opposed to an operating environment where more than one cable operator is involved. The latter would necessitate establishing business and operating agreements, prior to implementation.

2.16 Regional Hub Migration

The migration to this network architecture is graceful in that it provides a path to the future without stranding existing network capital investments. For example, cable operator #1 may choose to migrate the fiber node concept over time. Cable operator #2 may choose to migrate to 500 homes passed now; while cable operator #3 may migrate to the fiber hub and go no further. Obviously, the more closely the cable operator follows the network architecture migration path, the greater the functionality and revenue opportunities possible.

2.17 Benefits of the Regional Hub

The regional hub architecture concept is based on the philosophy of the original tree/branch topology, i.e., share as much of the infrastructure as possible before dedicating transmission facilities to each individual subscriber. Here are some of its advantages:

- centralized advanced functionality lowers price floor for services on a shared basis
- centralized advanced functionality allows for consolidation and elimination of some headends
- connectivity to regional markets that have typically been fragmented markets for the cable industry
- access to advanced intelligent network capabilities
- centralized human resources and reduced operating expenses
- an alternative to switching functionality and interconnections with public and private networks
- a platform for shared access to mass storage for multi-channel pay-per-view and multimedia applications
- a platform for information services providers to introduce new services and test the market in a large geographical area
- access at a single point of interconnection is available to other network providers, such as IXCs, LECs and private networks
- a platform for rapid prototyping of new technologies and services

A major advantage of the regional hub concept is that it allows flexibility in transitioning through new technologies and unproven marketing schemes. The initial commitment is only in one place, the regional hub. As success feeds growth, and demand and revenue streams increase for specific services, advanced functionality may be migrated further into the infrastructure closer to the subscriber.

As an example of this process, if mass storage costs are estimated to be $2 million for each headend for multi-channel pay per view, and a given regional hub ring provides access to 30 headends, the total cost for mass storage for these headends is $60 million. In order for the regional hub to be cost effective, the costs of the regional hub and the ring infrastructure must be less than the distributed functionality. Obviously, the aggregate of the cost savings associated with additional advanced functionality further supports the implementation of the regional hub. Of course, centralized functionalities also imply shared risks and benefits for cable operators using the concept.

3.0 TECHNICAL CONSIDERATIONS

Research at CableLabs is focused on resolving network issues to position cable as a transport provider of analog and digital video entertainment, multimedia, and PCS applications. There are a number of technical challenges which are discussed below.

3.1 Interactivity/Return Path

Most cable systems are able to provide bi-directional capabilities. The downstream direction can exist in available spectrum from 50 to 550 MHz and on some new systems, 50 MHz to 1 GHz. The return path, or the upstream direction, typically is limited to 5 to 30 MHz and it will serve as an interim solution until more efficient approaches are available.

The need for additional return path spectrum has led to research in designing a passive coaxial network, a parallel coaxial network design from the fiber node to the home, and a mid-split system. The passive coaxial design focuses on the elimination of all the active components in the network so that the spectrum for upstream requirements can be allocated in a dynamic fashion based on fixed or variable transaction-based requirements.

Applications such as PCS will require bi-directional functionality and some form of switching and control. Switching, as referenced here, should not be limited to traditional switching techniques. It may be as simple as multiplexing or more complex approaches, such as fast packet, may be appropriate.

A challenge for the cable industry is to clear a block of frequencies that can be allocated to multimedia and PCS applications. Locating large blocks of unused spectrum is a challenge since most cable operators utilize most or all of their system's existing spectrum. Channel alignment is largely a marketing issue that is not technical in nature because channels are lined up with those used by local broadcasters and others. Ultimately, however, a tiered approach to common channel line up will aid in the allocation of spectrum in a more uniform manner for each cable system nationwide.

3.2 Switching Requirements

PCS and wired telephony require switching functionality. Two approaches to switching are being considered: (1) traditional class 5 central office switching with centrex capabilities and (2) distributed switching. The centrex solution offers each cable operator or headend access to only the number of lines required for paying subscribers. As each operator's customer base grows, additional lines can be accessed without having to purchase more hardware. If an operator's customer base decreases, the number of lines can be reduced. Since the centrex system can be partitioned, security is not an issue.

The distributed switching approach offers the cable operator a "pay as you go" deployment methodology that adds switching fabric as customers join the network incrementally.

3.3 Bandwidth and Channel Capacity Requirements

Bandwidth is considered to be another limiting factor for multimedia applications on cable. In cable's existing and future designs, the view of multimedia is for highly asymmetric conditions, with the downstream bandwidth requirements greatly exceeding the upstream requirements.

Initially, one or two channels will handle the upstream demand. As demand increases, however, more cohesive plans for additional upstream spectrum must be developed to maintain pace with multimedia developments. These plans include migration of fiber further down the infrastructure, improvements in laser technology (that allow more than 100 channels on a single fiber), the passive coaxial network that supports dynamic allocation of bandwidth, and digital compression. (Section 3.7 discusses the additional impact digital compression has on multimedia.)

3.4 Throughput

Throughput for PCS can be managed with traditional telephony approaches, however, multimedia applications will require coding techniques to efficiently utilize the broadband bandwidth of the network.

The Multimedia and Hypermedia Expert Group (MHEG) is developing coding for multimedia to manage throughput on the transport infrastructure. Interleaving may be necessary for audio and video sequences. This coding is needed to determine if sufficient throughput on the network or storage capabilities is available for real time or non-real time transactions.

Ethernet applications over cable requiring 10 Mbps throughput are already available within a 6 MHz channel. Moving Pictures Experts Group (MPEG) applications will require bandwidth ranging from 1.5 Mbps to 100 Mbps. Other algorithms are being developed that will allow for throughput capabilities at 20 to 30 Mbps on a single 6 MHz channel.

3.5 Performance and Reliability

The migration of fiber deeper into cable's infrastructure improves network performance and reliability. This is largely due to the reduction in the number of active components in the network, i.e., amplifiers and line extenders. The largest improvement is achieved through the deployment of fiber from the headend to the fiber hub. This reduces amplifier cascades to no more than four amplifiers and two line extenders between the headend and any home. Further installation of fiber from the fiber hub to the fiber node provides only marginal improvement in network performance and reliability because the number of remaining active components eliminated can only be less than six. Future designs will seek to eliminate the active components on the coaxial plant entirely and add amplification at the residential unit. These migratory changes will result in continued improvements in performance and reliability.

Initial research indicates that a dual ring topology is preferred over a star topology because of a dramatic improvement in MTBF. The star approach yields a five-month MTBF, whereas a dual ring topology exhibits a 60.2-year MTBF.

The investment in the additional link to create the dual ring topology obviously has tremendous pay off. Because of its advantages, this technology could also be applied between the headend and the fiber hub. A summary of the results of this research will be made available in the near future.

3.6 Network Management

The existing approach to network maintenance is not reliable enough to support multimedia and PCS applications. For example, the practice of removing an amplifier from service to test its integrity cannot be tolerated with these new applications. The passive coaxial network makes it easier for the cable operator to eliminate this component and to introduce an automated, dynamic approach to network management from a centralized facility, such as the regional hub. This can lead to additional quality improvements and operating-cost economies.

Implementation of network management will evolve in three distinct areas: (1) dual ring topology, (2) cable distribution with two components, i.e., the virtual ring for route diversity and the local distribution over the coaxial, tree/branch topology, and (3) the virtual private ring network for business transport and access.

