SURA
Optical Networking Cookbook

A practical guide to planning and deploying optical networks
for research and education.

Version 1
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Developed by the
SURA Crossroads Architecture Working Group (AWG)
and collaborators

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SURA gratefully acknowledges the contributions of content, time, and energy from the following persons and organizations:

Project and Section Leads
Kathy Benninger, Pittsburgh SuperComputing Center
John Nichols, Virginia Tech
Ana Preston, University of Tennessee
Troy Travis, University of South Carolina
Mary Fran Yafchak, SURA

Major Content Contributors
Kathy Benninger, Pittsburgh SuperComputing Center
Leo Donnelly, Harvard University
Mark Johnson, North Carolina Research & Education Network
Ron Hutchins, Georgia Institute of Technology/Southern Crossroads (SoX)
Sarah Morford, Grant County Public Utility District
John Nichols, Virginia Tech
Ana Preston, University of Tennessee
John Streck, North Carolina State University
Troy Travis, University of South Carolina
Bill Wing, Oak Ridge National Laboratory
Advance Fiber Optics, Inc., http://www.opsinsight.com
Corning Cable Systems, http://www.corningcablesystems.com
RACO, Inc., Gretna, VA, Tel: 434-656-6676

Feedback and Review
Gary Crane, SURA
Beth Davidson, University of South Carolina
Joel Dunn, University of North Carolina at Chapel Hill
Doyle Friskney, University of Kentucky
SURA Crossroads Architecture Working Group

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Introduction

The concept for the creation of an Optical Networking Cookbook was developed as part of the planning for an NSF-funded Optical Technologies Workshop hosted by SURA, MCNC and NCNI on December 13-14, 2001 (See: http://www.sura.org/events/2001/optical.html). SURA and the SURA membership have developed and organized similar, practical tools for assisting the higher education and research community in utilizing emerging technology (see the Video Conferencing Cookbook: http://www.videnet.gatech.edu/cookbook/). Such tools offer guidance in topics of high interest to the community at times when critical information on the topic may be unavailable, highly dispersed and difficult to locate, or abundant but not digested in a way that easily enables R&E deployment.

The target audience for this Cookbook includes university campuses and local and regional advanced academic networking aggregators (gigapops) as they explore the use of optical networking technologies in support of their institutions and/or aggregations. Adhering to the cookbook analogy, the document is intended to be a practical resource listing the "ingredients" of optical networking and also offering "recipes" - implementation case studies - that illustrate what particular mixes of those ingredients can produce.

This first version of the Cookbook is divided into three primary sections. The first section is an overview of optical networking technologies, including an introduction to various components, the "physics" of fiber optics, and some pointers to best illustrations and practices that apply. The second section provides additional depth on the critical topic of building the basic fiber optic infrastructure that is necessary to support advanced research and network applications. The third section offers narratives on how optical networking and its related infrastructure are extending and enhancing networking capabilities today.

As necessitated by the rapid pace of networking technology development and the very fluid nature of the telecommunications marketplace, this cookbook is intended to be a work in progress. It is hoped that updates and additions can occur as the technologies and market conditions change and as community needs are re-examined or new needs are identified. As a community resource, this cookbook cannot continue to be relevant unless there is a sustained effort to contribute to its maintenance and development. Contributions to this effort are welcome. To participate, please contact SURA's IT Program Coordinator, Mary Fran Yafchak (maryfran@sura.org).

Optical Networking Technology Overview

We begin the overview of optical technologies by describing the four geographical size ranges of installation into which optical network implementations are typically classified. These four, from smallest to largest, are: campus, metro, regional, and long haul. The primary difference between each is the distance signals must be transmitted and the density of connections. Each has different implications for the optical network configuration and components.

The smallest area of coverage, the campus network, typically exists to interconnect the networks within several buildings of a university or business complex that are within few kilometers of each other. Next largest in size is the metro area network which comprises interconnections of building or campus networks within a metropolitan area, on the order of a few hundred square kilometers or less in scope. Beyond the scope of metro networks are regional networks, examples of which would be a statewide network such as North Carolina's or a network spanning adjoining states. Long Haul networks are cross-country or cross-countries.

The cookbook will focus on metro, regional, and long haul. However the fiber and component descriptions will also be applicable to the campus fiber network.

An understanding of current optical network components and technologies will help as you begin planning and designing your new network. Because a wealth of informative, detailed documentation already exists on-line, we do not go into the following topics in-depth. Rather, we have provided the basic need-to-know information and included pointers for further reading if you need more detail on any of the topics.

First we will cover the basics of the fiber itself and then proceed to cover equipment and the issues related to optical signal transmission.

Introduction

Goals of this section:

- To provide an introductory overview to the basic principles and characteristics of fiber optics.
- To provide pointers to where more detailed information can be found

The following sections cover basic optical components; the building blocks and how they fit together. Because optical technologies evolve very quickly we strongly suggest that you check out the resources provided. There are many resources on fiber optics – this section intends to highlight the most basic concepts.

This section builds on a tutorial given by Mark Johnson and Jerry Sobieski at the Joint Techs Meeting (May 2001), the original outline developed as a result of the MCNC Optical Networking Workshop held in North Carolina (Dec. 2001), and the many resources highlighted throughout.

Resources and pointers for more information on fiber optics

Books

- "Fiber-Optic Communications Technology" by Lowell L. Scheiner & Djafar K. Mynbaev, Prentice Hall; ISBN: 0139620699
- "Understanding Fiber Optics" by Jeff Hecht, Prentice Hall; ISBN: 0130278289
- "Optical Networking Crash Course" by Steven Shepard, McGraw-Hill Professional; ISBN: 0071372083

Web

- Light Reading Beginner's Guides, http://www.lightreading.com/section.asp?site=research&section_id=29
- Corning Cable Systems Basic Principles of Fiber Optics, http://www.corningcablesystems.com/web/college/fibertutorial.nsf/introfro?OpenForm
- Fiber 101, http://www.corning.com/opticalfiber/discovery_center/tutorials/fiber_101/of_cc.asp
- Illustrated Fiber Optics Dictionary, http://www.fiber-optics.info/glossary-a.htm
- How Fiber Optics Works, http://www.howstuffworks.com/fiber-optic.htm
- Fiber Optics Basics, http://www.tcomschool.ohiou.edu/its_pgs/fiber.html
- Introduction to Fiber Optics, http://www.commspecial.com/fiberguide.htm
- Optics for kids, http://www.opticalres.com/kidoptx.html
  A great little tutorial – very simply written – on basic principles of optics – written for children and available in both Japanese and Chinese.

The Basics

What is fiber optics?

In the simplest terms, fiber optic cabling can be described as a medium for carrying information from one point to another in the form of light. Unlike the copper form of transmission, fiber optic transport is not electrical in nature.

What is optical networking?

There are many definitions of this term but in simpleterms: when the lowest layer data transport is carried via light over fiber optic cable.

Fiber optics system: Transmission basics

Basically, in a fiber optic system, information (such as voice, data or video) is transmitted over fiber in the following way: once encoded into electrical signals, these get converted into light signals that travel down the fiber until they reach a "detector" which then changes the light signals back into electrical signals. Finally, the electrical signals are decoded into information in the form of voice, data, or video.

Broken in parts, again, the main components of a fiber optic system include:

1) transmitter. A transmitter converts information – such as voice, data, or video, encoded into electrical signals -- to light signals. The transmitter receives a modulated electrical signal and converts it into a modulated light signal, after which it sends the light signal into the fiber optic cable.
2) fiber optic cable – the medium which carries the signal
3) receiver: which accepts the light signal and converts it back into a modulated electrical signal.

We start first with the medium – fiber optic cable and the different types of fiber that there are. We then describe the "ends" of the system: transmitters and receivers.

Fiber optic cable: what is it and what types are there?

Fiber optic cables are made out of glass, although some are made of plastic. Most are silica based. Below is a cross sectional view of a typical fiber optic cable.

Inside an optical fiber

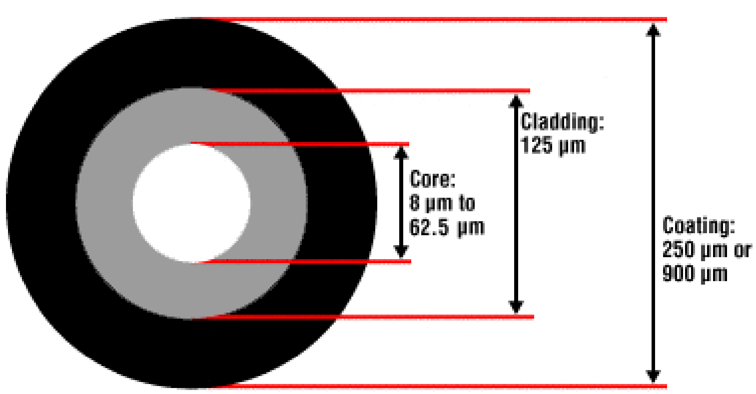


Figure X. From Corning online tutorial

You can think of an optical fiber as a “light guide” The components inside an optical fiber use materials of different refractive indices to confine and guide the light.

An optical fiber consists of three components:
1) core
2) cladding
3) coating

Sizes are measured in micrometers [µm] A micrometer, the unit typically used to express the geometric dimension of fibers is one millionth of a meter or a 10^{-6} meter.

Core
The core is the central region of an optical fiber through which light travels and the information is carried. The standard telecommunications core sizes in use today are 8.3 µm (single-mode), 50 µm (multimode), and 62.5 µm (multimode). Single-mode and multimode fiber are discussed further in this section.
The core has the lowest refractive index and is the primary light medium. (See section further below on How Light Travels through Fiber)

Interesting fact: A human hair is approximately 70 µm or 0.003 inch (vs. a 8.3 8.3 µm single-mode or 50 µm multimode fiber!

Cladding
The cladding surrounds the core. The cladding is also made of glass but has a lower refractive index than the core. This causes the light in the core to reflect off of the cladding and stay contained in the core. The diameter of the cladding surrounding the core is of 125 µm.

Interesting fact: The core and cladding are manufactured together as a single piece of silica glass with slightly different compositions, and cannot be separated from one another. The glass does not have a hole in the core, but is completely solid throughout.

Coating
The coating is the outer protective coating; it mechanically protects the fiber. Typically, the coating is made of plastic and protects the fiber from damage and moisture.
The coating is typically an ultraviolet (UV) light-cured acrylate applied during the manufacturing process to provide physical and environmental protection for the fiber.

During the installation process, this coating is stripped away from the cladding to allow proper termination to an optical transmission system. Coating standard sizes are 250 µm or 900 µm.

Types of Fiber
Once light enters an optical fiber, it travels in a stable state called a mode. There can be from one to hundreds of modes depending on the type of fiber. Each mode carries a portion of the light

from the input signal. Generally speaking, the number of modes in a fiber is a function of the relationship between core diameter, numerical aperture, and wavelength.

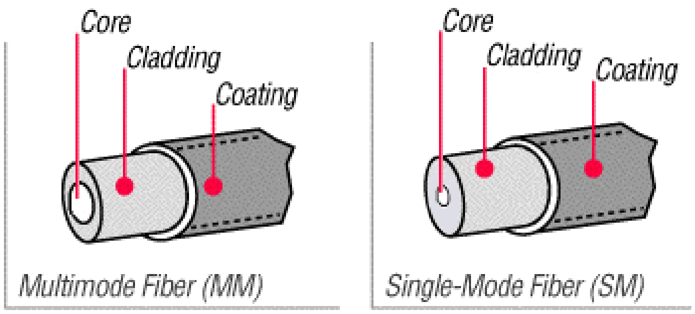


Figure X. From Corning tutorial

There are two primary types of fiber: single-mode or multimode. Both types act as a transmission medium for light, but they operate in different ways, have different characteristics, and serve different applications.

Single-mode (SM) fiber allows for only one pathway, or mode, of light to travel within the fiber. Typically, the core size is 8.3 µm. Because the core of the fiber is so small, the light contained in the core is forced to travel in a straight line. Singlemode fiber generally has greater capacity to carry information (bandwidth) and can carry that information over longer distance. Single-mode fiber also tends to be more expensive than multimode fiber. It is used in applications where low signal loss and high data rates are required, such as on long spans where repeater/amplifier spacing needs to be maximized.   As a practical note, single-mode fiber jumpers are always yellow.

Multimode fiber allows more than one mode of light. Common core sizes are 50 µm and 62.5 µm. In fiber cores of this size, light travels down a much larger path allowing the light to segment into multiple paths, or multimode. Modulation rates of up to 200 Mbs are possible with this type of fiber and for distances less than 100 meters, the bandwidth is virtually unlimited. Thus, multimode fiber is better suited for shorter distance applications. Where costly electronics are heavily concentrated, the primary cost of the system does not lie with the cable. In such a case, MM fiber is more economical because it can be used with inexpensive connectors and LED transmitters, making the total system cost lower.   Multimode fiber jumpers are orange.

