Preliminary

White Paper describing EtherLoop™ Technology

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TEXAS INSTRUMENTS

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CONTACT INFORMATION

PIC Telephone	(972) 644-5580
PIC FAX	(972) 480-7800
Email	networks@ti.com

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EtherLoop™ Technology

Abstract

EtherLoop is a technology developed by Elastic Networks Inc to provide high-speed data access to the home over POTS-standard twisted pair. EtherLoop uses the basic concepts of DSL technologies, such as HDSL and ADSL, and applies well-known packet delivery system algorithms executed on a programmable Texas Instruments Digital Signal Processor (TI DSP) platform. This combination provides a high-speed solution that overcomes many of the limitations of ADSL and HDSL, without sacrificing speed or data quality. Through the combination of programmable DSP hardware, advanced signal modulation, burst delivery technology and the Ethernet packet-data protocol, EtherLoop provides a solution that is simple to install, robust over distances up to 21,000 feet and efficient in power consumption.

The EtherLoop project was started by Jack Terry, a senior technologist at Northern Telecom. The project goal was to develop a technology that would allow telephone companies to compete with cable modems in the arena of high-speed local data access.

The basic concepts underlying this technology are:

- Utilization of existing physical plant and real-world expectations for noise and interference
- Minimal interference with existing services
- Relative low cost, with equivalent performance

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Related Documentation

The following web site specifies product names, part numbers, and literature numbers of corresponding TI documentation.

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Introduction

EtherLoop is a technology developed by Elastic Networks Inc (http://www.elastic.com) to provide high-speed data access to the home over POTS-standard twisted pair. EtherLoop uses the basic concepts of DSL technologies, such as HDSL and ADSL, and applies well-known packet delivery system algorithms executing on a programmable TI DSP platform. This combination provides a high-speed solution that overcomes many of the limitations of ADSL and HDSL, without sacrificing speed or data quality. Through the combination of programmable DSP hardware, advanced signal modulation, burst delivery technology and the Ethernet packet-data protocol, EtherLoop provides a solution that is simple to install, robust over distances up to 21,000 feet and efficient in power consumption.

The basic concepts underlying this technology are:

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- Relative low cost, with equivalent performance

Worldwide, there are 750 million twisted pair copper subscriber loops[1] installed. These loops are used to carry voice traffic from the subscriber's premise to the telco central offices (CO), for circuit switching to another subscriber.

Voice traffic utilizes only the "bottom" 4-kilohertz of analog bandwidth available in the copper wire. This is an extremely small portion of the actual bandwidth available. The amount of bandwidth varies with the quality of the loop and the gauge of the wire, but in general, most subscriber copper loops can reliably utilize about 1 megahertz of bandwidth. If it is made available, this unused bandwidth provides a substantial resource for the telephone companies.

This document describes the EtherLoop technology from four perspectives:

- The physical nature of the signaling, and how the devices communicate
- EtherLoop modem implementation with programmable DSP chipsets from TI.
- The network architectures where EtherLoop is being used.
- A comparison of EtherLoop with the competitive high-speed technologies.

[1] "Loop" is the telephone industry term for a single twisted pair of copper suitable for voice service

Signaling and Communications

EtherLoop was designed as a hybrid service – bringing the best features of the DSL (Digital Subscriber Line) services together with the best features of Ethernet. DSL provides high data rates at extended reach over real-world physical plant. The Ethernet half-duplex communications model, and "burst" packet delivery provides capabilities which mitigate some of the serious side effects of high speed DSL services.

To understand EtherLoop it helps to understand the features of DSL and Ethernet.

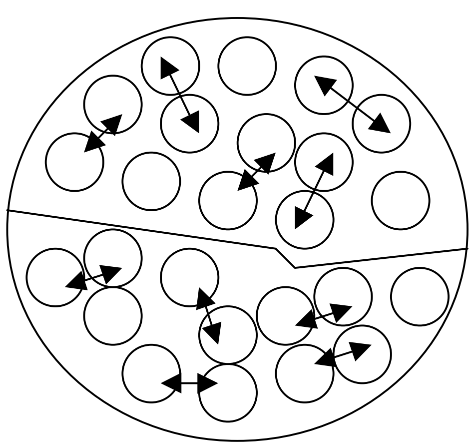
DSL

Digital Subscriber Line (DSL) is a technology that utilizes the additional bandwidth within the analog voice-grade twisted pair copper wiring. The copper bandwidth is divided into frequency bands. The lowest band (zero to ten kilohertz) is reserved for voice traffic. Those frequencies are left alone, to continue to support traditional voice traffic, while the higher frequencies are "borrowed" to support data traffic.

There are several DSL variants, each of which has distinct issues regarding installation and usability. The most prominent DSL variant is ADSL (asymmetric DSL). ADSL supports theoretical speeds up to eight megabits per second continuously in one direction over short distances, and lower continuous rates at its maximum range of 18,000 feet. ADSL provides a much larger downstream signal than upstream, thus increasing efficiency and reducing interference.

HDSL is a DSL variant that supplies a symmetric 1.544 megabit-per-second pipe over 1 or 2 pairs of copper wire. The 1.5Mbps rate is identical to the standard telephone company T1 data rate standard, although HDSL is easier to deploy than T1 and runs for longer distances. HDSL can be used for both data and voice applications, although because of the high-speed bi-directional traffic there are limitations on where and how HDSL can be deployed.

There are problems with these high-speed DSL services. Sending high-speed data requires substantial signal levels and power. The more signal delivered down the copper, the more signal "leaks out" and interferes with the other copper lines in close proximity. This is also known as cross talk. Copper wires are typically stored in a group of 25-50 tightly bundled pairs, and this



Sample 25-pair binder with 12/13 pair "sub-units".

Arrows represent incidence of high crosstalk.

bundling can cause considerable problems for other high-speed data users and potentially with other voice services. Typically for any one twisted pair in the bundle, there is one other pair that is closely associated with it, in terms of cross talk susceptibility. This is usually characterized in terms of decibels – any number larger than –60 dB incurs significant crosstalk.

For DSL services to reach their theoretical performance maximums, a near-ideal subscriber loop is required. In the real world, however, most subscriber loops are far from ideal. The wire may change gauge, ranging from 22 gauge to 26 gauge. This causes distortions and interference in a passing signal. It is also possible to have "bridge taps" on the loop, where a wire is attached to the main loop, but not connected to anything at the far end. Unconnected bridge taps cause reflections in the signal - some of the incoming signal will "bounce" backwards, and this reflection will interfere with the original signal, and it must be filtered out by the DSL transmitter/receivers at both ends. This requires extremely adaptable echo cancellation technology, which adds significant cost and complexity to the system. This is primarily a problem with CAP-based ADSL systems. DMT-based ADSL work better with bridge taps, but have other problems in turn.

