PERFORMANCE OF CABLE MODEM SYSTEMS

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Abstract

For the most part, the public telephone network is used to access the Internet from remote locations and data are transmitted at speeds ranging from 2,400 to 28,800 bits per second (2.4 – 28.8 kbps). With cable, however, data may be transferred at speeds up to 10 million bits per second (10 Mbps) — about 1,000 times faster than by using telephone wire. Cable offers a faster, more powerful alternative to telephony systems, and the result is an impressive increase in computer communications power.

Cable modem technology is in a unique position to harness the demands of users seeking fast access to information services, the Internet, business applications and cablecommuting. With the growing interest in data-over-cable service, there has been an increased focus on the issue of performance.

Cable data services are deployed on a shared access network. Thus a 30-Mbps service is shared by multiple users simultaneously. Due to the shared nature of these networks, there is interest in how the performance of the network as seen by a single user changes, if at all, as the number of users increases. This document will show that such degradation of service is minimal with proper design, and that cable modems will reliably deliver data to all users hundreds of times faster than existing phone modems.

ASSESSING THE CABLE MODEM BUSINESS

Over the final months of 1996, several cable operators began introducing high-speed data services on a limited commercial basis. An extended period of technology and market trials across the industry had yielded the same consistent results: People love the enhanced performance of cable modems compared to their much slower telephone dial-up modems. In fact, cable modems were found to vastly exceed the expectations of customers testing the devices. Once they experienced the tremendous increase in transmission speed and the benefits of being always connected, customers confirmed operators' hope that the public would embrace the service and be willing to pay for it.

The cable industry fully realizes it has a tremendous market opportunity to gain an early foothold in the burgeoning Internet access business. It is also known this window may be limited given the pace of developments in alternative access technologies by cable's competitors. Pent-up customer demand for more communications power is ripe for the taking, but operators also realize they must proceed with extreme caution. Cable's nay-sayers continually point to the failure of the industry to deliver on promises of new advanced services, as well as a past reputation of poor customer service. In order for cable to capitalize on this vast opportunity for new and lucrative revenue streams, we have to get it right the first time. It is absolutely critical to the industry that operators be able to offer reliable service and have the skills necessary to manage proactively this new data environment.

Cable Television Laboratories, Inc. (CableLabs) and many cable operators have taken a leadership role in helping the industry recognize the many challenges in running a data business. The fundamental problem is that cable modem service is new and not well understood. Many cable modem products are emerging from a variety of vendors, but few established products exist upon which operators may base their business. Virtually no empirical, quantitative performance data exist on these products. The end result is that the limitations, strengths and weaknesses of each vendor's product are not generally known. Further, there is no interoperability among the proprietary modem products from each vendor.

Scalability is another challenge which must be resolved. The effects on network performance of adding new users, increasing traffic loads and variances in traffic patterns are largely unknown. How these issues are addressed will have enormous network design and management implications. Added to all of this, fundamental aspects of the Internet and data services in general are in flux. The economic model of all-you-can-eat for $19.95 a month cannot continue. A metamorphosis of the business is underway, evidenced by the vastly different approaches of providers such as America Online, the Microsoft Network, NetCom and other Internet service providers.

Following is a synopsis of findings on cable data modem performance, as collected from member field trials and tested and simulated in the laboratory at CableLabs. Performance issues are examined through a series of steps. First, we look at network configuration (i.e., dedicated circuit vs. shared access) with a discussion of the advantages of a shared access network. Second, we study the medium access control (MAC) protocol and why it is the key element for determining performance. Third, we describe the high-speed. data-over-cable environment and how it was simulated and tested in the lab, with results provided. Fourth, there is a discussion on the importance of designing flexibility into the network when considering growth of users and deployment of enhanced services. Finally, support for enhanced services is discussed for ensuring that the network evolves gracefully as more demanding applications are added.