A great animation on single-mode vs. multimode fiber is available at: http://www.corning.com/opticalfiber/discovery_center/tutorials/fiber_101/multi_vs_single.asp .

Note that all fiber designs are compromises since the manufacturers do not know exactly how they will be used in practice. Cables are deployed in a variety of environments and cable types include direct buried/armored, underground, Arial ADSS, Arial OPGW.

For information on coating and cable design, see: http://www.fiber-optics.info/articles/fiber-types.htm.

Modulation

For optical signal transmission, the optical signal is modulated onto the fiber optic cable in the form of pulses of light. A signal is generated by turning a light source on and off. Ideally, the resulting signal would be a square wave, but in reality looks more like a sine wave (fig. X). Although modulation of the light source can be done directly by turning the light source on and off, in configurations with high data rates (multiple Gb/s) and distances greater than a few km, the modulation is typically done external to the light source. The light source is kept on at constant power while some type of shutter mechanism alternately blocks or lets the signal pass. A more detailed description of modulation is available at the Light Reading Web site, http://www.lightreading.com. (Look under the "Beginner's Guide" and "Modulation").

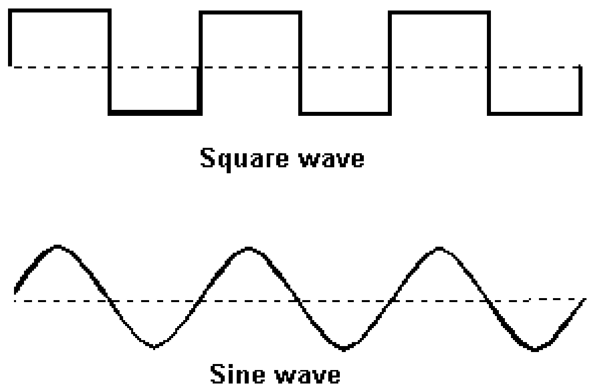


Fig. X

Transmitters

Transmitters accept coded electronic signals, process them to light signals (modulation), and send them off across the fiber. A **Light Emitting Diode** (LED) or a **Laser** can be used for generating the light signals. Using a lens, the light signals are then funneled into the fiber optic cable.LED's are common and relatively inexpensive light sources. They are usually low in power and are used generally where distance is not critical (e.g. between devices in a computer room which are separated by less than a few hundred meters). Laser diodes are typically more expensive than LED's and are usually used in high-end single-mode applications over much longer distances. They can easily be used as light sources in multimode fiber systems if necessary.

The light source emits light pulses at particular wavelengths. A wavelength is also referred to as a lambda (λ). The terms λ and wavelength are often used interchangeably. State-of-the-practice (Oct 2002) optical equipment supports data rates of up to 10Gb/s. Though the wavelengths are infrared and therefore invisible to the eye, they are nonetheless often referred to as "colors".

Transmitters are designed to emit light at one of three ranges of wavelengths: 850, 1310, or 1550 nanometers. LED's can emit light at both the 850 and 1310 nanometer range and have modulation frequencies of 200 MHz or less. A typical laser can transmit in the 1310 or the 1550 nm range and has modulation capabilities of greater than 1 Ghz (1,000 MHz).

Important note: One must never look into the end of a fiber which may have a laser coupled to it. Laser light is invisible and can damage the eyes. Viewing it directly does not cause pain. The iris of the eye will **not** close involuntarily as when viewing a bright light; consequently, serious damage to the retina of the eye is possible.

Receivers

At the other end of the fiber optic cable from the transmitter is the receiver which uses a photo-detector to convert the incoming light signal back into an electrical signal. The wavelength designation of the receiver must match that of the transmitter.

Important characteristics of receivers are System Performance, which is the Bit Error Rate (BER) for digital systems or Signal to Noise Ratio (SNR) for analog, Saturation and Sensitivity. The Bit Error Rate is the number of errors that occur between the transmitter and the receiver, a typical number is 10(-9) which means 1 error in every 1 billion bits transmitted. The Saturation defines the maximum received power that can be accepted. If too much power is received, the result is a distortion of the signal, causing poor performance. Sensitivity is the minimum power that must be received on an incoming signal. Too weak a signal can cause misread bits or low SNR.

How light travels through fiber

First, let's go over how light travels through an optical fiber. Very simply put, the light in a fiber-optic cable travels through the core by constantly bouncing from the cladding. This is the principle of **total internal reflection.**

Total internal reflection is when a light signal traveling in one material hits a different material and reflects back into the original material without any loss of light occurring.

Since the core and cladding are constructed from different compositions of glass, theoretically, light entering the core is confined to the boundaries of the core because it reflects back whenever it hits the cladding. For total internal reflection to occur, the **index of refraction** of the core must be higher than that of the cladding.

Illustrative images on reflection:

(1) http://www.esat.kuleuven.ac.be/teo/onderwijs/vakken/H245/SCIAM_FIBERS/SciAm_Optical_fibers.html
(2) http://www.corning.com/opticalfiber/discovery_center/tutorials/fiber_101/reflection.asp

Index of refraction

Index of refraction indicates a way of measuring the speed of light in a material. The index of refraction is calculated by dividing the speed of light in a vacuum (roughly 300,000 kilometers per second, or 186,000 miles per second) by the speed of light in some other medium.

The Index of Refraction of a vacuum by definition has a value of 1. The typical value for the cladding of an optical fiber is 1.46. The core value is 1.48. The larger the index of refraction, the more slowly the light travels in that medium. Interesting fact: In water, the typical index of refraction is 1.33; in air 1.0003.

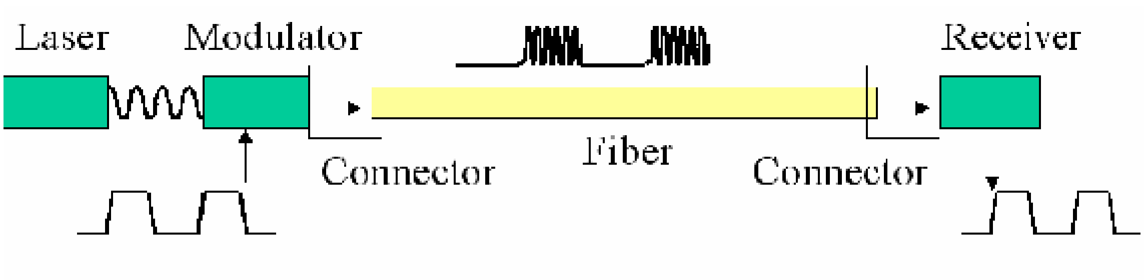
Acceptance cone
To ensure that light signals reflect and travel correctly through the core, the light must enter the core through an imaginary acceptance cone. The size of this acceptance cone is a function of the refractive index difference between the core and the cladding. More simply explained, the acceptance cone is the angled area that light must enter in order to "bounce" down the fiber or travel between the core and the cladding.

For more information on optics and total internal reflection, see:

- http://www.lightlink.com/sergey/java/java/totintrefl/
  a great java applet that illustrates total internal reflection
- Optics Basics, Jeff Hecht, Understanding Fiber Optics, Prentice Hall PTR – excerpt at http://zone.ni.com/devzone/prenticehall.nsf/webmain/E01201A5BBD9A74D86256AED007934A9?opendocument

A wonderful resource on understanding lightwave transmission is available at http://www.bell-labs.com/technology/lightwave/

The basics of an optical system – review
First, a review of the architecture in fiber optic system:
1. Light source (typically a laser) emits a light signal.
2. Modulator "blocks" according to electrical bit stream (Intensity Modulation)
   - Direct modulations of laser typical in lower data rates
   - External modulation more common in high speed data rates
3. Receiver detects the signal and regenerates electrical bit stream from modulated optical signal



Limiting factors of fiber optics (useful for Design parameters)

The following section will highlight some of the limiting factors of optical fiber. In practice, these factors combine to limit the distance and bit rate that can be supported by a fiber optic system because they make it more difficult for the receiver to distinguish a one from a zero.

Fiber optics are "pretty clear", but not perfectly clear. There can be impurities and construction limitations that will constrain the optical transmission properties.

As we have seen previously, because the cladding does not absorb any light from the core, the light wave can travel great distances. However, some of the light signal degrades within the fiber, mostly due to impurities in the glass. The extent that the signal degrades depends on the purity of the glass and the wavelength of the transmitted light (for example, 850 nm = 60 to 75 percent/km; 1,310 nm = 50 to 60 percent/km; 1,550 nm is greater than 50 percent/km). Some premium optical fibers show much less signal degradation -- less than 10 percent/km at 1,550 nm

Additionally, many of the design properties of fibers are based on inherent technology capabilities and limitations of the light sources available at the time. For example, at some point LED sources were good for multimode fibers in the 850 nm range. Higher speed lasers at 1310 nm required lower attenuation and dispersion in the fiber – and vice versa. Higher data rates required still further evolution into the 1550 nm range. Attenuation and dispersion are discussed in more detail in the section below on Linear and Non-linear effects.

Linear effects vs. Non-Linear effects

As optical fiber data rates, transmission lengths, number of wavelengths and optical power levels have increased, non-linearity effects arose.

In the early days of fiber optics, the big worries were fiber attenuation and sometimes, fiber dispersion (defined below). These issues can be easily dealt with using a variety of dispersion avoidance and cancellation techniques.

Non-linear effects of fiber became apparent with specialized applications such as undersea installations. Some of these effects – and important to know when designing fiber optics systems, include: stimulated Brillouin scattering (SBS), stimulated Raman scattering (SRS), four wave mixing (FWM), self-phase modulation (SPM), cross-phase modulation (XPM), and intermodulation (mixing).

Non-linear effects limit the amount of data that can be transmitted on a single optic fiber. System designers must be aware of these limitations and the steps that can be taken to minimize the detrimental effects of fiber non-linearities.

We will first provide an overview of linear effects, which are a function of the fiber length. Linear effects include **Attenuation** and **Dispersion**.

A very simple animation on attenuation vs. dispersion is available at: http://www.corning.com/opticalfiber/discovery_center/tutorials/fiber_101/attenuation.asp .

Attenuation

Attenuation is the loss of optical power as light travels down a fiber, resulting in a signal that is too dim. It is measured in decibels (dB/km).

Over a set distance, a fiber with a lower attenuation will allow more power to reach its receiver than a fiber with higher attenuation.

- Attenuation Coefficient
  The rate of optical power loss with respect to distance along the fiber, usually measured in decibels per kilometer (dB/km) at a specific wavelength; the lower the number, the better the fiber's attenuation. Typical multimode wavelengths are 850 and 1300 nanometers (nm);

single-mode wavelengths are 1310 and 1550 nm. Note: When specifying attenuation, it is important to note whether the value is average or nominal. (from Corning glossary)

While low-loss optical systems are always desirable, it is possible to lose a large portion of the initial signal power without significant problems. A loss of 50% of initial power is equal to a 3.0 dB loss. Any time fibers are joined together there will be some loss. Losses for **fusion splicing** and for **mechanical splicing** are typically 0.2 dB or less.

- Fusion Splicing
  A permanent joint produced by the application of localized heat sufficient to fuse or melt the ends of the optical fiber, forming a continuous single fiber.

- Mechanical splicing
  Joining two fibers together by permanent or temporary mechanical means (vs. fusion splicing or connectors) to enable a continuous signal (from Corning glossary)

Attenuation can be caused by several factors, but is generally placed in one of two categories: intrinsic or extrinsic.

- **Intrinsic attenuation**
  Intrinsic attenuation occurs due to something inside or inherent to the fiber. It is caused by impurities in the glass during the manufacturing process. As precise as manufacturing is, there is no way to eliminate all impurities, though technological advances have caused attenuation to decrease dramatically.

  If a light signal hits an impurity in the fiber, one of two things will occur: it will **scatter** or it will be **absorbed**.

  Scattering is the loss of a light signal from the fiber core caused by impurities or changes in the index of refraction of the fiber. Light is re-directed by the molecular properties of the fiber resulting in leakage into the cladding, jacket, or loss at junctions, or reflection back to the source.

  Rayleigh scattering accounts for the majority (about 96%) of attenuation in optical fiber. Light travels in the core and interacts with the atoms in the glass. The light waves elastically collide with the atoms, and light is scattered as a result.

  Rayleigh scattering is the result of these elastic collisions between the light wave and the atoms in the fiber. If the scattered light maintains an angle that supports forward travel within the core, no attenuation occurs. If the light is scattered at an angle that does not support continued forward travel, the light is diverted out of the core and attenuation occurs.

