Broadband Access Networks: Evolution and Convergence Implications for Equipment Providers

Timothy J. Brophy
Motorola BCS

Abstract

Commercial pressures to deliver to users the so-called triple play of video, voice, and data continue to drive network operators to providing both cost effective and complete system solutions. Operators today work within a segmented market that occurred naturally as each of several services was provided via an infrastructure optimized for the delivery of its own service. Increasingly, this provincial optimization is becoming less attractive as operators attempt to tie consumers to their own service so as to maximize control of the revenue stream.

In this paper, the broadband access market is reviewed from the point of view of an equipment provider traditionally operating in the CATV marketplace. The network providers in this market include the range of Multiple System Operators (MSO) of the CATV distribution networks, the Broadband Service Providers who are currently overbuilding in many markets, and the traditional telephone company providers (ILEC) and their competitors (CLEC). An overview of the segments and the pressures which are driving common infrastructure solutions are considered.

The several architectures employed will be required to work together for the delivery of essentially common information types. Consideration will be given to the end-customer desired information stream, the competitors and their goals to be achieved, some critical issues which will drive choices among the solutions, and ultimately the technological underpinnings of an eventual solution. Overlap examples of Metro Access, Hybrid-Fiber-Coax, and traditional telephony solutions will be given. The push to get the fiber closer to the home is leading to definition of enabling technologies, and the definition and limitations of some of these will be identified. The coaxial portion of the network will change, and some consideration for what these changes will mean will be considered.

Introduction

Broadband access systems are those which allow high bandwidth content to be delivered to consumers from service providers. The signals delivered may be video comprising standard or high-definition television, voice signals of common telephone calls, or data from a variety of sources usually attributed to internet traffic. The delivery of such content may be done via a single point to multipoint broadcast system (continuous and always on, as in traditional CATV delivery), on a conditional access basis with specific addresses permitted to receive broadcast information (e.g., pay-per-view), single point to single point switched circuit of traditional telephony, or single point to single point via a shared medium

The delivery of broadband services has traditionally been one of video delivery, and as such has been in the realm of the CATV service provider or multiple system operator (MSO). The MSO provided their signals to a primarily residential customer, who until recently received a broadcast signal containing analog video channels. The business community was served most effectively by the local telephone company (the incumbent local exchange carrier or ILEC), whose networks evolved to add on additional or aggregated voice channels which could be used for data transmission increasingly demanded by their customers for computer data or internet traffic.

The Players

The competing service providers often operate within the same geographic realm *because* they currently employ different architectures. For example, telephony companies which offer switched circuit distribution of their voice service have devised ways to provide the video content they have traditionally lacked, and extended the data services initially provided to businesses to their residential customers. In each of these cases the content requested by the customer is provided at a hub location where the tuning of the circuit switches is easy. Thus switched digital video (SDV) and xDSL services round out the traditional voice offering of the telephony company.

Multiple service operators using the hybrid fiber-coax architecture of CATV strength has been the delivery of analog video content selectable at the customer location via either a

0-7803-6540-2/01/$10.00 (C) 2001 IEEE

standard television set or, for more advanced services, a set-top converter. Digital data services supplement the analog content via the use of cable modems, increasingly following the DOCSIS standard for operation. Voice services are carried in an internet protocol (IP) telephony format and handled as content specific data packets contained in the network. The two-way or bi-directional capacity of these networks have been the most frequent limitation to the implementation of the advanced and supplementary services.