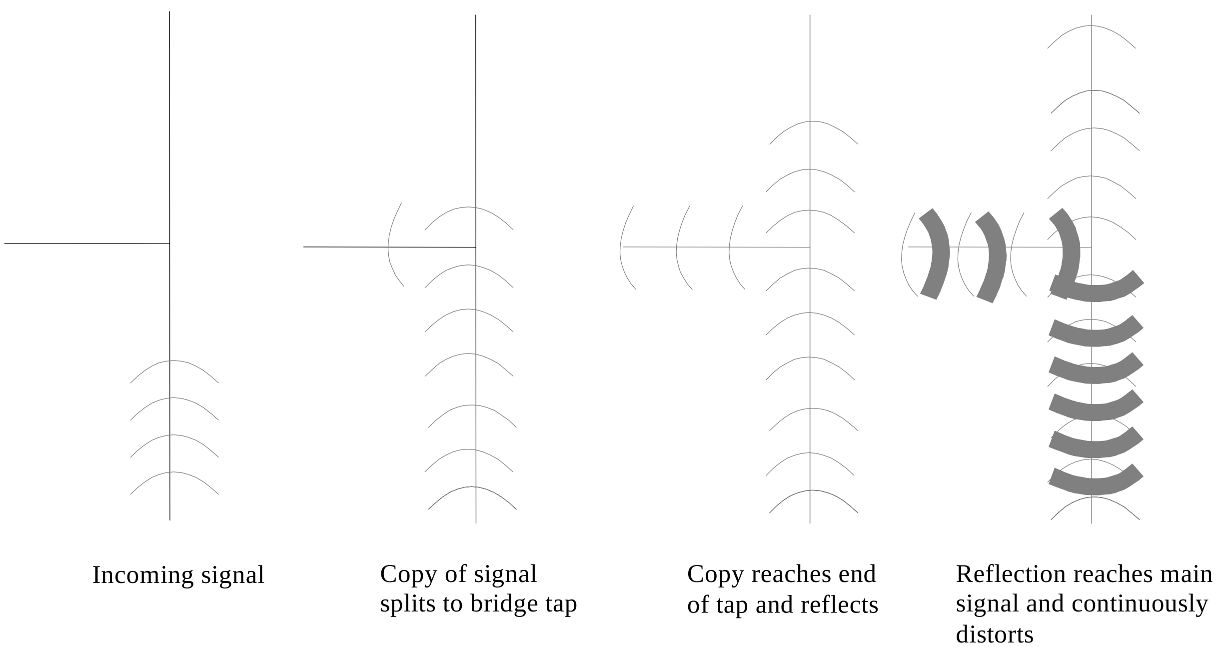


Figure 1: Bridge Tap distortion in Continuous network

Loading coils are also a significant problem. These are metallic coils that are attached to subscriber loops to increase the usable length of the wire. This is typically used when the subscriber is 18 kilofeet or more away from the central office. However, in many cases, a subscriber may be closer to the central office, but yet still possess loading coils on the loops because of the way wires are used over time. Loading coils cause a nearly complete degradation of higher-level frequencies, which effectively eliminates the possibility of delivering high-speed services on these "loaded" loops.

Lastly, ADSL requires continuous power levels to deliver signal from the client to the master and vice versa when it is operating. In the telco[2] environment, or any other 'high density' ADSL deployment (ports/cubic foot) the heat from multiple modems must be dissipated to keep the components from overheating, which increases both the complexity of the DSLAM, and the price of the components.

Ethernet

Ethernet is the dominant protocol in the local area network (LAN). It is a packet-data protocol, which works over standard twisted pairs, in somewhat special configurations. It has two characteristics that make it highly desirable as a high-speed protocol to be used on the copper loop.

- Burst-mode packet delivery system
- Very mature, well-tested technology

Burst Technology

Data is, in most environments, considered "bursty" – i.e. there are long periods of silence, followed by a brief flood of data packets. Bursty data has an important advantage over continuous bit rate services, such as xDSL. Burst data allows the use of half-duplex communications (i.e. only one of the two ends talks at a time). This creates an advantage when dealing with bridge taps and gauge changes. When the data signal is reflected back to the sender, the sender doesn't care, since they aren't simultaneously receiving. The receiver (at the far end) is able to filter the weaker secondary signal out fairly easily.

All packet data protocols essentially follow the same model: only speak (send out signals) when there is something to say. When there is no data to transmit, they send nothing, or at worst, a very low level carrier signal. This, in turn, provides bursty data another advantage over continuous protocols – power. If the transmitter has nothing to say, it requires very little power to operate. It has been found that under normal conditions, a packet-data system will be idle almost 98% of the time. Given this idle time, the average power consumption rate is significantly lower than the maximum power consumption rate.

The Ethernet Standard

Products built on the Ethernet standard are readily accepted into the majority of local area networks. In addition, since the technology is mature, it is possible to purchase extremely inexpensive chips to integrate into a device to provide Ethernet compatibility. Lastly, this mature technology is well understood, and expertise in building and installing Ethernet networks is relatively easy to find.

[2] Telephone company

Disadvantages

Ethernet delivers data frames across networks in a broadcast fashion. In a broadcast network, it is not possible to predict who will talk at any given moment, so Ethernet uses a collision detection system, to determine when a remote device is talking, and avoids talking during the same time period. It is not, however, possible to completely avoid collisions in half-duplex Ethernet. Each collision requires the network devices to stop talking, and wait for a short time before speaking again, which reduces the total bandwidth available for data delivery.

EtherLoop

EtherLoop takes the best features of DSL technology, then utilizes burst technology to reduce the interference problems and uses the Ethernet packet-data model to reduce the cost of connecting to a data network. EtherLoop also manages to avoid the collision problem of Ethernet. Since EtherLoop is used in a point-to-point fashion (between the CO and the subscriber premises), it is possible to define one device as a “master”, and the other as a “slave”. The slave only speaks when the master allows, which effectively eliminates all collisions.

Because the subscriber loop is generally of lower quality in terms of bit error rate (BER) than a private LAN, EtherLoop also manages frame error checking and retransmission, using the Ethernet checksum. This is typically not done on LANs since the bit error rate is low. It is, however, an appropriate action to take on a noisy copper telephone loop.

EtherLoop also takes advantage of the flexible symmetry available in a half-duplex Ethernet communication link. The amount of time spent transmitting in each direction is directly proportional to the amount of traffic being offered in each direction. If the user is downloading a file, then most of the time is spent transmitting in the downstream direction. In this case nearly all the EtherLoop bandwidth is used for downstream communication, with only a small proportion of the available bandwidth being used to transmit acknowledgements upstream. If the user is uploading a large file, then nearly all the available EtherLoop bandwidth is used for upstream communication. If the user is engaged in a video conference, then the bandwidth is split symmetrically. These are only a few examples of how the EtherLoop bandwidth can be split. Any combination is possible. EtherLoop does not impose a fixed upstream/downstream bandwidth ratio on the user, but instead allows the user traffic to dynamically set the symmetry.

