Wideband Community Network

Technology Assessment Report

Prepared for:

Los Alamos County

The Wideband Community Network Committee

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June 1999

Acknowledgement

The following members of the Wideband Network Committee deserve to be *especially* recognized for their guidance and numerous insights.

Mr. Kenneth Milder, Utilities Board
David Rosselle, Media Connections Group
Tim Merrigan, Los Alamos National Labs
Mike Krumm and Pat Barnes, Nortel Networks
Brian Wilkin, Lucent Technologies
Dick Griffiths, Telmac Consultants
Charles Ferrell, Tularosa Basin Telephone Company

Spivak Associates wishes to thank the entire Wideband Network Committee for giving their time to attend meetings, provide comments, feedback and suggestions, and especially for their participation in the one-on-one interviews reported in this document.

Joe King, Chairperson, Los Alamos County
Christopher D. Wiggs, Deputy Chairperson, ICF Kaiser
Bill Cabral, Bill's Computer Shop
Dan Caimi and Carlos Ramirez, UNM
Tony Hotten, Adelphia Cable
Chris Dissinger, Los Alamos Monitor
Alyn Ford, LANL-Telecom
Elizabeth Girtman, Schools (K-12)
Suzie Havemann
Kevin Holsapple, Los Alamos Commerce and Development Corporation
Mary Pat Kraemer and Margaret Weaver, Mesa Public Library
Ken Milder, Utilities Board
Greg Ogburn, Los Alamos Commerce and Development Corporation
Elmer Salazar, LANL-IPO
Daniel Sanchez, US West
Steve Santistevan, Medical Center
Sidney Singer, Regional Development Corporation
Mike Walters, LA County Utilities
Lee Weinland, PAC 8
Barbara Yeamans, Yeamans Machine Shop

Spivak Associates thanks Dr. Karlene Spivak for proof reading and editing.

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BACKGROUND

This report was produced for the Los Alamos County (LAC) Wideband Network Committee under contract PSA 1122-98, executed June 10, 1998. This contract resulted from a competitive bidding process and was awarded to Spivak Associates based on their response to LAC Request for Proposal #98-1261.

The purpose of this report is to provide an assessment of technologies relevant to a Wideband Community Network (WCN) in Los Alamos County. This is the third (Deliverable #3) of five reports. Briefly, the contents of the reports are:

Regional Considerations (#1)--This report describes telecommunications activities in New Mexico and communities in other states that could impact or influence a WCN feasibility study. It also identifies and discusses relevant national policy and policy implications. Key learnings are described as well as possible federal funding sources.

Existing Infrastructure (#2)--This report examines the telecommunications and cable television infrastructure already deployed in Los Alamos and assesses the quality of US West copper loop plant for high-speed digital services, such as xDSL and ISDN. Report #2 provides fiber-optic cable maps, assesses the quality of the Adelphia plant for two-way, high-speed digital services, and provides an inventory of relevant network components, services, resources, and facilities.

Technology Assessment (#3)--This report examines the relevant technologies, costs per subscriber, and types of network topologies and architectures for a WCN. It also analyzes the development trends of key technologies over the next five years.

Market Analysis (#4)--This report analyzes the needs and requirements of Los Alamos businesses and residences for WCN services. It includes an analysis of the economic impact and gross receipts tax effects of a WCN project on Los Alamos and the region, assesses the viability of various WCN content services, and discusses the merits of a pilot implementation. It identifies WCN competitors, barriers and impediments.

Implementation Recommendations (#5)--This report describes alternative approaches and recommends an implementation model for the WCN, including a business model, conceptual design, and cost estimates. It also assesses the viability of a WCN from an investor's point of view.

INTRODUCTION

This report identifies, discusses, and evaluates key Wideband Community Network (WCN) protocols, technologies, architectures and topologies. See the WCN Regional Considerations Report[1], for information on the networks that other communities are considering and/or have implemented. Information is also provided on new and emerging key technologies. These key technologies are critical to the successful operation of a WCN and are necessary to ensure WCN extensibility (i.e. capacity, flexibility, performance and scalability). Stable, well-established technologies are not addressed because they are readily available now, will in all likelihood be available for the next decade, and are not undergoing rapid changes.

Many key technologies are now in the test or initial deployment stage. These technologies are examined and evaluated in detail because: 1) there have not been widely deployed, 2) they will evolve quickly, 3) they are critical for ensuring WCN extensibility, and 4) ensuring future compatibility and interoperability. The selection of the key technologies is dependent on several factors: the unique features and needs of the user community, the purpose for which the technology will be used, and the network topology. The evaluation is presented in terms of relative advantages and disadvantages, with a long-term (at least five-year) viability assessment. An evaluation criterion was applied to each technology based on its attributes (capacity, performance, flexibility, maintainability, and price). Each criterion was assigned a point value. An evaluation was done for the technology as it now exists and it's expected evolution. The now and future evaluations were then weighted to yield a single, point value score. The evaluation weights reflect the relative importance of each criterion. Larger weightings were assigned to key technology characteristics that are the most important, lesser weights were assigned to characteristics of lesser importance.

This report was developed after reviewing reference books, trade magazine articles, manufacturer white papers, searching Internet sites, and interviewing manufacturers, other experts, and system operators--approximately 140 sources of information have been synthesized for this report, see References starting on page 48. The author also tempered the assessment with 30+ years of his own telecommunications experience. The long range views and forecasts in this report are based on extrapolation of the knowledge available today. Technology breakthroughs resulting from serendipity and sheer luck are unpredictable and can not be addressed in this report. In the author's opinion, a technology breakthrough that would significantly change the overall recommendations in this report is unlikely, but is possible.

This report is organized to discuss key technologies by their function within a network topology. Access technologies are discussed starting on page 14, followed by access protocols starting on page 24, node technologies starting on page 32, backbone technologies starting on page 35, and network interconnects and topologies starting on page 39. Figure 1 illustrates how the key technologies interconnect.

The access technology (method and medium for distributing and collecting information from the home and business) is the most critical area for rapid technology development. The access technology and access protocols involve the physical medium (copper wire, coaxial cable, fiber-optics, etc.) and the protocols (ISDN, xDSL, wireless, etc.) that operate over the physical medium. For a description of the market forces at work that are pushing for faster access speeds to the home and business, see The Need for Speed, starting on page 8.

Critical node technologies are next discussed. The term Node is used as a generic term that may denote a telephone company central office, a cable operator's head-end or any other central location for the aggregation and redirection of information. Unless the node technologies keep pace with the increasing speeds of the access technologies bottlenecks will result. Discussion of node technologies starts on page 32.

Backbone (network connection) technologies are also discussed. The backbone must transport the information aggregated at the node and interconnect with other local and long distance carriers. Discussion of backbone technologies starts on page 35.

Network topologies and architectures, and their advantages, disadvantages, and relative costs, are discussed as they relate to a WCN implementation, starting on page 39. The topologies and architectures refers to the way that access lines, nodes, and backbones are interconnected. Different types of interconnection can give the network dramatically different properties.

The following general architecture model illustrates the relationship between the critical technology categories discussed above.

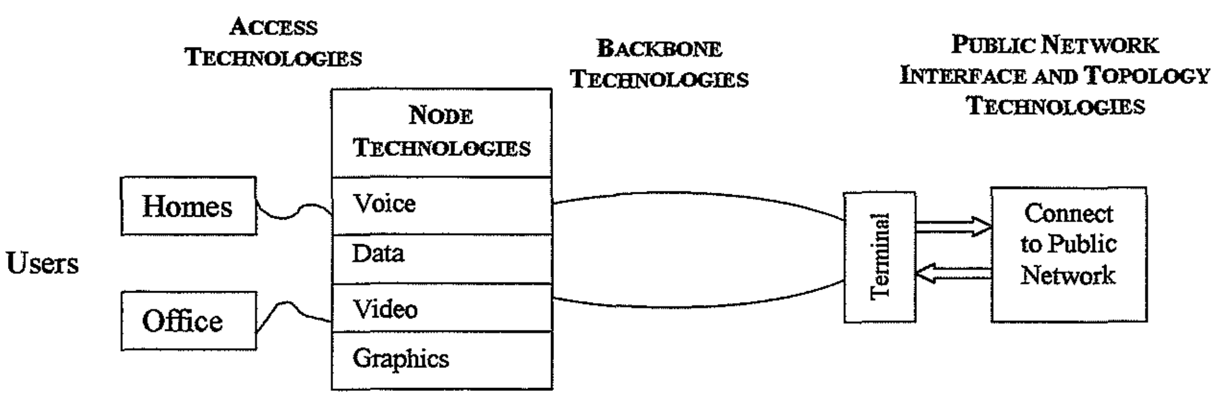

FIGURE 1 GENERIC NETWORK ARCHITECTURE

The Public Network Interface is the connection to US West, Competitive Local Exchange Carriers (CLECs), Interexchange Carriers (IXCs) and others.

The Need for Speed

To fully understand the evolutionary direction of the technology and the necessity for making the right choices in technology it is helpful to consider the factors that are driving applications and technology development.

The marketing of user applications by computer and component manufacturing corporations is a powerful force. In order to drive sales, Intel, the world's largest manufacturer of computer processors, releases a new processor family about every 18-24 months. Every three to six months, manufacturers like Dell, Gateway, IBM and Compaq release a new and enhanced computer model usually accompanied with price reductions for older models. By making regular, dramatic increases in processing speed and by reducing processor prices, Intel books record sales year after year. Likewise, Microsoft and other software developers design their software suites to fully utilize the power of Intel's newest round of processors. New software revisions that capitalize on faster speeds lead to record sales for software companies. The premise on which the industry has grown is that the need for speed will never be sated.

Unfortunately for Intel shareholders, the prognosticators miss-read the market need. The current levels of processor speed are satisfactory for most business and home computer applications. Users who depend on stand-alone computer applications like accounting, word processing, spread-sheets, and taxes, do not benefit significantly from the faster speeds provided by the latest round of Pentium III processors. There is now plenty of computer power to drive the most common business and home-use applications -- or is there?

Continued sales growth requires that the focus of Intel and Microsoft shift from the stand-alone computer to networked computers *and the Internet.* Indeed both companies are betting their futures on the growing success of networked computers and the Internet. The direction of Intel and Microsoft is also critical to the entire computer and telecommunications industries. About a quarter of the Fortune 500 companies have a stake in boosting computer and networking speeds. There is no doubt whatsoever that corporate America will do everything possible to create attractive and beneficial applications that will drive the *need for speed.*

Microsoft and Intel are driving multimedia applications into the markets. Multimedia applications require the latest processors, as well as expanding the capabilities of the communications networks, including the node, access, and backbone technologies. Multimedia is a catchword for the combination of voice, video, graphics and data. One promising multimedia application is document collaboration, face-to-face meeting or conferencing over a private network or the Internet. In deed the forth coming release of Microsoft Office 2000 emphasizes these features.

The primary multimedia drivers are streaming audio and video delivered over the Internet. This means the ability to listen to Internet audio information through your personal computer speakers, as well as web sites that will talk and show video clips. Real-time audio broadcasts over the Internet will be commonplace. Likewise, streaming video applications will provide TV quality video clips. The clips won't be freeze-frame video; they will be at least television quality. Streaming audio and video will require at least 1 Mbps of access speed to the home and business. The allure of the new streaming audio and video information technology will attract many people that have been resisting the Internet. Likewise, multimedia conferencing, including document collaboration is a powerful business feature. At least that is the Intel and Microsoft bet.

