Cable Modem: Old Protocols for a new Paradigm

Frank R. Koperda
Scientific-Atlanta, Inc.

ABSTRACT

Cable modems should take advantage of the lessons learned from the data communications and the cable video communications environments. The resulting system should embody the robust protocols created for the digital video cable delivery system and provide the advanced features of the protocols in today's data communications networks.

*The merging of these environments will require changes to existing data and cable protocols to make them useful. ATM is emerging as a low cost delivery solution optimizedfor a point-to-point delivery system. ATM must be **modified** in several ways to **fit** into the point-to-multipoint topology. Similarly, the digital video systems deployed have substantial delay due to interleaving the data of many programs to keep a noise burst from corrupting any single channel.*

This paper will explore the systems issues involved in building an optimal data delivery system for cable systems. We will examine changes to standard protocols and how these will work in the new cable paradigm.

INTRODUCTION

Data communications is changing the types of possible applications for the home just as it has changed the applications in the business environment. Analog television is giving way to digital television with the advent of MPEG. The evolution of computing in the home environment is continuing with the emergence of the cable modem as a new product which will need to merge the video and data services. To operate in this new situation, existing protocols from both services will need to be altered to create a functional system to meet the needs of a new market.

The first task is to choose a topology that will lead to easy operations and the most efficient use of investment. Figure 1 represents a likely network topology for the delivery of data services. The network consists of three distinct physical blocks. They include the Master Headend (MHE) equipment, Distribution Hub (Headend) equipment and the Home unit. The topology of this network enables the operator to centralize the operations and the location of information serving computers, thus lowering operational and capital costs. Among the functions likely to be performed at the MHE are billing, level-of-service authorization, and network operations control. The MHE supports several Distribution Hubs and therefore is a logical point to perform inter-hub switching or routing, as well as serving as a gateway to external networks.

COMMUNICATIONS PROTOCOLS

There are several communications protocols that will be important in the new paradigm. Of interest are TCP/IP, ATM, MPEG, X.25, Frame Relay, DAVIC, IEEE 802.14, and IEEE 802.2 which includes Ethernet and Token Ring. Figure 2 illustrates their usage in the various parts of the cable network.