Lastly, EtherLoop utilizes unique "Spectrum Management" software that is not derived from any other technology. During the times that the transmitter is silent, the quality of the signal is monitored. Crosstalk and interference can be measured, and the device can constantly change internal frequencies to reduce crosstalk and avoid interference. This is used as a continuous rate adaptation technique. This rate adaptation allows the modem to immediately adapt to any noise it receives or generates, and generally improves the quality of the modem’s transmissions and reduce its interference with the other 49 lines in the cable bundle.

In summary, EtherLoop has the following characteristics:

- High-speed interface either to and from the subscriber, based on data traffic.
- Little or no interference from reflections caused by poor wiring (bridge taps and gauge changes)
- Low power and heat dissipation.
- Collision avoidance.
- Intelligent burst management to optimize data bandwidth and direction for a given application.
- Instantaneous frequency adaptation directed by firmware-based spectrum management features that ensure maximum data throughput and spectral compatibility with other data services in the telco binder.

The combination of DSL signaling technology, burst mode delivery and Ethernet frame technologies gives EtherLoop its competitive advantages. DSL technology allows the use of the existing telephone infrastructure, and Ethernet burst technology reduces interference, power consumption and provides a low cost interface.

Signaling

For high quality subscriber loops EtherLoop is designed to use a range of frequencies from approximately 30 kHz to 3 MHz. This frequency range is divided up into 10 overlapping frequency spectra, only one of which is active at any point in time. The lowest spectrum has a total frequency range of 62.5 kHz, and the highest has a frequency range of 1.667 MHz. Historically speaking, one Hertz is equivalent to one symbol per second, which would give EtherLoop a theoretical maximum symbol rate of 1.667 megasymbols per second. Using standard signal modulation techniques, such as BPSK, which support 1 data bit per symbol, this would translate to 1.667 megabits per second.

The Bad News

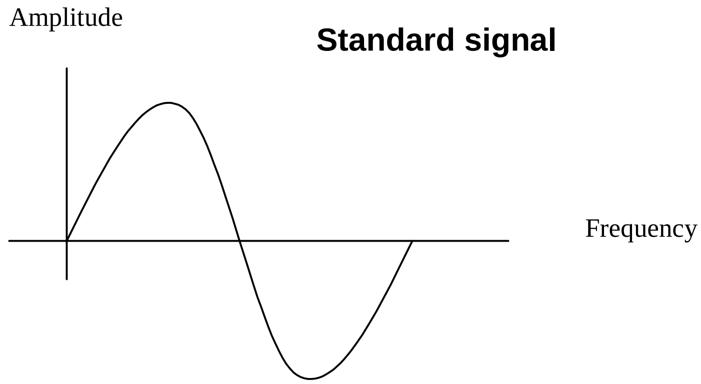
Not all of the frequency spectrum, however, can be used effectively in all cases, based on crosstalk, loop quality and so forth. This reduces the maximum symbol rate.

The Good news

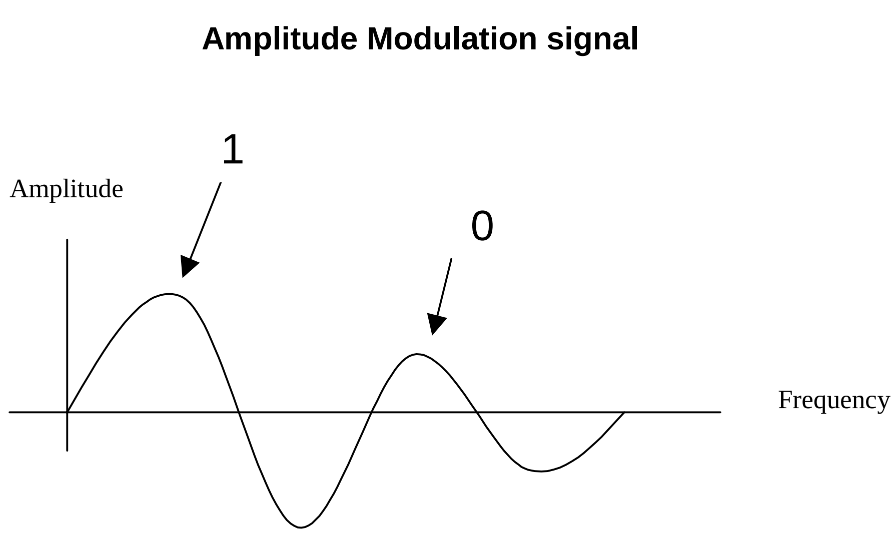
Equalization technology can improve the bit rate considerably, and at shorter distances (less than 6 kilofeet), which have less noise, the symbol rate can start to reach the 1.667 megasymbol limit.

Signal Modulation

There are a variety of advanced signaling techniques that "squeeze" more than one bit out of one Hertz. Several of these techniques have been used within analog modems, to bring the maximum speed of the modem up to 56 kilobits per second. Other techniques, such as 2B1Q and CAP are used with ISDN and some versions of ADSL. EtherLoop uses two related signal modulations techniques: QPSK (Quadrature Phased Shift Keying) and QAM (Quadrature Amplitude Modulation).

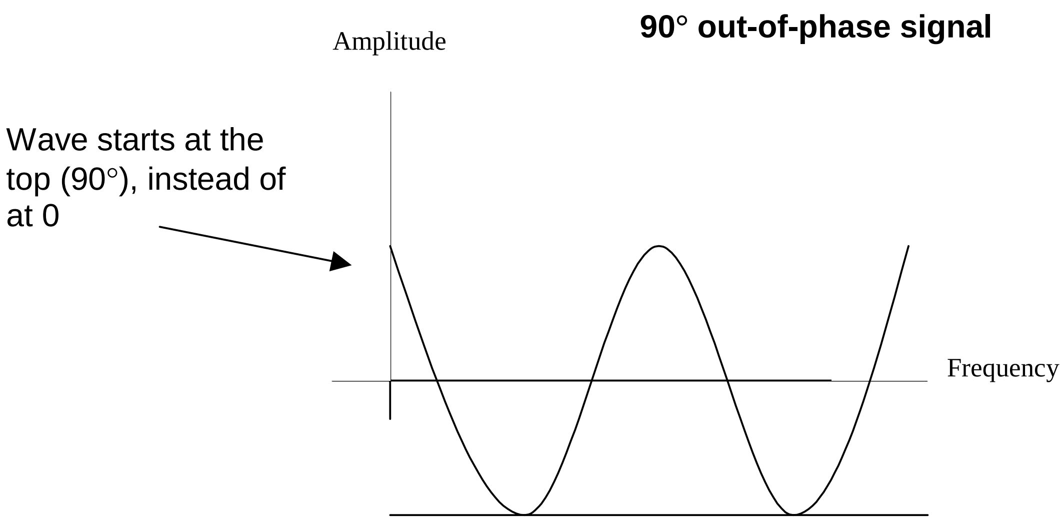


The previous figure represents a standard carrier wave. The sine wave starts at 0 height, and cycles through a fixed maximum and minimum amplitude. An amplitude modulated signal uses different amplitudes to represent different values. If two amplitude values are possible, one that represents a one, and another that represents a zero, then one bit per symbol may be transmitted.