Spivak Associates believes that multimedia conferencing will become an application with enormous business, and eventually residential, appeal. Video conferencing (multimedia conferencing is the next generation of video conferencing) has been around for many years and has not achieved wide-scale acceptance because of the complexity of the equipment, the cost of operating a video conference room, and the lack of intimacy (the feeling of actually being there and being able to "read" other people). Tomorrow's multimedia conferencing applications will involve desktop-to-desktop conferencing rather than requiring specially equipped videoconference rooms. The desktop multimedia conferencing setup will be greatly simplified, controls will be easy to use and the feeling of intimacy will be greatly improved.

Multimedia conferencing will enable workgroups of engineers, scientists, and production specialists to meet in cyberspace. Companies that incorporate multimedia conferencing in their operations will be able to deliver new products to the market faster than their non-multimedia competitors. Indeed, multimedia applications will become a strategic corporate initiative. Collaborative business groups will use multimedia conferencing as easily as telephone conference calling is used today.

Multimedia conferencing will maximize the effectiveness of today's changing workforce. Project employees or consultants, who may live anywhere in the world, can be drawn together for a specific project or problem. The conventional workforce of employees who all live within physical commuting range may soon be geographically dispersed and able to work from any location. Overhead costs for business space will be minimized. As these benefits are realized, high-speed data to the home and business will become a requirement, not an option.

What this means to users in communities like Los Alamos is the ability to capitalize on the fast growth markets, find niche business opportunities, and provide leading edge solutions. It's about being compatible and competitive with other high-technology solution centers in this country and around the globe. Communities that implement Wideband Community Networks *now,* will help facilitate the endeavors of their residents and businesses in the future.

Steaming audio and video requires at least 1 Mbps from the Internet *to the desktop,* but only requires low-speeds (56 Kbps-256 Kbps) *from the desktop* to the Internet--this is called an asymmetrical service since the upload speed (desktop to the Internet) is much less than the download speed (Internet to the desktop). However, multimedia conferencing requires at least 1 Mbps upload *and* download speed, because of the need to send and receive similar video signals. Since the upload and download speed requirements are the same, multimedia conferencing is called a symmetrical service.

SUMMARY AND FINDINGS

Because of the continued rapid growth in high-speed networking to the home and business, fiber-optics will play an increasingly important role in access line infrastructure. While copper wires are generally cheaper and easier to maintain than fiber, overall data capacity will be the deciding factor. Typically, fiber will be extended closer and closer to the home, gradually replacing copper wires, as access line infrastructure is upgraded. However, fiber will not *enter* the home; copper wire operating at very high data speeds coaxial cable, or new wireless systems will be used for last few hundred feet to the home. Business will likewise have fiber to the wiring closet, and depend on copper, coaxial cable, wireless or plastic fiber to connect the desktop to the wiring closet.

Copper wire and coaxial cable will be the access mediums of choice for many years to come. Copper wire systems will offer xDSL services. xDSL has two very important variants for the future. 1) S-HDSL is a high-speed data service for customers that send and receive large amounts of data. 2) RADSL is ideal for customers that receive more data than they send (e.g. casual residential Internet use). RADSL provides asymmetrical services, but will not be generally attractive to home-based professionals that send and receive large data files over the Internet. Because cable modems offer two-way (symmetrical services) at speeds of 1 to 10 Mbps coaxial cable will be preferred by home-based professional and employees.

Wireless services have not yet been introduced for the "last mile" service (between the node and the home), although the new 2.4 and 5.7 GHz frequencies may spawn wireless technologies. These technologies can potentially overlay existing "wired" access infrastructure and interconnect the desktop and wiring closet. The availability of new frequency spectrum and improvements in semi-conductors will make wireless technology a cost-effective alternative for conventional copper wire or coaxial cable. While wireless systems show great promise, we don't believe that they will be readily available for at least three to five years.

Satellite access technologies are in their infancy. The technologies are still evolving and prices are high. It will take at least three years before prices drop and satellite access is readily available. Satellite services will generally be of two types: First, a satellite receiver providing the downlink, connecting the Internet to the desktop, with a telephone line connecting the desktop with the Internet. This system is available in some locations today but has a long delay from sending keystrokes to receiving data. Second, will be systems using the satellite for both up and down links. Such systems should offer high-speed and short delays, but will be difficult to install because of precision satellite dish alignment requirements and will have higher prices because of the satellite transmitter electronics in the satellite dish.

Synchronous Optical Network (SONet) is the overall best choice for a fiber backbone protocol because of its robust design. However, Gigabit Ethernet may be desirable campus backbones and in specific applications where low price is essential. See page 35 for further discussion.

Technologies and protocols only change rapidly where there are technology breakthroughs, bottlenecks, new massive markets or rapidly changing applications. The following discussion is organized to explain compare and evaluate areas where specific key technologies and protocols are undergoing rapid change and development. The key technologies and protocols described are critical to the extensibility of a Wideband Community Network. Other technologies and protocols are not discussed either because they are expected to be relatively stable over the next ten years, do not have a large impact on the network, or have numerous direct substitutes.

(A Glossary of terms is provided for the reader's convenience starting on page 46.)

Emerging Approaches and Trends[2]

Most current implementations of xDSL require a technician to make a visit to the home or office to install the xDSL terminal. A technician may also be required to remove bridge taps from the access line. (The MVL implementation by Paradyne does not require a technician to visit the customer premise nor remove bridge taps, page 22). Technician's time is expensive and can delay xDSL installations. The industry is addressing the technician requirements with a variant on RADSL called Universal DSL (UDSL)[3]. UDSL will use a new protocol called G.lite. G.lite eliminates the need for a technician visit to the customer premise and also reduces the sensitivity of the equipment to access line bridge taps. UDSL products will probably be introduced by mid 1999 and will greatly speed delivery of UDSL, while lowering the installation cost.[4]

The fast growth in Internet traffic (see The Need for Speed, page 8) is causing dramatic changes in data networking equipment, technology development, and architecture design. UUNET, the largest Internet backbone network, reports an 800% per year increase in traffic. Data Communications[5] commissioned a panel of 12 carriers (5 long distance carriers, 3 ILECs, 1 CLEC and 3 ISPs) to evaluate key access and transport technologies. The panel was asked to rate the level of deployment of each technology as it is now, in 3 years and in 5 years. The results were:

Access Technologies--Cable modems, leased lines and dial-up modems were identified for the most rapid growth. ISDN will continue to be used, but use will decline in the future. DSL was rated as minimally deployed now, but with strongly increasing future use.

Transport Protocols--IP and ATM protocols were shown as strong today with increasing deployment over the next 5 years. IP, SONet and ATM can be used together with some loss of efficiency. New protocols will probably combine the best attributes of these three protocols.

Transport Platforms--DWDM and SONet will continue to be increasingly deployed but DWDM will gradually dominate single-channel technology as transport capacity increases.

A critical element in accelerating the evolution of Internet data speeds is the ability to do real-world testing before mass deployment of new technologies. Prior to the Internet, new technologies were deployed very slowly and carefully. However, the Federal Government and the research community are providing sophisticated test-beds for service providers to test new technologies quickly, safely and easily. The Future Internet, described starting on page 44, will accelerate the introduction of higher-speed Internet connections and Internet backbones, new applications and new ways of working.

ACCESS TECHNOLOGY[6]

The access technologies involve two primary components: the physical medium and the communications protocol. The physical mediums are fiber-optic cable, copper wires, coaxial cable, wireless or satellite. The communication protocols may be analog, or digital. Analog protocols are used by today's modems, for voice calls and by cable modems. Digital protocols by xDSL technologies and Integrated Services Digital Network (ISDN). The combination of the medium and the protocol will determine the types and quality of services that can be offered to the subscriber.

Access Technology Evaluation Criteria

An evaluation criterion has been selected that can best achieve the short and long term requirements of a Wideband Community Network. The criteria are composed of five different criterion. The selection of criteria and the weighting points assigned to each criterion provide a guideline to identify promising current and future technologies for use in the design of the WCN.

Data Capacity - 25 points
Data capacity refers to the amount of data that can be transmitted or received. As it relates to bandwidth, high scores mean faster data speeds. Future applications like multimedia conferencing, telemedicine, and video entertainment will require networks that maximize data capacity.

Performance – 25 points
This criterion includes several sub-criterion as follows:

- Reliability--the ability of the technology to operate to at least 99.99% reliability (average of less than 6 minutes of outage per year).
- Range--the ability of the technology to operate over long distances, without substantially impacting cost or maintenance.
- Operation--the ability of the technology to deliver consistent and continuous operation at full speed.

Flexibility - 20 points
Flexibility in this context means the ability of the technology to incorporate future enhancements and upgrades without expensive, basic equipment replacements or extensive physical work. This also covers the ability to expand an existing system and the ability of various generations of technology to continue to operate side by side. It also includes the ability of the technology to support multiple access protocols.

Maintainability – 15 points
Maintainability must allow fast and economical trouble diagnosis and repair, including ease of localization, component failure and system damage assessment. Information for decision making must be available on the amount and cost of spare equipment and the stocking levels for fast repairs, including the amount of technician training required to maintain and operate the technology and the cost and complexity of test equipment and tools.

Price - 15 points
This criterion evaluates the equipment purchase, engineering, installation, maintenance and repair costs. Maintenance and repair costs are spread over the useful equipment life.

The evaluation criteria are applied to each of the technologies described under the Physical Medium Feature Highlights, following. The results of the evaluation are shown on page 22.

Physical Medium Feature Highlights

Fiber-optic Cable[7]

Fiber-optic cable systems involve a central office terminal that converts electrical signals to pulses of light. The light is sent on the fiber-optic cable from the central office to neighborhood nodes where the light signals are routed through other fiber-optic cables to individual nodes or businesses. One or more neighborhood nodes may be connected in a cascade arrangement to reach all of the customers. Each customer must also have a terminal to convert light signals to electrical signals. The electrical signals are usually distributed within a home by copper wire or coaxial cable. Businesses may distribute the light signal to individual floor closets within a multi-tenant or multi-floor building before converting the light signal to an electrical signal. Each neighborhood node and terminal must have a source of electrical power, and in most cases, a source of reserve electrical power if commercial electric power is lost.

Advantages:
- Extremely high data capacity.
- Ideal for digital applications.
- Impervious to moisture, dust, water, and corrosion.
- Impervious to induced voltages, noise, and radiated energy.
- Operational range is up to 40 kilometers (without amplifiers) for single-mode fiber.

Disadvantages:
- Access protocols have not yet been defined for fiber. Today's access protocols use adaptations of SONeT or Asynchronous (T-1 and T-3) protocols.
- Uninterrupted power is required at the node or business for continuous operation if the commercial power fails. This is very costly.
- Fiber is very expensive to repair and difficult to test, well beyond the skill level of the typical home or business owner. Maintenance requires a trained technician and expensive test and repair equipment.
- Cable, connectors, test equipment, etc. are only available at specialty stores and are relatively high priced.
- Operational support systems for local access are adaptations of other systems. Customer programming may be required.

Long Term View:
Fiber-optic accessories are extremely expensive today. They are not cost-effective, except for homes or businesses with a need for very high data speeds. It will take 5-10

years for the evolution of fiber-to-the-home protocols and cost-effective optical-electronics. Today's deployment scheme is to provide fiber to the wiring closet for businesses, and then to convert the fiber signal to conventional telephone data signals (DS-1 or DS-3) for distribution within the business. Within two years standard desktop computers will typically be capable of accepting direct connections to fiber for high-speed data applications and fiber connections will become commonplace. Plastic, rather than glass fiber-optics will be used within businesses for connections. Although desktop computers can be connected directly to fiber today, they can not take full advantage of the capacity of the fiber.

Fiber-optic cables will be extended further and further into residential neighborhoods and will terminate at neighborhood nodes. Copper wire, coaxial cable, or wireless systems will be used to deliver WCN services from the node to the home. Within ten years fiber-optic cables will routinely go to the side of the home. Copper wire, coaxial cable or wireless will continue to be used within the home for at least the next ten years.