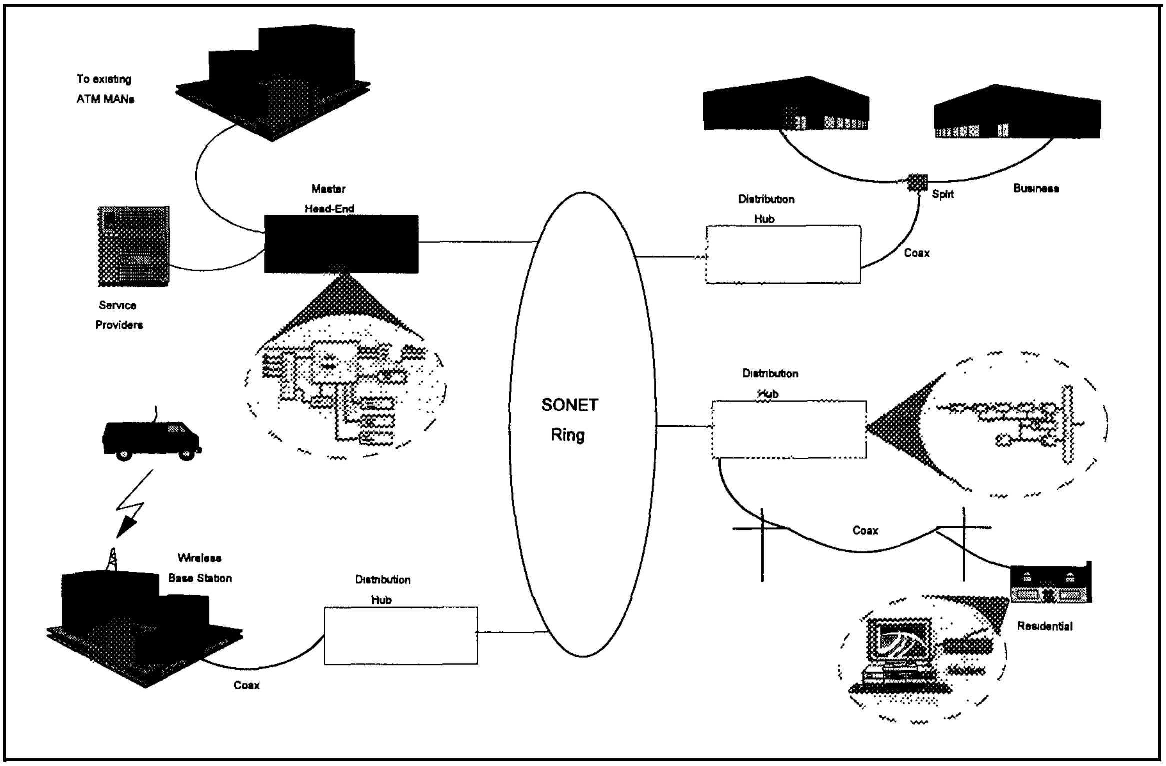

Figure 1. Network Topology

The cable modem will likely exist as a stand-alone box during the first few years. Two primary reasons for it to remain separate from the computer are potential liability issues and obsolescence. Operators will be reluctant to open up the PC, install a card and incur the responsibilities and liabilities of making such a device operational. A customer is unlikely to buy such without knowing that it will be usable over their cable system now and in the event of moving to another cable system. As new standards emerge, the operator will specify compliance to a standard and the ownership of an internal modem will be possible by the consumer. This should then allow a reduction in the price of the modem.

The PC will connect to the cable modem using a LAN card of the type found in many office environments. The cards are relatively inexpensive, are available on most hardware platforms, and are supported by all major operating systems. Ethernet using a 10BaseT interface should meet the various requirements for this situation. As an evolutionary course, the 25 Mb/s ATM might also emerge in several years in response to a need for greater speeds.

The cable modem is connected to the headend using an existing cable plant that has had the reverse path activated. The RF modulation technique will probably be QAM-64 that allows 30 Mb/s of data to be transmitted in the 6 MHz channel typically used for a television channel. On reverse channel, the RF modulation technique used will be some form of QPSK. Proposed data rates of 256Kb/s, 1,544 Mb/s and 2.048 Mb/s have been mentioned in the various standards groups. As seen, this implies that highly asymmetrical data rates will occur, which affects existing protocols that have been optimized assuming symmetrical data transfer rates.