NETWORK CONFIGURATIONS: DEDICATED CIRCUIT VS. SHARED ACCESS

Two of the most prevalent network configurations in the communications world include a dedicated circuit connection and a shared access connection (shown in Figure 1).

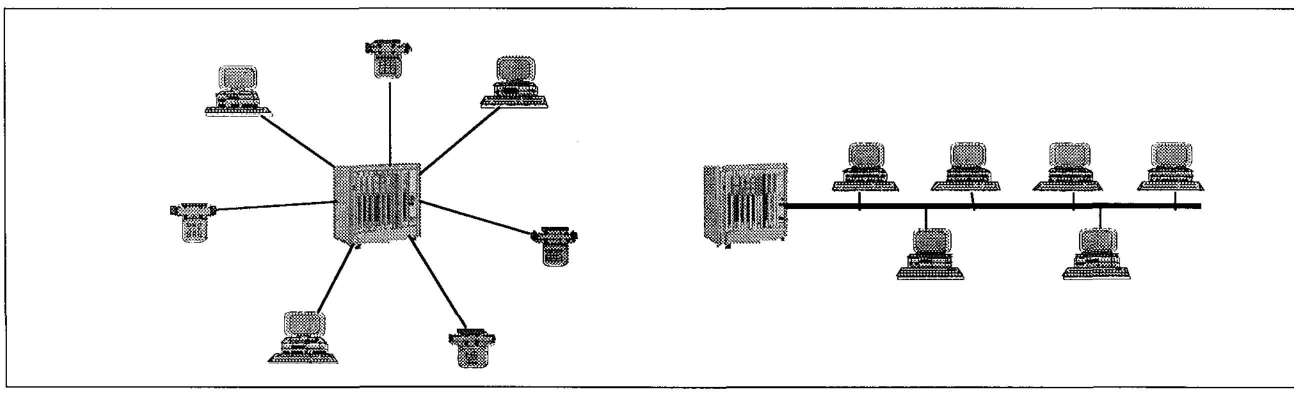

Figure 1: Dedicated Circuit Connection (left) vs. Shared Access Connection

The dedicated circuit architecture is used by telephone companies for services such as voice, telco data modems, and ISDN. In this configuration, a user establishes a dedicated, non-shared connection with a host computer on the other end. A single connection is set aside for each user's sole benefit until it is terminated at the user's discretion (e.g., user hangs-up). Typically, these connections offer maximum throughput of around 64 kbps to 128 kbps using ISDN, or 2.4 kbps to 28.8 kbps with a standard telephone modem.

A shared access connection similar to that employed in many local area networks (LANs) as well as in a data-over-cable environment is quite different. In the shared access connection, there is a single high bandwidth "pipe" shared among many users. This pipe might provide throughput capacity of anywhere from 10 Mbps up to 30 Mbps in a single 6-MHz channel that currently carries one video program. Since multiple users all share a common pipe, there is a need for a common set of rules followed by all users to share that resource in a fair and efficient manner. This set of rules is the MAC protocol and will be described later in some detail.

MYTH VS. REALITY IN A SHARED ACCESS WORLD

People grow up with the knowledge that a single apple pie shared between two people yields one-half a pie to each. Given this knowledge, it seems reasonable to assume that with respect to data communications, a single 30-Mbps pipe shared among, for example, 10 users yields effective throughput to each user of around 3 Mbps.

Fortunately, for the users of corporate LANs and data-over-cable services, such simple mathematics do not apply to shared access networks. People who have access to a 10-Mbps Ethernet LAN in the office know that such simple division does not work. It is commonplace to have 50 or 100 users on such a network and yet the individual performance seen by a single computer is much greater than 1/100th of the 10-Mbps connection. File transfers or Web pages representing several million bits of information pop up on the screen in a second or two even though the simple math described above would predict such transfers would take half a minute or more.

Why is this so? The answer lies in the inherent "bursty" nature of the data communications traffic that traverses such shared access networks.