Copper Wire

Copper wire is connected to a voice switch at a serving central office. Copper cables (with densities as large as 3600 pairs) are buried or strung on utility poles to neighborhood nodes where they are cross-connected to eventually reach homes and offices. The neighborhood nodes are used to connect the pairs from one cable to another cable. The nodes may also contain Subscriber Line Carrier (SLC) equipment. The SLC equipment allows multiple voice channels to be combined onto two pairs of copper wires. SLC is used where it is more economic to "derive" additional lines through terminal electronics rather than to run new cables through the streets. One or more neighborhood nodes may be connected in a cascade arrangement to reach all of the customers. At the customer's premises a network interface device is installed to create a clear demarcation between the telephone company wire and the premise wiring (the responsibility of the customer).

Advantages:
- Easy to install, maintain and repair by homeowners and electricians.
- The introduction of xDSL technology has definitely extended the capacity, and hence the useful life, of copper wire.
- Ideal for analog and digital applications.
- Well understood and accepted technology.
- Cable, connectors, etc. are readily available at low prices.
- Telephones can be powered over the copper wire for high reliability.
- Operational support systems are fully developed and low cost.
- Operating range is 4-6 miles depending on the wire gauge. However, for copper wire equipped with ADSL the operating range is reduced to 2-3 miles.

Disadvantages:
- Can corrode, susceptible to damage from water and subject to electro-magnetic interference.
- Bandwidth is limited and is a function of the physical length, type and density of the cable and the number of bridge taps on the cable.

- High-speed data can sometimes cause cross-talk and interference between copper wires in the same cable.
- Poor cable conditions (length, cable type, etc.) may exclude some subscribers from obtaining high-speed data services.

Long term View:
Copper wire has been used for telephone access lines for over 100 years. The local exchange carriers have invested approximately $250 Billion in copper access lines. Hence, the continued support for copper access lines is assured because of the enormous amount of embedded copper facilities. Even though copper access may not in all cases be the best choice of technologies the familiarity, simplicity and momentum of this technology assures its support for many years. However, new installations will use fiber-optic cable to the maximum extent possible.

Coaxial Cable

Coaxial cable is generally only installed by cable television operators and is used primarily for one-way video signals. Multiple video signals are received and combined at the Cable Head (central office for the cable operator) and distributed on coaxial cables go to different neighborhoods. Repeaters must be installed on the cable every half to two miles, depending on the bandwidth of the cable. A system of taps and splitters allow the video signal to be sent on multiple cables and eventually to the home or office. The coaxial cable enters the home or business and is directly connected to a television, set-top converter, VCR, etc.

Advantages:
- Large bandwidth allows voice, data and video to be sent over the same cable.
- Telephones and other terminal devices can be powered over the coaxial cable for increased reliability.
- Coaxial cable, connectors, etc. are readily available.
- Operational support systems for video (television) services are readily available and are cheap.
- Can be installed and serviced by a competent homeowner or electrician (more difficult than copper wire, less difficult than fiber).

Disadvantages:
- Test equipment needs to be somewhat more sophisticated (expensive) than equipment used for copper wires, but is less expensive than equipment used for fiber-optic cable.
- Requires expensive terminals to combine voice, data and video signals onto a coaxial cable.
- Operational support systems for combined voice, data and video are available but are not widely used, hence are expensive and not full-featured.
- Operating range depends on the quality of the cable, the electronics, and the highest usable frequency (high frequencies attenuate faster than low frequencies thus limiting distance). In a typical situation, an operating range of half to two mile is typical.
- Line amplifiers may be required to achieve maximum performance. This adds additional cost.

- Kinks or sharp bends can easily damage coaxial cable. Cables require care during installation and repair.
- Because of the short operating range, neighborhood nodes or amplifiers are required. This adds cost to a system installation.
- Coaxial cable is subject to radiation leakage and to infiltration of external noise, especially at connectors and joints.

Long Term View:
Coaxial cable is very low cost for the available bandwidth; hence considerable development effort has been spent on improving the operation of coaxial cable and in compensating for the inherent disadvantages of coaxial cable. Coaxial cable will continue to be used for at least the next decade for the delivery of one-way video (cable TV systems). Direct satellite broadcasts are competing with cable as a distribution medium for video programming.

Hybrid Fiber Coaxial Cable (HFC)[8]

The emergence of Hybrid Fiber Coaxial (HFC) systems has combined the best attributes of fiber and coaxial cable for the delivery of voice, data, programming and the full range of multimedia applications. The HFC systems use fiber-optic lines between the programming source and a neighborhood node close to the subscriber's home. HFC is similar to a coaxial cable system except that the video signal is sent from the cable head into the neighborhood on fiber-optic cable, instead of coaxial cable. Fiber-optic cable does not require as many repeaters as coaxial cable. Generally HFC systems are designed to maximize the use of fiber-optic cable and minimize the use of coaxial cable, resulting in only a few hundred feet of coaxial cable to reach each customer. Many different communications protocols and devices are used for converting HFC systems from one-way video systems to two-way multimedia systems.

Two-way multimedia[9] systems can operate over HFC. Technically, multimedia can operate over an all-coaxial cable system, but the technical problems and operational difficulties make it cheaper to convert to an HFC access structure. Two basic generic systems exist as follows:

One-way systems, where HFC provides standard cable TV signals and data to the user over the HFC system, are the simplest types of systems and are very similar to an all coaxial cable network. All data communications from the user to the Internet are provided over the phone line. These systems require a special set-top box that connects to the TV with a standard coaxial cable, or to a PC with Ethernet (using twisted copper wire or coaxial cable), and to the telephone line (for sending data from the PC to the Internet). This type of system can deliver information from the Internet at 1 to 10 Mbps, but the return channel (from the user to the Internet) is limited to 56 Kbps or slower. This is the easiest type of system for a cable TV operator to provide, but it is limited to Internet surfing and is probably not useful for home businesses or home offices, and is definitely not useful at a multi-user business location. In early March 1999, US West announced that they will trial this type of service, called USWest@TV. So far US West has not identified any trial sites in New Mexico.

Two-way systems also use HFC, but they carry the return data (from the user to the Internet) on the HFC system. This eliminates the requirement for a telephone, as in the one-way system. The two-way system can be set to provide from 1 to 10 Mbps access to and from the Internet. Likewise, the system can be set by the system operator to provide a variety of slower speeds at different pricing levels. The two-way system can also provide data services to other locations served by frame relay or ATM services. The two-way system is somewhat more expensive for the system operator, but it can serve the needs of the casual Internet surfer, the home business/home office, and the business, usually with much lower fees than those charged by the telephone companies.

The current system that Adelphia operates in Los Alamos is an all-coaxial cable system with the exception of a fiber-optic cable from Los Alamos to White Rock. (See the WCN Infrastructure Report for more details on the Adelphia system.) This system must be completely overhauled and converted to HFC before it is capable of providing multimedia services. The overhaul and conversion will amount to a complete system rebuild except for the coaxial segments that connect to the individual homes and the Los Alamos-to-White Rock fiber.

The cable television industry, through its CableLabs research arm, is working to speed cable modems to the marketplace. CableLabs has developed a standard protocol called Data Over Cable Service Interface Specifications (DOCSIS)[10]. DOCSIS will allow different manufacturer's cable modems to be used interchangeably and will offer a consistent suite of services. 3Com, Bay Networks (now owned by Nortel), Broadcom, and General Instruments are some of the key manufacturers working on DOCSIS. DOCSIS compliant modems will offer telephone service, high-speed data, and television programming.

CableLabs has also adopted a protocol called Firewire (IEEE 1394)[11] to define the in-home multimedia bus of the future. Firewire provides a hub for telephone and cable TV with serial and parallel ports for computer access. Firewire supports two-way data speeds of 100, 200 or 400 Mbps.

Wireless[12]

Wireless systems interconnect with local exchange carriers and long distance carriers. The wireless operator must also have a digital switching system to allow the wireless customers to interconnect to other carriers for the completion of their calls. The wireless digital switch will connect to neighborhood cell sites. Each cell site contains an antenna, transmitter, and receiver. Each customer's wireless telephone is in constant communication with one or more cell sites--this communication occurs even if the phone is not being used for a call. Different wireless systems may use different frequencies and different protocols, hence it is not possible to have one digital telephone that will operate anywhere (except for Motorola's Iridium service, which offers global wireless calling using a system of satellites and local cellular services).

Advantages:
- Fast to deploy.
- Low cost for large deployments.

- Easy to operate.
- Easy to install and maintain.
- Ideal for mobile applications.

Disadvantages:
- Poor privacy, but with spread-spectrum and encryption privacy can be improved.
- Since reception requires "line-of-sight", additional engineering and expense maybe required to provide coverage in valleys or in areas shielded by tall/large buildings.
- The Federal Communications Commission controls the use and allocation of radio frequencies; obtaining a license for system expansion may prove very slow and expensive.
- Improving system performance may require changing the customer's terminal equipment. Customers maybe resistant to such changes because of the expense to upgrade.
- Communities usually have concerns over the size, physical appearance, and radiated energy from base stations.

Long Term View:
Wireless is ideal for mobile and other line-of-sight applications, especially to/from locations that are very difficult to reach through wireline technology (e.g. crossing a canyon or a highway). Today's cellular and PCS (Personal Communications System) systems demonstrate how volume deployments can reduce costs. Ten years ago the top of the line analog cellular phone sold for $1200-$1500. Today the same basic phone, and additional features, is available free with a cellular subscription.

Wireless technology will continue to improve as new and better protocols are designed along with advances in battery power and size. Customer demand will remain strong as long as prices continue to decline and performance continues to improve.

Current wireless technology can't replace wireline technology (copper, coaxial and/or fiber), except in special cases, such as mobile, canyon crossings, etc. However, in another five to ten years, advances in wireless may outstrip wireline, causing a swing to basic reliance on wireless services.

Entrepreneur Craig McCaw[13] is famous for selling McCaw Cellular Communications to AT&T for $11.5 billion. He has subsequently assembled five new wireless companies. These companies are positioned to provide nationwide cellular phone service (no roaming charges) through NEXTEL, build fiber rings in cities to provide telephone service to business (NEXTLINK), provide high speed data access from satellites (TELEDESIC), connect cities together with fiber (INTERNEXT), and provides wireless point to point access for voice and data for business customers (NEXTBAND). McCaw has a track record of successful ventures and he is clearly betting on wireless as the way to directly connect with business customers.

Two new wireless protocols are currently being released. These protocols are enhancements to today's digital cellular protocols, and will allow data speeds up to 2

Mbps. The protocols are called CDMA2000 and ACIS (Advanced Cellular Internet Service). A new European standard, G3, is a variant of CDMA2000. Both of these protocols have been developed to provide Internet access for mobile laptops and laptops in semi-mobile environments. Although there is no forecast for the availability of cellular services using these products, based on previous product cycles in the cellular industry, products should reach the market place within the next three years[14], (barring intervention by the Federal Communications Commission).

Satellite[15]

Two-way satellite systems require a satellite antenna (dish) that can receive and send signals. The signals are transmitted to a satellite where they are beamed to an earth station. The earth station then connects to a wireline system, cellular carrier, or other carrier. The dish requires a fixed orientation because it must lock onto a satellite. New satellite communications systems being offered by Motorola (Iridium) do not require a dish because they use low-earth-orbit satellites that can be reached with a multi-directional antenna. One way satellite systems are broadcast only to the subscriber. It is possible to use a one-way system for two-way operation by using a telephone line for the voice return.

Advantages:

- ➢ Very broad (regional to national) coverage.
- ➢ Not restricted by line-of-sight terrain, however must have open view of the sky.