  Some scattered light is reflected back toward the light source (input end). This is a property that is used in an Optical Time Domain Reflectometer (OTDR) to test fibers. This same principle applies to analyzing loss associated with localized events in the fiber, such as splices.

  Absorption is the second type of intrinsic attenuation in fiber. Light is absorbed due to chemical properties or natural impurities in the glass. Unlike scattering, absorption can be limited by controlling the amount of impurities during the manufacturing process. Absorption accounts for 3-5% of fiber attenuation.

The biggest problem with any optical fiber has to do with losses in one form or another. Some losses, such as the absorption of some light energy by the glass itself, cannot be avoided.

- **Extrinsic attenuation**
  The second category of attenuation is extrinsic attenuation. Extrinsic attenuation can be caused by two external mechanisms: **macrobending** or **microbending**. Both cause a reduction of optical power.

  Macrobending -
  If a bend is imposed on an optical fiber, strain is placed on the fiber along the region that is bent. The bending strain will affect the refractive index and the critical angle of the light ray in that specific area. As a result, light traveling in the core can refract out, and loss occurs. This loss is generally reversible once bends are corrected.

  To prevent macrobends, all optical fiber (and optical fiber cable) has a minimum bend radius specification that should not be exceeded. This is a restriction on how much bend a fiber can withstand before experiencing problems in optical performance or mechanical reliability. The rule of thumb for minimum bend radius is 1 1/2" for bare, single-mode fiber; 10 times the cable's outside diameter (O.D.) for non-armored cable; and 15 times the cable's O.D. for armored cable.

  Microbending -
  The second extrinsic cause of attenuation is a microbend, a small scale distortion, generally indicative of pressure on the fiber. Microbending may be related to temperature, pulling stress, or crushing force. Like macrobending, microbending will cause a reduction of optical power in the glass. Microbending is very localized, and the bend may not be clearly visible upon inspection. With bare fiber, microbending may be reversible; in the cabling process, it may not.

Saturation, the inverse of attenuation, means that the signal is too bright. While saturation is not a “limiting factor” in the same sense as attenuation and dispersion, it still must be taken into account as the fiber optic system is being designed. If the signal is too bright, the receiver can become overdriven which may result in data errors or failure to detect any signal. In this situation it is necessary to add “attenuators” to the system to bring the signal level down to an acceptable level.

Dispersion

Dispersion is the "spreading" of a light signal as it travels down a fiber and is the cause of bandwidth limitations in a fiber. As the pulses spread, or broaden, they tend to overlap, and are no longer distinguishable by the receiver as 0s and 1s [the digital waveform is “smeared” and the rise/fall time expands over the length of the fiber). Light pulses launched close together (high data rates) that spread too much (high dispersion) result in errors and loss of information.

Dispersion limits how fast, or how much, information can be sent over an optical fiber. The basic problem caused by any dispersion effect is that it limits the rate at which data may be transmitted through the fiber. If the light amplitude is modulated at too high a rate, dispersion tends to level out the changes so that the light at the far end of the fiber is of nearly constant amplitude. The end result is that the modulations become indecipherable, and all data is lost.

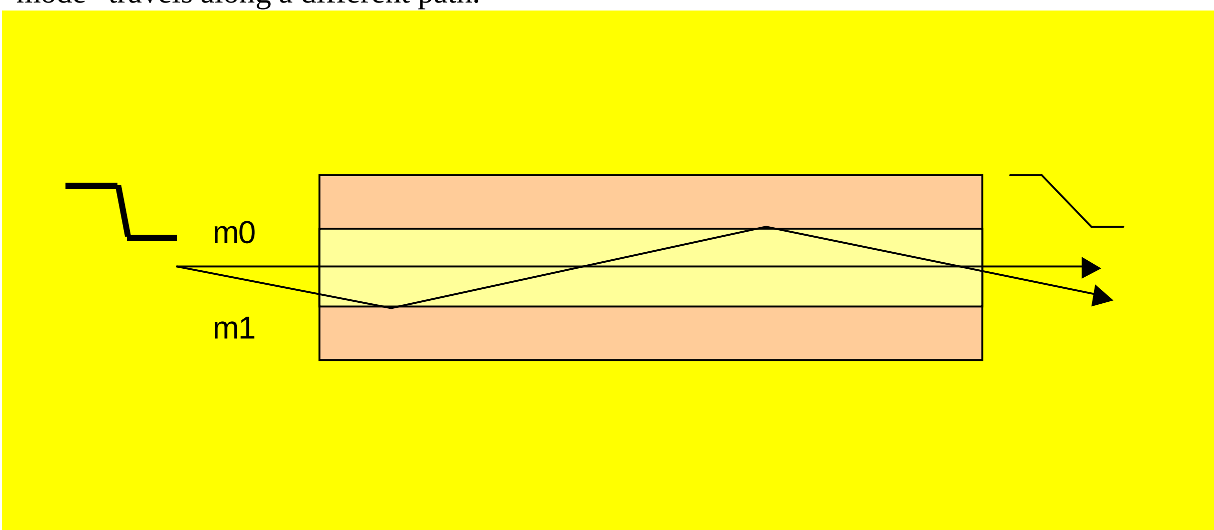
The major types are:

(1) modal dispersion
(2) chromatic dispersion
(3) polarization mode dispersion

Dispersion is measured in units of picosecond per nanometer and varies with the wavelength and length of fiber span.

Modal dispersion

Modal dispersion (also referred to as multimode distortion) is caused by differential optical path lengths in a multimode fiber; differing "modes" traverse different paths in the fiber, .e.g, each "mode" travels along a different path.



For example, as shown in the above diagram:

–Light enters the guide from different insertion angles along path m0 or m1
–Each path has a different length and so arrives at different times]

Modal dispersion is a primary limiting factor of multimode fiber for high speed communications: the various modes of light traveling down the fiber arrive at the receiver at different times, causing a spreading effect.

Multimode fibers have a core diameter of 50 microns to 62.5 microns

- Less rigorous tolerances make construction easier
- Splicing and connectors are more easily engineered
- Typically under 2 kilometer distances (less at high data rates)

By sizing the diameter of the core properly as a function of wavelength and refractive indices of core and cladding, the wave guide can be constrained to carry only a single "mode" of the incident laser signal.

- Single-mode fiber has a core diameter of approximately 8-11 microns
- SM fiber does not exhibit modal dispersion (The larger the diameter of an optical fiber's core, the more different propagation modes it can support, and the more pronounced the modal dispersion effect will be. On the other hand, if we make the core small enough, we can block all except the basic mode, and minimize this effect.)

Chromatic dispersion

Chromatic dispersion is caused by a differential delay of various wavelengths of light in a waveguide (fiber optic cable) material. Chromatic dispersion occurs as a result of the range of wavelengths in the light source. Light from lasers and LEDs consists of a range of wavelengths (lasers do not emit a single wavelength). Each of these wavelengths travels at a slightly different speed (different wavelengths of light travel at different velocities in a given medium – see also index of refraction). Over distance, the varying wavelength speeds cause the light pulse to spread in time.

Examples of dispersion calculations:

How would chromatic dispersion affect an OC48 link with laser at +/-1nm spectral line?

- Bit period = 416ps
- 2 nm spectral band * 5 ps/nm/km = 10 ps/km
- Result: rise/fall time is 25% of bit period over 10 kilometers.

OC192 with a .005 nm spectral width

(From http://www.atis.org/tg2k/ - Spectral width is the wavelength interval over which the magnitude of all spectral components is equal to or greater than a specified fraction of the magnitude of the component having the maximum value.)

- Bit = 104 ps
- .005 nm spectral band * 5ps/nm/km = .025ps/km
- 25% rise time after 100 km
- The finer the laser line, the less chromatic dispersion affects the emitted signal.

Polarization Mode Dispersion (PMD)

Polarization mode dispersion is an inherent property of all optical media. It is caused by the difference in the propagation velocities of light in the orthogonal principal polarization states of the transmission medium.

Essentially the “electric” and “magnetic” components of the light wave are propagated at different speeds through the fiber

- Caused by inconsistencies in the fiber ?
- Not well understood
- Typically only of concern at data rate in excess of 2.4 Gbs
- Measured in ps/sqrt(km)

Like chromatic dispersion, PMD causes digital transmitted pulses to spread out as the polarization modes arrive at their destination at different times. For digital high bit rate transmission, this can lead to bit errors at the receiver or limit receiver sensitivity.

For other effects of dispersion, see http://www.fiber-optics.info/articles/dispersion.htm

Non-Linear effects

Non-linear effects limit the amount of data that can be transmitted on a single optic fiber. System designers must be aware of these limitations and the steps that can be taken to minimize the detrimental effects of fiber non-linearity.

Non-linear effects include: stimulated Brillouin scattering (SBS), stimulated Raman scattering, four wave mixing, self-phase modulation, cross-phase modulation, and intermodulation (mixing)

Compensating for the Limiting Effects

A key part of implementing a fiber optic system is to understand what needs to be done within the system to handle attenuation, saturation, and dispersion. As the technology advances to support higher bit rates, these factors become increasingly significant because the light pulses become closer together in time and potentially more difficult for the receiver to distinguish. The system must be designed to compensate for these fiber optic characteristics.

Some of the devices used to overcome the various linear and non-linear limiting effects require conversion of the signal from optical back to electrical then back to optical (often referred to OEO, or optical-electrical-optical signal regeneration). This is expensive in terms of efficiency.

Amplification

An amplifier is used to boost the power of an optical signal that has been degraded due to attenuation. Amplification can be done without converting the signal back to an electrical signal (i.e. does not undergo OEO conversion).

Regional and Long-Haul (and perhaps large metro) optical networking typically require some type of amplification or regeneration at intermediate points to overcome loss in the fiber optic cable. For large metro or regional networks, amplification may boost the signal a sufficient amount. At distances greater than a few hundred km, the optical signal will need to undergo what is referred to as the "**3R's**":

- Re-timing
  - Verify and compensate for clocking drift
- Re-shaping
  - Compensate for attenuation and/or dispersion
  - Sharpen the "eye"
- Re-generation
  - Completely decode and re-create the digital bit stream.

Amplification essentially reverses attenuation, but may introduce other problems. For example, while an amplifier boosts the signal level, it also boosts the noise level and add noise itself, thereby decreasing the SNR. This places a limit on the number of amplifiers that can be chained together.

Dispersion Compensation
To maintain signal integrity and overcome the effects of dispersion, some type of dispersion compensation is required. It is possible, and often sufficient, to buy “dispersion managed cable”. This cable includes fiber with dispersion-compensating characteristics inline along the length of the cable, eliminating the need for external dispersion compensators.

In single-mode fiber applications:

Chromatic dispersion is the sum of the wave-guide dispersion (+, depends on core radius and numerical aperture of the fiber and the wavelength) and material dispersion (-, depends on bulk material of fiber)

- Fiber design can vary the amount of wave-guide dispersion in order to cancel the material dispersion at a desired wavelength
- This type of fiber is called Zero Dispersion-Shifted Fiber (ZDSF)

Non-linear effects are dampened by dispersion, so…

- Shift the zero dispersion point a bit past the operating wavelengths.
- This type of fiber is called Non-Zero Dispersion Shifted Fiber (NZ-DSF)

Dispersion can be positive or negative.

- Negative dispersion fiber can counter effects of normal fiberThis type of fiber is called Dispersion Compensating Fiber (DCF)

Regeneration
When amplification or dispersion compensation are insufficient to restore a signal to a level within the system specification, additional processing of the signal - the "3R's" - is required. Unfortunately from the performance standpoint, the 3R’s are expensive because the signal must be converted from optical to electrical for processing, then reconverted to optical for continued transmission (OEO conversion). This is a time consuming process. Amplification is preferred when sufficient because it can be done without the OEO conversion.

Typically, today, regeneration needs to be done on spans in excess of ~50 miles.

Multiple lights on the fiber – Wave Division Multiplexing

Early optical networking systems used a single wavelength of light on one fiber. However, the bandwidth capacity of fiber optic cable is much greater than the amount of data that can be encoded on a single wavelength. In order to take advantage of this extra capacity and maximize use of existing fiber infrastructure, the technology of Wavelength Division Multiplexing (WDM) has been developed and is being deployed. WDM combines different wavelengths of light onto a single fiber optic cable to increase the total throughput. As noted above, 10Gb/s is the highest data rate commonly in use at this time for a single wavelength. Therefore, in configurations without WDM, the peak bandwidth capacity of a single λ on a single fiber is 10Gb/s. With a WDM implementation, a single fiber can carry multiple λ’s, supporting multiple 10 Gb/s data streams.