3.7 Digital Transport and Compression

Applications like multimedia, PCS and wired telephony will require digital transport over cable's infrastructure. In the digital domain, it is likely the reference will continue to be a 6 MHz channel. However, over time, the reference will be a function of compression and bits per second as related to a channel.

Digital compression will have a significant impact on the digital video component of multimedia. For example, using 150 existing downstream channels with 70 channels devoted to digital transport, a 10:1 digital compression scheme will produce 700 digital channels, with the balance of 80 channels remaining analog. For cable operators who choose to offer digital source over existing 550 MHz systems, the spectrum can be allocated with analog programming residing between 50 to 300 MHz and the digital source between 300 to 550 MHz. At 10 to 1 compression, this split will provide over 400 digital programming choices coupled with over 40 analog programming choices simultaneously.

In the initial stages of digital video, compression facilities will be located at the satellite uplink facility with decompression functionality at the home. However, the next migration of compression and decompression will likely occur at the regional hub.

3.8 Synchronization

Some form of global synchronization is necessary for multimedia applications. Synchronization is used to correct the multimedia application when unacceptable delays occur in the transport of the various data streams.

Digital video compression is only one of at least four components of multimedia (audio, data, graphics and video). While algorithms of up to 10:1 are being used for digital video, schemes for audio and data communications are likely to use a different compression algorithm. From a transport perspective, this may mean four separate signals or a single bit stream, and it obviously represents increased complexity. With these signals residing in different compression formats, a lossless network compression scheme will be necessary in addition to the compression formats already applied to MPEG.

In addition, the audio component must be synchronized with the digital video to ensure lip synchronization. Bit stuffing while an application is idle may be required. This approach assumes a dedicated channel for each user, which may not be feasible. A more likely approach on a cable infrastructure is to allocate bandwidth dynamically for each session.

If synchronization is the responsibility of the computer and consumer electronics manufacturers, then this requirement may be innocuous. If, however, it is a function of the network, then it is likely that no single synchronization plan will be achievable without a worldwide protocol. This is largely due to the dissimilar characteristics of transport providers and storage capabilities, along with the various stages of functionality that may reside within these networks, i.e., digital and analog and other divergent functionalities. This requirement is likely to be the source of great debate for some time to come.

3.9 Video Coding and Systems

It is desirable to design a decoder that is low cost, with the majority of expense and complexity in the encoder. The encoder will initially reside at the satellite uplink with a migration to a cable regional hub that serves multiple headends in large geographic regions.

3.10 Mass Storage

Typically, transport rates exceed the processing capabilities of most computer systems. The variability between speed of transport and of processing necessitates storage on a large scale. To minimize the cost of mass storage systems, it will first be essential to locate storage capabilities as high as feasible in the infrastructure, such as at the regional hub. Studies indicate that as the demand for video source increases, it will be necessary to migrate the storage capacity lower in the infrastructure from the regional hub to the headend, for example. For cable systems, mass storage may be shared among multimedia and other applications, such as multi-channel pay per view.

The economics of the storage problem will probably drive the final resolution of the mass storage dilemma. Mass storage in a compressed mode is an alternative to storing uncompressed video source. This method simplifies the network interface and ensures that the network is essentially transparent. It also would reduce the need for additional decoding and encoding functionality at the regional hub and the headend. Instead, the encoding and decoding functionality could reside at the satellite-uplink facility and in the home.

3.11 Security/Privacy

The use of a dual ring topology to access the regional hub and the headends raises issues of security and privacy of information. Several approaches can be implemented including customer-owned encryption or a scheme that is inherent within the cable infrastructure.

3.12 Data Stream Protocol

An open protocol is critical to the success of multimedia, PCS and other information services. Many of the technical attributes described above are being developed by CableLabs. This research focuses on an out-of-band data stream protocol that provides for constant bit rate, low-speed and high-speed protocols in predetermined frequencies common to participating cable systems, and variable bit rate capabilities that dynamically allocate spectrum over unused portions of the cable spectrum. Spectrum allocation will address the downstream and upstream paths for these applications. The data stream protocol in many cases emulates the inband capabilities of the vertical blanking interval (VBI), however, at higher data rates.

A low-speed protocol will support services such as an advanced program guide and low-speed multimedia applications. The low-speed component of the data stream protocol provides for a range of bit rates from 19.2 kbps to 1.5 Mbps.

A high-speed protocol is intended to support MPEG 2 type applications for multimedia. These data rates will include 10 Mbps with multiples of 10 Mpbs, i.e., 20 and 30 Mbps.

3.13 Administration, Operations and Support

Administrative, operations and support functionality, such as operator services, billing and signaling system 7, could be contracted on a third-party basis until demand justifies cable's provisioning of these capabilities internally. For example, these services could be acquired through negotiations with an IXC or IXCs, in turn for a reduction in access charges.

4.0 THE HYBRID FIBER/PASSIVE COAXIAL NETWORK

Coaxial-based systems are common throughout North America. The all-coaxial cable design is migrating to a hybrid fiber and coaxial network design when systems are upgraded or there is new construction. Both designs deliver analog signals.

Fiber is being deployed because it enables a substantial improvement in system performance and reliability through its low-loss, increased passband characteristics, and significant reduction in the number of active components. This greatly increases downstream passband capability.

4.1 Fiber Hubs and Nodes

In the hybrid fiber and coax system, fiber cables are provided from the headend to fiber hubs that are centrally located among about 2,000 homes passed. (See Figure 12.) These hubs feed fiber to nodes that serve 200 homes passed. Thus, 10 fiber nodes are served by a single fiber hub. (Figure 2 illustrates the hybrid fiber and coaxial cable system network architecture hierarchy.) The connections between the headend and the fiber hubs and the hub-to-hub interconnections provide "virtual" ring capability and true physical routing diversity.

The fiber node improves system performance, reliability, and flexibility and reduces operating costs. By using a fiber node to bring fiber closer to the subscriber, we may be able to eliminate active components, i.e., amplifiers and line extenders, in the coaxial, tree/branch portion of the network. This means that the signal that is transmitted from the fiber node must be strong enough to reach the home without amplification. The signal then is amplified at the home by a low-noise amplifier (LNA). The specifications of the LNA are currently under development at CableLabs.

4.2 Low-Noise Amplifier

The LNA would not only amplify the signal, but serve as a line of demarcation between the network and the home and protect the cable system from noise generated within the home. (See Figure 2 for the LNA in the home.) It also would support an increasing number of television sets, VCRs and other display systems in the home. The LNA could be integrated into the consumer electronics interface that may be part of the converter or set-top box, or it could be a separate device attached to the side of the home.

Amplifiers and line extenders have been necessary in existing networks, but they represent a bottleneck in re-allocating spectrum for return path transport. Once the active components of the coaxial plant are eliminated, the bandwidth on the coaxial transmission medium can provide additional spectrum for upstream requirements on a transactional basis. CableLabs is examining methods to dynamically allocate spectrum through the use of an LNA in the home on a passive coaxial network design. (See Figures 13 and 14.) This functionality of the LNA may ultimately be integrated into a home server or point of entry device.