Disadvantages:

- ➢ Most efficient as a one-way medium. Two-way operation is limited.
- ➢ Cost and control of the satellite(s) are extremely expensive.
- ➢ Bandwidth is limited by the design of the satellite transponder.
- ➢ Sending signals back to the satellite requires high power and, for mobile use, large batteries.
- ➢ Satellite communications can cause extensive delay that can be annoying for voice calls and may disrupt data traffic.
- ➢ A two-way operation requires precise antenna orientation.
- ➢ Subject to signal fading in extreme weather.
- ➢ No privacy on the downlink, some privacy on the uplink.

Long Term View:
Satellite technology is excellent for a few very specific niches, primarily for one-way broadcasts and for providing point-to-point data links to difficult to reach locations. Satellites are used for voice traffic, especially for transoceanic hops, and for specialized voice communications (Motorola's Iridium system). The cost of satellites, the limited bandwidth, and the extensive support system required all argue against satellite technology serving a broader role than it does today. By 2003 a new reusable launch vehicle (replacing the current space shuttle) will dramatically lower launch costs, making satellite communications systems cheaper.

The leader in voice satellite communications is Motorola's Iridium[16] system, which started operations in the fall of 1998. Iridium uses a constellation of 66 low-earth-orbit satellites and dual-mode phones. The phone will first try and complete calls using a standard cellular system. However if a cellular system is not available, the phone will automatically switch to a satellite. Besides Motorola, Hughes, Boeing, Lockheed Martin, Loral, Alcatel, Teledesic, and Orbital Sciences all have filed plans to provide space communications. The total investment for these systems is a whopping $30 billion if they are all built. While Iridium is focused on voice, other systems are focused on high-speed data, with promises of 2 Mbps uplink and speeds as high as 64 Mbps downlink.

Physical Medium Comparative Analysis

Table 1 provides a comparative analysis of the various options available for Wideband Community Network implementation consideration. The overall rating is a composite of the current and future status of the technology, assuming at least current levels of product research and development.

The evaluation methodology involved "netting" the advantages and disadvantages of each access technology, and assigning a representative point value. A point value was assigned for the technology as is currently (*now column)* available, and a second point value as the technology is expected to be in 3 years (*future column)*. The point values were then added together (50-50 weighting) to generate an overall score. The netting processes, assignment of points, and now-vs.-future weightings are subjective and are based on the experience of Spivak Associates, information from the reference articles, and advice from other industry experts.

Evaluation Criteria vs. Technology	Fiber-optic		Copper*		Coaxial		Wireless		Satellite	
	Now	Future	Now	Future	Now	Future	Now	Future	Now	Future
Data Capacity - 25	25	25	10	10	15	20	5	15	5	15
Performance - 25	20	25	10	10	10	15	5	15	5	15
Flexibility - 20	15	20	15	15	10	15	5	15	5	15
Maintainability - 15	3	7	10	10	10	15	10	15	5	15
Price - 15	2	10	10	10	5	10	5	15	5	10
Sub-Totals	65	87	55	55	50	75	30	75	25	70
Total Score	152		110		125		105		95	

TABLE 1: PHYSICAL MEDIUM EVALUATION

*--The evaluation of Copper wire assumed the copper was equipped with xDSL technology that could deliver xDSL service.

The above criteria ratings, especially the price criteria, assume a new build-out (no existing infrastructure). If existing infrastructure does exist, then the pricing and maintainability ratings would change.

Physical Medium Conclusions

The total scores show that coaxial cable and fiber-optics are the most promising current and future technologies. The combination of the two technologies in a Hybrid Fiber-Coaxial cable system is especially strong. The tremendous data capacity and performance of fiber, coupled with the capacity of coaxial cable, makes a powerful combination. Although fiber-optic technology has some drawbacks, it is the best choice now and in the foreseeable future. Copper wire appears close to the end of its development potential (barring some fundamental breakthrough in basic science). Wireless has very strong future scores and may rival coaxial cable as the technology of choice for the last few hundred feet to the customer's home. Wireless has a tremendous (potential) advantage over copper and coaxial cable, because it doesn't require any special wiring or in-home cables. Satellite technology may be very useful in some rural areas, especially where mobility is necessary or where wireline and wireless services are not available.

The scores for copper wire, coaxial cable and wireless are all very close. While coaxial cable has a slight lead, a laboratory development could easily swing the total point count to favor copper wire or wireless. However, one conclusion is clear--that fiber-optic cable to the neighborhood is the right direction. Options should be left open to deliver services from the fiber node to the home on coaxial cable, copper or wireless or possibly all three.

ACCESS PROTOCOLS

We have just finished a discussion of the physical medium that connects a residence or business to a telecommunications center. The electronic protocol (that performs the information addressing and packaging scheme) will determine the types and characteristics of the services that can be offered over the physical medium.

Analog protocols were generally developed before 1975. The analog protocols were developed to send and receive voice. By employing modems, the analog protocols can be used to send data. Analog technology is low cost, reliable, and widely deployed, but it is restricted to low-bandwidths over copper wire. Analog protocols and technology appear to have gone about as far as they can. There aren't any "block-buster" technologies in the laboratories that could breathe new life into analog protocols. Once a promising technology is identified in the laboratory, it takes about five years for development of the technology standards and technology testing before it is ready for the marketplace. Analog modems appear to have reached their peak performance with V.34 and V.90 protocols, which yield speeds of 56 Kbps.

The future belongs to digital technologies. The convergence of cheap, customized computer chips (know as digital signal processors) and the rapidly growing demand for high-speed data, has caused a tremendous amount of research and development focused on digital protocols and technologies. Digital protocols have been adopted for cellular and PCS wireless telephones because of increased bandwidth efficiency. Likewise, digital protocols and technologies have now reached a level of development where they are cheaper than comparable analog technologies, and digital technology offers higher bandwidth.

The most promising new digital access protocol is xDSL (multiple flavors of Digital Subscriber Line). xDSL allows high-speed data to be provided over one or two pairs of copper wires to the home or business. Data speeds using xDSL can be as fast as seven Mbps. Compared to 56 Kbps for analog technology, xDSL allows a wide range of new high-speed data services, as shown in Figure 2.

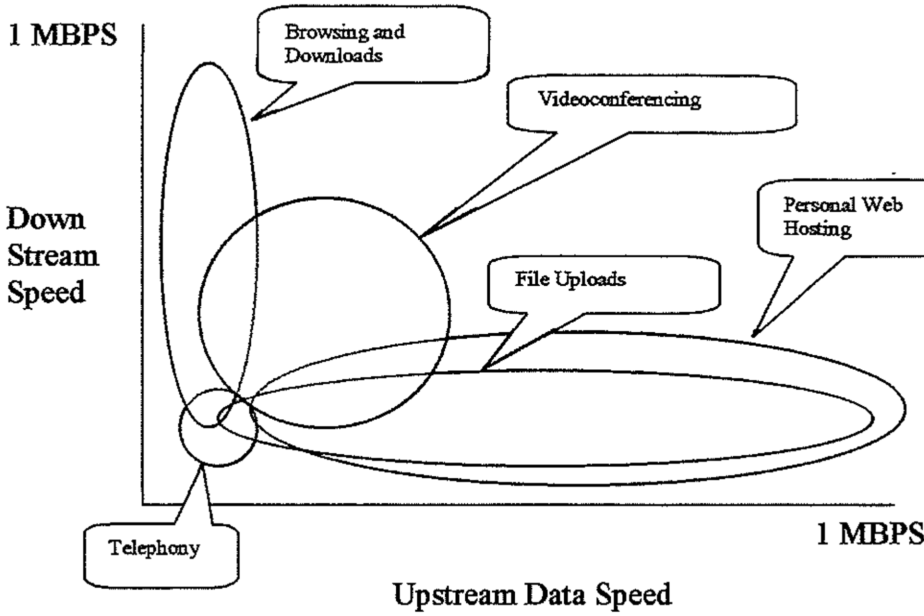

FIGURE 2 xDSL BANDWIDTH FOOTPRINT

Figure 2 illustrates the bandwidth footprint possible with xDSL compared to the analog "Telephony" footprint.

Access Protocol Feature Highlights (xDSL)[17]

xDSL comes in many variations. The 5 major variations are:

xDSL Variations	HDSL	S-HDSL & SDSL	ADSL	RADSL	MVL
Operating Range	13,000 ft.	9,000 ft.	13,500 ft.	15,000 ft.	20,000 ft.
Maximum Speed Downstream	1.544 Mbps	768 Kbps	Up to 6 Mbps	52Kbps to 1.54 Mbps	Up to 768 Kbps
Maximum Speed Upstream	1.544 Mbps	768 Kbps	128 Kbps	640 Kbps to 2.4 Kbps	Up to 768 Kbps
Copper Pair Req.	2	1	1	1	1

Reference: PairGain Communications & Networking Technology Guide

TABLE 2: xDSL VARIATIONS COMPARISON

HDSL (High Speed Digital Line) is the name of the technology used to provide DS-1 or T-1 services offered by US West and other Telco's. HDSL is the name of a new technology that has replaced older T-1 devices. Over 300,000 HDSL-equipped circuits are in operation today providing point-to-point T-1 service. HDSL requires two copper wires, one for each transmission direction. (Note: T-1 is the generic name for the technology that provides point-to-point 1.544 MBPS private-line service. DS-1 (Data

Speed 1) is the name of the T-1 service as described in US West tariffs; (DS-1 and T-1 are used interchangeably in this report).

S-HDSL or SDSL (the S means a single pair of copper wires) is just like HDSL, except that it requires only one pair of copper wires. However it only delivers half of the speed of HDSL.

ADSL was originally designed for residential web surfing. Very little pure ADSL was deployed because of the need to address various market segments and vastly different operating environments. ADSL has since migrated into RADSL

RADSL (Rate Adaptive Digital Subscriber Line) has many variations on upstream and downstream speeds, and will automatically adjust speeds to compensate for poor quality copper wire. Analysis of the copper wire gauge (diameter), the length of the access line, and the number of bridge taps (connections for extensions, etc.) determine the quality of the copper wire. Loading coils are often installed on long access lines to increase the range, but they must be removed if RADSL is installed. Preparing the copper access lines for RADSL can be costly (e.g. removing bridge taps, grooming cables, assigning binder groups, etc. Also, copper wire is wrapped together in binder groups within the cable and some versions of RADSL restrict the number of copper wires that can be equipped with RADSL in a specific segment of the copper wire cable.) RADSL offers the Telephone Company the ability to control the maximum speed offered to a customer regardless of the quality of the copper line. This allows data-speed-sensitive pricing. Some RADSL units are powered from the central office, while others require power from the home or office. This is an important consideration for public safety (911) access.

MVL (Multiple Virtual Line) is a proprietary implementation of DSL by Paradyne, Inc. MVL uses a modem protocol rather than the standard CAP protocol specified by the xDSL standards committee. MVL has several advantages over xDSL, i.e. immunity to bridge taps and lower power settings than normal xDSL, hence it has less cross-talk and is more immune to interference than xDSL. MVL does not require a technician to visit the customer site, while xDSL does require a technician visit. Paradyne's use of a non-standard protocol will probably doom MVL to a relatively small market, even though the performance is superior to RADSL in many respects. The new UDSL/G.lite protocol will allow RADSL to have the same advantages as MVL.

SkyDSL[18] is one of the most interesting xDSL developments. SkyDSL uses satellites to deliver DSL service to the home or business. SkyDSL was not included in the evaluation matrix (Table 2) because it is not in operation at this time. Satellite use has generally been ignored by many companies because a satellite channel is approximately 4 to 10 times more expensive than a landline channel of comparable bandwidth. However, a startup named Aloha Networks claims that they have developed a protocol that increases the efficiency of the satellite channel and makes DSL via satellite practical. The downstream speed is 500 Kbps and the upstream speed is 64 Kbps. The cost of the base-station is estimated at $100,000, and each customer dish is estimated at $2,500. One base station will serve about 3,000 customers.