Multiplexers/Demultiplexers (MUX/DEMUX) are used to combine (MUX) and separate (DEMUX) multiple wavelengths in a WDM system. The MUX function is performed at the transmitting end of the connection, DEMUX at the receiving end.

The spacing between wavelengths must be sufficient for the receiver/demux to separate the individual wavelengths. The International Telecommunication Union (ITU) sets the standards for wavelengths and wavelength spacing. The reference frequency is 193.10Thz (1552.52nm). The number of λ's that can be multiplexed onto a fiber depends on whether the equipment supports Coarse Wavelength Division Multiplexing (CWDM) or Dense Wavelength Division Multiplexing (DWDM). ITU-T Recommendation G.694.2, the newest standard for metro CWDM, specifies 20 nm spacing (see http://www.spectrum.ieee.org/WEBONLY/resource/aug02/nmetro.html).   In contrast, the current wavelength spacing for DWDM is 0.8 nm (also referred to as ITU 100GHz spacing). Future ITU-specified DWDM wavelengths are likely to be based on decreasing spacing between wavelengths: 0.4nm, 0.2nm, etc.

Examples of ITU Grid values for DWDM λ's in the 1550nm range (not the entire Grid)::

Channel (#)	**Frequency (GHz)**	**Wavelength (nm)**
21	192100	1560.61
22	192200	1559.79
23	192300	1558.98
24	192400	1558.17
25	192500	1557.36
26	192600	1556.56
27	192700	1555.75
28	192800	1554.94
29	192900	1554.13
30	193000	1553.33
31	193100	1552.52
32	193200	1551.72
33	193300	1550.92
34	193400	1550.12
35	193500	1549.32
36	193600	1548.52

With larger spacing between wavelengths, CWDM components have less stringent requirements on tolerances. Therefore, CWDM equipment tends to be less expensive than DWDM equipment. The tradeoff is that the ITU CWDM grid only defines 18 wavelengths, while the DWDM grid defines over 100 wavelengths. (Product brochures include tables similar to the above listing the wavelengths/frequencies that are supported by the equipment.

CWDM is often adequate for metro networks. DWDM is the more appropriate choice for regional and long haul implementations. "WDM" is used generically in the following discussion when the text applies to both CWDM and DWDM.

Equipment (in WDM systems) -

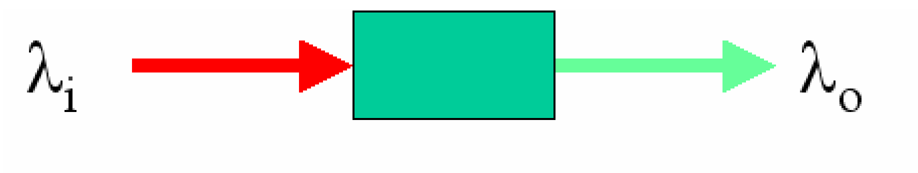
Client side and line side

Optical networking with WDM uses some components that are similar to those used in single-wavelength systems. Signal conversion is one of the main functions of WDM equipment. Electrical and optical signals from devices such as routers, switches, and end hosts typically need to be converted to optical signals that are compatible with the overall WDM system. This is done via “client” or “tributary” interfaces for OC-3, OC-12, OC-48, OC-192, FastE, or GigE, which are commonly available.

For a simple example, say we want to send a router OC-48 output over the WDM infrastructure. The appropriate OC-48 “tributary” or “client” interface will need to be installed in the WDM chassis. Even if the OC-48 signal is optical, it will require conversion to a wavelength compatible with the ITU grid and with the overall WDM implementation. Typical host equipment interfaces conform to the 850nm or 1310nm LAN interface standards while WDM signaling is usually implemented at 1310nm or 1550nm.

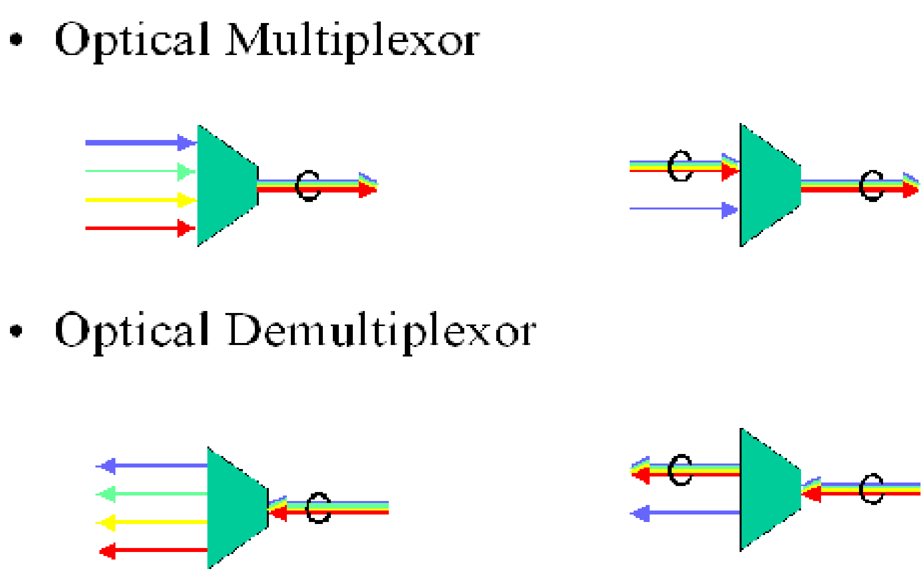
Wavelength Converter

- Often requires electrical intermediate step
- New devices allow conversion in optical domain



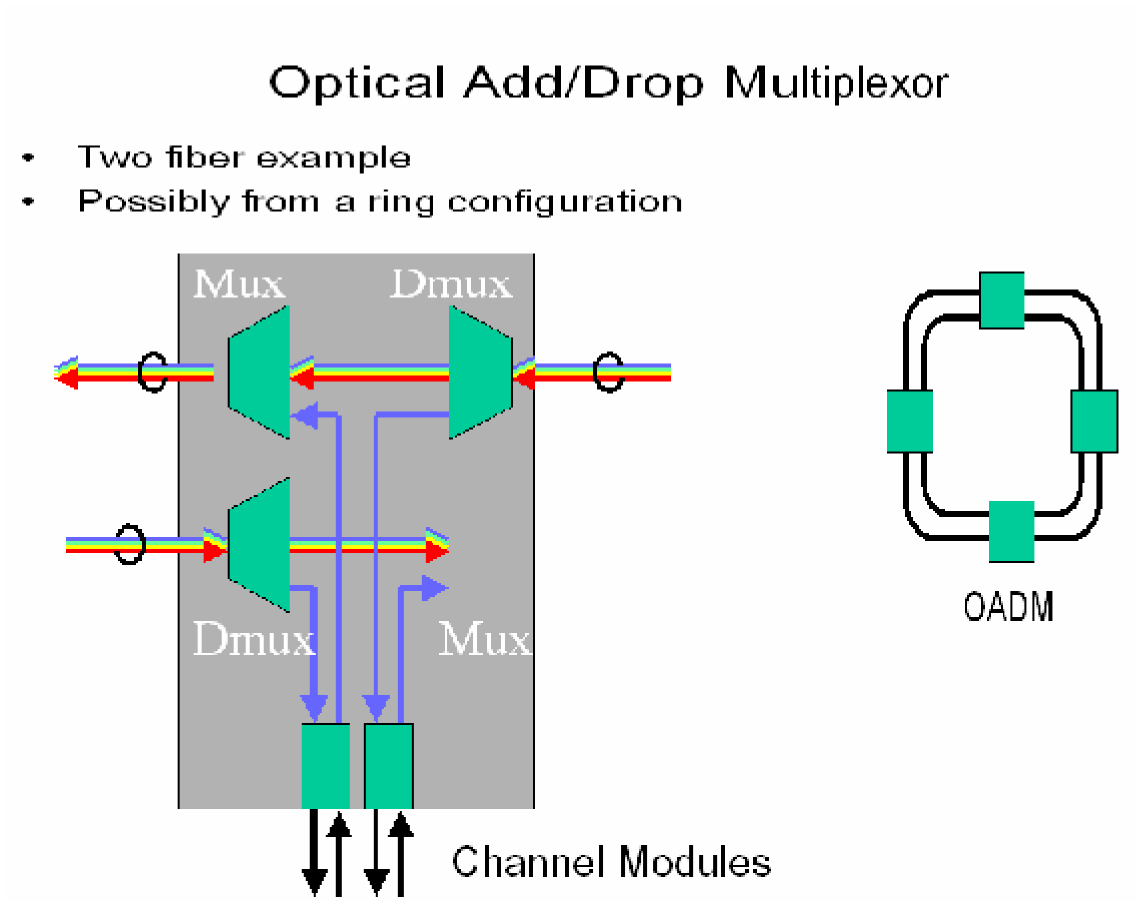
How a converter works

Multiplexing
Once the signal has been converted to the assigned λ, the next step is to multiplex it with other λ’s. Optical multiplexers combine multiple wavelengths onto a single fiber for transmission across the optical network to other WDM equipment. An optical demultiplexer at the receiving end is then used to separate the λ’s on the incoming multiplexed signal.



Optical Add/Drop Multiplexer (OADM)

The typical WDM system includes multiple nodes. However, not all of the wavelengths are necessarily destined for every node. It is possible to either add or separate a particular wavelength by using an optical add/drop mux (OADM). Use of an OADM avoids a demux/mux step of the entire spectrum being transmitted. The following diagram illustrates a simple OADM configuration:



Direction reference

The terms "east" and "west" are used to refer to directions of signal flow. Though their assignment in any particular case may appear to be arbitrary, the important point is that "east" on one piece of WDM equipment connects to "west" of the adjoining WDM box.

Fiber Optic Network Transport

In this section we build on the basics of fiber, wavelengths, and equipment and discuss transport issues to be considered with optical networks.

SONET and Ethernet are the two most common link layers being implemented in optical networks.

SONET (synchronous optical network) was and still is the transport protocol for telephony networks. SONET were developed to provide a highly reliable carrier class environment (outside the enterprise) with a digital hierarchy of payload (stream within streams, DS0, DS1, DS3…) with fault detection and automated recovery capability built in. One of the critical concerns when dealing with metro and long haul transport systems is the need for rapid fault detection, isolation and repair. The telephony providers were driven by severe penalty clauses to develop and install a transport protocol to run over a fiber optic infrastructure that existed for the circuit switched copper infrastructure.

The SONET protocol and related network management systems allow for a rapid isolation of where in the path a network loss or anomaly is present. This allows the carrier's outside plant support staff to rapidly send the repair crew to further diagnose the problem in the particular network element/s (Regeneration or ADM) of the fault-ridden segment.

It is worth while to digress a little to refresh on SONET 101, in that the path between two terminal equipment elements (i.e. where the signal is added and removed from the backbone.) is split into three constructs - the path, the line and the segment. The path is the circuit defined from end to end, i.e. from terminal equipment to terminal equipment. The line subdivides the path circuit into subsections from terminal equipment (ADM) to terminal equipment (ADM). And finally, the segment is the smallest unit of the circuit that cannot be subdivided between network elements. Or to put it in easier terms to visualize, if you have one or more regeneration units between terminal equipment elements (which could be an ADM or a Regenerator), then each subsection from terminal equipment to Regen or Regen-to-Regen is a segment. (Note: that the minimum number of segments in a line section is 2, and zero is invalid since a line can not equal a segment.)

The other nice attribute of SONET transport infrastructure was the design to automatically correct for faults. This recovery is accomplished by sensing a SONET path failure and the terminal equipment automatically rerouting the circuit to a reserved alternate path. The specification for this recovery is the well-known 50-millisecond time. This option does not exist for all SONET circuits but only for those that protection has been designed in.

The basic SONET protection scheme can be explained as follows. The designation for the normal path for the traffic flow is called the WORKING path and the emergency path has the designation of the PROTECT path, this is pretty self-explanatory. If the network designer must have 100% protection then a 1 for 1 scheme is used, one PROTECT circuit for every WORKING circuit. If the network designer believes that the traffic is critical but some down time is allowed (99.99% up time or 99.999% up time) for multiple failures then a 1 for N scheme is used, i.e. one PROTECT path for every N WORKING circuits.

SONET transport equipment can be arranged into two basic layouts; line mode or ring mode. In line mode the transport equipment is arranged in a point-to-point linear fashion. As with line mode the ring mode is just what one expects, terminal equipment arranged in a ring layout. The layouts are not interesting unless one looks at why someone would use the ring layout of transport equipment. The primary reason that carrier and providers deploy SONET ring systems is to guard against inadvertent construction damage. The backhoe is the most feared machine in the Carrier/Telco/Fiber industry. With a ring topology the network designer can provision a PROTECT circuit in the reverse path of the ring to minimize the possibility of a network outage. Unfortunately, there can also be the folded ring scenario, in which both forward and reverse fibers for the ring are in the same fiber jacket or conduit, in which case the backhoe wins.