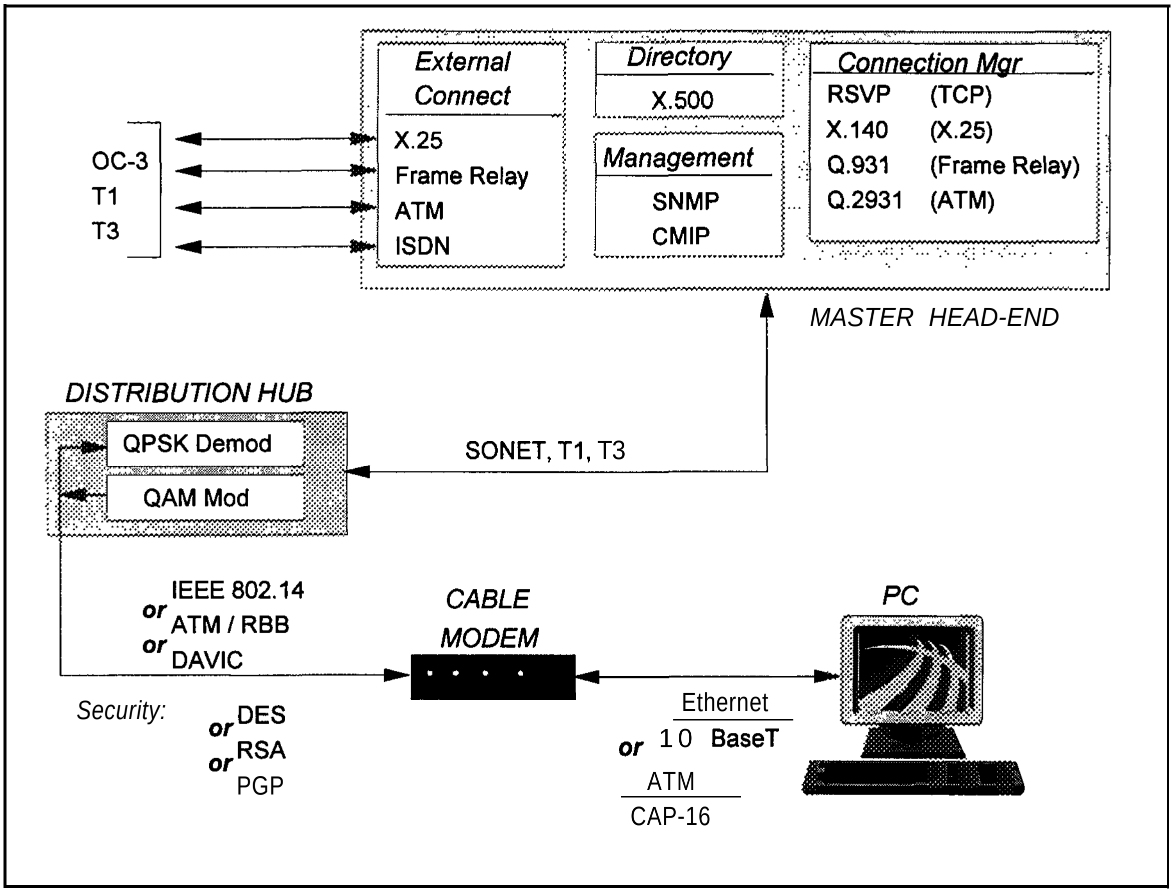

Figure 2. Protocols used within a cable modem network.

Another characteristic differentiating this link from many other link protocols is that it has a point-to-multipoint topology downstream, but a multipoint-to-point topology upstream. Because a single entity controls the downstream, multi-access techniques are not required, but security for user data becomes important because many stations are listening. Upstream, it is difficult for other stations to hear each other because of uni-directional taps, but users of the system perceive their data may be in danger of interception and therefore will desire security. Potential encryption algorithms include DES, RSA, and PGP.

Having many stations sharing this upstream link will require new implementations to control which stations have access to the upstream bandwidth resource. Since bandwidth is a scarce resource, one user should not be allowed to monopolize the link as is possible over existing LANs today. Also, a user may need to be billed based on the level of service being provided. Having a 64 Kb/s tier, 384 Kb/s tier and a burst 1.5 Mb/s tier for example will require a network to guarantee a station can achieve that performance. It must also ensure that the usage for a station does exceed that performance for a given tier.

The link from the modem to the headend is being 'standardized' by several groups. The Digital Audio-Visual Council (DAVIC) is targeting its 1 .1 specification to address data transport issues. The IEEE 802.14 committee is also drafting a standard that defines both the link protocols and system connectivity issues. The Residential BroadBand (RBB) group of the ATMForum has indicated interest in this link but may adopt the IEEE 802.14

recommendations for HFC (Hybrid Fiber Coax) systems.

The benefits of adopting products based on well known standards should allow rapid growth, low prices, and additional functions and features from manufacturers.

From the headend, some information that originates within the area will flow back downstream and some will flow to the MHE. Typical physical connections will be provided by T1, T3, OC-3, OC-12 or even higher speeds. The logical protocols may be ATM or Fast Ethernet. Data from the headend may go to local servers at the MHE, out to other headends or out to the public network.

