Using Cable TV's Hybrid Fiber Coax (HFC) Infrastructure for Data Communications

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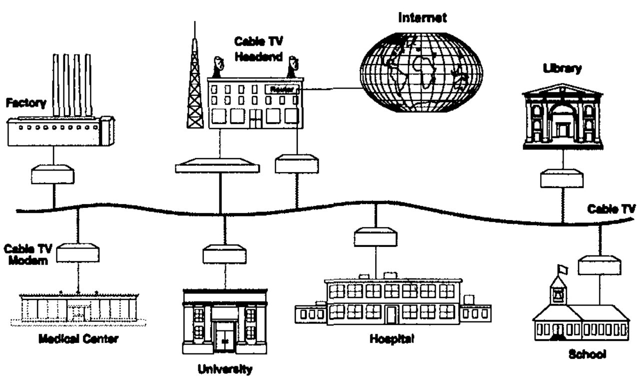
ABSTRACT

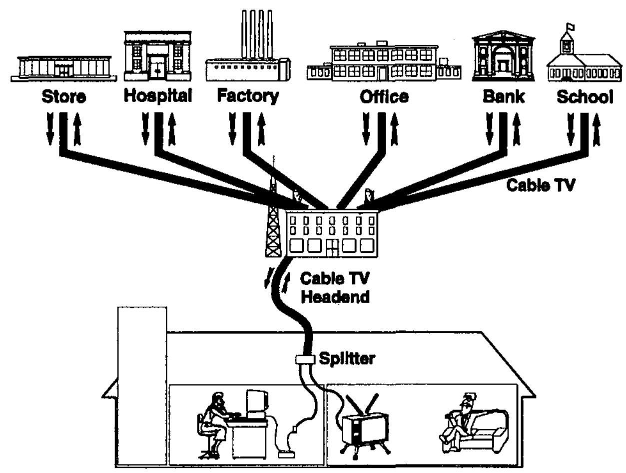
Using the available cable TV infrastructure, cable TV modems can interconnect homes, offices and municipal governments within our towns and cities. However, complex technical issues must first be overcome to create city-wide data over cable TV services offering cable operators a viable new source of revenues. This paper provides a conceptual overview of the cable TV operating environment, the types of information services that can be offered over cable TV, and a description of the enabling technology—cable TV modems—which make high-performance data communications over cable TV a reality.



Typical Cable TV High-Speed Data Network

INTRODUCTION

Today's cable TV infrastructure connects businesses, homes, shops, schools and government organizations city-wide. Cable TV internetworking is simple, because network connections are distributed, unlike telephone networks which only support point-to-point links requiring complex modem networks. The types of information services that are being provided over cable TV are as varied as the homes and businesses the cable passes. Internet access services, local area network interconnectivity, work-at-home, multimedia database services and multimedia conferencing are just a few of the many applications communities are employing to run their companies, teach their students, occupy their leisure time and improve productivity. Generating significant new revenue streams from the existing cable TV infrastructure, cable operators are first provided the enabling technology—cable TV modems—enabling the necessary high-performance yet economical city-wide data connectivity.



Work At Home Concept

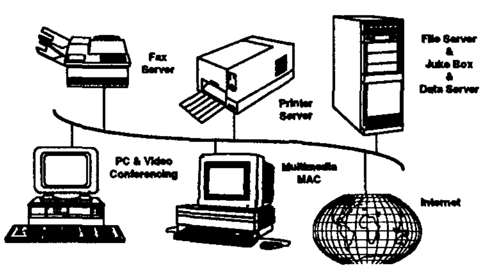
OPPORTUNITY OF DATA COMMUNICATION SERVICES OVER CABLE TV

Providing information services over metropolitan cable TV plants places unique operational requirements on the communications equipment used. These requirements are based on the two fundamental areas of data communications: the physical layer (PHY) and the media-access layer (MAC).

The operating characteristics of the transmission medium are defined by the physical plant, and in the cable TV world this includes the cabling, splitters, diplexers and amplifiers. The media-access layer defines the control of access to the physical layer that is shared among many connected users. The cable infrastructure is powerfully attractive for providing information services. Initial technical certification of the environment must first be addressed to ensure technical and commercial success for the cable TV operator.

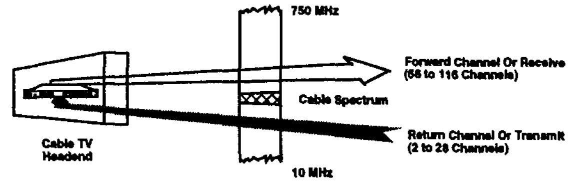
Technology which has been designed from the ground up to operate within the requirements imposed by the physical and media-access control layers provides information services over cable TV reliably. This technology is now available to provide the required high-performance levels over diverse operating conditions—and at market-driven prices.