4.3 Parallel Coaxial Network Design

An interim step to increasing bandwidth on the return path is the deployment of parallel coaxial plant with amplifiers directed upstream. (See Figure 15.) Access to the parallel coaxial transmission facilities will be provided to subscribers desiring interactive services. This will minimize the noise funneling effect on the return path.

4.4 Local Distribution Transport Protocols

One protocol that shows promise is the IEEE 802.6, DQRAP. While this protocol is in the development stages, it appears to be far more efficient than Ethernet for the tree/branch topology with multiple points of contention. Each branch on the tree/branch topology is a single point of contention. The drop appears as a LAN connection to the bus infrastructure. DQRAP is a slotted protocol that allows multiple attempts without denying access to all users attempting to access the network in the same time slot. This protocol promises to support the delivery of video entertainment and other information services from the headend to the home, on an end-to-end basis.

Since DQRAP is a physical layer protocol, it may well provide the necessary physical transmission functionality needed to support ATM. As was pointed out earlier, lost cells are likely to enter into the use of ATM over the tree/branch, coaxial network, either in a passive or active coaxial infrastructure. The loss of cells should be negligible in the hybrid fiber/coax distribution. While ATM may be a useful protocol higher up in the infrastructure, use of ATM over DQRAP will require further analysis to determine the feasibility over the tree/branch, coaxial component of the local distribution.

Migration of ATM into the local distribution of a cable network is dependent on technical and economic considerations. Even more important, when traffic that is fixed bandwidth, constant bit rate, is dominated more by variable bit rate, bursty applications, it begins to impact the traffic congestion and contention on the infrastructure. Initially, ATM is likely to be implemented on the regional hub dual ring for PCS and multimedia applications and the virtual private ring network for business applications. However, the use of ATM for voice remains an issue due to packet fill and corresponding delays in transmitting voice in a fast-packet environment.

4.5 RADs at Fiber Hubs and Nodes

The fiber hub and fiber node are candidates for housing a remote antenna driver (RAD) in the cable network. The RAD is a distributed radio antenna technology that provides service to PCS cells. The RAD design takes advantage of bandwidth on the cable infrastructure while centralizing complexity higher in the cable infrastructure at a remote antenna signal processor (RASP) or base station translator. This approach allows the cable operator to deploy these RADs at locations like the fiber node without the distributed complexity used in other approaches to PCS.

4.6 Fiber to the Fiber Node

As it becomes more economical, fiber (4 to 10 fibers in a sheath) will be deployed from the fiber hub to the fiber node, with each fiber node serving no more than 200 homes passed. Since the fiber hub and fiber node do not have switching or multiplexing functionality, no concentration of transmission facilities currently exists at the fiber hub, with each fiber hub serving approximately 2,000 homes passed. As a result, 40 to 100 fibers transit from the fiber node to the headend

Eventually, as the traffic migrates from a predominantly fixed bandwidth analog network to a hybrid analog and digital network with variable-bit-rate, bursty transactions, some form of switching may be distributed to the fiber hub or fiber node from the regional hub or headend. As a result, concentration may be used that would free up many of the fibers between the headend and the fiber hub for other applications, including the virtual private ring network for business access.

4.7 Distributed Switching

Studies indicate that most of the calls made in the local distribution of the PSTN do not go beyond the area served by a remote switch. As the demand increases for new applications, such as PCS and wired telephony, distributed switching will need to be deployed at the fiber hub or fiber node in cable's infrastructure to support these call patterns.

5.0 INTERFACE REQUIREMENTS

CableLabs is represented on various American National Standards Institute (ANSI) work groups and other fast-track standards organizations that establish the appropriate interface standards for multimedia and PCS.

Before multimedia becomes a common fixture in our society, the single most important attribute to be addressed is an interface platform that must be simple and transparent to the end user. Currently, a proliferation of interfaces exists in the computer, consumer electronics, and information provider industries.

The initial interface from cable network to multimedia applications may be through a data port on the set-top converter. A more desirable approach to this interface, as far as the cable operator is concerned, will likely be some form of multiport, such as an IS-15 protocol approach, which is integrated into the back of the computer system or the consumer electronics device.

For the computer industry, the transport provider should focus on interfaces that already exist and are well understood. CableLabs' focus will initially be on the attributes of the physical, data link, and network layers in an effort to position for whatever interface standards may be adopted for multimedia applications. However, it will be necessary to understand the transport layer and other higher layer attributes relative to specific applications. This will ensure that cable is compatible with multimedia interfaces as they are defined.

MPEG may play a significant role in simplifying the interface requirements for multimedia applications. The series of MPEG standards addresses digital compression and decompression relative to motion picture and audio source used in computer systems.

A common air interface for PCS will be required and is being developed by standards organizations (Telocator, T1A1, T1E1, T1P1 and WIN Forum) of which CableLabs is a member.

6.0 REGIONAL HUB FIELD TESTS

CableLabs regional hub field tests are structured as a series of small tests. They will examine the following:

- redundancy levels on the dual ring facility and possibly on the equipment in the regional hub
- measurements of distance limitations
- coupling of rings
- delay, echo, and frequency shifting at the headend
- the need for amplification on the dual ring
- throughput capabilities
- bandwidth requirements
- measurement of BER
- security, and other relevant tests.
- evaluation of the number of nodes that are achievable on a ring using frame relay
- analysis of a series of protocols

Another important aspect of the field tests is to show that the architecture is independent of the transport medium but that transport is dependent on the bandwidth requirements of the various applications. As part of this experiment, compressed digital video will be tested through a microwave link. The following list summarizes field tests scheduled for 1993.

6.1 Boston

The Boston regional hub which will be used in testing consists of a fiber link that is soon to be upgraded to a SONET fiber infrastructure. It will serve as the backbone for the field test. The field test will focus on advertisement insertion, centralized PCS switching, and cable-commuting applications.

The potential participants of this field test include Continental, Time Warner, TCI and Cablevision Systems. The advertisement insertion test will involve insertion of advertisement into existing programming from a regional hub to one or more headends. The switching for the PCS field test would use the Teleport 5ESS with base stations placed on the Continental and Time Warner systems. Another application will address cable-commuting, using DEC and LANCity equipment to provide a 10 Mbps Ethernet link over an existing 6 MHz channel.

These applications are directed toward validating the interactive capabilities of the dual ring infrastructure coupled with two or more headends linked to a centralized switching facility on the ring or coupled to the ring.

6.2 Northeast

The field test activity tentatively slated for the Northeast will test the notion of tightly coupled rings, and the use of SONET as a physical layer transport with specific attention directed toward the add/drop capabilities of the SONET equipment. Another possible application will include advertisement insertion. One potential candidate for this test is Adelphia and their CAP affiliate, Hyperion.

6.3 Seattle

Potential cable participants for a field test in the Pacific Northwest later this year are TCI and Viacom. Because TCI and Viacom already have established a separate entity to provide advertisement insertion, this appears to be an excellent location to test this functionality on the rings.

The rings transit over the greater Seattle area and interconnect TCI and Viacom. The ring transport is likely to be provided by a competitive access provider, as yet undetermined.

The topology will consist of two rings tightly coupled at a point in north Seattle. One ring will cover the region around Lake Washington. The other will provide the transport between Snohomish County and the city of Seattle.

6.4 Toronto

CableLabs and Rogers are currently examining the possibility of testing centralized network management for the dual ring infrastructure and the local distribution on an existing cable system. Another likely candidate would be advertisement insertion.