Most Ethernet implementations today are fine for campus and limited Metro layouts in which the Ethernet fiber interfaces drive directly into dark fiber. When the Metro gets to be complex or the distance becomes large then the lack of SONET transport technology becomes a limitation to assurance of four or five nines for up time guarantee (i.e. 99.99% or 99.999%). There have been discussions of adding this type of fault management into the light paths that would interconnect the Ethernet elements for a Metro or WAN topology.

With the rapid increase in the use of light paths (Coarse or Dense Wave Division) the need for fault management is amplified (either SONET Transport overlay or SONET like such as Digital Wrappers, (ITU-T G.709).)

Data rates using these two types of fault management are comparable, with SONET at OC-192 and Ethernet at 10 Gb/s being the current high-end standard. Ethernet implementations are less expensive due to the lack of automated fault detection and fault recovery mechanisms. One option is to take advantage of both protocols by interfacing Ethernet to existing SONET infrastructure. There are various encapsulation techniques being investigated to support this (see http://www.commsdesign.com/design_corner/OEG20020418S0005).

Protection schemes

BLSR (Bi-directional Line-Switched Ring) and **UPSR** (Unidirectional Path-Switched Ring) are circuit protection schemes that are used in SONET and are also implemented in WDM systems. Both are based on a ring architecture, but each implements redundancy or protection in different ways.

More information is available at:
http://www.networkmagazine.com/article/NMG20020329S0010/3, and
http://www.onixmicrosystems.com/pdfs/fopn%20opt%20layer%20p&r.pdf.

BLSR -
Under normal operation, data travels around the ring in one direction. When a break occurs, the nodes on either side of the break detect the failure and reverse the direction of the signals around the ring and away from the disabled section.

UPSR -
Each WDM device sends two identical signals, to the east and west, on the ring. The destination node receives the same signal from west and east, compares the signals, and chooses the stronger of the two. In UPSR protection, the signals do not change their direction of travel around the ring. It's up to the destination node to select the signal with better quality.

RPR (Resilient Packet Ring see http://www.rpralliance.org/ for more information) is the emerging IEEE 802.17 standard for packet-based services provisioned over metro fiber rings. It supports native-rate Ethernet data interfaces such as 10/100Base-T, 100Base-FX and Gigabit Ethernet. It is intended to also support packet protocols other than Ethernet.

Ethernet in the LAN and WAN

Ethernet was developed as a LAN technology, however with the development of the 10GigE standard, Ethernet is moving into the WAN. The IEEE 802.3ae 10GigE standard, approved in June 2002, specifies 10GigE characteristics that enable it to be implemented in either the LAN or WAN. In both cases, the desire was to maintain compatibility with existing Ethernet. Refinements to the standard - **LAN PHY** and **WAN PHY** - were introduced.

A key consideration for the WAN PHY standard was to allow 10GigE to use existing SONET infrastructure. The WAN PHY differs from the LAN PHY by inclusion of a SONET/SDH framer for WAN PHY support. Because the data rates are close, a MAC (Media Access Control) implementation serves to interface LAN PHY at 10Gb/s to WAN PHY at ~9.6Gb/s. Much more detailed information is available on the 10 Gigabit Ethernet Alliance web site (http://www.10gea.org)

Future Topics

The following topics are also of importance to understanding optical networking technology and are intended for greater coverage in future versions of the Cookbook.

Enabling Protocols for **Optical Networks**, including more on the basics of routing and other network protocols as they relate to optical networks.
IP and Optical Networking Integration, covering issues surrounding the integration of the IP and the optical layers.
Emerging Technologies, including more on 10Gbps and 40 Gbps, also the evolution of optical systems and equipment (e.g., more on amplifiers --- Raman, EDFA, Silicon Optical, Tunable Lasers/filters, etc.)

Guidelines for Building Fiber Optic Cable Plant

Chapter Contents:

- Sources of Practical Information for Planning and Engineering
- Why Fiber Optic Infrastructure is Needed
- Major Steps for Planning and Building Fiber Optic Cable Plant
- Implementation, System Design and Management Tools
- Generic Cost Information for Fiber Optic Infrastructure
- Fiber Optic Cable Plant Quality Assurance Checklist
- Additional References and Sources

Sources of Practical Information for Planning and Engineering

There are numerous books on fiber optic technology, but relatively few that explain how to plan, design, and build fiber optic infrastructure. Some of the best sources are from BICSI, SCTE, RUS, standards organizations, and product manufacturers. For fiber optic infrastructure design, one needs to understand the capabilities of optical network interfaces by referring to manufacturer specifications. Cisco's web site is useful because they provide easy access to detailed specifications for a wide range of equipment types that the cable plant may need to support. There are additional sources of information from non-telecomm fields, such as electrical power, HVAC, Civil Engineering, GIS, construction, project management, and business that can help address the full scope of a project. An important objective for this document is to identify useful sources of practical information and knowledge. Useful references that you may wish to have close at hand are listed below. Many additional references are listed at the end of this chapter.

- BICSI *Customer-Owned Outside Plant Design Manual*
- BICSI *Telecommunications Distribution Methods Manual*
- BICSI *Telecommunications Cabling Installation*
- SCTE *Recommended Practices for Optical Fiber Construction and Testing*
- *USDA Rural Utilities Service telecomm publications from 7 CFR parts 1751, 1753, and 1755*
- ANSI/TIA/EIA-758 *Customer-Owned Outside Plant Telecommunications Cabling Standard*
- *Fiber Optic Cabling,* by Barry Elliott and Mike Gilmore
- *Fiber-Optic Systems for Telecommunications,* by Roger Freeman
- *Fiber Optic Installer's Field Manual,* by Bob Chomycz
- *Fiber Optics Technician's Manual,* by Jim Hayes
- *The Lineman's and Cableman's Handbook,* by Thomas Shoemaker and James Mack
- *Access Solutions Guide,* by Corning Cable Systems
- *Design Guide, Release 4,* by Corning Cable Systems
- Telecommunications standards from Telcordia, ITU, IEEE, ANSI, EIA, and TIA (see http://global.ihs.com/)

Why Fiber Optic Infrastructure is Needed

Many communities, cities, service providers, universities, and others need to build, or have built, fiber optic infrastructure to support network access and transport for economic development and to provide affordable high-speed services.

Fiber optic infrastructure is needed to support high-speed access and transport speeds that currently reach 10 gigabits per second and for higher speeds in the future. For outside plant, this typically requires the use of single-mode fiber. No other communications media can support the scalable speeds and capacity of single-mode fiber over the distances involved, so it is the most future proof communications media available.

In the past, telecomm and cable TV networks were built to meet the needs for delivering their particular services. These copper, "last mile," networks will not meet near future needs for delivering symmetrical 10/100/1000 Mbps and 10 Gbps services. Also, DSL and cable modems, while superior to dial-up, are inadequate for many applications today and will become less adequate over time. Communities wishing to position themselves to compete in the "Information Age" need access to high speed communications that are best delivered over fiber optic infrastructure. There are high-speed wireless and copper solutions, but they do not provide the scalable speeds and capacities of single-mode fiber optics.

Economic development funds may be better spent investing in an infrastructure that will last, as opposed to solutions that are short-lived. Since communications devices and protocols evolve and change, sufficient fiber should be installed from the premise to the network backbones to support whatever services and protocols are needed over the expected 20 year, or longer, life of the infrastructure.

Cost for local access and backbone networks that use the latest technologies is decreasing while speed and capacity are increasing. For example, some providers are delivering symmetrical access speeds from 100 megabit per second to a gigabit per second for less than $100/month. The cost of T1 lines (up to 1.5 Mbps) with Internet access in most areas is much more for much less (e.g., $1000 to $2000 per month). Unfortunately, many small business and residential users are relegated to low speed dial-up modem access and they will not be able to compete effectively in the "Information Age." Even if DSL and cable modem services are available in an area, they do not provide the speeds and capacities needed for many of today's applications, much less future applications.

For an in-depth discussion of technical and economic issues related to fiber optic infrastructure, see the well-researched and well-written book, *Optical Networks*, by Debra Cameron.

Major Steps for Planning and Building Fiber Optic Cable Plant

There are three major steps to planning and building fiber optic cable plant. First, put a project plan together along with all the details. Second, do what is needed to contract the work. Third, oversee the build-out.

Develop Project Plan

The first step is to put together all the details for the project plan. One needs to: define goals and objectives; determine locations, spaces, and intermediate access points for the fiber optic cables and associated equipment; plan to purchase, build, or lease, spaces if needed; plan cable routes and obtain permits and Right-of-Way agreements; specify the materials; estimate the budget. Since the infrastructure must be specified, documented, and maintained, a GIS and cable plant management system is needed. Also, determine what planning can be done in-house, or if some tasks need to be outsourced, such as determining the cable routes and getting permits and Right-of-Way agreements. Once the required work is fully defined, then one can either do the work, or find someone to do it.

Contract with Engineering and Construction Firm

The second major step is to contract with an engineering and construction firm to do any remaining planning and engineering. This could be divided into two separate steps with one firm doing the planning and engineering, and a second doing the construction work. If a competitive bid process is needed, then prepare an RFI and/or RFP and put it out for bids. If adequate preparation was done in step one, then most of the information needed for the bid request should be available. One sticky area may be defining and negotiating a contract. If the job is relatively simple, then it may be sufficient to get a few quotes and award to the selected bidder. The engineering/construction firm will need to document the cable route, the materials, and the work for project manager approval. Ideally, the preliminary engineering drawings and associated data bases would have been developed in step one so that the contractor can use them to continue the design and engineering work. After the work is complete, the computer drawings and geodatabases should become the as-built documentation. Next comes the fun part.

Build Cable Infrastructure

Finally, the contractor can start building. Hopefully, all the issues with permits and Rights-of-Ways were resolved so that there will be no further delays. Other considerations for the build may include procurement of materials by owner and/or contractor, safety, security, milestones, and quality of work. Do not wait until the job is done to check on the work, because it may be too late—"an ounce of prevention is worth a pound of cure." Quality assurance should start in step 1 and continue to the end. Any changes in the design should be documented in the GIS/Fiber Network Management system as they occur, so that when the job is done, all the documentation is up to date. If quality control is maintained throughout the build, then all that is left at the end is to make final checks and accept the work. The GIS/Fiber Plant Management System is needed to maintain the system documentation and for OAM&P (Operation, Administration, Maintenance, and Provisioning) after the build.

Implementation, System Design and Management Tools

The following introduction to outside plant management tools is provided by Advance Fiber Optics, Inc. (http://www.opsinsight.com), for inclusion in this Cookbook. While this section has a distinct commercial flavor to it, the concepts presented apply just as aptly to academic network initiatives.

Introduction

With the deregulation of telecommunications around the world, new providers appear on the scene daily, ready to offer voice, data, cable TV, and Internet services either faster or cheaper than incumbent providers. In an industry which would normally see two or three competitors, there are now hundreds vying for the customer's business, and in many cases these upstarts have constructed new telecommunications networks, mostly out of fiber optic cable, to meet the projected demand of customers in this new century.

This guidebook is intended to help you, the outside plant engineer, organize the records of your network, and put them into an electronic system that will archive all essential network assets, and provide a rapid means of locating faults and effecting preventative maintenance in order to keep you network running at peak performance.

Why You Need a System for Managing Your Network

For a telecommunications provider to remain competitive, it is imperative they perform a number of day-to-day activities to not only maintain the existing system, but plan to expand the network and introduce new technologies. These tasks also happen to be those that a Fiber Management System not only aids in executing, but in many cases completes the tasks in seconds where it now would take tens of minutes or even hours. Thus, for the tasks listed below, an FMS can save hundreds of man-hours per year.

Some specific examples…

1. Management of OSP Facilities
    - (3) System Capacity Accounting
    - (4) System Build Accounting
    - (5) Lease / Own Accounting
    - (6) Bandwidth Accounting

2. Maintenance of OSP Facilities
    - Cable Cut Restoration
    - Traffic Routing
    - Call Before You Dig
    - Ability to Locate Facilities
    - Equipment / Hardware Mortality Planning
    - Test Equipment Interfaces

- Technician’s General Understanding of the Network

3. Designing OSP Facilities
    - Protoyping and Analysis
    - Planning and Budgeting
    - Loss Estimation Analysis
    - Splice Cut Sheets

4. Planning OSP Facilities
    - Marketing Analysis
    - Sales Analysis

5. Customer Support
    - Trouble Ticket Management
    - Provisioning Support

6. Future Technology Analysis
    - WDM Studies
    - Polarization Maintaining Fiber Studies
    - Fiber-to-the-curb Studies
    - Erbium-Doped Fiber Amplifier (EDFA)

A central repository

A primary reason for implementing a system is to organize all of your network documentation – maps, engineering drawings, photos, documents, OTDR traces, etc. – into one archive so that you can actually find information about your network on demand. Currently, most providers have this information in paper form stuffed into filing cabinets, secured in binders, or maybe archived electronically in a few Excel spreadsheets. This makes these documents hard to locate, and even harder to relate to other data.