Because there may be connectivity beyond the local network, the protocols within the network are affected. For example, many network protocols such as TCP have local naming and addressing. This option cannot be used external to the network; hence, resolving names requires connection into other Domain Name Servers (DNS) and the local operator must deal with getting blocks of addresses. The X.500 protocol is a popular choice to map the number addresses to user names.

Security protocols are also affected because it is impossible to ensure that all destinations outside the cable network use the same type of security. For this reason, the HFC link should have local encryption and decryption. Application layer encryption is also required for end-to-end protection. However this encryption is beyond the operator's control and should be left to browsers, shopping, and banking applications that can ensure protection using many different methods appropriate to the expected level of attack.

The MHE also has a number of other system elements to ensure a functional network. Network Management is spread throughout the system with the central control intelligence located at the headend. Common platforms for this are NetView® by IBM and OpenView® by HP. They use the CMIP and SNMP protocols to communicate with various units in the network to monitor performance and to determine the location of problems.

Billing systems need to operate with the equipment to authenticate devices that wish service, determine the amount and type of service permitted and gather connection statistics. These statistics may consist of the length of the connection, number of packets sent and received, or identification of servers contacted. These types of statistics may be saved away so that the user can be billed for the amount of network and system resources that were used. These systems are currently varied and often unique.

As mentioned earlier, the quality of the connection will likely be very important to the user. For this reason the parameters for the type of connection desired could be requested from the network. Several different Quality of Service (QoS) standards exist that can communicate the connection parameters from the user to the system. These QoS protocols are linked to specific protocols. The X. 140 standard is used with the X.25 protocol. TCP uses RSVP, Frame Relay uses Q.931-Q.933 and ATM uses Q.293 1. Other protocols may also reuse some of these QoS standards.

These QoS standards have similar types of parameters. Requested bandwidth for forward and reverse paths, maximum delay, amount of packet delay variations, maximum length of a packet, number of packets in a transmission burst and maximum error rates are examples of these parameters. It is very important that the network keep its QoS contract with a user's connection to ensure proper operation of the applications. Mechanisms that the network uses to implement this contract are planning routes through the modulators, demodulators, switches and links; monitoring congestion; putting packet admittance procedures in place as data enters the network; and delaying data that is not time critical.

Moving the discussion from the network to the protocols within the PC, Figure 3 provides a useful reference. The LAN adapter within the PC may be one of the better ways to tie the PC into the network. The 10BaseT adapter can often be purchased for $40-$60 and supports the IEEE 802.2 Link Layer Control (LLC) for packet transfer. Drivers are required to support the Upper Layer Protocols (ULP) such as TCP/IP, NetBEUI, NetBIOS, Appletalk, IPX/SPX (Netware) and SNA. These drivers exist for various hardware platforms and operating systems such as Windows, UNIX, and OS/2.