The evolving Client/Server computer network model and Internet utilization patterns confirms that the source of information for data, video conferencing, application services and the Internet is distributed throughout the network. Therefore, it is clear not to assume that all information can originate at the headend and propagate down the forward channel.



Client / Server Computer Model

Data rates on both the forward and reverse channels must provide high transfers to support the distributed computer and multimedia paradigm. Ten megabits per second (10 Mbps) and above on the forward and reverse channels provide the necessary data rates to run the multimedia applications of the 1990s.

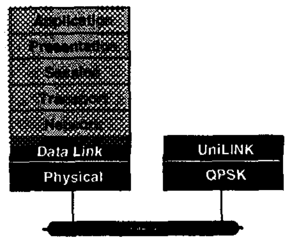


Cable TV Headend 2-Way Infrastructure

The many types of information services a cable operator provides for incremental revenue streams—video conferencing, multimedia databases, work-at-home, etc.—each have their own requirements for data rates, latency times and periodicity of access. Because of the scarcity of return channels to the headend, these different levels of services must all be provided within the same 10 Mbps streams and 6 MHz channel.

The diverse information services requirements are as follows: Efficient resolution of access contention and recovery from congestion is provided, because the coax cable which connects multiple users to the headend is a shared medium. Fair and stable access under varying traffic conditions is also required. Additionally, the technology itself is very easy to install, configure and maintain, so that the cable operator controls access, operational parameters and configures the network remotely. Operational visibility allows for easy troubleshooting and fault isolation. Security mechanisms prevent illegal tampering and use. Finally, a cable TV media access control protocol—which acts like a traffic cop directing traffic on and off the network—allows connected nodes to exchange multimedia information at very high performance levels.

A MAC-layer protocol for the metropolitan-area environment which addresses the above requirements and is being successfully installed on many cable TV systems worldwide is named UniLINK™ and was developed by LANcity Corporation.



OSI Model As Related To UniLINK™ Model

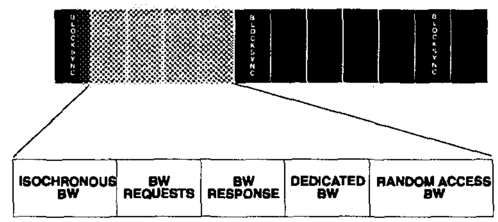
Offering enhanced digital signal processing modem technology, this cable TV protocol is uniquely positioned to provide easily installable, high-performance information services to homes.

CABLE MODEMS FOR THE METROPOLITAN ENVIRONMENT

The following sections provide an overview of the modem technology which allows a high degree of operating efficiency in the metropolitan cable TV environment.

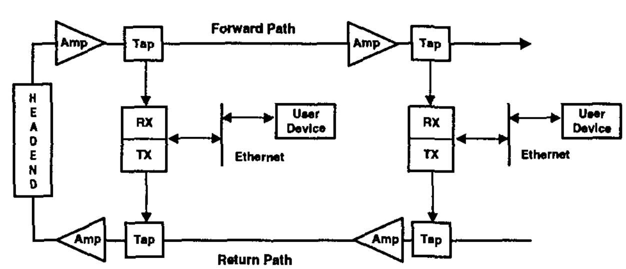
UNILINK ADAPTIVE ACCESS PROTOCOL

UniLINK™ is a media access control protocol which addresses requirements for providing information services to the cable TV user over metropolitan areas. It provides two modes of operation, enabling the many different types of applications described earlier to operate efficiently and reacts to changes in data traffic loads by reallocating the available bandwidth to relieve congestion situations. Both shared contention and dedicated reservation-based access are allowed within the same operational channel. Contention access provides almost immediate access under light loads but tends to bog down with higher levels of data traffic because of collisions and backoffs. UniLINK™ has the unique ability to switch from contention- to reservation-based access to help relieve congestion during high traffic loads. The protocol supports a simultaneous mix of both types, and it switches dynamically as necessary to maintain peak efficiency on the network. A "traffic cop" allows traffic to flow at its own pace until congestion occurs, at which point it starts directing who has access to the roadway until the congestion clears. A similar concept exists with the UniLINK™ Access Method.



UniLINK™ Access Method

Both forward and reverse data rates are provided at 10 Mbps to offer standard local area network levels of service to users. Increased distances do not degrade the overall throughput, because each node determines and compensates for its distance from the headend—especially important because of the distances involved in cable TV systems. Each node times its transmissions on the network to timing reference packets provided by a single pacer node. Any node may serve as the pacer, which is determined by an automatic election process. Multiple packets can be outstanding on the network, precisely following each other, because of the synchronous and distance compensating nature of the protocol, which allows efficient channel use. The data communications channel timing system can be compared to an Interstate Highway System, which is efficient because it allows multiple vehicles to travel simultaneously.