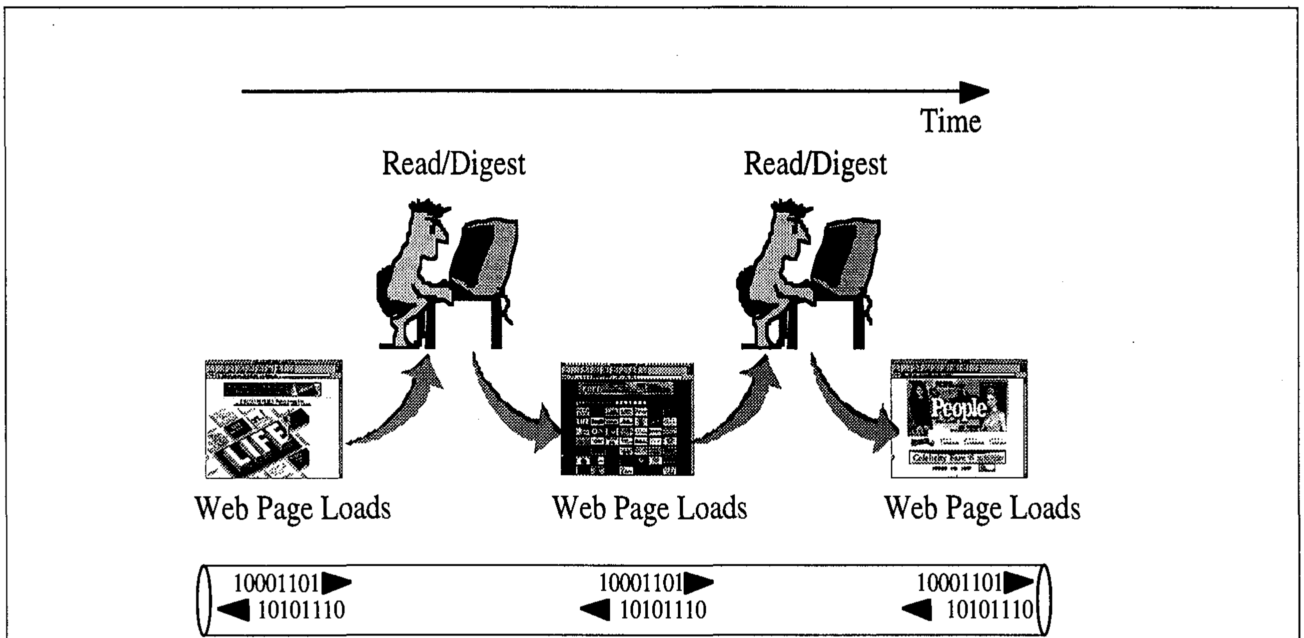

Figure 2: Web Surfing Process

Figure 2 shows a typical Web surfing sequence and the associated information flow in the network. The user requests a Web page. During the download of this page, bits of information flow on the wire. Once the transfer is complete (i.e., the page arrives), the user reads the page and during this time no data are flowing on the wire. Soon the user selects another link and information starts flowing again. This concept of short bursts of information flow followed by periods of quiet time is typical of many data services that run over the Internet.

To understand better the nature of this information flow, engineers at CableLabs designed a WWW (World Wide Web) surfing experiment. In a controlled laboratory setting containing both the PC performing the surf and the server holding the pages being requested, the engineers performed a typical 60-second surf of a popular Web site. During this surf, the engineers analyzed the traffic flowing on the broadband network connecting the two machines. Figure 3 shows the traffic flowing during this experiment. There is an obvious burst of information flow each time a Web page is requested and then a quiet time for several seconds while the page is read before the next page is selected. During this typical 60-second surf, 1.26 Megabytes of information flowed "downstream" from the server to the PC and the PC returned approximately 69 kilobytes of information in the opposite direction. This "upstream" traffic represents user mouse clicks and acknowledgments from the PC that it received the downstream traffic correctly.