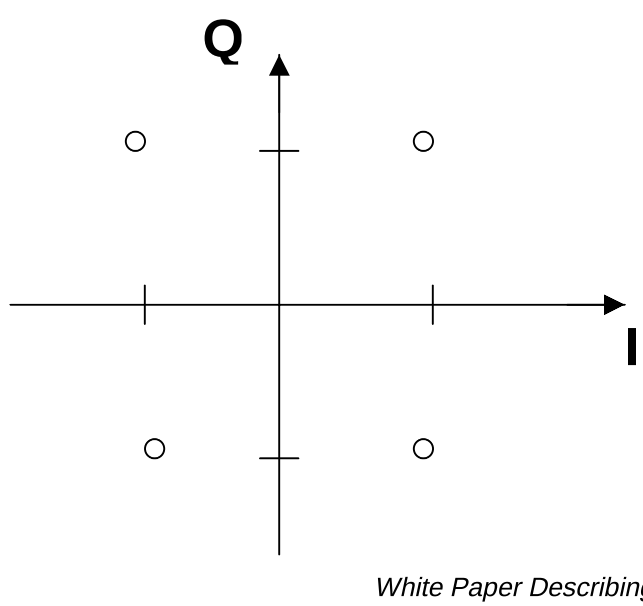
QPSK

QPSK (Quadrature Phase Shift Keying) uses phase shifting to represent different values. The figure below shows a carrier which begins 90 degrees out of phase from the unmodulated carrier.



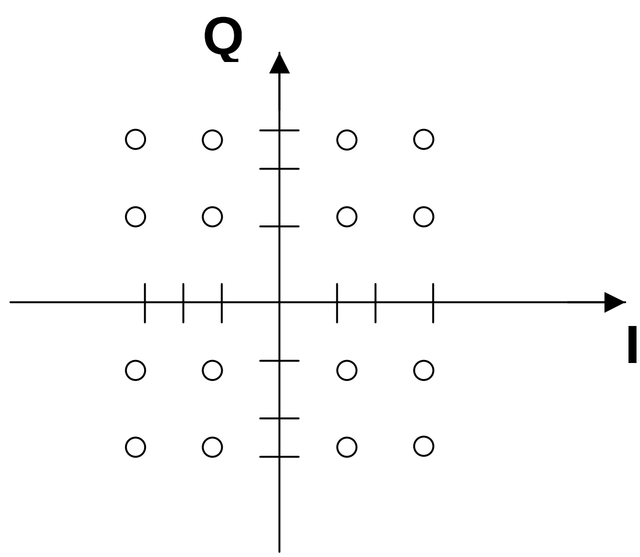
The four possible symbols used in QPSK are a carrier with 0°, 90°, 180° and 270° of phase shift These four possible symbols can represent $log_2(4)$=2 bits. This would allow 1.667 megasymbols per second to represent 3.33 megabits per second.

These symbols can be represented as the sum of two different carriers. One carrier has zero degrees phase shift, and is call the In phase (I) component. The other carrier has 90 of phase shift and is called the Quadrature (Q) component. If the four symbols described above are rotated by 45 degrees, to give an equivalent set of symbols with phase shifts of 45°, 135°, 225° and 315° then they can be represented as I+Q, -I+Q, -I-Q and I-Q. This can be graphed as shown below.



QAM

It is possible to improve beyond this, by combining amplitude and phase modulation. QAM16 (Quadrature Amplitude Modulation) supports 16 possible symbols. These symbols are created by allowing two possible amplitudes for each component, such as I+3Q, or 3I-3Q. This is illustrated below



The 16 possible symbols allow for $\log_2(16)$=4bits/symbol, giving a total 6.666 megabits per second for an EtherLoop link that supports 1.6666 megasymbols/second. This concept can be extended further, using more possible amplitudes, for instance QAM64, would support $\log_2(64)$=6 bits/symbol, corresponding to 10 megabits/second for 1.667 megasymbols/second. Note that as the number of symbols increases it becomes more difficult to distinguish them from each other, so less noise can be tolerated in the communication channel. This means that QAM64 will only yield better results than QAM16 for relatively short loops.

Note

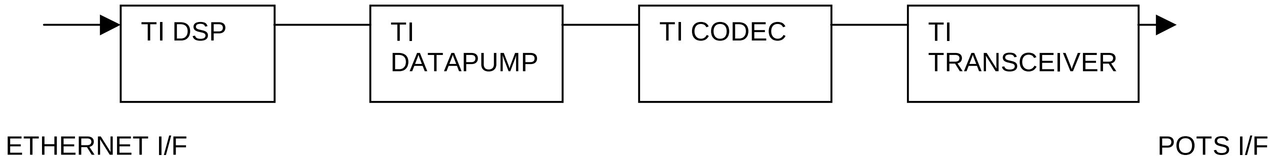
These speeds vary based on the quality of the loop, the length of the loop, the types of services in the binder, and a number of other factors. It is not realistic to expect that every subscriber will receive the maximum bit rate all the time.

Maximum Bandwidth

The physical limits of ADSL and EtherLoop are nearly identical. Any speed that can be reached with ADSL can be reached, or at least approximated with EtherLoop as well. EtherLoop has an advantage over ADSL however. While ADSL delivers data in both directions simultaneously, EtherLoop delivers data in only one direction at a time. This allows EtherLoop to reach peak bandwidth equivalent to the sum of the upstream and downstream bandwidth for an ADSL link. For example, a 6-megabit per second downstream and 1-megabit per second upstream ADSL service on a particular copper wire could become a peak 7-megabit EtherLoop link in either direction on that same wire. EtherLoop can adaptively divide this 7 megabits/second bandwidth between upstream and downstream in any way, dictated by the user traffic.

EtherLoop modem implementation with TI DSP

The following diagram shows a client EtherLoop modem based on the TI Digital Thunder™ DSP.



TI CLIENT ETHERLOOP MODEM

The TI EtherLoop chipset consists of the following devices

- Programmable Digital Thunder™ DSP
- Datapump
- CODEC with integrated filters.
- Transceiver

Ethernet data is presented directly to the TI DSP. The DSP executes EtherLoop firmware from local flash memory and sends the resulting data stream via a glueless serial interface to a TI EtherLoop datapump. The datapump sends a sample stream to the TI EtherLoop CODEC which directly drives the TI EtherLoop transceiver. The system leverages the TI digital Thunder ™ DSP in the following ways.