7.0 RESULTS OF THE REGIONAL HUB FIELD TESTS

The initial field test results will be evaluated by CableLabs staff and the CableLabs Technical Advisory Network Development Subcommittee. After a thorough analysis, the data will be made available to CableLabs member companies.

8.0 AREAS OF FUTURE FIELD TESTS

Future tests will include the following areas: the migration of fiber from the hub to the node, the virtual ring for route diversity between the headend and fiber hubs, and the virtual private ring for business access and interconnection of the regional hub to other networks, such as interexchange carriers, local exchange carriers, and private networks.

9.0 CONCLUSION

Cable's next generation network architecture will provide a uniform structure for migrating network designs. While the migration path may differ from one cable operator to another, ultimately it will provide a common structure that will serve to position cable for future revenues and business opportunities. It will allow cable to increase functionality and reliability, to eliminate active components in the coaxial plant, and to migrate functionality to a lower level in the network hierarchy as demand increases.

The regional hub concept allows rapid prototyping of new services, shared investment and benefit, uniformity of network access for large and small operators, and interoperability with other networks.

With the migration of fiber into cable network designs, improved reliability and signal quality and increased capacity are yielding many opportunities to transport new applications and to explore many new business opportunities.

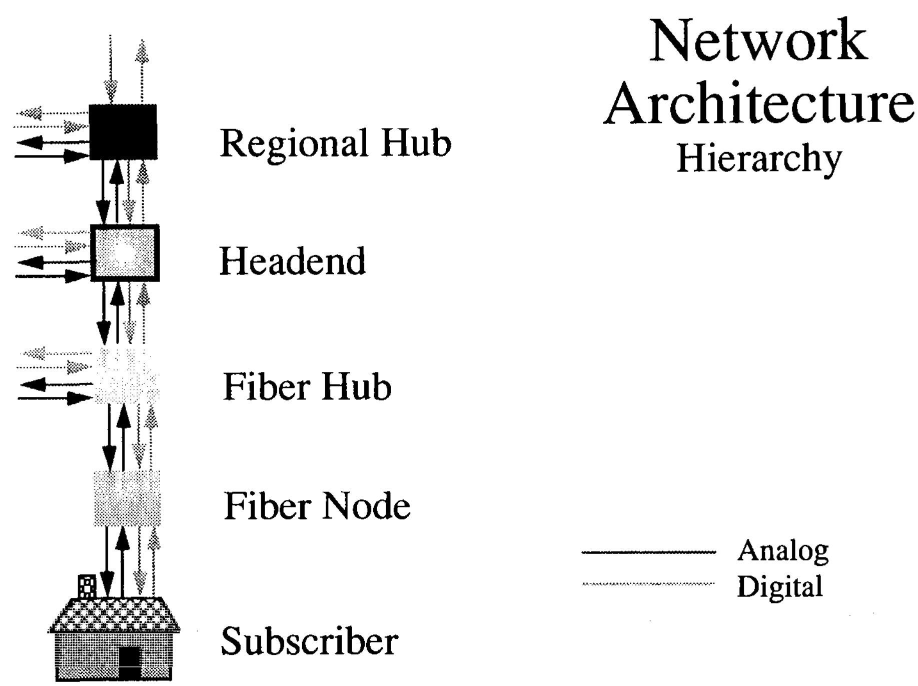

Figure 1

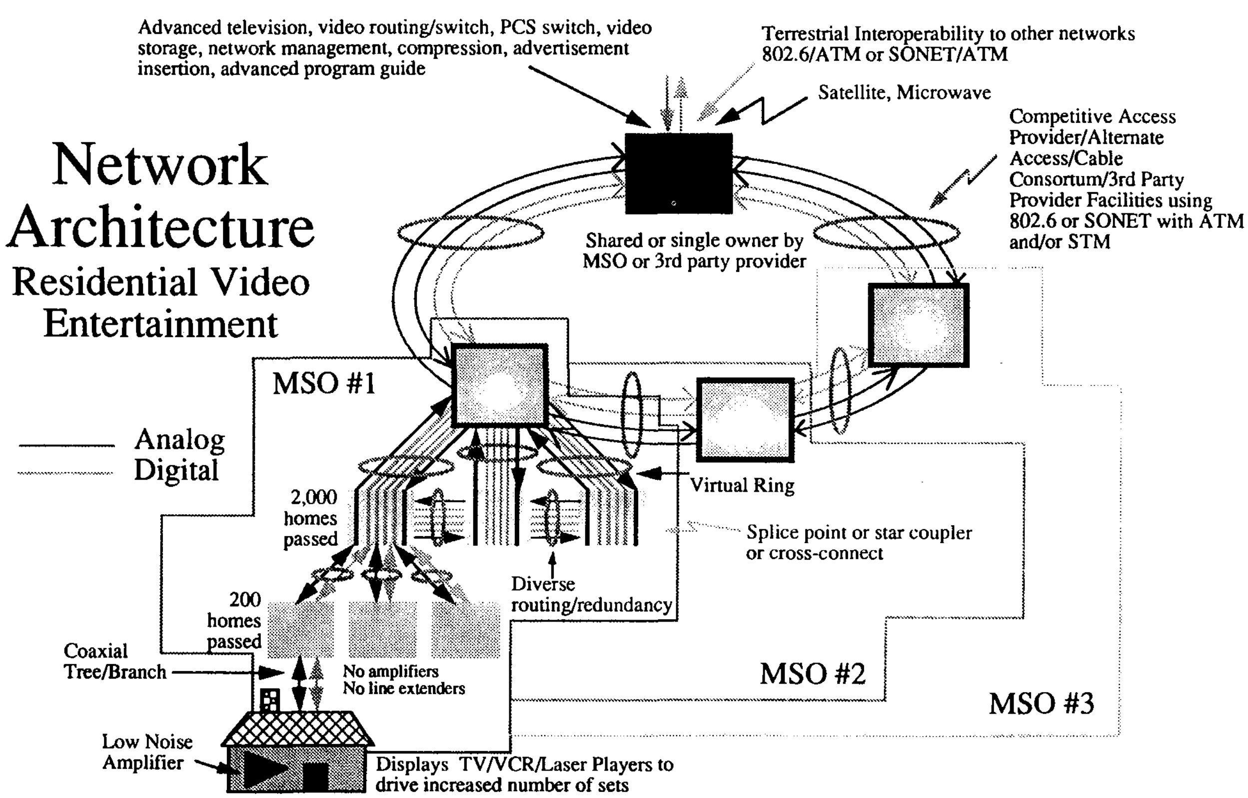

Figure 2