Effective network management will be

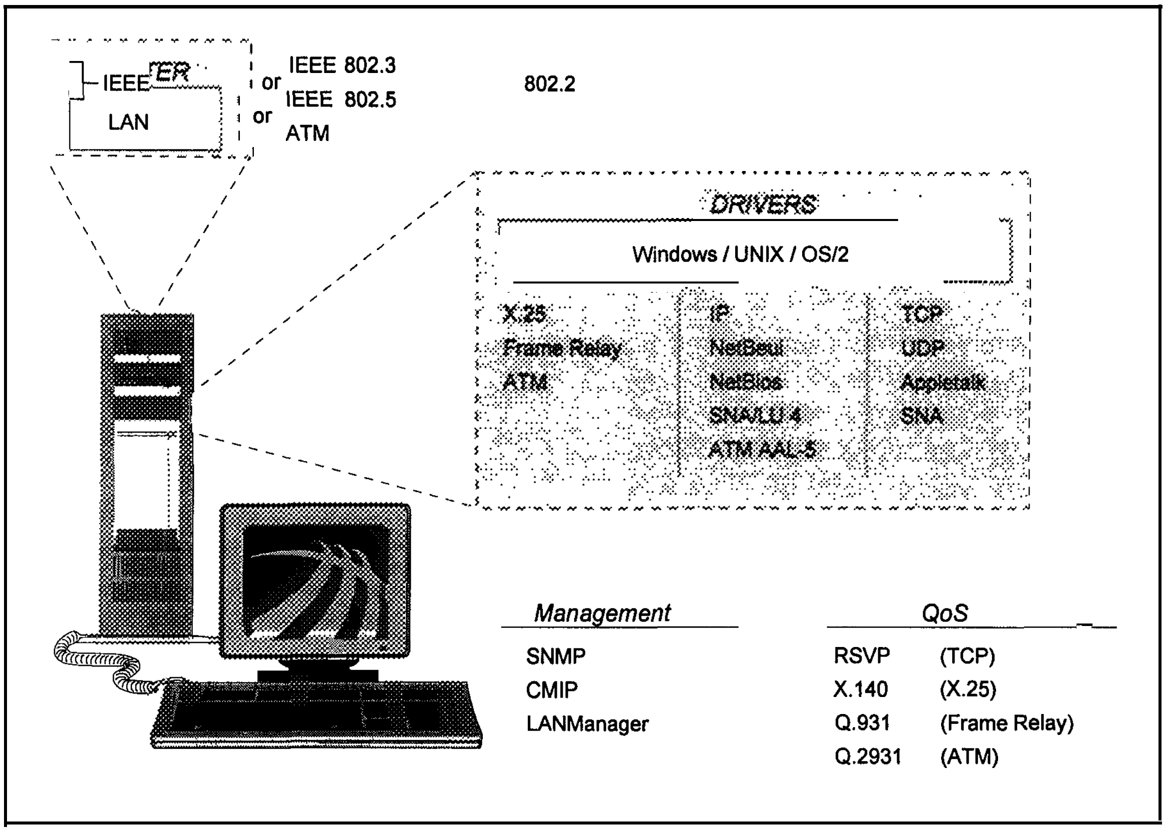

Figure 3. Protocol stack within the PC

Using the serial or parallel ports has some advantages and disadvantages to connect the computer to the cable modem. One advantage is that they are often provided with the system but a disadvantage is there is little existing communications software that make use of them. The serial port also does not have the required speed of several Mb/s, and the parallel port is often used for the printer and often goes to 800 Kb/s.

important for the broadband network because of the cost incurred by an operator for on-site support. It may become a requirement that the modem run an SNMP or CMIP agent that can gather statistics about the connection, and feed it to the network operator automatically to help diagnose the source of problems. The user may need to become aware of these features to participate in a conversation with a network administrator in trying to track down faulty equipment. The system should be as transparent to the user as possible and ideally enable the operator to correct problems before they degrade to the point of being noticeable to customers.

Quality of Service will be increasingly important to customers as more intelligent applications are created. Videoconferencing is an application that will need to communicate with the network to establish a 384 Kb/s link with delays under 50 ms. Efforts are underway to establish the Application Programming Interfaces (API) that will allow the user's applications to convey its requirements to the various network elements required to implement the request.

The above discussions demonstrate only one of several valid configurations that may emerge. A variant of this is to have the downstream cable supplying data, but have the upstream data sent via a standard teleco modem. This will have a useful life for a few years until more of the reverse cable plants are activated. Another alternative is to have a less powerful computer for the user connected to centralized servers to perform many of the tasks. This will allow for cheaper home units, more economical maintenance of software which is done at the servers, and a sharing of the cost of computing. The type of protocols to support this system are somewhat different from those illustrated.

OLD ATM FOR A NEW PARADIGM

ATM may become an important protocol for use in the cable modem systems. Internet access will be a key application and is implemented using TCP over IP. For low capacity nodes, routers are a good option. As the network grows, switching becomes a better option. Routers work by looking inside a packet to understand what functions need to be performed working at the OSI layer 3. Packet switches work at layer 2 of the OSI model and operate by looking at the destination address. They do not have any understanding of the protocol nor the contents of the packets. For a given capacity, switching is about 1/3 of the cost of a router. A useful axiom in network design is to 'switch when you can, route when you must'.