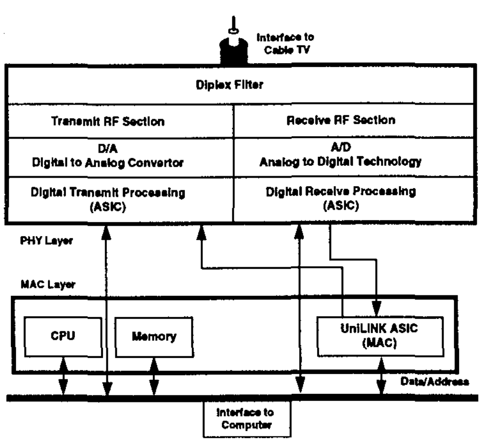
Data Communication Over Existing Cable TV Infrastructure

Both an Interstate Highway System and the information superhighway would be of limited usefulness if only a certain type of vehicle were allowed to travel on it. So the UniLINK™ protocol has been designed to service the traffic patterns that will be created by the varying applications on the cable TV network. Constant bit rate (CBR) with no jitter for voice applications, variable bit rate (VBR) with limited jitter for multimedia applications, and available bit rate (ABR) for basic data services can all be supported in the same 6 MHz channel.

The UniLINK™ protocol addresses the distance, changing data traffic, multiplicity of applications and congestion relief so prevalent in the cable TV networking environment.

ADAPTIVE MODEM FOR THE CABLE TV ENVIRONMENT

The new generation of cable TV modems that has evolved allows robust, high-performance within a harsh RF cable operating environment. The field-proven UniLINK™ protocol provides technology that compensates for various aspects of signal degradation using adaptive equalization mechanisms. The advantages of using the UniLINK™ protocol are that it provides periodic timing references on the network that can be used to sample signals on the cable TV HFC cable at specific times, regardless of whether actual payload data can be derived from the signal.



Data Cable TV Modem Architecture

The process used to allow both the forward and reverse channels to be compensated and is proven to independently compensate for the effects of the forward and reverse paths through a cable TV plant with no equalization training overhead for individual packets.

Cable plant characteristics will vary over time. Each node can periodically recheck its forward- and reverse-channel tilt and delay coefficients to provide peak performance levels at all times. Equalization can be performed every few hundred milliseconds to take into account "channel surfing" effects.

Cable TV modem technology described herein has been implemented in two Application-Specific ICs (ASICs) totaling 200,000 gates, allowing for compensating for the following channel characteristics:

Operating Characteristic	Forward Channel	Reverse Channel
In Channel Group Delay Error	<= 240 nsec	<= 800 nsec
In Channel Tilt	<= 6 dB	<= 6 dB

Cable Plant Adjustment Range

These channel characteristics can and most likely will be different for each drop on the network in both the forward and reverse paths, because a signal must traverse a unique path from the drop to the headend and conversely from the headend to each individual drop. Fixed, predetermined and static equalization information is therefore precluded because of the individual path variations that can change over time.

TODAY'S CABLE TV MODEM REQUIREMENTS

The cable TV modem technology incorporates a 10 Mbps QPSK transmitter and receiver and is designed to operate on a subsplit cable TV plant, allowing operation in the 5 to 42 MHz frequency range. Because of the mentioned operating characteristics introduced by the forward and reverse channel paths, the cable TV modem incorporates equalization filters in the transmitter and receiver to provide for dynamic equalization to compensate for these characteristics. These filters allow the cable TV modem to function with severe channel tilt, reflection, and group-delay effects.

The cable TV modem uses fully independent transmit and receive equalization filters, so that individual path errors to and from the headend can be fully compensated. Additionally, a transmit power adjustment on each transmitter and a received power sense circuit allows each modem to sense and adjust its transmit power in reference to a node at the headend, so that dynamic power adjustment can take place network-wide. A wide dynamic range on both transmit power and receive range allows compensation for widely varying levels in both the forward and reverse signal paths.

Much of advanced modem functionality has moved from the analog domain into the digital domain, which reduces manufacturing complexity and manual tuning requirements, and allows powerful digital signal processing techniques to be used to compensate for operating conditions. The modem transmitter consists of a high-speed Digital-to-Analog converter, a lowpass filter, a PIN diode attenuator and an output amplifier. The transmit baseband filter, transmit frequency generation and QPSK modulation functionality are implemented inside of a digital ASIC.

The Digital-to-Analog converter (D/A) has been selected to provide adequate signal-to-noise ratio over the entire transmit band and operate at a high enough sample rate to make the reconstruction filters achievable.

The input to the transmit equalization filter is the I/Q data at a 5 megasymbol-per-second rate. The filter coefficients are derived from the equalization process. The carrier is generated using a numerically controlled oscillator using a sine and cosine generator. The sine and cosine outputs of the numerically controlled oscillator are sent to the modulator where they are mixed with the I & Q channel data. The output of the modulator is sent to the digital to analog converter in the modem transmitter analog section.