Aloha Networks is not the only company using satellites. Hughes Network Systems offered an Internet access service in 1995 that used a one-way satellite broadcast for the downstream and a telephone line for the upstream path. The service has attracted only 70,000 customers worldwide, primarily because of the slow upstream speed and long delay between upstream commands and downstream response. The Hughes experience does not bode well for Aloha Networks, unless the upstream speed can be significantly increased, delay reduced and the price of the customer terminal unit decreased.

New protocols can be easy to design but difficult to standardize. The standardization process can delay product acceptance by one to five years. Typically, new protocols go through a lengthy standard setting process controlled by the IEEE, ANSI or the ITU. During this process, vendors, users, and operators debate potential protocols and finally emerge with a consensus decision to support a specific protocol. This process can take years to complete. Alternatively, vendors with significant market power may introduce a product line using a non-standard protocol and through aggressive selling hope to win a significant place in the market and force the protocol to be adopted as a standard. Aloha Net will clearly try to create a defacto protocol standard.

Communications Protocol Comparative Analysis

The xDSL family of protocols currently operates over copper wire. The following evaluation uses the same criteria and weights as were used in Table 2, but only compares xDSL variations.

Evaluation Criteria vs. Technology	HDSL*		S-HDSL & SDSL		ADSL		RADSL		MVL	
	Now	Future	Now	Future	Now	Future	Now	Future	Now	Future
Data Capacity - 25	10	10	5	10	15	15	15	15	15	15
Performance - 25	15	15	10	15	10	10	10	10	10	10
Flexibility - 20	15	15	15	15	5	5	15	18	10	10
Maintainability - 15	10	13	10	15	10	10	10	12	10	10
Price - 15	10	12	10	13	10	10	10	15	10	10
Sub-Totals	60	65	50	68	50	50	60	70	55	55
Total Score	125		118		100		130		110	

TABLE 3: COMMUNICATIONS PROTOCOL EVALUATION

Integrated Services Digital Network (ISDN)[19]

US West has announced availability of ISDN (Integrated Services Digital Network) service in New Mexico. ISDN is a 10-year-old service that was designed to provide high-speed access through a digital switching system. ISDN utilizes two 64 Kbps data channels and one 15 Kbps signaling channel. The 64 Kbps channels can be used for either data or voice. The channels can be combined to deliver 128 Kbps data service. If data compression algorithms are used, the effective throughput of ISDN can be about 500 Kbps. ISDN is a symmetrical service giving the same speed for sending data as for receiving data. ISDN and xDSL use the same underlying protocols. The primary difference between ISDN and xDSL is cost, symmetry and speed.

ISDN is inherently more costly than xDSL, because ISDN is an integral part of the operation of a digital switch, and is inherent more costly it requires additional digital switching equipment. Also, digital switches are designed for voice calls that have short call times of 5-8 minutes. The adaptation for digital switches to handle a substantial volume of data calls, which typically last 15-30 minutes, is quite expensive. xDSL does not go through the digital switch and does not impact the cost or design of the digital switch.

ISDN is a cul-de-sac on the way to high-speed access. While ISDN may perform satisfactorily at 128 Kbps, it is more costly for consumer than using a v.90 modem equipped with two telephone lines. It will also be more costly than xDSL service from the CLECs or ILECs. Additionally, ISDN is limited to 128 Kbps, while xDSL has a wide variety of available bandwidths.

Access Protocol Issues

HDSL is in wide scale deployment today, and is one of two protocols used to provide point-to-point T-1 or DS-1 service (1.544 Mbps). HDSL requires two copper pairs, which is an extremely significant drawback. S-HDSL or SDSL provides half of the data speed of HDSL and operates at a reduced range from HDSL, but requires only one pair of copper wires. Future development of S-HDSL will probably allow it to have performance comparable to HDSL, and only require one pair of copper wires. See Table 2 for a comparison of performance parameters. Thus, S-HDSL will become the T-1 workhorse of the future and be used anywhere symmetrical service (same maximum speed up and downstream) is needed.

RADSL will likely replace all of the deployed ADSL (very little has been deployed). RADSL is now the dominant xDSL technology for all of the equipment makers and the ILECs. The volume purchasing power of the ILECs will help to drive RADSL prices down and to improve performance. RADSL will be the protocol for residential use where asymmetrical service (faster speed downstream, than upstream) is used.

No mention is made of VDSL (Very high speed Digital Subscriber Line), because of the short operating range. However, VDSL may have application from the neighborhood node to the home, where the distance may be a few hundred feet. VDSL can operate up to 26 Mbps and could compete favorably against HFC.

ACCESS SERVICE PRICING[20]

An important consideration in WCN planning is the pricing that US West is likely to offer for RADSL, ISDN and Frame Relay Service.

US West's Services

ISDN costs $41/month for residence and $76/month for business with an installation charge of $110. ISDN also requires a network interface device (NID) to be installed at the home or office at a cost of $150 to $200.

Frame Relay service is available at 56Kbps for $90/month and 1.544 Mbps for $320 to $390/month. The monthly charge assumes that the customer is within 1 mile of the US West central office. If the customer is further than 1 mile then extra charges apply. The 1.544 Mbps rate varies depending on the length of the service contract. Prices range from $390/month on a month-to-month basis to $320/month for a five-year contract.

RADSL

In trials in California and Texas, SBC charged $250/month for 384 Kbps access. Source: SBC Corp. Covad (a competitive exchange carrier in California) charges $90/month for 144 Kbps, $125/month for symmetrical 384 Kbps service, and $195/month for 1.5 Mbps service.

Bell Atlantic has announced their RADSL service offering called "Infospeed".

Version	Speed to User (download)	Speed from User (upload)	Price/Month	Price/Month with Internet Access
Personal	To 640Kbps	To 90 Kbps	$ 39.95	$ 59.95
Professional	To 1.6 Mbps	To 90 Kbps	$ 59.95	$109.95
Power	To 7.1 Mbps	To 680 Kbps	$109.95	$189.95

Source: Bell Atlantic

During the introductory period, the set-up fee will be $149, which includes the ADSL modem, inside wiring service, and an Ethernet card. Alcatel, Globespan and Westell are providing ADSL equipment.

Bell South has announced plans to offer ADSL for a $100 installation fee, a $200 charge for the ADSL modem and monthly recurring charges of $45 for 1.5Mbps download/256Kbps upload. Customers must be within 18,000 ft. of the serving central office. Source: Bell South.

ISDN

California is the low price leader with a residential charge of $31/month, which includes 200 hours; for business subscribers the charge increases to $35/month for 200 hours. SBC offers ISDN for $46/month in Texas with unlimited usage. US West offers ISDN in

Colorado for $60/month with unlimited usage and for $69/month in Arizona with unlimited usage.

Wireless

Teligent, a wireless competitive exchange carrier, offers 1.544 Mbps T-1 access using 28 GHz radio. They are offering their service in Dallas at about half the rate charged by the incumbent local exchange carrier, SBC. As an example:

T-1 Circuit Charges	Teligent	SBC
Set-up	$631	$1658
Monthly Recurring	$635	$1198

Source: Teligent Pricing (9/4/98)

Wireless innovation continues. Santa Fe Trails[21] offers a wireless ISP service in Santa Fe with expansion plans for all of New Mexico by the end of 1999. The service uses a combination of the 900 MHz and 2.4 GHz public use radio bands (no special FCC license is required). A range of speeds will be offered from 64 Kbps (priced at $49/mo.) to 2 Mbps (priced at $1,199/mo.). Because anyone can use these frequencies, some interference can be anticipated. Establishing this service will involve building neighborhood transmitter sites at 2.5 to 5 mile intervals that are within line-of-sight of the customer. The technology is proprietary to Santa Fe Trails and uses the Direct Sequence Spread Spectrum (DSSS) protocol.

Cable Modems[22]

Marcus Cable is the 9th largest Cable Company in the USA with 1.2 million customers. In January 1998, Marcus announced a 12,700 home beta test in two suburbs of Dallas. The test area has approximately 40% cable and computer penetration in the households. Marcus provided @Home service (an Internet Portal service) and a complete installation and equipment package for $299 and $39.95/month for cable subscribers. The @Home service includes, 3 email addresses, 15 Mbps for personal web hosting, a customized browser, access to news and chat groups and @Home portal services. Marcus will not say exactly how successful the beta test was, but they have announced that they be expanding to cover 300,000 homes in Fort Worth, with later expansion in Birmingham.

MediaOne[23] has introduced a telephone-over-cable service. Comcast has recently bought MediaOne and the combined company passes over 17 million homes. Their strategy is "...offer several options for full-featured, local digital telephone service with number portability at a price below incumbent local exchange carrier rates". The company offers single and multiple-line, local phone service with options of caller ID, call waiting, call forwarding, speed dialing, voice mail and last call return. The service is currently being trialed in Culver City, California and Atlanta. Pricing for a full feature business phone line in Culver City is $39.95/month compared to $75/month from Pacific Bell. In Atlanta the price is $24.95/month compared to $32/month from Bell South. MediaOne does not have an installation charge and their service package includes 500 minutes of local calling. Long distance calling is provided at 10¢ per minute with a $3.95 monthly service fee. MediaOne uses the copper wires in the home for its service, hence rewiring is not necessary. MediaOne reports penetration rates of 8-20% and is quite pleased with this level of penetration. MediaOne is silent on plans to offer high-speed data over cable. MediaOne has been working at upgrading their system to HFC (hybrid fiber-optic and coaxial cable) since 1995, in preparation for offering telephone service.

NODE TECHNOLOGIES

As shown in Figure 1, access lines converge to one or more buildings that house centralized equipment. The telecommunications industry calls the buildings Central Offices, the cable TV industry calls the buildings "Head Ends", etc. In this paper we shall use the term NODE to describe the physical building that houses centralized multimedia processing equipment. A node will have the following types of equipment:

- Air-conditioning and heating systems that can maintain the equipment within manufacturer's environmental requirements.
- Back-up power supplies capable of providing 72 hours of power, if commercial power fails.
- Main Distribution Frames (MDF) to allow the access lines to be connected to the appropriate equipment and to allow the equipment to be interconnected.
- Terminal equipment for each of the access lines.
- Voice, Data, Graphics and Video equipment to send signals to customers and to process incoming signals from customers.
- Backbone network equipment to concentrate and direct customer signals to carriers, ISP's, etc. that will be remotely located from the node.
- Network Management Systems that will allow technicians to establish and change the configuration of customer services, continuously monitor and control the quality of customer service, record usage information for billing purposes and diagnose trouble reports and equipment failure conditions.
- Customer service systems for orders and billing.
- Engineering systems to keep track of the specific wiring for each piece of equipment and for each customer.

Clearly the operation of a node is a serious matter, the above list only highlights the major equipment types. Many administrative, maintenance and repair processes must also be performed, which require extensive computer systems. The customer service equipment in a node is designed to deliver 99.99% reliable service. That means that the objective maximum outage time for any line is about 6 minutes per year. Also, most large node buildings are staffed 24 hours per day, 7 days a week or they can be connected to a remote monitoring site that provides continuous surveillance and can dispatch technicians if a problem is indicated.