As multimedia applications continue to develop, it is important to have a network to support the applications by guaranteeing the performance of the data transfer. Two important reasons to guarantee the performance are to minimize buffering costs and reduce the delays between the end stations. Applications without proper network guarantees will see their videoconference images become very jerky and excessive delay hinders communication when responses are delayed by seconds.

An important method of guaranteeing performance is to use fixed length cells instead of variable length packets. Packets make it

Attribute	Current ATM	Future Cable ATM	Motivation
Data transfer	Symmetrical	Asymmetric	Ingress noise
Speeds (Mb/s)	25.6, 52, T3 (45)	1.5 (up), 27 (down)	RF modulators
Access Methods	Point-to-Point	Point-to-Multipoint (down) Multipoint-to-Point (up)	Cable topology
Security	optional	mandatory	Multiple access
Data Pacing	OAM cells	leaky bucket	Asymmetric bandwidth
E. 164 Addresses	Fixed per port	Movable between ports	Alternate routes

Table 1. Migration of ATM for cable

difficult to control the variation in arrival time since multiple packets of indeterminate length can get in front of critical packets. ATM appears to offer several advantages in the cable environment by reusing equipment available for the LAN environment and connecting easily into the public networks. A summary of changes for migrating standard ATM to the cable environment is shown in Table 1.

Data transfer in standard ATM is accomplished using a dedicated, point-to-point connection with a symmetrical data transfer rate. In the LAN environment this data rate is 25.6 or 52 Mb/s. It also appears at data rates of T1 , T3, OC-3 and above in the public networks. Security is not a primary concern because the links are usually secure. If security is a concern, bulk encrypters that encrypt all the connections on the link simultaneously are used.

The new paradigm of cable modem places different constraints on the network transport system. The primary link causing this difference is the connection between the headend and the home which is the cable plant. The forward data transfer is well maintained and transfers existing television signals in 6 MHz channels typically in the 50-750 MHz band. Quadrature Amplitude Modulation (QAM) is a prominent digital modulation technique in this situation and it has an effective 27 Mb/s data rate.

The reverse path is usually not activated, or, if it is, presents a challenging RF environment operating in the 5-40 MHz band. Some types of splitters in the home have notches in the 5-l 0 MHz band. CB transmitters, electrical appliances, and amateur radio are sources of in-home contamination in that band. Outside the home, international short-wave, corona discharge from nearby power lines, changes in temperature, corroded connectors and nicks in the line all cause degraded signal quality. To avoid these noise sources, 1 MHz channels scattered around the band are used with the robust modulation technique known as Quadrature Phase-Shift Keying (QPSK) which gives an effective 1.5 Mb/s data rate.

The bandwidths available for data transfer fundamentally cause the asymmetric data transfer that alters standard ATM data rates. The broadband system offers a significant cost advantage over conventional telephone links by spreading of the cost of a single cable among many users. Downstream that means a single point going to multiple users and upstream that means having multiple users share a single cable.

Having multiple users share a single cable implies a loss of privacy and thus the need for encryption of the data to regain security. For a standard telephone line, users feel somewhat more protected because each station has its own dedicated wire. ATM has no specific mechanism for dealing with alternating between security keys and maintaining proper decryption synchronization. This feature will need to be added.

ATM employs a mechanism to keep buffers from overflowing during heavy network usage. OAM (Operations, Administration, Maintenance) information cells are the feedback mechanism whereby the status of the buffers is sent to the originator. If the same mechanism were used in the asymmetrical environment of the cable modem, there would be little upstream bandwidth left for user data. For example, the OAM cells downstream could be 5% of the bandwidth and at 27 Mb/s that would mean 1.35 Mb/s would be consumed by the OAM cells. If this were fed back upstream, the 1.35 Mb/s would consume 87% of the 1.5 Mb/s leaving little bandwidth for data. The pacing of upstream packets using the ‘leaky bucket’ algorithm and having the switch block

OAM cells from going downstream may be an adequate solution to the problem.