Network Architecture

Regional Hub Concept

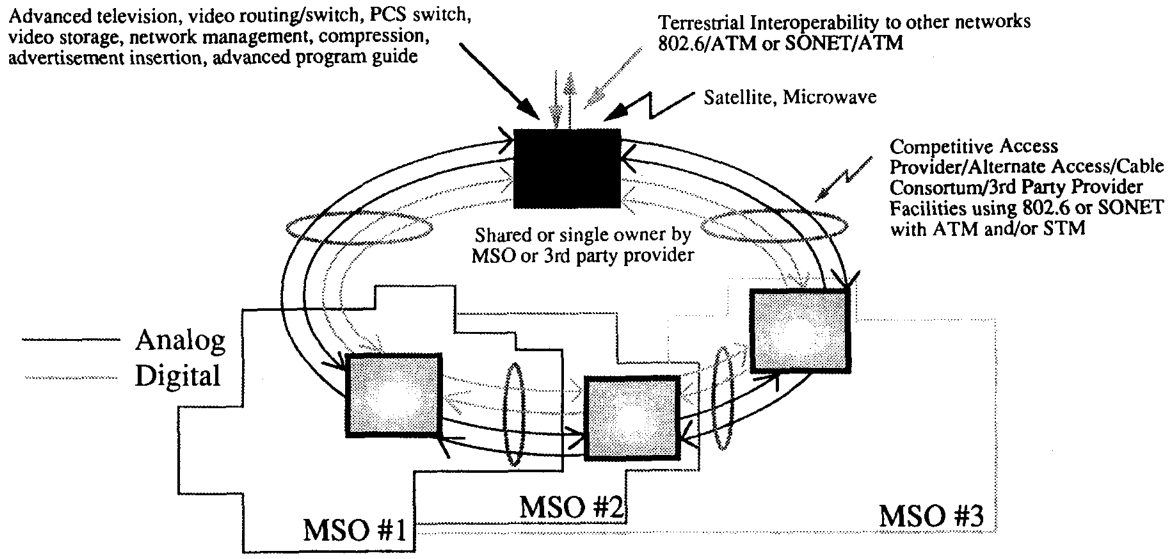

Figure 3

Network Architecture

Systems Redundancy

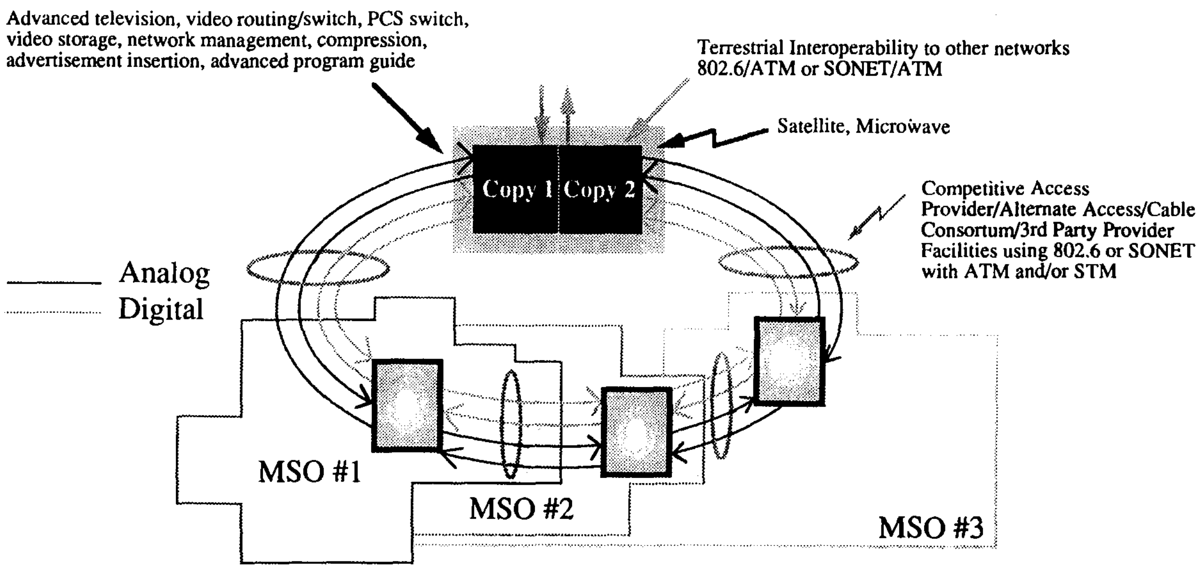

Figure 4

Network Architecture

Regional Hub Distributed Redundancy

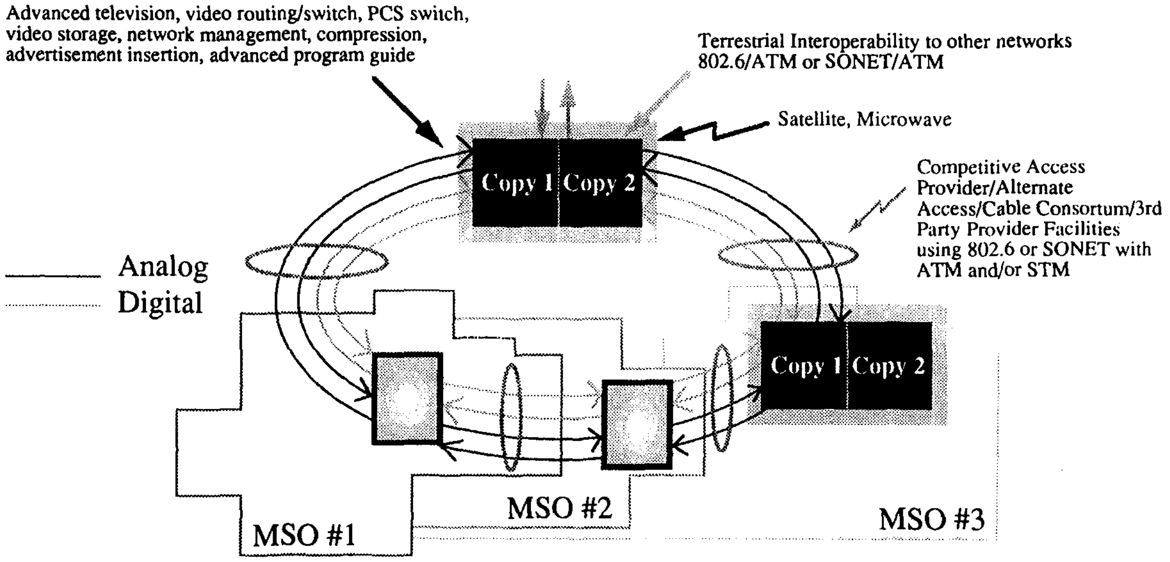

Figure 5

Network Architecture

Regional Hub Gateway

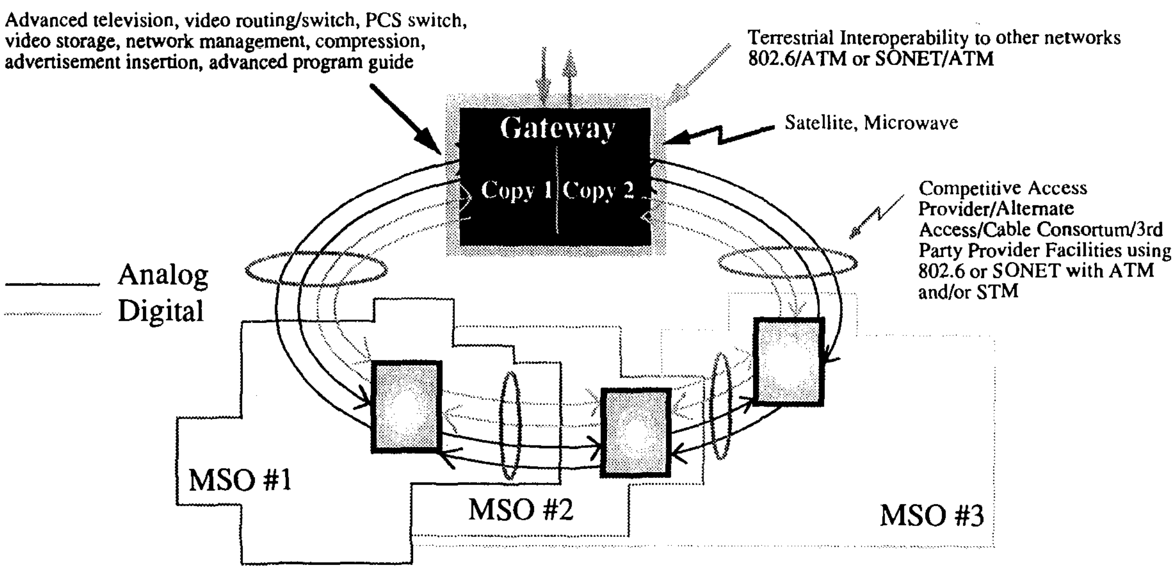

Figure 6

Network Architecture

Coupled Rings

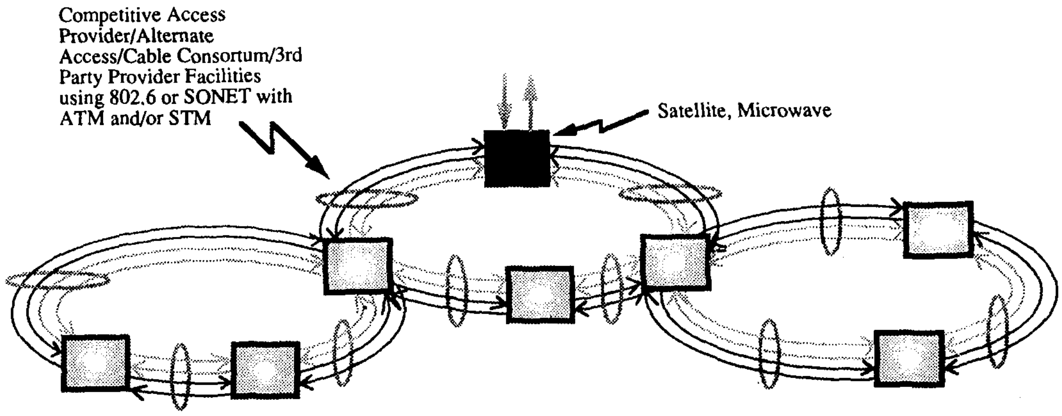

Figure 7

Network Architecture

Avoiding Single Points Of Failure

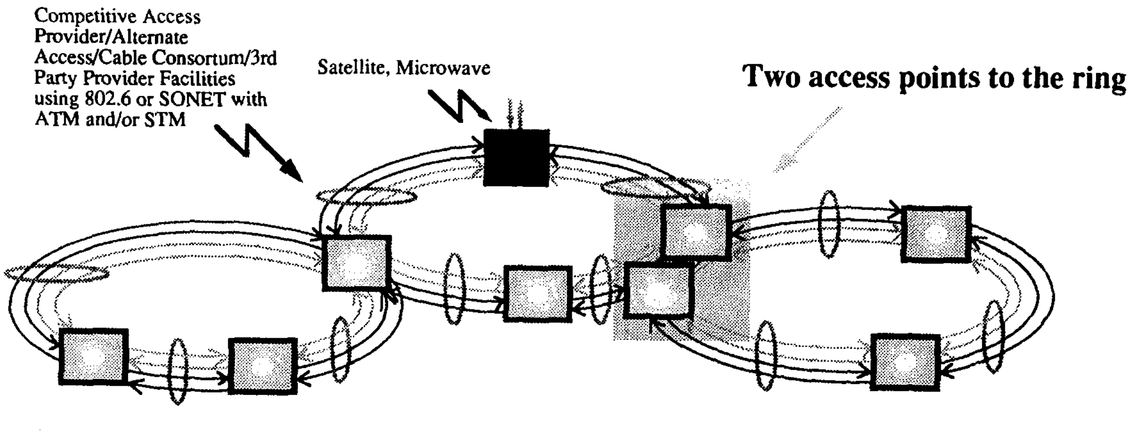