The voice, data, graphics and video equipment is of primary interest. The communications protocols for each of these equipment types have been in use for many years and are not discussed in this report. The node equipment is interconnected in the following manner:

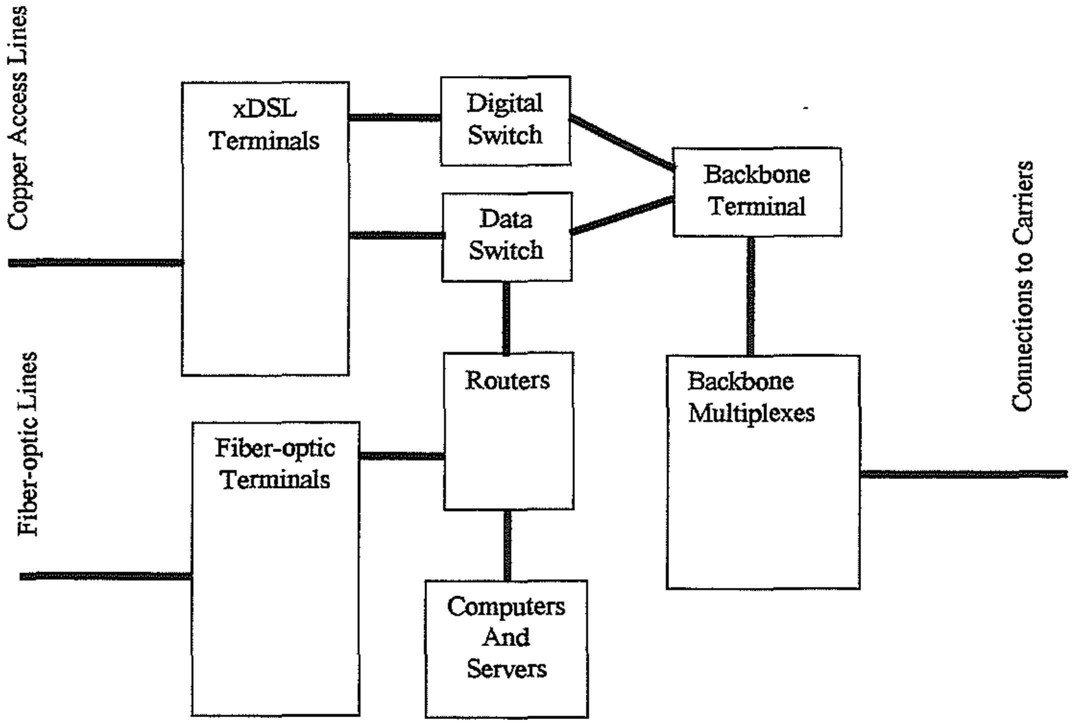

FIGURE 3 TYPICAL NODE EQUIPMENT CONFIGURATION

A brief description of the different functions of the major node equipment follows.

Digital Switch--Standard equipment for switching voice calls is a digital switch. Digital switches are in common use and are readily available from Lucent Technologies, Nortel, Ericsson, Alcatel, Siemens, NEC, and Fujitsu. Other manufacturers also make digital switches designed for specialized applications. The digital switch records billing information about the call, communicates with distant voice telephone offices for routing of the call, and assigns the call to the proper voice communications channel. The switch then controls the call and resets all of the electronics when the call finishes.

Data Switch and Routers--These equipments perform the data packet header or addressing examination and route of data packets to the proper terminal. They can handle a variety of communications protocols and will translate protocols; e.g. data may be received from an Ethernet source and converted to Frame Relay for communications over long distances. Companies such as Lucent Technologies, Nortel, NEC, Cisco, and 3COM make data switches and routers that are compatible with digital switches.

Fiber-optic Terminals--Pulsed light is used within the fiber to carry the signal. Terminals convert light pulses to electrical pulses so semi-conductors can do signal processing. Terminals those converts light to electrical pulses are very expensive, but are required for signal processing. Semi-conductors that will directly process pulses of light will not be available for the next 10-20 years. Good node planning is necessary to minimize the number of terminals required.

Backbone Terminals and Multiplexers—This equipment is necessary to combine low-speed data signals into one high-speed signal that can be sent from the Node to other distant nodes. Fiber-optic cable is primarily used to interconnect nodes, however radio relay links are sometimes used.

Computers--General-purpose computer are used for billing, record keeping, accounting, etc. Computers also provide information, control, deliver service orders, and provision services. Computers are also used for general business purposes including administration, data storage and for internal networking.

Data Switching[24]

Manufacturers of data routers offer layer 2 or 3 or 4 switching capability to address scaling. The product architectures, prices and performance does differ by layer of switching as follows:

Switching* Layer	Description	Performance	Price
2	Switching is done in software.	Low throughput <100,000pps	Fast Ethernet/port = $200 (adding capacity)
3	Switching is done primarily in hardware with frequent destination caching.	Medium throughput, 100,000 to 1 million+ pps and traffic to a few destinations	Fast Ethernet/port = $ 700 (adding capacity)
4	Same as Layer 3, but makes smarter routing decisions by interrogation at the applications level.	High throughput, 1 million+ pps, and traffic to many destinations	Fast Ethernet/port = $900

* "Switching" is the process of routing of data packets. In all other sections of this paper "switching" is defined as the establishment of a temporary circuit for the transmission of voice or data.

The decision to use layer 2, 3 or 4 switching is dependent on the types of data being switched, the total amount of data being switched and the budget.

As custom chips replace software pricing will continue to fall rapidly and prices between the switch layer types will begin to converge in the next 12-18 months.

BACKBONE TECHNOLOGIES[25]

The telecommunications industry has agreed upon an incredible number of protocols that are recorded in standards and design documents. These protocols, or standards, are set by Bellcore (now a subsidiary of SIAC, but at one time a wholly-owned subsidiary of the Bell companies, and formerly part of Bell Telephone Laboratories), ANSI (American National Standards Industry), and IEEE (Institute of Electrical and Electronic Engineers). Interface and operating standards have been agreed to for the telecommunications portion of the node, i.e. the fiber terminals, digital switch, backbone and various equipment interfaces.

The protocols that control the speed of the backbone technologies are the most critical to any network. These protocols must ensure that the physical facilities (fiber-optics, radio systems, satellites, etc.) can transport the data between nodes, and can deliver data to long distance carriers, exchange carriers, and Internet service providers. The transport of information must be extremely reliable, have very high quality (low error rate), and *NOT* create a bottleneck. The backbone carries information in digital form and is often a mixture of voice, data, graphics and/or video signals.

SONet[26]

SONet (Synchronous Optical Network) is a protocol that is about 15 years old, but SONet equipment has only been available since 1990, due to standards approval delays. Bellcore developed the SONet protocol at the direction of the Bell Companies. The purpose of the protocol is to fully utilize the capability of fiber-optics for data transmission. Prior to the introduction of SONet, all data speeds faster than 45 Mbps (T-3) required vendor-proprietary data terminals and could only be used for point-to-point services. SONet terminals can be interchanged between vendors, substantially reducing the price by creating competition among suppliers of high-speed terminals.

Also, SONet is scalable. The basic SONet speed is 50Mbps (called Optical Channel 1 or OC-1). Thus, T-3 (or 28 T-1) signals will fit in an OC-1 channel. 3 OC-1 channels are usually combined to form an OC-3 channel (155 Mbps). Equipment is available to handle OC-12, OC-48, up to OC-196 (almost 10 Gbps). Because the SONet protocol is scalable, and it can match the top speed of the fiber-optic cable. As breakthroughs are made and the speed of the fiber is increased the SONet protocol can be used to define faster and faster speeds without involving standards setting bodies. 100 Gbps, prototype fiber systems for LAN/WAN applications are available, with 400+ Gbps systems anticipated by the end of the year. 400 Gbps systems are currently available for long haul telecom transmission.

SONet has defined a special terminal, called an add-drop multiplexer so that T-1, T-3, OC-1 or OC-3 data channels can be added to or dropped off the SONet backbone. Before SONet was defined, several different types of equipment were necessary to combine the data channels for fiber-optic transmission. SONet specified one piece of equipment to handle the combining and de-combining process. This is a substantial cost saver compared to older systems.

SONet standards also have defined a topology composed of counter-rotation fiber-optic rings. The purpose of the ring architecture is to provide a self-healing capability. If a SONet ring is broken (the fiber cable is cut) the SONet terminals automatically reverse the direction of some of the data to create an alternate route. SONet can switch to an alternative route in about 200 milliseconds. This capability gives very high reliability to a SONet system. A network is often composed of many SONet rings.

Following is a diagram of a typical SONet ring.

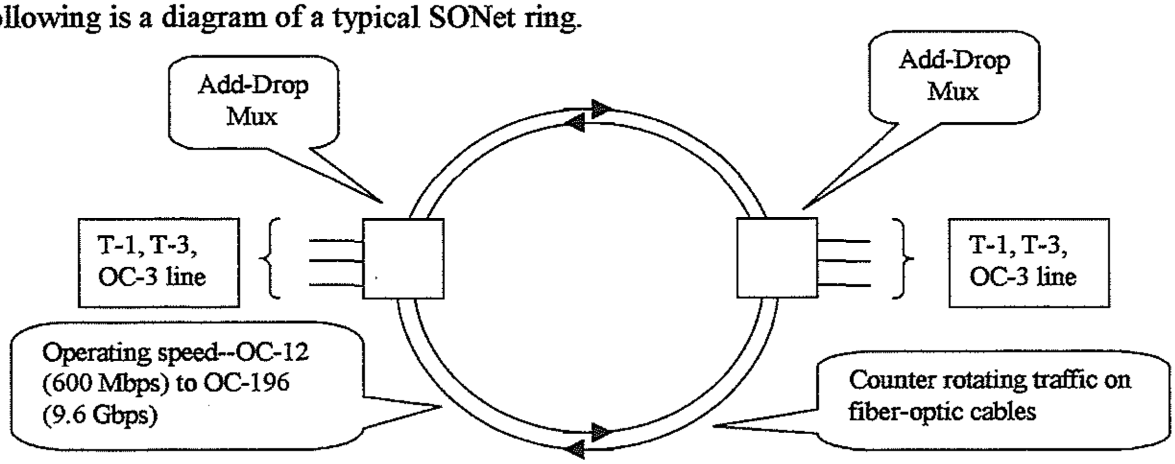

FIGURE 4 SONET TOPOLOGY

Gigabit Ethernet[27]

Another protocol of interest is Gigabit Ethernet. Ethernet was originally designed in the early 80's to operate over coaxial cable at 2 or 4 Mbps. Ethernet uses a packet protocol that is efficient for almost all data, but is not efficient for voice or video because of variable latency or delay times. Ethernet speeds were increased to 10 Mbps and a new standard was approved in 1990 to allow the use of copper wire instead of coaxial cable. The copper wire standard is known as 10 Base-T. 10 Base-T requires special copper wire, normal telephone cable is not adequate. In the mid-90's, agreement was reached to increase the speed of Ethernet from 10 Mbps to 100 Mbps. Most new Ethernet Network Interface Cards (these cards fit into a personal computer or workstation) are equipped for operation at Ethernet speeds of 10 or 100 Mbps. Recently, Ethernet has been further enhanced to operate at 1 Gbps, hence the name Gigabit Ethernet. A typical Ethernet topology is:

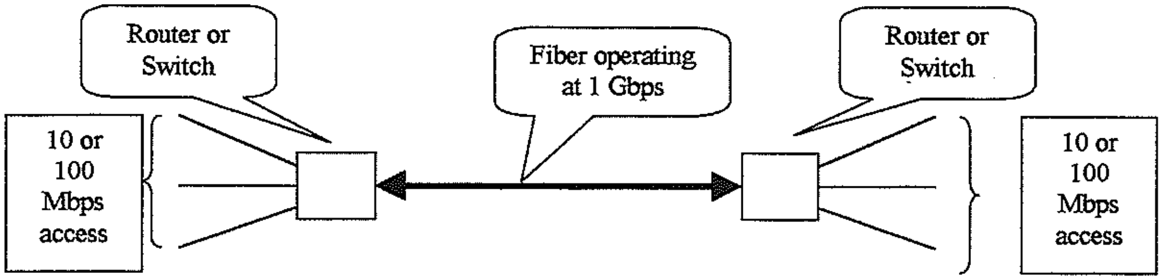

FIGURE 5 GIGABIT ETHERNET TOPOLOGY

Gigabit Ethernet products are now available, but are many years behind the SONet development. However, for a business Local Area Network or Wide Area Network backbone, Gigabit Ethernet may be a very cost-effective choice. Gigabit Ethernet has the advantages of not requiring a protocol change between the desktop device and the backbone, and not requiring extensive retraining of network technicians that are already familiar with Ethernet terminology and management. Although, Gigabit Ethernet has specific applications, it does not have the robustness of SONet. Gigabit Ethernet is not expected to be a significant challenge to SONet even though there are some situations where the two will compete directly. In these cases, Gigabit Ethernet will usually win because of its lower price, unless reliability, scalability, or multimedia are primary considerations.