- Ethernet and high speed serial interfaces integrated within the TI DSP ensure low system cost and power dissipation.
- The programmable TI DSP allows the modem firmware to be dynamically reconfigured via Flash update as necessary. This allows the EtherLoop firmware and Spectrum Management software to be flexible.
- The programmable TI DSP allows functional enhancement of the basic modem for example by running routing or Voice over IP software in addition to EtherLoop modem firmware.
- The TI EtherLoop CODEC and transceiver integrate programmable filtering and gain control functions that reduce system footprint, cost and power consumption.
- The TI DSP and CODEC will support connection to multiple transceivers in a Central office application. This allows an ultra low cost and low power system in which one modem manages data from multiple POTS lines.

Network Architecture

EtherLoop technology was purposefully designed to follow the format of the Ethernet IEEE 802.3 standard as much as possible. This has a dual purpose. First, it allows EtherLoop to appear like Ethernet natively, which reduces the product costs of performing a protocol conversion. Second, it allows EtherLoop devices to fit into an existing network, in almost any location where an Ethernet device operates now. There are some limitations, however:

- EtherLoop is only appropriate in a point-to-point link
- EtherLoop provides a lower peak bandwidth on longer/lower quality loops
- EtherLoop will always be more expensive than Ethernet

These limitations are not as severe as they first might appear. Much of the existing Ethernet now in place use the 10baseT substandard, which requires point-to-point connections between a network device and a hub. Peak bandwidth is important, but is a combination of technical improvement and fundamental issues of distance and wire quality. Even conservative estimates of EtherLoop's capabilities indicate that it should reach 10 megabits per second at 3000 feet on a majority of existing wiring, while simultaneously supporting an analog voice channel. The expense of EtherLoop is only a factor when the network is completely within the limited (100 – 150 meter) ranges where Ethernet operates correctly.

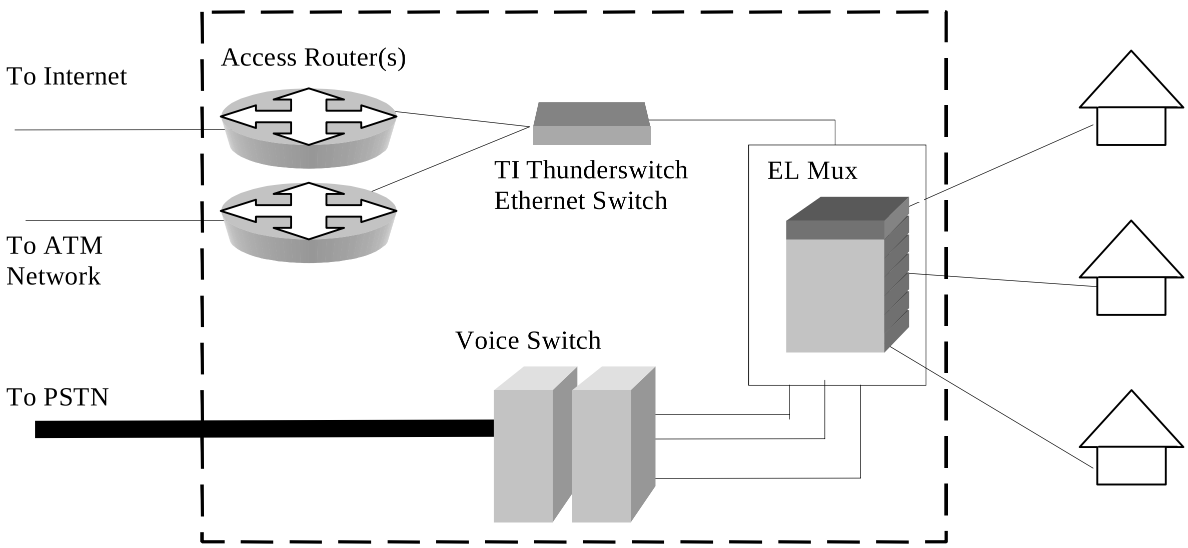
Given these limitations, it is clear that EtherLoop market niche is long-range Ethernet network extensions. There are five major markets where long-range Ethernet is a viable product:

- Residential Internet Access
- SOHO (Small Office Home Office) Internet and corporate access
- Hotel/Hospitality/Lodging Internet Access
- CAN (Campus Area Network) deployment
- Data T1 Replacement (LAN extension)

Central Office Configuration

The EtherLoop CO configuration is relatively straightforward. Each subscriber is brought back to an EtherLoop Multiplexer shelf product, which is EtherLoop ready. The voice and data channels are separated, and the voice channel is passed on to the PSTN switch. The data channel is passed on to a TI ThunderSWITCH Ethernet switch, which then connects to any standard TCP/IP or ATM network. Depending on the needs of the customer, multiple networks can be attached, for example, some users may wish to use the public Internet, some may wish to use the telco's regional broadband network, and some may wish to connect to private corporate networks.

In Figure 3, the end-user maintains a very simple network, with a connection back to a Central Office Internet Access point. The CO access point provides semi-intelligent connection management, providing different access gateways for subscribers of different services (for example, competing ISPs, corporate networks, etc.) The discrimination of service is performed by the TI Thunderswitch Ethernet switch, which intelligently routes the data to the appropriate remote resource (either the Internet, or one of potentially several private networks), based on the destination. The multiplexer in this picture provides management of the EtherLoop master



modems, and the first stage of Ethernet packet multiplexing.

Figure 3: Basic CO Access Model

Note that this figure is only one of many possible network architectures. Ethernet networking is very well understood, and there are numerous ways that data can be delivered in secure and flexible ways.

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Residential Access

The Residential access model is the most straightforward. The end-user will typically have only one device connected to the EtherLoop link, which simplifies the overall architecture. The CO end provides Ethernet switching, to deliver data to one of several routing resources, which could be connections to the Internet, to private Intranets, or to an ATM/Frame Relay transport network.