The modem receiver also relies on digital technology for the implementation of major functional blocks, including the Automatic Gain Control (AGC) circuit, the receiver equalization filter, symbol clock recovery and the QPSK demodulator.

PLUG & PLAY FUNCTIONALITY

Cable TV data modems must adhere to the philosophy of simple installation and maintenance, coined "Plug in and walk away." The only requirements of the end user site is to make the physical connections to electric power and the cable TV. The node then begins frequency surfing to find its operational channel.

Other installation considerations must be addressed by the cable TV operator to allow plug-and-play functionality. These issues are minor and are associated with the cost of doing business, similar to installing a headend signal processor or frequency modulator to provide additional or upgraded video services. The only end user requirement is to make the physical connections to the power, cable TV and computer.

COST EFFECTIVE DESIGN

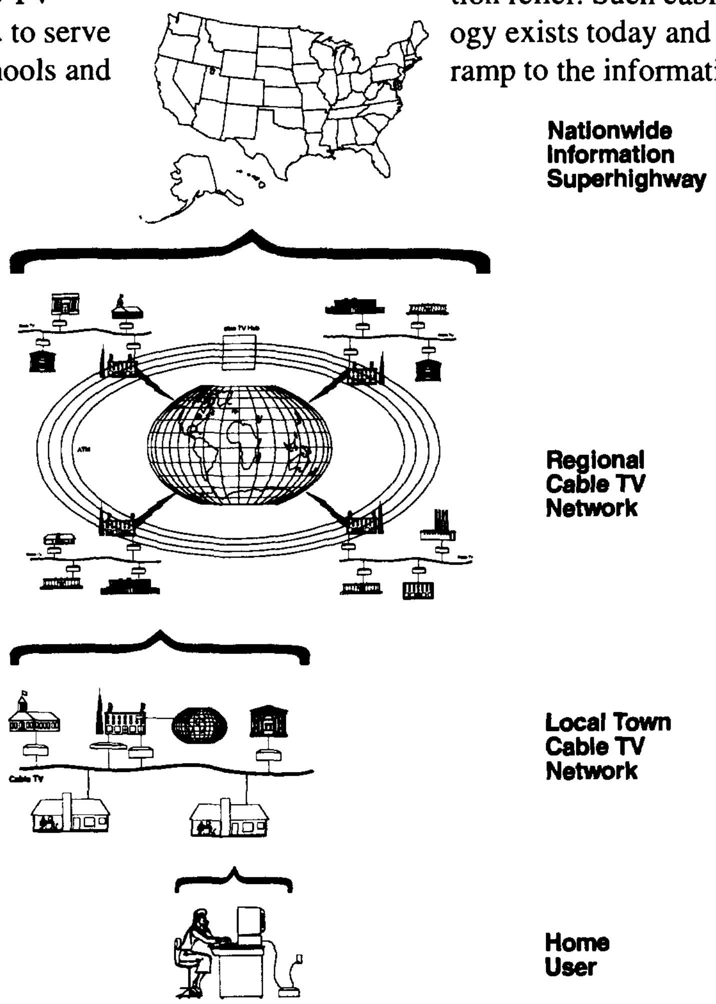
Product technology has been designed to meet the demands of the consumer or "at-home" market. A good design reduces the part count by increasing the level of integration through ASIC technology and utilizes components which have application in the consumer electronics market place. At the heart of the design is the Digital Signal Processing ASIC, which provides a high level of channel equalization and Automatic Gain Control functionality. The RF section uses components widely available for the cable TV set top box and cellular telephone market.

LIFETIME COSTS

The cost of equipment is a small percentage of the lifetime cost to maintain and troubleshoot a network that covers metropolitan distances. Easy, low cost installation coupled with remote operational information easily accessible through network management are the keys to prevent high, long-term maintenance costs not apparent at the time of purchase.

SUMMARY

The existing cable TV infrastructure is poised to serve homes, businesses, schools and governments with a wide variety of information services, generating a significant, new source of revenues for today's cable TV operators. To ensure commercial success, the requirements imposed by the two fundamental areas of data communications—the physical and media-access layers—must be designed to provide high performance levels over wide operating conditions. Key operating characteristics include high data transfer rates on both the forward and reverse channels at or above 10 Mbps to accommodate two-way data communications; a 6 MHz channel to compensate for the scarcity of return channels and to support the unique requirements for data rates, latency times and periodicity of access; and a digital signal processing protocol to address the prevalent issues of distance, changing data traffic, multiplicity of applications and congestion relief. Such cable TV modem technology exists today and can serve as the on-ramp to the information superhighway.



Business Model