Rapid advances have been made in data bridging, routing, and switching devices that direct data-packets to and from their destination. All data traffic has an address (information combined with an address is called a packet) which tells the data handling equipment where to send it. The demands of Internet and business networking, as well as the increasing speed and capacity of fiber-optics have caused rapid advances in this equipment. Bridges perform the simple function of regenerating packets and sending them out to all destinations. The terminals at each destination decide if the packet should be saved or discarded. Routers are more sophisticated because they read the address information and only send the packet on the specific channel associated with the packet address or destination. Switches are the most sophisticated and are generally designed to operate in very high traffic applications, e.g. Internet Service Providers (ISPs). The Switch uses computer algorithms to further speed the processing and routing of packets. Switch manufacturers designate their switches as Layer 2, Layer 3 or Layer 4 to denote the sophistication of their algorithms, see also the Data Switching discussion beginning on page 34.

Advances in data switching will accelerate to keep pace with the Internet and with the capacities of fiber-optic cable. Custom semi-conductors and volume sales will continue to reduce prices while increasing the performance of the switch. Most manufacturers make their switches upwardly compatible so customers can upgrade to the latest speeds at reasonable costs. Cisco and 3COM are leaders in the switch area.

Internet Protocol (IP)

IP dates its development to the late 1970s in the Defense Department ARPANet project. IP is a simple packet protocol with a 40-byte header or address and a variable size payload of 40 to 64,000 bytes. IP was designed for data traffic; but it can also carry voice, graphics and video information in the form of data traffic. IP is compatible with SONet, although much of the information carried in the SONet header is redundant with information carried in the IP header.

Asynchronous Transfer Mode (ATM)[28]

ATM was developed in mid 1980s as an efficient protocol for handing multimedia traffic. The ATM protocol is composed of a 53-byte packet, with a five-byte header or address, and a 48-byte payload. ATM was designed for the signal processors available in the mid 80s. The design of the protocol represents a compromise between the available processor power and the types of multimedia traffic that ATM would be used to transport. ATM and SONet are compatible through the use of tunneling protocols.

An ATM protocol has not been defined to extend ATM from the node to the home. However, businesses connect their Wide Area Networks directly to their network operator by simply installing an ATM interface card in their WAN router. Envisioning the day when an ATM interface is commonly used at the home and business, Microsoft[29] has built a native-mode ATM application interface into Windows NT 4.0 and 5.0.

Dense Wavelength Division Multiplexes (DWDM)[30]

DWDM is not a protocol; it is a transport platform that will have a profound effect on backbone capacities. Today's fiber-optic cables use digital lasers at either end of the fiber. One laser is excited by an electrical signal and emits a burst of laser light into a fiber-optic cable. The distant end receives the light and produces a corresponding electrical signal. The maximum data capacity of fiber-optic cable is dependent on the speed of the lasers and on the optical characteristics of the cable. Today, the practical limit is about 10 Gbps. Since lasers operate at very specific frequencies within the visible light spectrum, multiple lasers can be connected at each end of the fiber-optic cable, with each laser tuned to a different light frequency. Presently 400 Gbps DWDM systems are in production for long distance telecommunications. Forecasts are for 2 Tbps systems to be available in the next one to two years.

TOPOLOGIES AND ARCHITECTURES[31]

Network Convergence[32]

There is a trend well underway for companies and organizations to combine their voice and data traffic into one network. Today mid-to-large size companies operate at least six different communications networks: voice, data, Intranet, Internet, international voice, and international data. All of these networks can be combined (or converged) into one network. Network convergence will result in tremendous operational savings for companies and telecom carriers. Companies save money by reducing the complexity of their systems and by moving their voice traffic to more efficient and cheaper data lines. Telecom carriers will also save money because they will not need to add expensive equipment to support increases in voice traffic. One network is more efficient at handling information than six.

Voice over IP (VOIP)[33]

The Internet Protocol (IP) can be used to packetize and send voice traffic over a data network. This function has been named "VOIP". Today, a voice call uses a circuit to connect calling parties. The circuit is capable of handling 56 Kbps and is available for the entire duration of the call. VOIP compresses the voice so that it only requires about 10.3 Kbps compared to 56 Kbps. Also, VOIP makes use of silence on the circuit to send other people's packets. Assuming the increased efficiency of compression and 20% silence on a typical voice call makes VOIP almost 7 times more efficient than a conventional voice circuits. VOIP is being offered by many new competitive telecom providers and is particularly attractive for long distance calling. Typically, coast-to-coast calling rates for VOIP prices can be as low as 3¢ per minute, compared to 7-9¢ per minute under high-volume business contracts.

Advantages of VOIP (compared to a dedicated voice circuit).

- More efficient use of network facilities, than available using dedicated circuits.
- Network simplification for users and telecom carriers, because one network can be used instead of two (voice network and data network).
- Much higher bandwidth efficiency than today's voice network.
- Stepping-stone to enable desktop video conferencing and other multimedia applications.
- Tremendous potential for reducing voice telecom costs.

Disadvantages of VOIP (compared to a dedicated voice circuit).

- VOIP equipment is not large enough or fast enough now to handle high-volume voice traffic.
- VOIP billing systems are not very sophisticated, compared to conventional voice billing systems.
- Network management systems are also not very sophisticated.
- Reliability is low, compared to voice telecom standards of 99.99% availability.

Long Term View:
It will be two to three years before VOIP equipment will begin to replace today's voice equipment. A new generation of VOIP equipment takes about 9 months to reach the market; hence in two or three generations (12-18 months) it will be ready for large-scale introduction into the voice telephone networks. The first market for VOIP will be the corporate user, where direct connections can be made between digital PBXs or Key Systems, and a router or data switch connected to an IP network. A home computer can easily support VOIP, using xDSL or a cable modem, making residential desktop video conferencing feasible within three years. However, VOIP may never replace the "stand-alone" analog telephone because of the additional cost of an IP-capable telephone. For residential use the conversion of analog to digital will be done at the node. However for business the conversion from analog to digital will be done at the desktop. AT&T, Sprint and MCI/WorldCom have announced plans to use VOIP for more efficient utilization of the domestic network facilities, the next step will be to offer VOIP directly to customers. This will dramatically improve their network efficiencies. These carriers are now offering VOIP to customers for international calling.

Integrated Access Devices[34]

A typical node is a very complicated collection of devices, as shown in figure 3. The complexity stems from the different techniques and protocols necessary for handling multimedia information (voice, data, video and graphics). A new family of products, called Integrated Access Devices (IADs), is now making there way to market. These devices will ease the operational burden by integrating, what are today, different devices; this should result in cost savings for the network operator. The IADs offer many advantages over discrete components:

IAD advantages compared to discrete components:

- IADs have one operating system, resulting in lower cost for maintenance and operations. Multiple discrete components require complex operating systems and extensive training.
- IADs should offer highly cost-effective solutions because operators will install only those interface cards needed for services.
- IADs offer a one-vendor solution that should allow for faster trouble identification and repair.

IAD disadvantages compared to discrete components:

- An IAD may sub-optimize one or more aspects of multimedia performance, where discrete components can address all aspects of multimedia performance.
- IADs are not as flexible as discrete components.

Long Term View:
IADs and VOIP are the wave of the future; they will be in general use in three to five years.

COSTS[35] PER SUBSCRIBER

The following are broad-gauge cost estimates for planning and budgeting purposes. These costs are industry averages and reflect pricing anticipated for 1999.

- Fiber-optic cable deployment--$50,000 to$100,000/mile (assumes buried cable). Source: Boarder States.
- Copper wire access--$1,200 per subscriber. Source: Bell System averages.
- Hybrid Fiber-optic Coaxial (HFC)--$650-700 per subscriber home passed. Source: Cable Labs, Media Connections Group.
- ISDN--$150-$200 for premise Network Interface Device (NID) and $75 for digital switch ISDN line card. Source: Lucent Technologies.
- Cable Modem--$250 to $300 per modem, assuming HFC is installed and equipped for 2-way operation. Source: Scientific Atlanta
- Integrated Access Devices-- Premise device $35-50K, backbone device $75-$100K. Source: Cisco.
- Ethernet--$161 per port. Source: Borthick.
- ATM LAN--$1400 per port. Source: Borthick.
- xDSL equipment--$500 to $1000 per subscriber (Premise modem $200 to $500 and central office DSLAM $300 to $700). Source: Paradyne.
- xDSL installation cost at customers premises, $150. Source: Bell Atlantic.
- Router/Hub for fiber-optic network, $100-250,000. Source: Cisco Systems.
- Wiring Closet equipment--$500-$750. Source: 3M.

Using the above broad-gauge costs yields the following information:

Cost for adding DSL to an existing access line: $300 (customer buys premise modem and a technician visit is not necessary) to $650 (customer is supplied with modem and a technician visits premise)--does not include Internet access.

Cost for adding ISDN to an existing access line: $75 (customer buys Network Interface Device (NID) and no technician visit) to $475 (customer is supplied with modem and a technician visits premise)--does not include Internet access.

Cost for adding cable modems to an existing HFC system: $250 to $300 per subscriber--does not include Internet access.

Additional broad-gauge costs are provided in the Implementation Recommendations report.

CONCEPTUAL WIDEBAND COMMUNITY NETWORK DESIGN

Spivak Associates has carefully studied the key technologies and recommends that the WCN be composed of a Hybrid Fiber Coaxial (HFC) network to serve the residential areas with telephone, video programming, and high-speed Internet Access. Fiber optic cable deep into the residential areas is a safe investment for at least the next decade. Currently coaxial cable from the fiber node to the home looks like the best technology selection, see table 1, on page 21, however copper wire or wireless could easily become more attractive. Spivak Associates also recommends an all-fiber network to serve the main business district of Los Alamos. The White Rock business district can be served by a smaller fiber deployment or by the HFC network. The Implementation Recommendations report contains conceptual maps and a financial analysis of the WCN network.

Figure 6 illustrates the entire WCN and its interconnections to the Internet Service providers; the public switched telephone network, and video programming services.