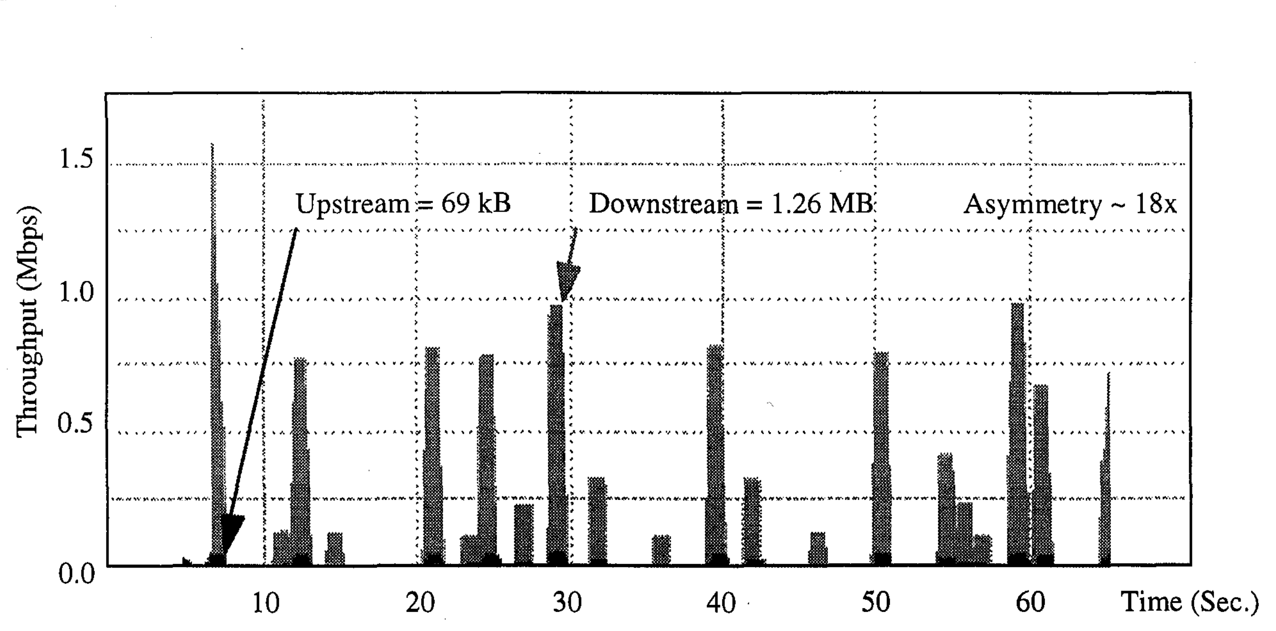

Figure 3: Typical Web Surf Throughput

This bursty nature of traffic flow is a big part of the reason shared access networks work so well in supporting multiple users. When a user wants to download a Web page, the user accesses the broadband network and transmits for a short burst at a high rate and then goes quiet. The next user then transmits during the first user's quiet period, and so on. This phenomenon is called statistical multiplexing of network traffic. During a time window of one or two seconds, it is not a requirement that only a single user be transmitting. In fact, with a 30-Mbps data-over-cable service, tens of users may simultaneously receive information at any instant in time. With a dedicated connection, the user has a low bandwidth connection tied up whether or not it is being used effectively: With a shared access network, the user is only using the network resource at the precise moment it is needed and then relinquishing control of that resource for others to use.

MEDIUM ACCESS CONTROL

The key element for supporting a large number of users on a single shared access network is split-second timing and coordination. Such coordination is supplied by an important piece of the modem technology called the MAC protocol. It is a set of rules followed by all network users to ensure that they share the bandwidth fairly and efficiently without performance degradation for others. The protocol allocates bandwidth to the users, arbitrates among users, and keeps track of all users' activities so that each user receives the desired throughput and assures the network is performing optimally. In order to understand how performance will change, if at all, as large numbers of users are added to the network, an understanding of the MAC protocol is necessary.