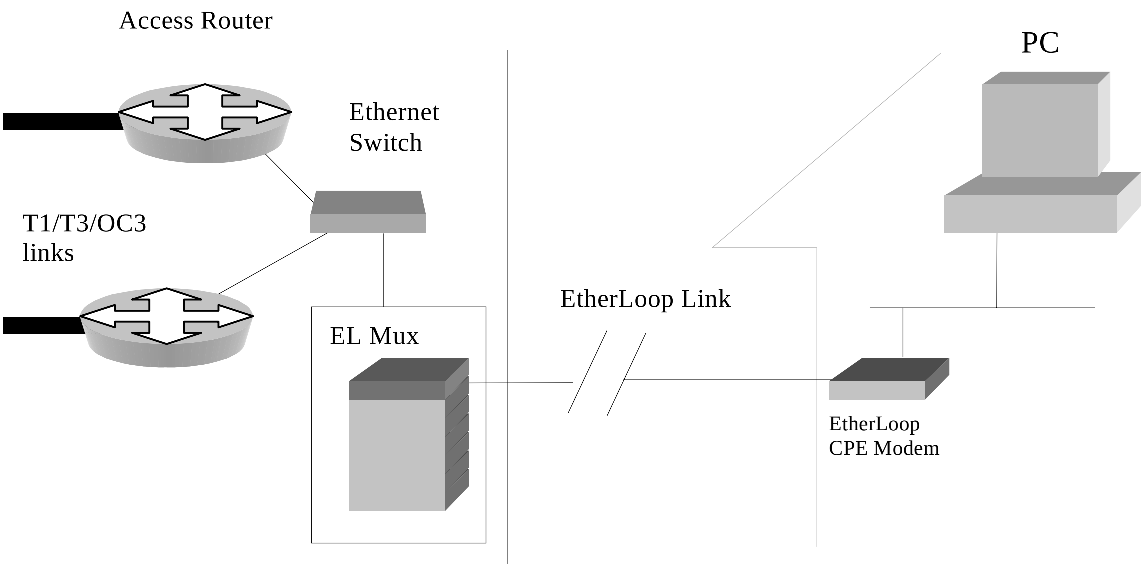


Figure 4: Residential Internet Access

The home user will typically be assigned one or more static IP address (addresses that does not change each time the user connects to the network), or alternatively have an IP address provided at boot-up per-computer via DHCP (the Dynamic Host Configuration Protocol).

SOHO Corporate Access

The SOHO model differs moderately from the residential access model. Typically, there will be a more extensive LAN in the subscriber's home/office than the residential user. In this case, the CO and CPE modems must take on the additional responsibilities of bridging Ethernet traffic, keeping local traffic on the subscriber premises side of the link. This capability is already built into the EtherLoop CPE and CO modems. In that configuration, an external modem is more appropriate.

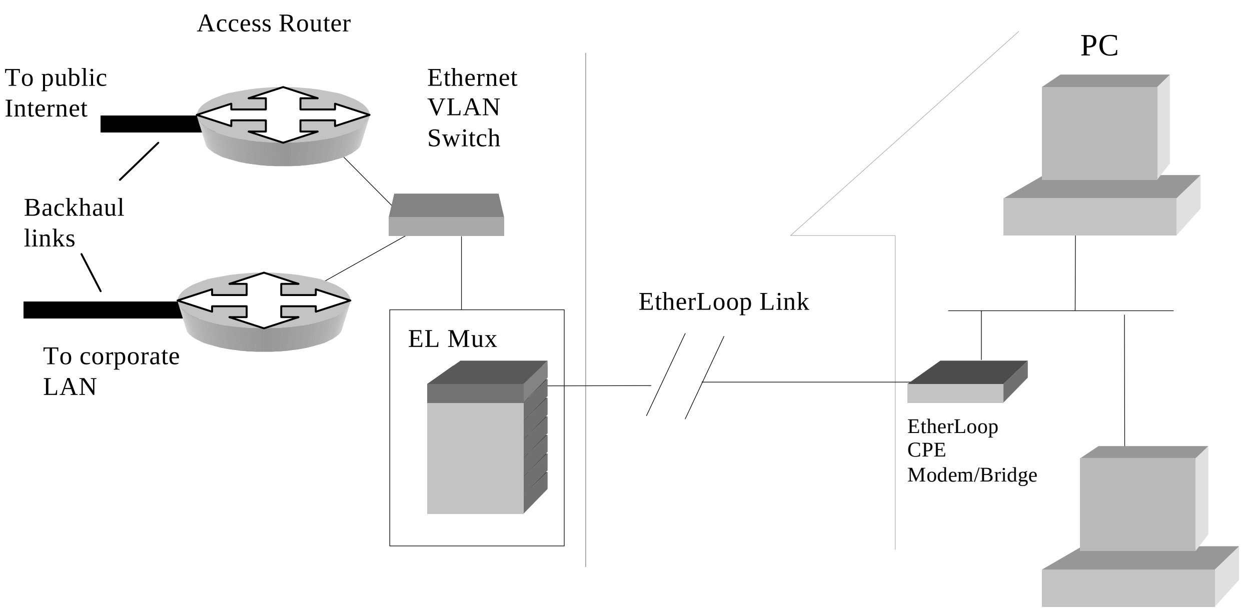
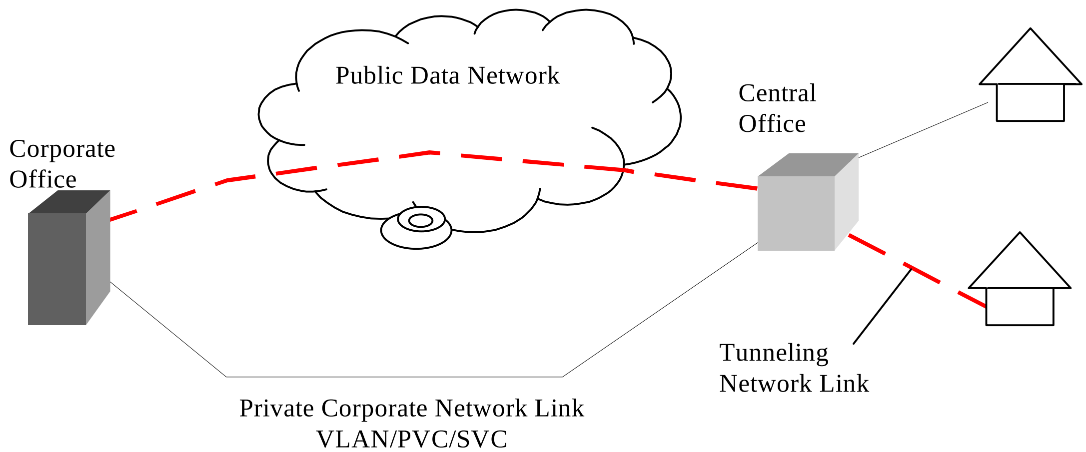


Figure 5: SOHO Corporate Access

This model requires some additional resources – typically either VLAN or PVC-enabled TI ThunderSWITCH Ethernet switches to correctly route the correct traffic to the corporate network, or tunneling protocol software, to encrypt packets that are delivered over a public network to the corporate access point.