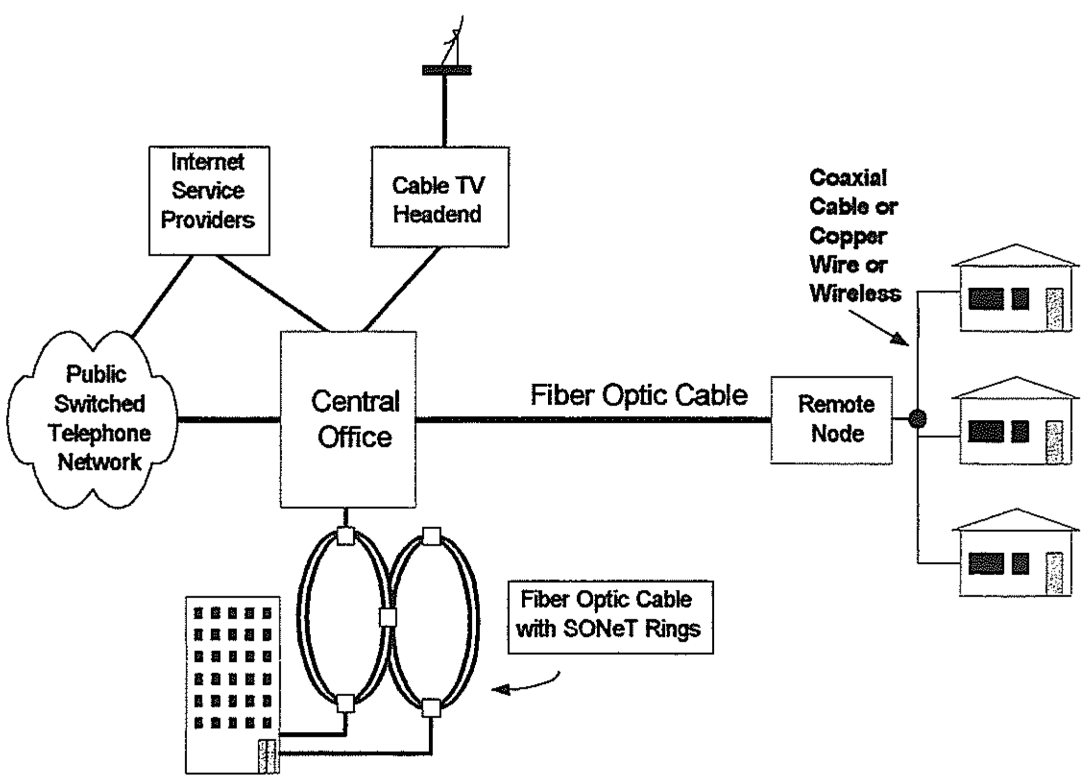

FIGURE 6, CONCEPTUAL WCN INFRASTRUCTURE DIAGRAM

Business district network--As shown in Figure 6, fiber-optic cable is used to serve the business district. The architecture of the fiber-optic cable is a counter rotating ring with Synchronous Optical Network (SONet) protocol. The operation of a SONet ring is shown in Figure 3. SONet has three main advantages over other architectures; 1) reliability, 2) efficiency, and 3) scalability. The SONet ring achieves reliability by sending and receiving data simultaneously over two rings, so that if the fiber cable is cut at any point the data has an alternative route. SONet offers an efficient architecture for handling multiple T-1, T-3, OC-3, etc. channels on the fiber rings. SONet is a scalable architecture and can accommodate data speeds up to the limits of the fiber-optic cable, without expensive retrofits.

Residential network--The Hybrid Fiber network should serve 75-125 homes per fiber node. Coaxial cable, copper wire or wireless technologies can be used to interconnect the node and the home. This design will handle extremely heavy Internet usage for each home as well as heavy telephone calling. In the actual network layout, the neighborhood fiber deployment should include allow multiple feeds to each neighborhood so that a damaged fiber cable will not cause a loss of service to the neighborhood. In this way, very high reliability can be obtained and if service is lost only a few homes will be impacted.

The in-home connections to the WCN are extremely important. Systems that require a technician visit to every home can be very expensive to install and maintain. The ideal home system will allow high-speed Internet access and telephone connections over the existing house wiring. The homeowner should be able to install additional telephone or data jacks without worrying about using special data-grade cable or calling an electrician. Such a system is available from Tut Systems and is illustrated below. A typical home WCN connection is shown in Figure 7.

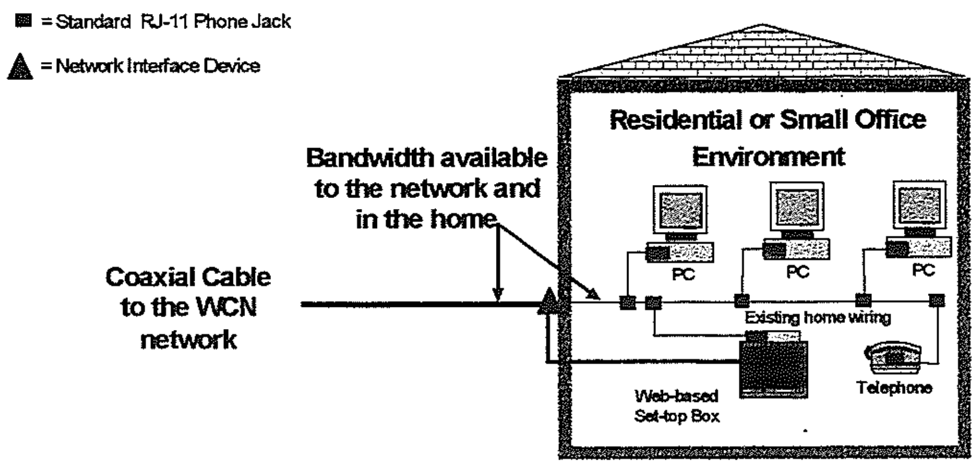

Figure 7, Home Wiring Diagram

THE FUTURE INTERNET[36]

A full description of Government, university, and industry efforts toward developing the future Internet could fill volumes. The following information is designed to give the reader a glimpse of the efforts that are now going on. After reviewing some of the information on future Internet activity, the following conclusions became evident:

Internet technology will support ever-increasing demands for speed and performance is indeed being developed today and will be ready for tomorrow's networks. Enough development, planning, and testing are going on today to assure adequate Internet capacity for the next five years. If Federal funding is reduced, capacity problems are likely to arise, but not for several years.

Government research efforts are focused on developing partnerships with industry, and this will lead to much faster availability of commercial products. The old Government paradigm of directing specific research efforts seems to have been put aside for Internet research, much to the future benefit of all parties.

The Government views investments in future Internet development as critically necessary to keep the information technology revolution on track, keep the economy humming and maintain USA leadership in global information technology. (See our WCN Regional Considerations report.)

Today, work is going on to extend the capabilities and capacities of the Internet. NASA, through the Next Generation Internet (NGI) project, has defined four classes of networks as follows:

Network Class	Description	Examples:
Class 1	Network Research--Bleeding edge, breakable networks	CAIRN, NTON, SVTT, MONET, ATDnet, AAI
Class 2	Research Networks--Leading edge, advanced applications	NREN, ESnet, vBNS, DREN
Class 3	Operational Networks--State of the Art	NI, Aeronet, NSF Connection
Class 4	Production Networks--Commercially available	Sprint, MCI/WorldCom, AT&T, AOL, @HOME, etc.

The NGI project focuses on Class 1 and 2 networks. NGI is a partnership between industry, government and academia with the goal of creating the foundation for networks and networking applications for the 21st century. NASA, along with Department of Defense (DoD), Department of Energy (DoE), National Institute of Health (NIH), National Institute of Standards and Technology (NIST), and National Science Foundation (NSF) has committed to spend $85 million over the next five years on NGI. NGI has three foci, 1) investigate next generation network applications, 2) increase network speed and capacity, and 3) improve network intelligence.

The NGI project work will take the form of supporting applications demonstrations, sponsoring new technologies and services, and establishing high-performance test-beds. NGI is targeting a 100-to-1000 times improvements in network end-to-end performance and developing more than one hundred high-importance applications. This will include collaboration and peering with the Internet2 community to reach university research centers. NGI is especially interested in Gigabit/Terabit technologies, hybrid-networking involving wireless, IP switching, multicasting, virtual networks, and traffic aggregation. The NGI project is intended to reach a broad base of commerce along with education, health care, environment, general science, manufacturing, libraries, etc. Over 100 universities and research institutions are onboard with NGI, while 53 Internet Service Providers and two universities have won High Performance Connections awards from NSF.

Internet2 is currently confined to academic, government research centers and a handful of non-profit organizations. Internet2 is not a separate network; it is a project to upgrade existing networks. One of the research topics for Internet2 participants is to develop quality-of-service guarantees, which do not exist on the current Internet. The core of Intenet2 is a very-high-speed backbone called vBNS, a joint effort of the National Science Foundation and MCI/WorldCom. vBNS runs at 622 Mbps and links NSF supercomputers. ATM, SONet, and HPPI are just some of the protocols under test with Internet2.

GLOSSARY OF TERMS

ADSL	Asynchronous Digital Subscriber Line
ANSI	American National Standards Industry
ATM	Asynchronous Transfer Mode
bps	bits per second
CAT 5	A type of premise wiring used for Local Area Networks.
CATV	Community Access TeleVision
CDMA	Code Division Multiple Access
CDROM	A high-density storage medium used by computers.
CLEC	Competitive Local Exchange Carrier
CO	Central Office
CRADA	Cooperative Research and Development Agreement
DOC	Department of Commerce
DOCSIS	Data Over Cable Service Interface Specification
DOE	Department of Energy
DREN	Defense Research Network
DS-1	Same as T-1
DS-3	Same as T-3
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Module
DWDM	Dense Wave Division Multiplexing
EDI	Electronic Data Interchange
ESNet	DOE network, similar to the Internet.
ESS	Electronic Switching System
FDDI	Fiber Distributed Data Interchange
FRS	Frame Relay Service
Gbps	Giga bits per second (1000 Mega bits per second).
G.lite	xDSL protocol
GHz	Giga Hertz (1 billion Hertz)
GigaHz	See GHz
Hertz	Cycles per second
HFC	Hybrid Fiber-optic and Coaxial Cable
IAD	Integrated Access Device
IEEE	Institute of Electrical and Electronic Engineers
ILEC	Incumbent Local Exchange Carrier
ILEC	Imbedded Local Exchange Carrier e.g. US West
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISDN	Integrated Services Digital Network
ISP	Internet Service Provider
ISP	Internet Service Provider
IT	Information Technology
IXC	Interexchange Carriers
LAC	Los Alamos County
LAN	Local Area Network

LANL	Los Alamos National Laboratory
Mbps	Mega bits per second (1 million bits per second)
MDF	Main Distributing Frame
MHz	Mega Hertz (1 million Hertz)
MVL	Multiple Virtual Line
NASA	National Aeronautic and Space Administration
NGI	Next Generation Internet
NIC	Network Interface Card
NIH	National Institute of Health
NREN	NASA Research and Education Network
NSF	National Science Foundation
OC	Optical Channel
PBX	Private Branch Exchange
PC	Personal Computer
POTS	Plain Old Telephone Service
PPS	Packets Per Second
PPTP	Point to Point Tunneling Protocol
PSTN	Public Switched Telephone Network
RADSL	Rate adaptive Asynchronous Digital Subscriber Line
RISC	Reduced Instruction Set Computing
RSM	Remote Service Module
RT	Remote Terminal
S-HDSL	Single wire High speed Digital Subscriber Line
SLC	Subscriber Line Carrier System
SONet	Synchronous Optical NETwork
T-1	24 voice channels or 1.544 Mbps data channel
T-3	672 voice channels or 44.23 Mbps
Tbps	Tera bits per second (1000 Giga bits per second).
UDSL	Universal Digital Subscriber Line
UNM	University of New Mexico
UNM-LA	University of New Mexico at Los Alamos
vBNS	Very High Speed Backbone Network Service
VDSL	Very high speed Digital Subscriber Line
VOIP	Voice Over Internet protocol
WAN	Wide Area Network
WCN	Wideband Community Network
WCN	Wideband Community Network
xDSL	Variations of the Digital Subscriber Line protocol

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NSF Connections	http://www.vbns.net