PREDICTED HIGH-SPEED DATA-OVER-CABLE ENVIRONMENT

In advance of results from full-scale deployment, many techno-savvy cable consumers, as well as cable's high-speed data competitors, are asking just how many customers can cable data service support? To answer this question, CableLabs has been using a combination of modem performance simulation and laboratory tests of actual modems.

First, a sophisticated computer model of various modem manufacturers' MAC technology was constructed. Connected to this MAC model were a number of simulated Web surfers all performing a 60-second surf very similar to the example described above. The model was verified with actual laboratory test results on 30 real modems to ensure that the simulation was producing valid results. The number of simulated users was then increased better to reflect full-scale deployments. The results are very encouraging.

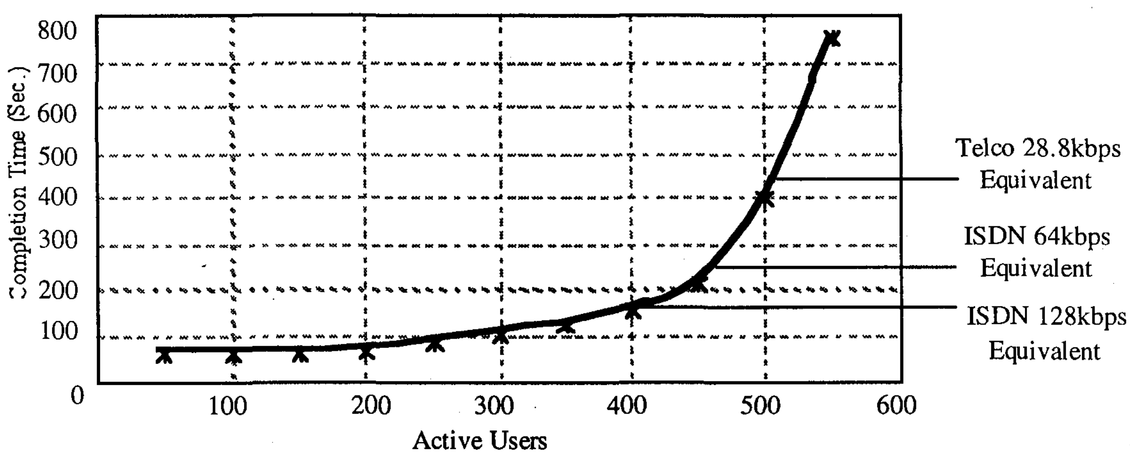

Figure 4: Predicted Data-Over-Cable Network Performance

Figure 4 shows the time it took to complete the typical Web surf as the number of simultaneous active users was increased from 50 to 550 users. One can see that with up to 200 simultaneous users, the typical surf took only the allotted 60 seconds to complete (i.e., the user saw no degradation in performance even when 199 other active users were on the network). As the number of users continues to increase above 200, the time to complete the surf begins to increase slightly, and when the number of simultaneous users reaches 400, the typical surf takes twice as long to complete. It is important to note, however, that even with 400 cable modem users simultaneously requesting service, the network performance still exceeds that of a 128 kbps ISDN connection, and the cable modem network performance with 500 simultaneous users exceeds the performance of the fastest telephone connection typically available today.

DESIGNING FLEXIBILITY INTO THE NETWORK TO SUPPORT FUTURE GROWTH

So what do the simulation and testing results mean? A network that only supports several hundred simultaneous users seems ridiculously ineffective in a city of several million potential subscribers, right? Not necessarily. The answer to this question exists in the design of to-day's modern cable plant. Most cable operators deploying advanced services such as high-speed data are doing so on upgraded 750-MHz hybrid fiber/coax (HFC) architecture. This approach (as shown in Figure 5) combines the use of optical fiber from a central headend to a fiber node, and then coaxial cable from the fiber node to the house. Such design allows the operator to subdivide a large city into many different sub-networks each with between 500 to 2,000 potential subscribers.