Another interesting change to standard ATM is the assumption that a station address (E. 164 address) remains fixed to a specific switch port. Under a multiple user-per-modulator scenario, there will now be several E. 164 addresses on a single port and it is likely the station addresses will move between RF frequencies (ATM ports). If a user requests a new connection and the existing channel over a QAM modulator does not have sufficient remaining bandwidth to satisfy the request, the station should move to an alternate QAM channel. It is likely that a modem will only have one downstream tuner and thus all of the existing connections must move to the new QAM channel which is connected to a different ATM port.

PERFORMANCE EXPECTATIONS

The broadband network will have data traffic that will take on the characteristics of both the local LAN and ATM trunk links. It will also have unique characteristics to handle interactive video games, services that vary by time of day and billing that will alter the users' traffic patterns. A variety of experimentation will occur over the next few years as providers try to offer the right combinations of services, cost models and feature sets.

The basic applications that may shape the architecture of the network are:

- Internet access
- Access to CD-ROM library including video-clips
- On-line chat services
- Interactive games with a server and peer-to-peer
- Access to community services such as schools and event calendars
- Work at home (LAN emulation)
- Videoconferencing

Application	Packet Size	Traffic Shape	Query Times	Peak Speed
Web Browsing	1500 Bytes	Asymmetric (100:1) / bursty	once / min	Available
On-Line Chat	300 Bytes	Asymmetric (20:1) / bursty	once / 20 min	Available
LAN Emulation	70% - 64 Bytes 30% - 1 KByte	Asymmetric (6: 1 server) / bursty Symmetric (peer) / bursty	once / 30 min	Available
Interactive Game	1500 Byte 500 Byte	Asymmetric (100: 1 server) / bursty Symmetric (peer) / bursty	once / 5 sec once / sec	90 Kb/s
CD-ROM Video	1 KByte	Asymmetric (100: 1) / Continuous	once / 2 min	2 Mb/s
Video Conferencing		Symmetric / Continuous		384 Kb/s

Table 2. Application Characteristics

An interesting aspect of the network usage is that these applications will have peak demands (Table 2) at different times (Table 3). This implies that there will be a need for dynamic bandwidth management and cost recovery by the operators will allow creative solutions. Business applications can support higher cost rates than interactive video games and access to community information may be free to build initial usage.

The operators must recover the cost of building and operating the network consisting of the above applications. It is possible to have billing based on tiered performance, usage or connect time. The proper selection of the

Application	Peak Time of Day	Network Traffic (Peak)	Application Value
Web Browsing	Evening	30 % Users / 30 % data	Moderate
On-Line Chat	9-11 PM	70 % Users / 10 % data	Moderate-High
LAN Emulation	10 AM / 3 PM	70 % Users / 20 % data	Very High
Interactive Game	Afternoon	40 % Users / 5 % data	Low
CD-ROM Video	Afternoon / 7 PM	15 % Users / 30 % data	Moderate
Video Conferencing	10 AM / 3 PM	20 % Users / 70 % Data	High

Table 3. Application Usage

Note: % Users are the % of active users for that application during that time period.
% Data is the % of the network data attributable to that application during that time period.

method is based on the cost models of the network and the customer's perception of the worth of the application.

CONCLUSION

Although the term 'cable modem' implies a device that should behave like today's modem which is attached to a telephone line, the new data paradigm requires a new awareness of the needs of customers. We are moving from a communications paradigm where users have a dedicated link and are assured privacy and dedicated bandwidth. We are moving toward one in which security, performance tiers and shared bandwidth are the norm. Applicable elements of older LAN, ATM and network management protocols are being reshaped to fit the new network paradigm.

Author

Frank R. Koperda
Scientific-Atlanta, Inc.
4386 Park Drive
Norcross, GA 30093

Telephone: (770) 903-5057
Email: Frank.Koperda@sciatl.com