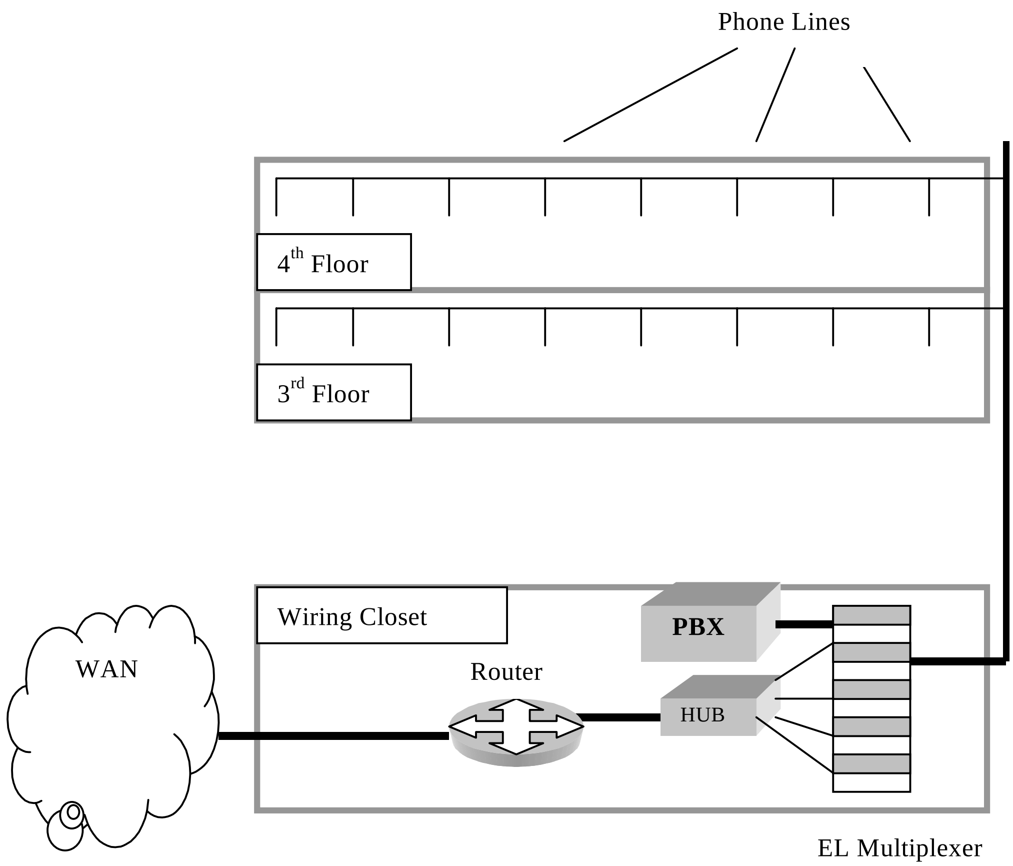
Each of these secure communications strategies has advantages and drawbacks, the discussion of which is beyond the scope of this document. Future EtherLoop products that would enhance this market include EtherLoop/Ethernet switches and VLAN switches, EtherLoop-based routers and ATM/Frame Relay interfaces.

Hospitality Industry

EtherLoop provides a straightforward way to provide high-quality data to every room in a hotel through the existing telephone infrastructure. The primary model installs an EtherLoop modem into the wall of each room, providing an Ethernet-enabled RJ45 jack adjacent to the RJ11 telephone jack. The modem brings the voice and data channels back together, and delivers them down to a wiring closet or PBX closet. Here, an EtherLoop Multiplexer separates the voice from the data, and passes the data on to a TI Thunderswitch Ethernet switch or router as before.

This provides an advantage over wiring with Ethernet. Half the cost of a new Ethernet installation is in the cost of the re-wiring, and distances are typically limited to 330 feet. In the EtherLoop model, since the distances are limited to about 4000 feet for Ethernet-grade data rates (10 mbps), the amount of equipment needed to deploy service is greatly reduced, decreasing cost and improving maintainability.

IP access to the WAN is provided through another Elastic Networks product – the Elastic Internet

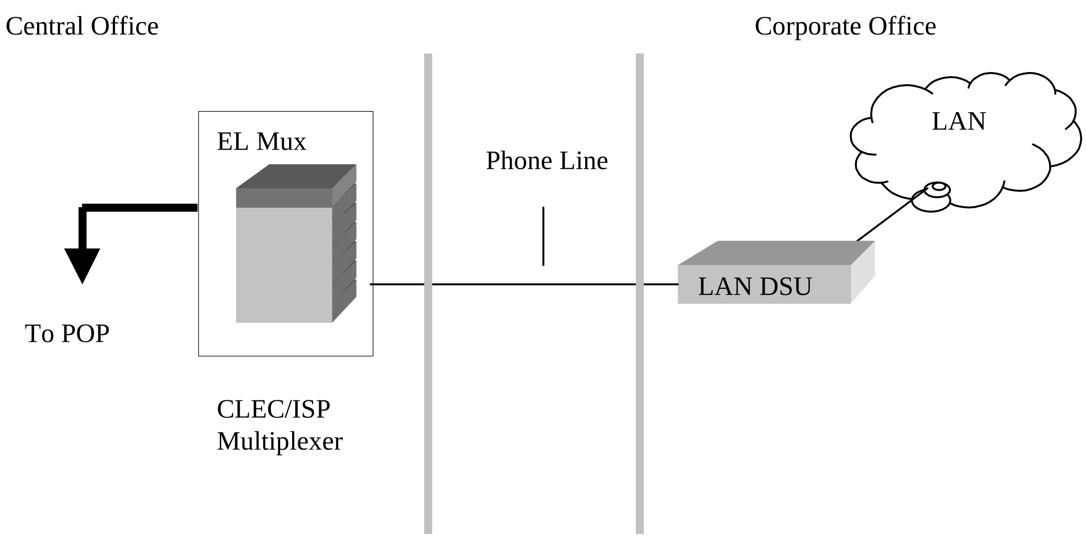


Proxy (InterProxy). A discussion of the InterProxy is beyond the scope of this document. The enhancements for the hospitality model are similar to the others: concentrating modems, built-in Ethernet switches, and VLAN capabilities, etc.

Campus Networks/T1 Replacement

In a campus or downtown environment, EtherLoop can be used to provide data network access to corporations, universities or institutions at speeds of up to 10 megabits per second, over existing voice lines.

In this environment, a rack-mounted EtherLoop LAN DSU will be installed at the customer premise, with a corresponding connection either in a central office, or at a nearby site, depending on the nature of the copper access regulations.



Technological Comparisons

This section describes the basic differences between EtherLoop, ADSL, HDSL, MVL and Cable Modems. Note that with the ever-changing nature of high speed technology, some of this information may be out of date.

Duplex Mode

HDSL, ADSL, and G.Lite are all full-duplex services. In other words, both the CO and the CPE (Customer Premises Equipment) modems are communicating simultaneously. MVL appears to be a highly adjustable full-duplex service, based on described capabilities.

Cable Modems can be either full or half-duplex services, depending on the technology used and the requirements of the network connection. At the time this document was written, it appears that most are half-duplex.

EtherLoop is a half-duplex service. Only one of the two devices may be communicating at any time.

Full duplex provides the advantages of better link resource utility, since one side does not have to wait for the other to communicate. The trade-off for this, is the divided bandwidth. Each side must either use distinct transmit and receive wires, or a carefully separated upstream and downstream spectrum, to avoid interference.