Each group of homes served by a single fiber node functions as a stand-alone entity and can be thought of as an individual sub-network.

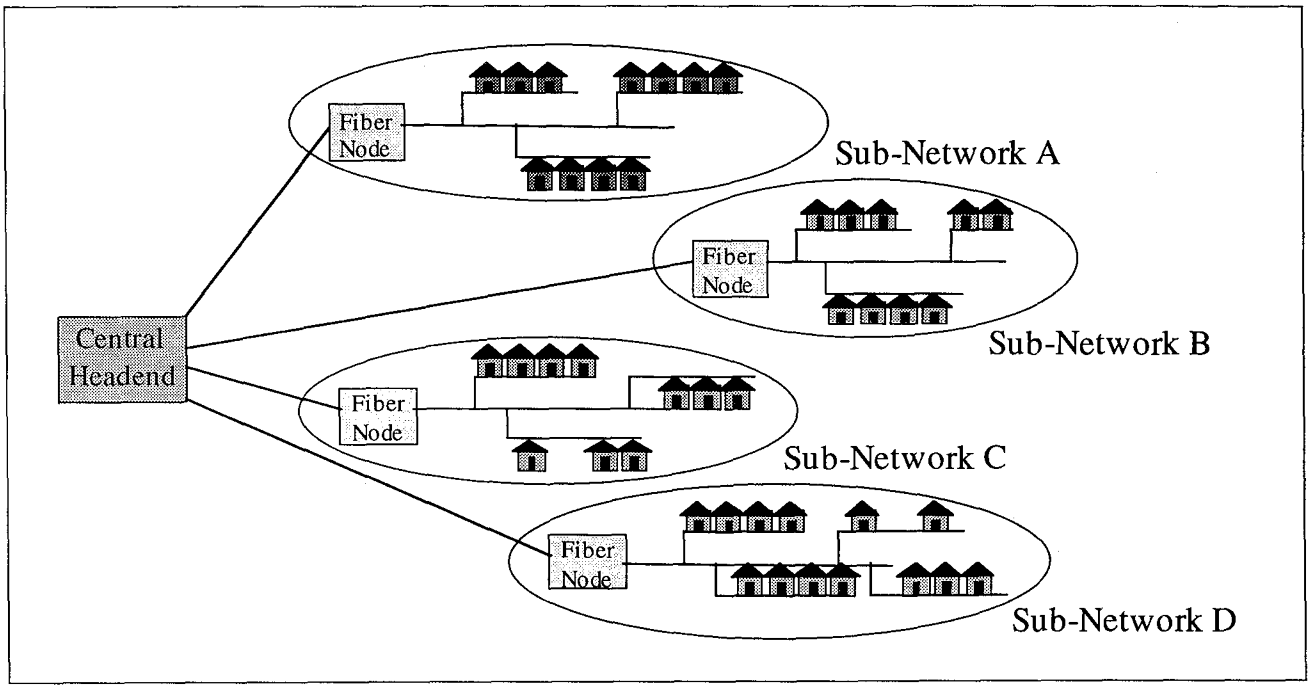

Figure 5: Sub-networks on an HFC Architecture

Thus, the cable operator need only design a single fiber node sub-network to provide effective service and then simply repeat that to reach millions of subscribers. The benefit of such a design means that if high-speed data over cable works for a single fiber node, then it can be repeated multiple times to support a large city. The following breakdown shows that even some of the largest nodes supporting 2,000 homes will likely see data service requested by only 129 simultaneous users during the peak period (busy hours) in the foreseeable future.