Into this fray, which has long been the access-to-the-home battleground for the above two competitors, come two additional service providers: the hybrid fiber-xDSL supplier and the broadband service provider (BSP). The latter are usually labeled "overbuilders" in the sense that they often provide an infrastructure which—in part or whole—mimics the existing structure in place in communities or franchise areas of a CATV MSO or ILEC. Backed in large part by venture capital funds hoping to cash in on the broadband boom, many of these companies are hoping to entice the premium-paying residential customer by delivery of high-speed digital services which include digital TV channels, high-speed data for internet access, voice, and a host of special services such as home security and private networks. Further, by providing the digital fabric for these services, they hope to extend their reach into the business community offering data transfer services and LAN gateways or private networks for campus use. In this way, they intend to serve the constituencies of both the LEC and the CATV customer communities. The cost of building the infrastructure to support these services is quite high. Rather than try to send all the information (which requires enormous bandwidth) over the digital plant, many of the entrants into this market have determined that it is cheaper to build dual plants and separate the lower-cost but higher penetration analog video delivery system from the high-speed data centric plant. This has the dual benefit of reducing their infrastructure cost (by reducing the bandwidth requirement of the digital plant) and increasing their potential for acceptance (and therefore number of subscribers) in residential communities whose customary network interface appliance is the standard analog television set.

In the case of the fiber-DSL supplier (who is often a CLEC), shared fiber-based transmission plant is constructed to push optical signals closer to the end user location. These locations are usually closer to the subscriber than the central office of the ILEC, and build out of copper plant from the location of the optical-to-electrical conversion point can be controlled so as to maximize the distance over which the various x-DSL protocols can operate. These two-way plants are overbuilds of the POTS plant which have at their core strong data-centric and standards-based transmission schemes. Thus, for guaranteed voice (the so-called lifeline or 911 service) and for definable quality of service at adjustable bandwidth (and bit-rate dependent line charges), these providers have a well-defined solution. Their plants are made to be high-bit rate capable, and they frequently employ the switched digital video techniques of the ILEC for delivery of video services. Their limitations are the same as their telco counterparts: conversion of the digital information for reception by an analog TV set requires a converter box for each set, and the bandwidth required for each additional television set increases the plant bandwidth requirements (i.e., it is not a broadcast service, but an on-demand one).

The Prize

The steady revenue stream from both the business and residential customers is the driving motivation for the service providers. Most of the service providers assume that they (the incumbent) will continue to be the provider of choice once the demand for ever more data intensive applications increases. As such, they are striving to be ready to provide the bandwidth required by future networks, and they continue to upgrade current plant to assure the ability to deliver today with the promise for tomorrow so as to maintain their incumbency. The expectations for this customer demand stems from the concept of the seamless communications networks which provide customers with flexible bandwidth on demand at whatever the customer location at any given time. This may mean, for example, switching a wireless to a wired connection when proximity to a wired network portal is detected, or delivering content to a remote location when a customer is traveling. In any case, the service provider would like to be the sole gateway for a customer to receive the diversity of services which he will increasingly come to expect.

Architectural Evolution: one possibility

The cost to build networks is high and there are no shortcuts to the installation of infrastructure. Operators in the access marketplace will need to focus on the services they provide to their end customers as well as the business relationships they build to provide content or access to content over their networks. Infrastructure built today is predicted to last from 5 years—if the demand for services far outruns the ability to provide the information—to as long as 25 years for some portions of an incrementally expandable network. Additionally, the access portion of the network is not the only place many of the providers will operate. Access infrastructure will be connected to metropolitan area networks and eventually through the long-haul backbone to obtain information from remote sources such as un-mirrored server sites or to distant telephony switches. Public policy concerns will undoubtedly play a role in the availability of such connections (see, for example the national information infrastructure (NII) charter) and will reach from the local access level to international gateways.

As more and more of this infrastructure to support the Broadband Access is built—in the access portion, in the metro arena, and in the backbone networks—the more pressure there will be on the owners to extract the promised revenue form it. I believe that this will result in business partnership deals wherein the owners of the metro and backbone pipes, whose networks will have expanded to become an interconnected mesh of available physical channels, will begin to lease bandwidth to each other on either a unit basis or on a in-kind repayment for access to competitive channels. The logical extension of this is a nationwide mesh network with many interconnected nodes with route redundancy built in for protection and guarantees of delivery. The various routes will be owned and operated by different service providers: long haul, metro area, and local access players.