Half duplex provides the advantage of full bandwidth utilization in both directions. For the time that they are transmitting, each device has the entire link to itself. However, there is a turnaround time, which will reduce the average bandwidth. Half duplex is not suitable for continuous bit rate services, such as broadcast-quality video. However, it is suitable for packet-based video delivery.

Privacy

HDSL, ADSL, MVL, G.Lite and EtherLoop are all point-to-point, private services. The only way to eavesdrop on a point-to-point service is to physically tap the line. Once the signal leaves the local loop, this privacy is subject to the nature of the network that the data resides upon.

Cable Modems utilize a shared network, where all devices are visible to all the other devices on the cable segment.

Privacy is important for corporate data integrity, and for personal privacy. The market has shown, however, that most individuals consider privacy to be unimportant with regard to residential Internet access. Business customers, however, value privacy, which can be provided by a combination of physical security and encrypted data streams.

Delivery System

HDSL, ADSL, G.Lite and MVL are all continuous data network products. In other words, they continuously transmit, whether there is data on the local loop network to transmit or not. When there is no data to transmit, these devices deliver idle data until they are shut down.

EtherLoop and Cable Modems are both packet data network products. They do not deliver idle data when there is no data to send.

The advantage of a continuous data network is the quantifiable reliability of the link. It is possible to provide continuous data services, such as voice and video, without any compromise for quality or network congestion. Either you have enough bandwidth, or you do not.

The advantage of a packet network is efficiency. Many network applications do not require continuous data to operate properly, and continuous data networks reliability is wasted. In addition, some continuous data services, such as voice traffic, can be characterized as packet data. Voice traffic has a significant amount of silence, which makes the “real” data pattern of a voice call fit the profile of a high-speed packet network very nicely.

A side effect from the only-speak-when-necessary nature of a packet network is the reduction in power consumption. Since it does not require high power when it is idle, a packet network uses significantly less power than the equivalent bandwidth continuous data network.

Protocols

Because of the continuous data delivery system, HDSL, ADSL, and G.Lite can be adopted fairly easily to provide an ATM interface. This allows these products to take advantage of ATM’s carefully planned traffic management and data delivery systems.

Again, any continuous data product can provide a packet data network interface, by placing idle data in-between the valid packets. As mentioned before, this is inefficient in power consumption, but still possible. Therefore, HDSL, ADSL, and G.Lite can provide Ethernet and other packet-network protocols, with the appropriate conversion logic.

Cable modems can provide ATM services, but the bandwidth requirements to each home/office reduce the number of users per system considerably when compared to Ethernet or other packet based cable modem systems. Most cable modem systems use Ethernet as the communications standard because of its efficiency in serving large numbers of customers with one shared medium.

EtherLoop and MVL are primarily designed to operate with Ethernet and other packet networks. They use many components of the Ethernet protocols internally, which allows the conversion to and from “true” Ethernet to be handled very efficiently and reliably. EtherLoop should be able to provide ATM services at a high rate of speed if interfaces such as FUNI (Frame User Network Interface) are used. It may also be possible to provide continuous ATM at low (256 kilobits per second) speed, but this capability has not been investigated.

Concentration

HDSL cannot be easily concentrated. It is designed to be a point-to-point continuous pipe.

ADSL and G.Lite can be concentrated, but it is complex to do so. The data characteristic must be “bursty”, like the data that is found on a packet network, and the CO modem processor must run significantly faster than the CPE modem. It is not possible to concentrate a continuous data system, unless the speed of the communications link far exceeds the utility of the link by the individual users. For example, if the reliable bandwidth available on a local loop is 8 megabits per second, and each CPE modem sends and receives data at 2 megabits per second, it is possible for 4 subscribers to utilize the same CO modem. Another option is to pool ADSL modems amongst several subscribers, by allowing the subscribers to begin and end sessions. This is the same model used for dial-up access, and is an intelligent way to use these resources.

Cable modems are, by their very nature, concentrating devices. Only one device transmits at a time, and the ‘CO’ modem (or head-end) uses exactly the same technology as the individual subscribers.

MVL appears to be capable of concentration, based on the fundamentals. However, its service description depends on the ability to offer multiple services per line, which may not be compatible with a concentration model.

EtherLoop can provide concentration of multiple subscribers because of the statistical likelihood of idle time. This is the same principle that allows Ethernet to work in the first place. It is possible to monitor each of several subscribers in a rapid round-robin fashion, to detect incoming data, and respond to the data quickly. This system avoids the possibility of multiple transmissions because the CO and CPE modems are organized as master and slave. The CPE modem does not deliver data until the CO modem permits it. This allows one master device to support multiple client devices simultaneously.

Distance

HDSL is designed to travel up to 12,000 feet using one or two pairs of copper, depending on implementation. ADSL's maximum range is not certain, although current literature places the limit at 18,000 feet. Full-duplex Cable Modems are effectively unlimited in range. Half-duplex cable modems appear to be limited to approximately 16,000 feet. G.Lite operates at 20,000 feet, and MVL claims to work at 24,000 feet.

EtherLoop operates at distances up to 21,000 feet at this time. It may be possible to extend that range somewhat. It should be noted that the distances available to EtherLoop are, in theory, also available to ADSL. Note also that as distance increases, speed decreases.

Speeds

HDSL is a fixed-speed service, rated at 1.544 megabits per second, both up and downstream. This can be accomplished with two pairs, or with one. The single pair version (HDSL2) is just finished the standarization process, and is not expected to be deployed in quantities until late 1999.

Cable Modem speeds vary, based on the quality of the link and the equipment used. Currently, the best stated maximum seen is 40 megabits per second, shared amongst a substantial group of subscribers. As the number of users increases, the amount of bandwidth available for any one user decreases considerably. Typical values area 1.5 megabits downstream and 300 kilobits upstream.

ADSL speeds vary as well, also based on the quality of the link and the equipment used. Theoretical maximums of 8 megabits downstream and 1 megabit upstream are stated. In practice, however, with real-world loops, the equipment placed in the field typically has rates far lower than that. G.Lite advertise speeds in the 1 – 1.5 megabit downstream, 128 – 384 kilobits upstream range.

MVL advertises speeds of 768 kilobits, either upstream or downstream, but not both. It is possible to divide the bandwidth, for example, 64 kilobits up and 704 kilobits down, or 384/384.

EtherLoop is currently rated for speeds of up to 10 megabits per second with QAM-64 at distances of 4000 feet or less. Past that, EtherLoop can be expected to fall into the same general speed range as the addition of the upstream and downstream ADSL signal.

Conclusion

This paper has shown that, EtherLoop is not "just another DSL". EtherLoop is a communications architecture that leverages programmable TI DSP to "wring" the maximum possible bandwidth out of any twisted pair copper pipe, and it does this in a way that is flexible enough to comprehend a wide variety of data networking needs. In the long term, TI DSP based EtherLoop technology will have a measurable impact on the standard methods of transmitting packet data over twisted pair copper wiring.