Homes on a Single Fiber Node =		2,000
% of Homes Taking Cable =	x	65%
# of Cable Subscribers =		1,300
% of Cable Subscribers Taking Data Service =	x	33%
# of Cable Data Subscribers =		429
Data Subscribers Online During Peak Usage =	x	30%
# of Simultaneous Active Users =		**129**

The cable operator's ability to sub-divide or segment the larger network into many small sub-networks provides a great amount of flexibility to evolve as demand for services such as data over cable increases. In addition to the ability to sub-divide the network, the use of the 750-MHz platform offers some 115 downstream channels on each fiber node that can be used for video, data, telephony, or other services. The operator has the ability easily to add additional data channels (i.e., replace an existing video channel with data service) or further sub-divide the network by running another fiber line from the headend if demand grows faster than expected. With digital video compression beginning to be deployed, additional channels will become available, relieving currently crowded channel line-ups.

THE BENEFITS OF A SHARED ACCESS NETWORK

The combination of existing HFC plant design and the flexibility to reallocate resources as demand grows means that the concern about performance degradation with an increased number of users is a non-issue. With this concern eliminated, one can focus on the numerous benefits of a shared access network.

First, a data-over-cable shared access network provides superior information burst capacity. When a user clicks on a link, he/she wants that page downloaded immediately. The ability to deliver that page in a timely manner is known as the network's burst capacity. On a dedicated circuit, such as a 64-kbps ISDN connection, there are only 64 kbps of throughput burst capacity available to a single user. It is impossible for that user to borrow additional unused capacity from other idle users. With a shared access network, however, a user has the ability to grab a big piece (i.e., several Mbps) of the shared 30-Mbps pipe to download the requested Web page and then release that resource for allocation to the other users. This ability to use resource only when needed provides great performance benefit, as well as inherent economic benefit to both the service provider and the customer. So cable provides not only greater average speed, but much greater maximum speed.

Second, a shared access network gives the data-over-cable subscriber the ability to be online all the time without the hassle of setting up a network connection every time he/she wants to send an e-mail or surf for information (i.e., waiting for computer to dial, server to respond and set up connections, etc., which can take 30-60 second every time). With a dedicated circuit connection, the resource is tied up regardless of whether the user is actually delivering or requesting information, thus the service provider must charge for the time the user is connected to the network. This provides the user the incentive to disconnect when he/she is done with a session and go through the time consuming process of reconnecting later. With a shared access network the modem is only using resource at the split second that information is requested. Thus users can be online 24 hours a day and only consume bandwidth when actively transferring information across the network.

Third, all users on a shared access network are connected to the same information pipe. This gives the content provider the unique ability to broadcast data streams (i.e., send one data stream down the pipe and have hundreds of users see it simultaneously). This can be an extremely efficient and effective way of delivering services such as streaming stock tickers, news feeds, multi-player games, software downloads, etc. In the dedicated circuit world, such services can only be provided by making a copy of such information for each user and repeating that stream on every dedicated circuit, which is inefficient.

SUPPORT FOR ENHANCED SERVICES

The exploding popularity of the Internet, combined with users' desire to do more online, has fostered a rapidly evolving application environment. Several years ago, the Web didn't exist and the predominant Internet application was text-based information retrieval and e-mail. Today, text and still-image based Web surfing is rapidly being augmented with Internet phone, broadcast audio and video, video conferencing, and shared collaborative applications. These evolving applications put greater demands on all networks. Fortunately, the MAC protocols being deployed today and being envisioned for the future have the flexibility necessary to effectively and efficiently support a mix of more demanding services on cable data networks. Design engineers are constantly redesigning and upgrading these protocols (which can be done easily with software changes in the headend) to handle new and different advanced services. This flexibility will be the key to success for cable operators deploying these services.

Glossary

Term	Definition
Dedicated Circuit Connection	a designated circuit reserved for a specific user
Downstream	the signal from the headend to the user terminal
Ethernet	a LAN used for connecting computing devices within the same building
Headend	in cable TV systems, the point at which the signal originates
HFC	hybrid fiber/coax
kbps	thousand bits of information per second
LANs	local area network
MAC	medium access control
Mbps	million bits of information per second
RF	radio frequency
Shared Access Connection	a single network shared by multiple users simultaneously
Upstream	the signal from the user terminal to the headend