The independent physical links will not, in and of themselves, be important for the delivery of information separate from the aggregate network capacity. The key to supporting such an overlapping and potentially inconsistent network is in the technology that is employed at the nodes where the various lines physically meet. It is these cabinets or rooms or racks of equipment that will supply the processing, routing, grooming (up and down aggregation), conversion (wavelength and format, analog to digital and back) that will make the network transparent to the end user and content provider alike. This development will be the foundation or superstructure that supports the mesh and allows the independent variety of signaling to exist in the fully deployed community infrastructure. For convenience, or perhaps out the growth that will enable particular locations to become those nodes, this location will also be the demarcation point for the access provider to begin the separation of service to customers. The collection of these nodes and the customer sites attached to the infrastructure will define the service provider and his customer base. Information needed by that customer wherever he or she travels can be provided over competitive lines but still be billed by the primary service provider as selected by the customer. Thus at some level, the competitive forces of the marketplace will determine who succeeds. What will it take to get there?

It is instructive when determining how to build an access plant to determine the relative size of the area to be served and when appropriate, its location. For multiple dwelling units (MDU) such as apartment buildings or, by extension, business campus buildings with many offices, distribution of signal is often economical solely in the building, and as such, it becomes the location of a node. This can mean reduced environmental requirements on equipment, or more passive splitting or sharing of bandwidth within a restricted range or for restricted times of the day.

In the optical portion of the network, the cost of amplification will be a significant driver. As the fiber portion of the network reaches deeper into the plant, the link budgets will become larger. In particular, if many homes receive broadcast information as in the x-DSL or a passive optical network design, the fiber split loss will increase whether or not the link distances grow any longer. Conversely, for link distances which increase so that fiber information may be fed to fewer homes per optical termination point, the link budget will increase to drive that signal further. In both cases optical gain will be required to overcome even modest extensions envisioned. Typical optical gain media have a high fixed cost relative to marginal cost of the gain. Reducing that fixed cost will have a significant impact on overall system cost. Additional ways to provide similar benefits to increase source power and/or receiver sensitivity, so as to effectively reduce the cost per unit of supplied optical power. In a scenario which extends the optical portion of the network to the curb or to the home, low cost optical components will be required in order to amortize the cost over fewer consumers. Such a cost reduction and potential higher level of integration with processing power and increased budgets may be attainable from the increased use of integrated optics. The most likely first use of such devices is the integration of passive components (power splitters, WDM) with the active elements needed (LEDs or lasers and photodetectors) along with the requisite drive electronics and control and processing power for its smart integration. It would hardly be surprising that the long term solution remained in the 1550 nm window of operation, given the lower fiber loss and the technology already brought to bear on the issues of amplification, non-linear performance correction, and dispersion management.

Bi-directional communication flow will need to overcome the issues of return path aggregation of ingress noise and the signal combination. This is helped by the fiber deep architectures in that each link will be the aggregate of fewer sources. In traditional HFC architectures the deepening of the fiber link will mean fewer active RF amplifiers after the optical node (O/E conversion point). The RF output levels into the coaxial portion of the plant will have conflicting requirements of less stringent distortion performance due to the shorter cascades, but higher output power and higher crash points (hence improved distortion performance) in order to drive the required number of subscribers from a given optical node. For fiber to the last active type architectures (i.e., no RF amplifiers beyond the node) this condition is the most demanding. In any of the all optical, or the more common standard copper and hybrid fiber coax plants, solutions offered to service providers from equipment vendors will have to be scalable to meet the changing demands likely to be placed on the network services required and also to allow the pay-as-you-go incremental cost structure to match the expected revenue stream. Field friendly optical cable handling will be useful to allow low cost of the plant maintenance and craft interfaces.

Of course any of the schemes now being proposed or likely to be proposed will benefit from the tremendous amount of work that has gone before in digitizing analog signals and the advancements that have been made in DSP techniques. Combinations of those technologies along with the DWDM systems have been most evident in providing much of the broadband content today and may be supplemented in the future by other technologies and techniques in the realm of baseband digital transport, passive optical networks, Ethernet switching, or CDMA techniques either RF or optical.

I have provided a background for the driving motivations behind the Broadband access networks and considered the players, their goals, and a potential means of implementation. This was followed by some potentials for the underlying technologies which will be necessary for successful implementation.

HFC Network Architecture