Figure 8

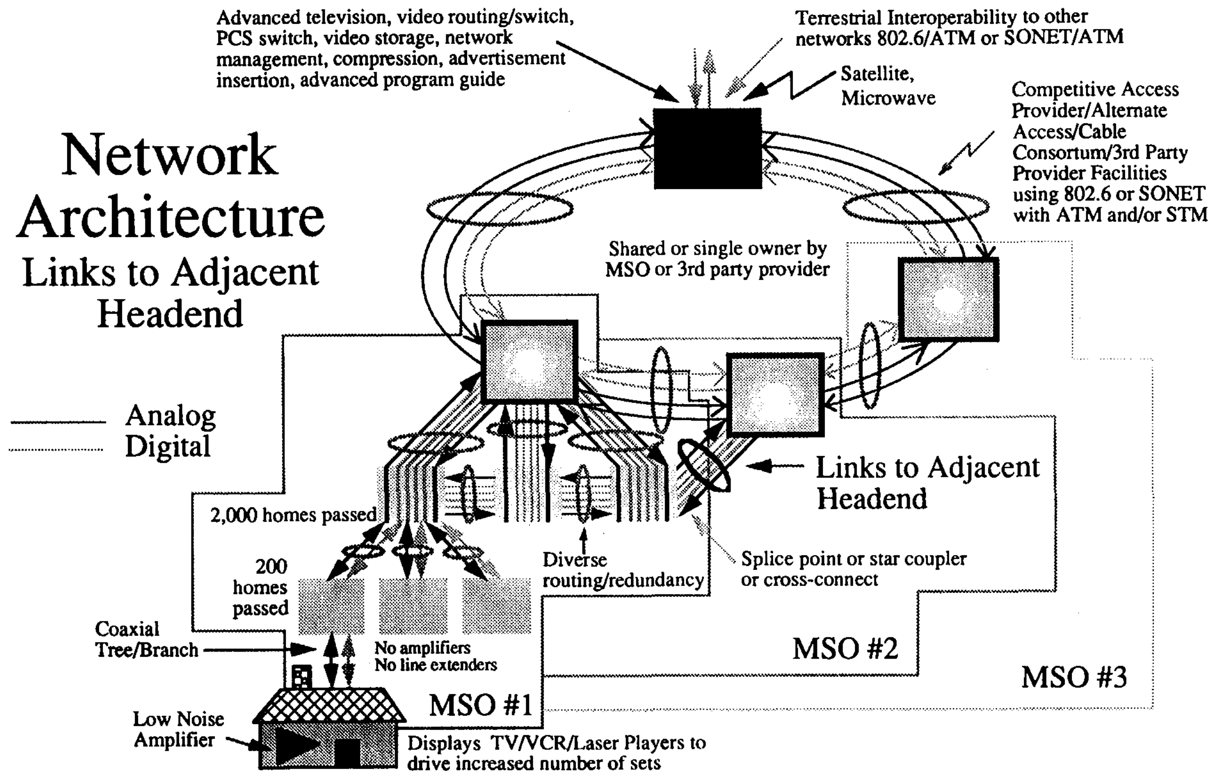

Figure 9

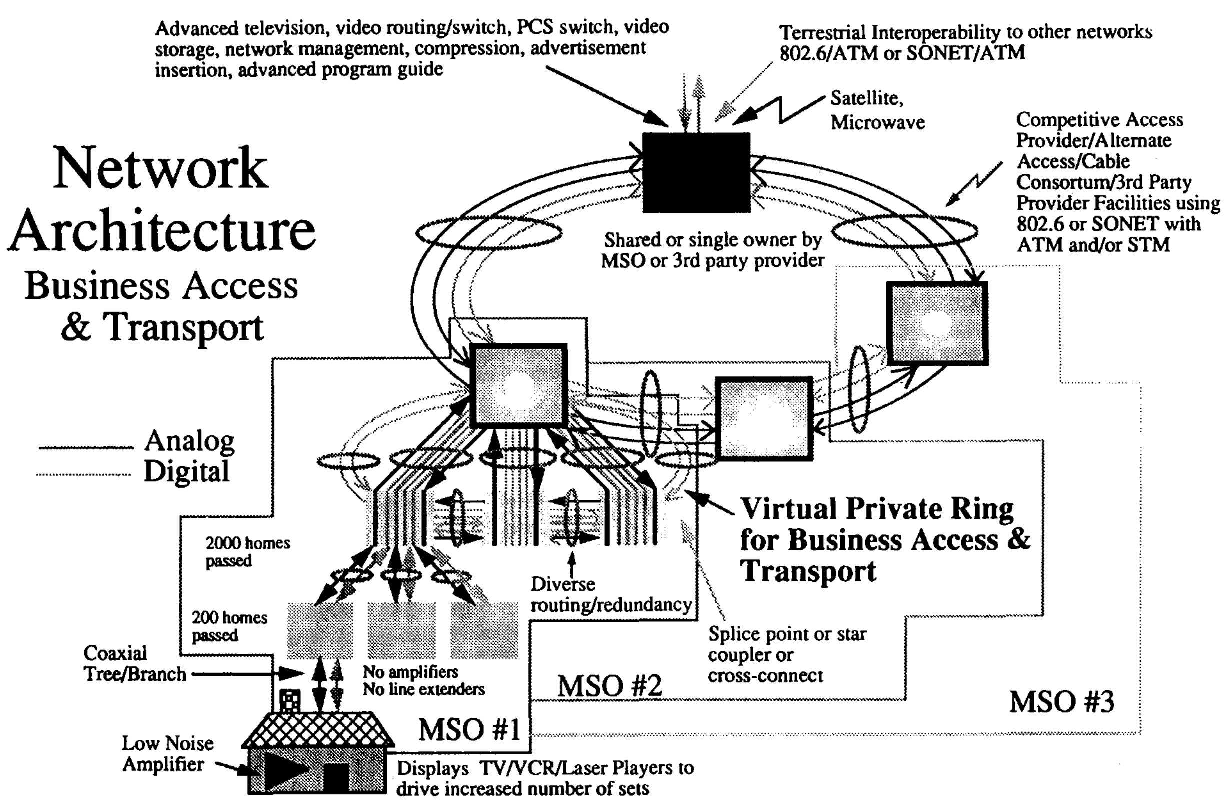

Figure 10

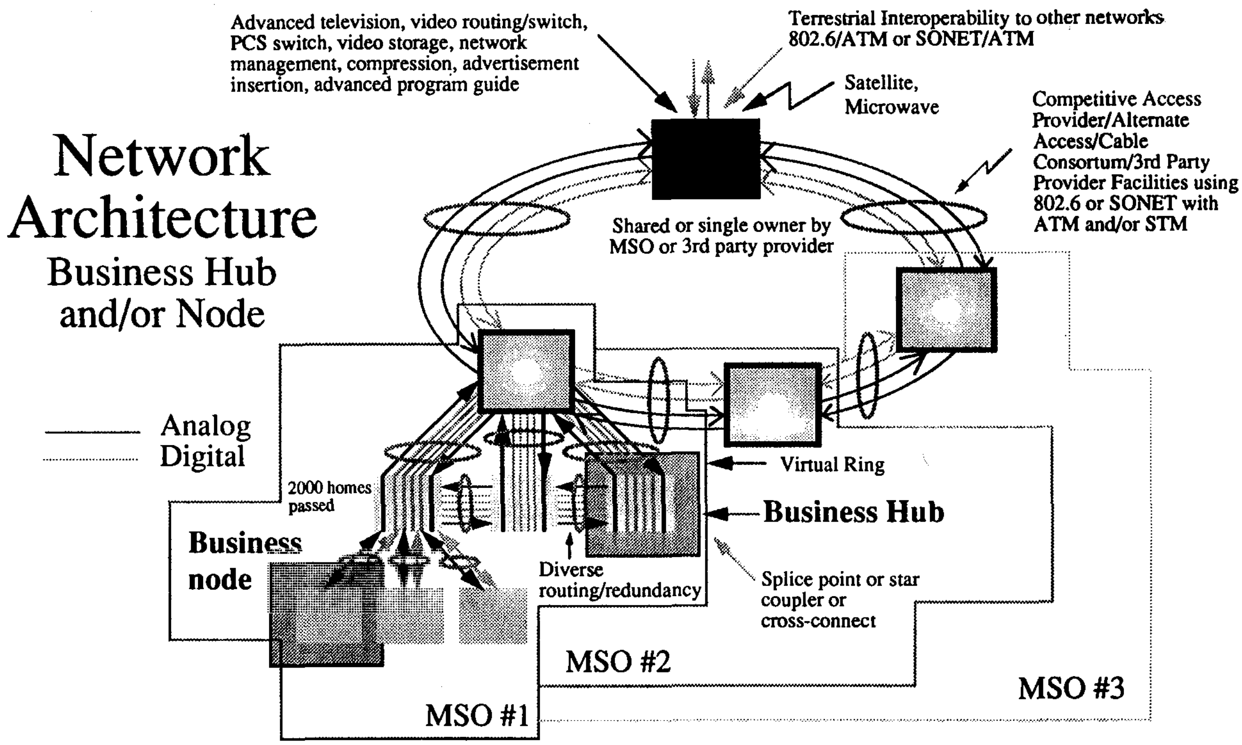

Figure 11

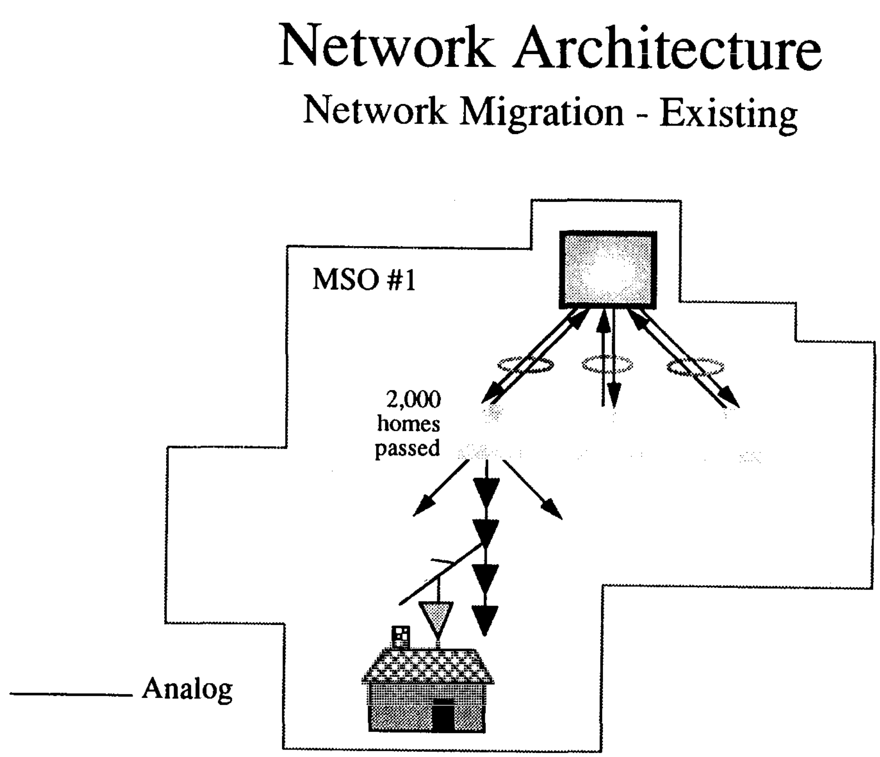

Figure 12

Network Architecture
Passive Coaxial Network Design

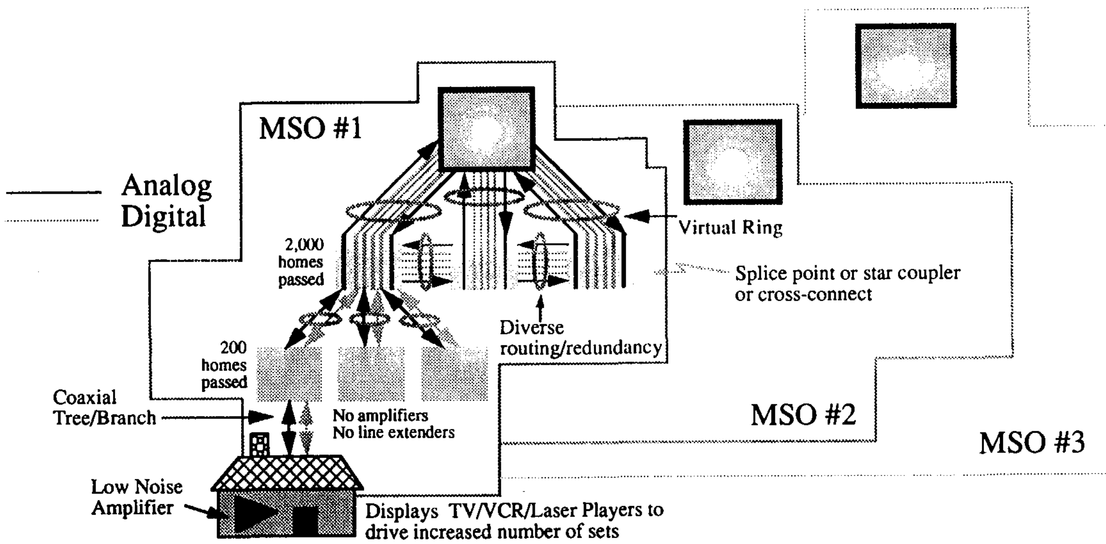

Figure 13

Network Architecture
Network Migration - Passive Coaxial Design

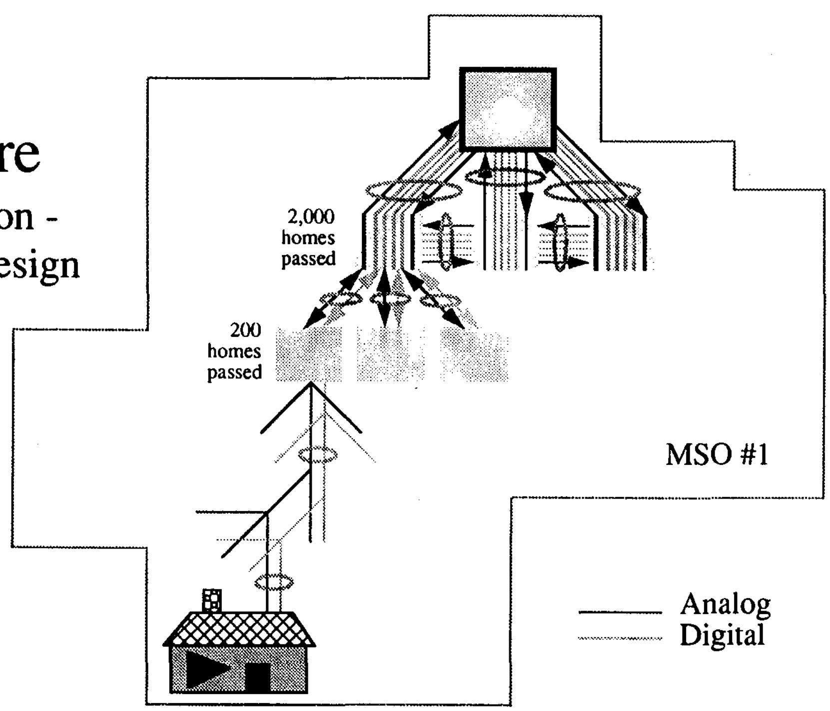

Figure 14

Network Architecture

Network Migration - Parallel Coaxial Network

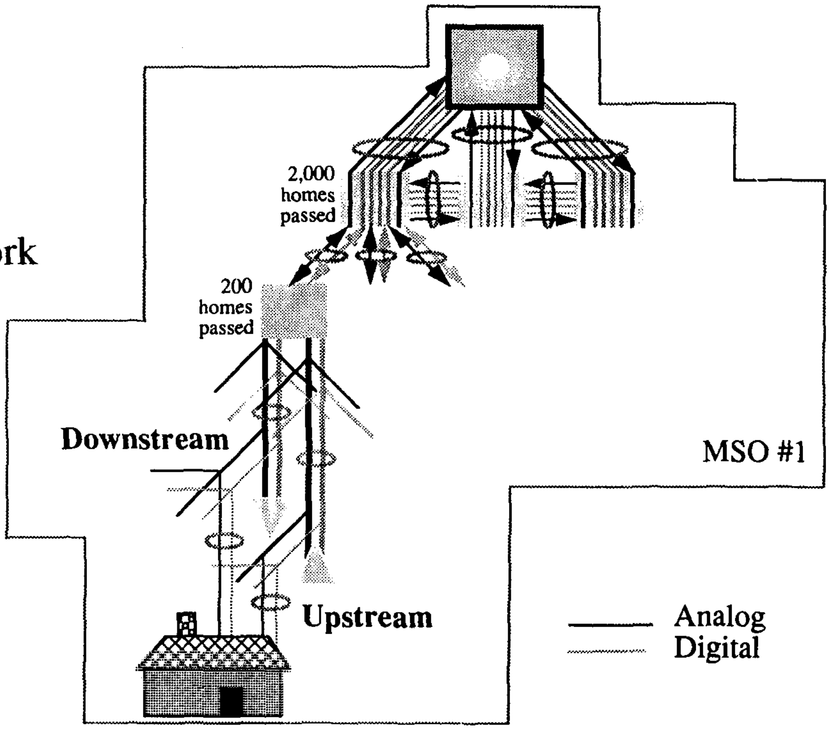

Figure 15