The more forward-thinking companies may actually have all of their CAD engineering drawings stored electronically and if they’re really looking ahead, their network mapped in a GIS system, such as MapInfo®, ArcInfo®, Intergraph®, and others.

However, even with maps and drawings archived on a server, there is absolutely no relationship between the maps, CAD, and any tabular data. In other words, the records are in disparate formats, and can only be retrieved by opening the application they are stored in. In any event, they are still difficult to retrieve, and difficult to relate to anything.

So, an electronic system which stores data and maps in a relational database, offers the ability to retrieve any information about the network – maps of fiber or copper routes, graphics of distribution panels, and data supporting every asset – on demand, and from different vantage points within the database (remember, its relational).

Day-to-day maintenance, operations and reporting

Having all of your network's information located in a single archive makes it possible to set up a schedule for daily operations and maintenance. An example of this could be the creation of a maintenance program as a result of failing equipment; say, a leaking splice enclosure. By identifying the faulty enclosure, the network administrator could perform queries on all enclosures, based on equipment type, or by manufacturer, or model, or install date, or by contractor. This would allow technicians to identify all enclosures specified by the query, and then establish a schedule to examine them for possible problems.

Additionally, reports on network growth (construction), fiber in service, fiber available, customer types, installed fiber and equipment in specific areas (for tax purposes), and a host of other needs can be easily and quickly performed.

Locating faults to minimize disasters

One of the most frustrating, and agonizing, tasks of managing a network is locating faults. While most networks have redundancy built in to prevent loss of service, the break in the fiber or copper cable must still be located and repaired as quickly as possible. The traditional method of finding a fault involves shooting the OTDR trace to obtain a distance to the break, then pulling out maps of the network and calculating, by the scale on each map, the distance to the fault. Multiple hours are generally required to accomplish this. However, with a fiber management system, the process is both faster and easier because:

- All data is in one location
- The data is also related
- You can identify the location from which the OTDR was shot, enter the distance into a fault locating field, and in a matter of seconds view the approximate location on an electronic map

Supporting documentation, such as maps, cable data, splice schematics at the nearest enclosure, and a report listing the customers that are on the affected fibers can be produced in just a few seconds. So by the time a fault is located the traditional way, it could be already repaired as a result of using a fiber management system.

Selling and distributing services to new customers

While aggressive sales folk provide the customers that support your company, they also provide many challenges to outside plant engineers by often "over" selling to prospects just outside of the service area. But you really can't blame them. They just need some tools to do their job. What's better is to empower them with data that offers a whole array of tools.

With a copy of your system on a laptop, a good salesman will be able to quickly identify potential customers within your service area. What's more, engineers can quickly find the fiber available for a new customer in a matter of minutes, and even plan routes to connect them to the network (see below).

Prototyping new routes

Engineering a new cable route, even when running a spur from the ring to a customer's location, can be an expensive proposition, especially when CAD drawing time costs are included. While fiber management systems aren't intended to provide the detail that CAD does, they can provide a nearly cost-free method for testing possible routes prior to actually engineering the build. And for budgeting, the prototype routes can be populated with equipment and materials to provide a complete picture of the upcoming build, and this can be given to the network designers to fully engineer.

What Needs to Be Documented

What you are trying to build is a virtual model of your network. And while "virtual" means an electronic facsimile, you are essentially mimicking every asset in your network: cable routes, equipment, splice enclosures, buildings, distribution frames--the works.

Of course, the amount of assets to be documented depends on how detailed you want your network model to be, and how your company intends to use the data. Most providers see a fiber management system database as a focal point for their entire business. In addition to serving the needs of outside plant engineers and maintenance, sales will use it to win new customers; marketing will leverage the data to expand your company's influence and market share. Accounting will want information for billing and tax purposes.

Conversely, a company might only require minimal data to run the system. Those items below that are marked with an asterisk (*) provide the minimum information required to establish a fiber management system. The rest are data categories necessary to create a complete outside plant fiber management database:

Cable Route Drawings

Cable Information
- The number of fibers in the cable*
- The cable type (manufacturer and model)
- Install year, company, and work order (if available)
- Reel info (reel number, test company, test year, optical length, physical length, attenuation) (if available)

Access Point Information (manholes, handholes, aerial splices or slack coil)
- Location (address, cross streets, placement, etc.)*
- Type/size
- Plate or cover markings

Splice Enclosure Information
- The access point where the enclosure is located*
- Closure type (manufacturer, model/part numbers, size, capacity, ports)
- Install year, company, and work order (if available)
- Splice key detail (what cables enter the enclosures and how are the fibers spliced)*

- Sequential numbers/markings (if available)

Building Information
- Location (street address, city, state, zip code, latitude/long coordinates)*
- Name*
- CLLI codes (if available)

Fiber Distribution Panels
- The building where the panel is located*
- The location of panel within the building (room, bay, shelf)
- The panel type (manufacturer, model number, panel layout, and connector type)
- Install year, company, and work order (if available)
- Termination key (what cables enter the panel and what jacks are the fibers terminated or spliced into)*
- Sequential numbers/markings (if available)

Equipment
- The building where the equipment is located*
- The location of equipment within the building (room bay, shelf, slot)
- Install year, company, and work order (if available)
- Type (OC-3, OC-12, etc.)
- Manufacturer, model number, and connector type
- OSP fibers connected to equipment*

Duct Information
- Conduit and type
- Innerduct
- The route of the duct/conduit
- The route of the innerduct

Pole Information
- The location of the pole
- The identification number
- The cables attached to the pole
- Cables of other providers and companies also attached to the pole

Customer Information
- Customer name
- Contact name and telephone number

Documents
- CAD drawings of routes
- CAD drawings of buildings (floor plans)
- Contracts, work orders, disaster recovery plans, etc.
- Photos
- Manufacturers' drawings
- Butterfly drawings of access point

A well-engineered software package will allow you to use it as a tool to catalogue your outside documents – CAD, photos, etc. – by location or equipment, making retrieval much easier and quicker.

How Data is Gathered and Input

While advances in computer technology have automated many business operations, the input of data is one that, for the most part, escapes it! While there are some functions that can be streamlined via simple utilities written to copy a field from one application to your fiber management software, for the most part it remains a very time-intensive, labor-intensive operation. Your company must be committed to creating a quality documentation system to ensure that time and manpower will be available to complete it.

Because of this time-consuming process, many companies decide to hire this out to a competent data conversion house.

The first task is to see what you already have.

Typically, telecom companies have:

- Maps of cable routes
- Splice schematics
- Lists of equipment, materials and customers/locations
- Specifications
- Terminations
- Fiber allocation
- Schematics of nodes and hubs, etc.

Most of this data will be in paper form – hard copies. However, some of it may in an electronic format such as Microsoft Excel®, or MapInfo® (mapping). Whatever the format, it has to be transferred from its present state to the proper editors in your fiber management system.
For those just initiating the construction process, this data can be gathered in the field during the build according to the requirements of the software. For example, our OSP InSight system comes with specially formatted worksheets in Microsoft Word® for documenting splice locations, termination locations, equipment, and poles.

Next, the data needs to be entered and verified in an orderly process. Here is what we recommend:

- Develop standards for all data. Decide on colors and line styles for drawing fiber routes. Create a naming/numbering standard for all network assets that all participants in the company will adhere to.
- Review the hard copy and electronic data first with engineering to verify accuracy

- You should create a "Data Input and Verification Report" sheet that accompanies the hard copy data in order to track and verify input progress and accuracy. Typically an engineer is responsible for this
- Input the data into your system. The person inputting the data should complete his or her section of the sheet in order to maintain a log for what data has been entered

- The engineer responsible should compare the hard copy data with that input into your system to verify accuracy. Remember, whatever goes in is what will come out when you need it most. And you don't want garbage going in…

Once the electronic data is verified, store the hard copies appropriately; NEVER destroy them.

Generic Cost Information for Fiber Optic Infrastructure

Information in this section is provided courtesy of RACO, Inc., Gretna, VA (Tel: 434-656-6676) for inclusion in this Cookbook. RACO provides cable plant engineering and construction services.

ENGINEERING---Basic Engineering Can Run From $6000 to $8000 per mile

Right of Way (ROW) selection and acquisition
Route design
Preparation of preliminary engineering drawings
DOT permit applications
Railroad crossing permit applications
Pole attachment agreement application
Preparation of as-builts

NOTE: If the engineering firm is required to prepare the overall bid package, assemble all the necessary forms and bid sheets, prepare specific definitions of all units, assemble completed bid packages, make multiple copies, conduct pre-bid conference, have an inspector on-site during construction, and then accept the project upon completion of construction, all of this can add **significantly** to the overall "per mile" fee.

AERIAL CONSTRUCTION ---$12,000 TO $15,000 PER MILE

Some of the variables involved in aerial construction include the price of strand, cable, and hardware.
One of the major cost variables will be how much pole "make-ready" work needs to be done in preparation for the additional cable, i.e., replacing poles, rearranging existing cable or power lines, Depending upon the county, city, or other entity with which you are dealing, this item can present a major "unexpected" expense.
It is critically important to know, as budgets are prepared for fiber optic infrastructure development, whether permission has been secured to attach to existing poles AND exactly what the costs will be.

BURIED CONSTRUCTION---$28,000 TO $32,000 PER MILE

Costs involved here can vary greatly depending upon how much "directional boring" will have to be done, whether the cable is buried by itself or placed in an innerduct, and the extent of rock conditions. Extensive rock can greatly inflate buried construction costs.

SPLICING

For a typical 40-mile project, with a combination of both aerial and buried construction, splicing costs can run from $90,000 to $110,000. This, of course, depends on the number of splices (and the number of fibers) called for in the engineering design.

CABLE/FIBER

Prices can vary significantly from supplier to supplier, depending greatly upon the fiber specifications, fiber count, and the total project footage.

MAJORS ISSUES TO ADDRESS

- Early identification of collaborators
- Pole attachment agreements
- Railroad crossing permits
- Land use permits from local DOT
- Clear understanding with local DOT what the project entails
- Clear understanding with local government officials as to the scope of the project
- Clear understanding between the owners and the general contractor as to timelines, expectations, quality of work, use of subcontractors, etc.
- Early identification of who can speak for and make decisions on behalf of the owner
- Development of a comprehensive construction, maintenance, and network management plan

Fiber Optic Cable Plant Quality Assurance Check List

This generic quality assurance check list is provided courtesy of Corning Cable Systems for inclusion in the Cookbook.

This section describes check lists for:

- Post Installation Inspection Overview
- Outside Plant (Aerial)
- Outside Plant (Duct Installation)
- Outside Plant (Direct Buried Installation)
- Inside Plant

At the beginning of each of the main sections that describe inspection guidelines for aerial, duct, direct buried, and inside plant, there are references listed that include Corning SRPs (Standard Recommended Procedures) applicable to the type of cable plant. The SRPs are available from Corning Cable Systems.

In addition to the references suggested by Corning, the following references are useful:

- BICSI Customer-Owned Outside Plant Design Manual
- BICSI Telecommunications Cabling Installation
- SCTE Recommended Practices for Optical Fiber Construction and Testing
- ANSI/TIA/EIA-758 Customer-Owned Outside Plant Telecommunications Cabling Standard
- USDA Rural Utilities Service telecommunication publications for 7 CFR parts 1751 and 1755

Post Installation Inspections:

Perform a visual inspection of the entire outside plant route, checking for any obvious problems, but additionally perform detailed inspections on randomly chosen sections and on all critical areas. The items to be checked will include:

Cable Bend Radius
Cable Location and Proper Clearance
Messenger Attachment
Bonding & Grounding
Drip Loops, Deadends, & Crossovers
Lashing; Splice Closures and Slack Storage
Ducts and Innerduct
Cable Exposure
Warning Signs
Documentation.

The inspection will be completely non-intrusive, meaning no sealed components will be opened for inspection.

Perform a thorough inspection of the Inside Plant optical network, checking for:

Cable Routing & Fire Safety
Hardware Installation
Rack Grounding
Splicing and Connectorization
Documentation
Testing

Finally, perform testing spot checks to validate the installer’s testing and to look for system connection errors such as cross-splicing.

At the completion of the inspection, provide a detailed Post Inspection Report, described below.

Specific inspection descriptions are below:

Quality Inspection of Outside Plant (Aerial)

References

Corning Cable Systems Standard Recommended Procedure SRP-005-010 “Fiber Optic Cable Placing – Lashed Aerial”

National Electrical Safety Code (NESC)

BICSI Telecommunications Distribution Methods Manual (TDMM)

Local Electrical Safety Codes (based on specific county or municipality)

Cable Bend Radius

Inspect Cable Bend Radius to ensure that manufacturer’s minimum cable bend radius is not violated at points where the cable turns (splice locations, pole transitions, slack storage, route direction changes that exceed 45 degrees, and transitions around installed equipment).

Inspection Frequency: 100% of slack loops, pole transitions, and direction changes exceeding 45 degrees shall be inspected.

Record/Report findings of compliance.

Cable Location and Proper Clearance

If the fiber optic cable is light in weight and its sag in aerial span is small, it should normally occupy the uppermost available communication space on the pole. (See SRP-005-010)

Inspect Cable Strand for proper minimum clearance from electric power lines and other cables that may sag near the fiber optic cable. Determine the clearance between the fiber optic cable and existing facilities, using an appropriate measuring rod or other means, and note whether clearance complies with the National Electric safety Code (NESC) and appropriate local safety codes.

This requirement applies to cable that is all-dielectric as well as that with metallic components, as there is always a risk of flashover (sparking) from a power line to the metallic messenger.

Inspection Frequency: 10% of pole spans shall be measured for clearance.

Record/Report findings of compliance.

Messenger Attachment

When the installation is a new build on a dedication messenger (i.e. not overlashed), verify the messenger Outer Diameter (OD).

Inspect the messenger for proper attachment to the pole, ensuring that standard hardware (eyebolts, clamps, etc.) are used.

Inspection Frequency: 10% of pole spans shall be inspected for correct messenger components.

Record/Report findings of compliance.

Bonding & Grounding

Inspect the installation for proper external grounding of all splice closures, to ensure the closure is grounded to the messenger.

Inspect installation of the messenger to ensure the messenger is connected to the pole ground.

No closures will be opened to determine whether the cable is properly attached to internal closure grounding components and whether the internal components are connected to external grounding components.

Inspection Frequency: 100% of closures shall be inspected for grounding to the messenger.

Record/Report findings of compliance.

Drip Loops, Deadends, and Crossovers

Ensure that drip loops are not used where optical cable is overlashed to existing coaxial cable, to prevent the possibility of the fiber optic drip loop migrating along the strand.

While this does not affect either cable plant reliability, or transmission quality, drip loop movement can detract from the overall appearance of the cable plant. (See SRP-005-010.)

When drip loops are not present, inspect pole crossings to ensure the cable will not rub against the three-bolt messenger suspension clamp. This can be accomplished by a larger spacer in the cable support strap or a split plastic tube surrounding the cable.

When drip loops are used, inspect the shape of the loop to ensure that it is the “smooth-curve” type. Under no circumstances should any other shapes be used. (See SRP-005-010 for proper dimensions and spacing).

When drip loops are used, inspect for straps and spacers (in the absence of lashing wire support) to support the cable, ensuring that they are installed at least 4 inches from the drip loop and are tight enough to prevent their movement along the strand while permitting longitudinal travel by the cable.

Inspect messenger intersections at deadends and aerial crossovers to ensure the optical cable is routed on the inside of the intersection.

Inspection Frequency: 10% of poles shall be inspected for drip loop compliance, and proper deadend/crossover routing.

Record/Report findings of compliance.

Lashing

Inspect lashing to ensure it is double-lashed when optical cable is installed over existing aerial cables or when cable is installed over railroads and roadways.

Inspect lashing to ensure that it is not loose, twisted, weaving, or unraveling along the strand.

Inspect lashing to ensure it has at least one wrap per linear foot, and is the correct size standard lashing wire for the cable and strand. (Actual spec depends upon stand and cable bundle OD).

Inspect lashing for proper termination at each pole with a lashing wire clamp, cable spacers, and a triple wrap around the messenger as it enters the clamp.

Inspection Frequency: 10% of pole spans shall be inspected for proper lashing and lashing termination.

Splice Closures and Slack Storage

Inspect splice closure locations to ensure that slack cable loops are stored at least 4 feet from the poles unless they are protected by a cable enclosure.

Inspect splice closures to ensure they are mounted to the strand per manufacturer's recommended procedures.

Inspect splice point slack to ensure enough slack remains to bring the closure to the ground and into a convenient work area, such as a tent or splice vehicle.

Inspect slack loops to ensure the cables do not exceed the recommended minimum bend radius.

Inspection Frequency: 100% of splice locations and slack storage locations shall be inspected for proper mounting and slack storage techniques.

Record/Report findings of compliance.

Documentation

Check installer's documentation to ensure it annotates the following:

- Exact location of all splice points.
- Sheath mark for at beginning and ending of every span, slack loops, and high risk intersections.
- Amount of slack stored in slack loops.

Inspection Frequency: 100% of splice locations, slack storage locations, and high risk intersections shall be inspected for proper documentation.

Record/Report findings of compliance.

Quality Inspection of Outside Plant (Duct Installation)

NOTE: All manholes and handholes are assumed to be readily accessible without pumping to see the components within.

References

Corning Cable Systems Standard Recommended Procedure SRP-005-011 "Fiber Optic Cable Placing – Duct"

National Electrical Safety Code (NESC)

BICSI Telecommunications Distribution Methods Manual (TDMM)

Local Electrical Safety Codes (based on specific county or municipality)

Cable Bend Radius

Inspect Cable Bend Radius to ensure that manufacturer's minimum cable bend radius is not violated at points where the cable turns (manholes, handholes, pull points, duct route, closure entries, transitions to aerial).

Inspection Frequency: 10% of manholes, handholes, pull points, pedestals, and storage locations for proper bend radius.

Record/Report findings of compliance.

Ducts and Innerducts

Inspect the duct or innerduct to ensure that the “fill ratio” does not exceed 50%.

Inspect continuous innerduct in manholes to ensure it is attached to racks without violation of cable bend radius and in accordance with locally prescribed standards.

Inspect that cable is covered by innerduct or split duct where innerduct is not continuous through a manhole (this includes places where innerduct is spliced together).

Inspection Frequency: 10% of manholes/handholes should be inspected for duct/innerduct requirements.

Record/Report findings of compliance.

Bonding & Grounding

Inspect the installation for proper external grounding of all splice closures, to ensure the closure is grounded to the manhole or handhole ground, and whether that ground is properly grounded.

No closures will be opened to determine whether the cable is properly attached to internal closure grounding components and whether the internal components are connected to external grounding components.

Inspection Frequency: 100% of closures shall be inspected for external grounding.

Record/Report findings of compliance.

Splice Closures and Slack Storage

Inspect splice point slack to ensure enough slack remains to bring the closure out of the manhole, handhole, or pedestal and into a convenient work area, such as a tent or splice vehicle.

Inspect slack loops to ensure the cables do not exceed the recommended minimum bend radii.

Inspection Frequency: 100% of splice locations and 10% of slack storage locations shall be inspected for slack storage techniques.

Record/Report findings of compliance.

Documentation

Check installer's documentation to ensure it annotates the exact location of all splice points.

Check installer's documentation to ensure it annotates the sheath mark at manholes, handholes, pull points, and pedestals and at every splice location.

Check installer's documentation to ensure it annotates the amount of slack stored in slack loops.

Inspection Frequency: 100% of splice locations shall be inspected for location and sheath marks. Spot check sheath mark and slack storage documentation for 10% of manholes, handholes, pull points, and pedestals.

Record/Report findings of compliance.

Quality Inspection of Outside Plant (Direct Buried Installation)

References

Corning Cable Systems Standard Recommended Procedure SRP-005-012 "Fiber Optic Cable Placing – Direct Buried"

National Electrical Safety Code (NESC)

BICSI Telecommunications Distribution Methods Manual (TDMM)

Local Electrical Safety Codes (based on specific county or municipality)

Cable Bend Radius

Inspect Cable Bend Radius to ensure that manufacturer's minimum cable bend radius is not violated at points where the cable turns (manholes, handholes, pull points, duct route, closure entries).

Inspection Frequency: 10% of manholes, handholes, pull points, pedestals, and storage locations for proper bend radius.

Record/Report findings of compliance.

Cable Exposure

Inspect that no cable is exposed along route.

Inspect that no cable is exposed at transition points, such as approaches to handholes, manholes, and poles.

Warning Signs

Cross-check installer's documentation to verify the actual location of buried optical cable warning signs are consistent with the documented locations.

Inspection Frequency: 10% of documented warning sign locations shall be physically verified.

Record/Report findings of compliance.

Documentation

Check installer's documentation to ensure it annotates the exact location of all splice points.

Check installer's documentation to ensure it annotates the sheath mark at manhole, handhole, pull point, and pedestal and at every splice location.

Check installer's documentation to ensure it annotates the amount of slack stored in slack loops.

Inspection Frequency: 100% of splice locations shall be inspected for location and sheath marks. Spot check sheath mark and slack storage documentation for 10% of manholes, handholes, pull points, and pedestals.

Record/Report findings of compliance.

Quality Inspection of Inside Plant

References

Corning Cable Systems Standard Recommended Procedure SRP-005-014 "Intrabuilding Installation of Corning Cable Systems Fiber Optic Cable"

National Electrical Safety Code (NESC)

BICSI Telecommunications Distribution Methods Manual (TDMM)

Local Electrical Safety Codes (based on specific county or municipality)

Cable Routing & Fire Safety

Inspect Cable Bend Radius to ensure that manufacturer's minimum cable bend radius is not violated at points where the cable turns (fiber entrance cabinets, duct entrances, hardware entrances, ladder racks, etc.).

Inspect cable routing to ensure the cable is not deformed, pinched, or otherwise compressed by other cables, securing straps, or sharp edges.

Inspect cable entrance to ensure that no more than 50’ of non-fire rated outside plant cable is routed within a building unless enclosed within a rigid metal conduit or EMT. Otherwise, the OSP cable must be transitioned to a flame-rated cable within 50’ of its entrance to the building. (See NESC Article 770-50)

Inspect all indoor cable to ensure that flame-rated cable is used solely within the confines of its rated application or a less restrictive application (for instance riser rated cable used in riser or general application only – not in a plenum environment).

Inspect the deployment of cables to ensure that they comply with all local codes and standards, in addition to the advisories of the National Electric Safety Code (NESC).

Inspection Frequency: 100% of inside plant cabling shall be inspected for compliance with fire & safety codes.

Record/Report findings of compliance.

Hardware Installation

Inspect that all hardware is properly mounted into frames per manufacturer’s recommendations.

Inspect each cable end to ensure the cable is properly strain-relieved to minimize risk to the fibers from accidental pulling on the cable or natural expansion/contraction effects.

Inspect each cable with rigid components (central members, rods, armor, etc.) to ensure the rigid components cannot damage the fibers in case of mechanical agitation or expansion/contraction effects.

Inspect each cable end to ensure it properly terminated per manufacturer’s recommended procedures for both the cable and the hardware to which it is attached.

Inspection Frequency: 100% of cable ends shall be inspected for compliance.

Record/Report findings of compliance.

Rack Grounding

Inspect that all fiber-related racks are properly grounded to the building ground.

Inspect that all hardware to which cable containing metallic components is mounted is properly grounded to the rack.

Inspection Frequency: 100% of cable ends shall be inspected for compliance.

Record/Report findings of compliance.

Splicing and Connectorization

Spot check fiber splice trays to ensure that manufacturer's recommended procedures have been followed (securing of splices, splice protection, routing of fibers, securing of tubes, etc.)

Spot check optical connectors to ensure that connectors have been installed per manufacturer's recommended procedures, checking for proper assembly, excess epoxy, security of boot, attachment to aramid yarns (if applicable), etc.

Inspect each connector installed into an adapter to ensure the connector is properly seated and that the fiber is not under tension or in violation of bend radius limitations.

Inspection Frequency: 10% of splice trays and connectors shall be inspected for compliance with manufacturer's installation guidance. 100% of connectors shall be checked for fiber tension.

Record/Report findings of compliance.

Documentation

Inspect hardware labels to ensure they have been marked with the proper usage labeling. Spot check to determine accuracy of labels.

Inspection Frequency: 10% of labels shall be spot checked for accuracy.

Testing

Perform spot checks to verify installer's system testing, including OTDR tests and End to End Attenuation testing.

Perform OTDR Tests on 10% of available fibers to compare to installer's test results. Although fibers should be chosen randomly in general, the selected set should include commonly cross-spliced fiber and tube colors (Brown, Orange, Red, Blue and Aqua).

Perform OTDR tests on all unterminated fibers, if the installer did not record OTDR traces on these fibers after installation.

Perform End-to-End Attenuation testing on 10% of terminated and unterminated fibers, to compare to installer's test results and ensure system operability.

Report all findings outlining contractor test results and verification results. Highlight non-compliant test results.

Post Inspection Report

Provide a detailed report to the customer on the findings of the inspection. The report shall consist of a listing of all sections chosen for inspection and any discrepancies or concerns noted at that location. Discrepancies will carry a notation as to the severity of the issue and whether it requires any corrective action.

Additionally, recommend a corrective action to remedy any discrepancies that require action for system performance or long-term reliability.

This report shall be provided to the customer within 5 business days following completion of the inspection.

Any discrepancies which constitute safety violations or pose an immediate threat to the operational system shall be identified to the customer as soon as possible after they are discovered, without waiting for the formal report to be issued.

Corrected deficiencies should be re-inspected and a final inspection report issues after all discrepancies have been corrected and re-inspected.

Additional References and Sources

Knowing where to look up information needed for planning, engineering, and building fiber optic cable plant can be valuable. Some of the references given in this section provide pointers to additional lists of references. This list is somewhat unique in that it attempts to cover the full scope of issues relevant to building fiber optic infrastructure.

This section includes the following categories of references:

- Practical References for Cable Plant Design and Engineering--these are listed first due to their primary importance for the Cookbook
- Optical Network Technology and Applications—these provide tutorial level coverage of technologies, vendors, applications, business issues, and political issues related to deploying fiber optic infrastructure
- Fiber Optic Network Technology and Theory—these provide more in-depth coverage of the technology
- GIS (Geographic Information Systems)
- Civil Engineering
- Writing RFPs and Grant Requests
- Construction Project Management, Contracts, and Cost Estimation
- Providing Services
- Organizations for Codes, Standards, Guidelines and Practices
- Manufacturers of Optical Fibers for MANs and WANs
- Manufacturers of Fiber Optic Cables
- Manufacturers of Components and Accessories
- Suppliers
- Periodicals and Magazines
- Studies and Reports on High-speed Infrastructure Deployment
- Market Research Organizations

Practical References for Cable Plant Design and Engineering

The BICSI manuals may well be the best single source of outside cable plant design and engineering information available. Some of their publications are available in both hard-copy and CDROM formats. The other sources listed below are also useful.

Customer-Owned Outside Plant Design Manual, 2^{nd} Ed., BICSI, 2001.

Telecommunications Distribution Methods Manual, 9^{th} Ed., BICSI, 2000.

BICSI *Telecommunications Cabling Installation*, 2^{nd} Ed., McGraw-Hill, 2002.

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Optical Network Technology and Applications

Note: There is worthwhile information in Debra Cameron's book for beginners, experts, and everyone in between.

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- Building Industry Consulting Service International (BICSI)
- Electronic Industries Alliance (EIA)
- Telecommunications Industry Association (TIA)
- Institute of Electrical and Electronics Engineers (IEEE)
- Insulated Cable Engineers Association (ICEA)
- International Standards Organization (ISO)
- International Telecommunications Union (ITU)
- National Electric Code (NEC)
- National Electric Safety Code (NESC)
- National Fire Protection Association (NFPA)
- Occupational Safety and Health Administration (OSHA)
- Society of Cable Telecommunications Engineers (SCTE)
- Telcordia
- USDA Rural Utilities Service (RUS)

Manufacturers of Optical Fibers for MANs and WANs

- Alcatel
- Corning Optical Fiber
- Fujikura Electric
- OFS/ Furakawa Electric
- Pirelli
- Sumitomo Electric

Manufacturers of Fiber Optic Cables

- Alcatel
- AFL Telecommunications (Alcoa Fujikura Limited)
- Belden Wire & Cable
- Chromatic Technologies
- CommScope
- Corning Cable Systems
- General Cable (BICCGeneral)
- Hitachi Cable Manchester
- Nexans/Berk-Tek
- OFS (Fitel/Furakawa Electric)
- Optical Cable Corporation
- Pirelli
- Remee Products
- Sumitomo Electric
- Superior Essex

Manufacturers of Components & Accessories (expand)

- 3M
- ADC Telecommunications
- AFL Telecommunications
- Corning Cable Systems
- Leviton
- Nexans/Berk-Tek
- Ortronics
- Pirelli
- Tyco Electronics/AMP

Suppliers (expand)

- Anixter
- GE Supply
- Graybar
- Power & Telephone Supply
- Teltek Sales, Inc.

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- LightWave

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Optical Networking Implementation Examples

Previous sections have provided insight to technology and guiding tools for optical networking implementations. This section attempts to highlight some implementation examples of optical networking. Please also recognize that this is not an exhaustive listing. This should be a dynamic and organic amalgamation of examples that we hope will become a growing collection of useful examples. Ultimately, such a collegial effort of input and dissemination could lead to many other possibilities such as a directory of collegial support, best practices in implementation considerations or negotiations, or even considerable expansion to include business case development and studies. The notion of business case studies could also be developed for academic purposes in educating communities of learners in traditional curriculums via case studies.

By presenting overviews of various implementations, it is desired that one may discover valuable insight to critical success factors, development issues, potential pitfalls, and unpredictable events that lead to creative optical networking implementations. By reviewing these implementations, one might also gain glimpses into the innovative thinking processes of recognized optical networking architects.

While there are many facets to optical networking, implementations may be viewed in three primary dimensions; physical, geographic and organizational. The table provides a simple perspective on these dimensions.

Physical	**Geographic**	**Organizational**
Dark Fiber	Local/Campus/Metro	Institution
Wavelengths	Regional/State	Communities/Affiliations
Services	National/International	Municipal/Government

It is often difficult to clearly delineate the implementations presented into the specific categories above. One overwhelming theme that is observed in optical networking design and implementations appears to be flexibility. Very often an architect or organization starts out to do one thing and discovers through a variety of circumstances that a completely different or a blended approach may be the best solution. The circumstances may encompass factors such as pricing, market forces, shifting needs, growth requirements, economic opportunities, new or shared partnering interests, or dominant organizational behavior. Regardless of the driving factors, it appears important to recognize culture, maintain an opportunistic attitude, and be willing to explore innovative ideas throughout the process. The implementations listed below are valuable examples of the success of this approach and will be discussed in greater detail in the sections below.

Oak Ridge National Laboratory - Regional high-speed wavelengths to Atlanta
This is an example of investigating multiple options and discovering opportunities that differed from initial assumptions. This implementation yields flexibility to add wavelengths over time below initial startup unit costs.

Harvard Joint Trench Project
This example of a local/metro fiber build utilizes dark fiber built through trenching, conduits and creative partnerships to create a three-mile run from a campus through a city to a major carrier hotel. The project had to navigate complexity of rights of way, licensing to open city streets, and interesting relationships.

NCREN3: North Carolina Research & Education Network
This illustrates state-wide networking with a series of Regional Points of Presence (RpoP) to create a new level of performance, reliability, capacity, services, and effective cost sharing. While the activity is targeted at specific objectives, optical networking plays a strong role in the implementation. The wide-area backbone utilizes unprotected wavelengths and Spatial Reuse Protocol (SRP) to create a backbone ring. The activity encourages local communities of interest to implement creative last mile implementations and dark fiber in the last mile where possible.

Virginia Tech E-Corridor
This example details a statewide program to serve as a catalyst for the deployment of affordable access to fiber optic network infrastructure. Utilizing a strategy to provide knowledge and specifications to communities, this program strives to develop a new approach to networking on a local and regional scale. Among other things, this approach leverages combinations of optical and wireless broadband, efficient construction methods, current infrastructure, and innovative organizational and market structures. By aggregating the needs and assets of communities, the program is able to leverage municipally-owned resources, such as rights of way and other utilities infrastructure.

Southern Crossroads (SoX)
This metro dark fiber implementation increases capacity and lowers prices to move a connection from Georgia Institute of Technology into a carrier hotel in downtown Atlanta.

Grant County Washington PUD
Beginning abstract: 2000 homes with 12,000 strand miles and targeting all with over 40,000 additional strand miles. Largest fiber to the home project in the world (self-proclaimed)… www.gcpud.org/zipp/news.htm)

Oak Ridge National Laboratory -
Regional high-speed wavelengths to Atlanta

Contact: Bill Wing, wrw@ornl.gov

What we set out to do -

For a variety of reasons outside of the scope of this document, it was decided that a high-speed (OC192) "local loop" to Atlanta was a requirement for developing future research opportunities in a number of fields. Equally important, we wanted this local loop to be the first step in an ability to add additional channels of OC192 connectivity.

How we approached the problem -

Our initial contacts with several potential vendors produced more or less the same reaction, that they would be delighted to quote us a price from their standard rate book, and "oh by the way - you qualify for this wonderful GSA discount." In general, these initial conversations yielded modest pricing discounts at best. We felt the pricing model at this point was simply market-price minus a discount and we wanted to pursue equipment-cost plus a profit as being more appropriate to our needs.

We decided to pursue a dark fiber solution, and located two sources willing to supply dark fiber to us on a short-term lease (three years, with two optional one-year extensions). One source could get
us from our reservation to Chattanooga, the second could get us from Chattanooga to downtown Atlanta. Each distance is roughly 110 miles. Both suppliers had pre-existing huts, co-location space, and in both cases were willing to provide maintenance services for the fiber and for hands-on work in huts or the co-location space. Pre-existing huts, co-location space and maintenance services were all important to us in consideration of capital, implementation and maintenance costs. The two suppliers are both slightly unusual, special cases.

The supplier in Tennessee (KDL, Kentucky Data Link) had installed a fiber sheath for Qwest as part of a contract Qwest holds to supply transport services to the Department of Energy. Part of the agreement between Qwest and KDL is a restriction on KDL's ability to sell or lease fiber in that sheath to a Qwest competitor. Thus, KDL can lease fiber to us, but not to a Qwest competitor, for example, Level(3). Short of installing 100 miles of new fiber, that sheath contains some of the only fiber that clears the reservation. Because there are not many providers who clear the reservation, pricing and competition is somewhat limited as described in the initial experience listed above regarding initial pricing responses.

The supplier in Georgia was GPW (Georgia Public Web), a subsidiary of MEAG, the Metropolitan Electric Authority of Georgia, they are both a CLEC and an IRS 501-c3 "not-for-profit" public organization. The pricing from these two organizations was very different. The price from KDL worked out to roughly $25k per month, the price from GPW came in at $10k per month.

In parallel, we were accepting bids from CISCO, ONI, Juniper, and others for the gear (DWDM, Intermediate Light Amplifiers (ILAs), and Routers) required to light this fiber and get traffic onto and off-of it The lease prices for this gear were converging toward $45 - 50k per month. The total price for the project was rapidly converging to $80-85k per month in total operating costs. This project pricing is roughly equivalent to the initial price offerings for only a 20 mile connection to the University of Tennessee in Knoxville. Our efforts and creativity seemed confirmed at this stage.

In parallel, with this, we continued negotiations with Qwest, pointing out at successively higher levels in their organization why this network connection would be strategic for them as well as for us (also outside the scope of this document).

Final solution -

The "strategic" issue finally reached the right set of ears in Qwest. Their approach to pricing, and the prices they were quoting changed dramatically. Our final contract with them for Q-Wave service at OC192 worked out to $750k up front and $35k per month recurring for the life of the contract. The contract is assumed to be five years, although it is still written as 3 + 1 + 1. The contract includes two Juniper M160 routers to funnel traffic on-to and off-of the network. It was also critical to us that we have growth options and those options are cost effective. Consequently, not only did we wind up with an exciting and cost effective solution, but the contract is structured in such a way that we can add additional lambdas (quantity-one) for even more attractive prices; Approximately $500k up front and $50k per year - yes that's $50k/year with on-going maintenance. Negotiations are on-going for bulk pricing (that is pricing for as much as 12 lambdas at one time). We believe the pricing at that point will be significantly less again.

Harvard Joint Trench Project

Contact: Leo Donnelly, Leo_Donnelly@Harvard.edu

Executive Summary

A Joint Trench Project can be defined as a consortium of participants who agree to share the costs of a construction build to install facilities, usually in the public right of way. Facilities can be defined as sewer, water, gas, or telecommunications infrastructure including the conduit and manholes. The coordinating of planning and construction is typically done by a "lead vendor" in the project. Municipalities across the country are beginning to look at this method rather than handling individual requests to open the public right of way.

Once a vendor seeks approval and permit to open the right of way, municipalities are seeking any additional public or private entities who may wish to install facilities along the path of the proposed Joint Trench. This is done by public notice in some municipalities. Once complete and street preservation has occurred the municipalities usually impose a moratorium on the opening of the resurfaced roadway. This time frame is typically 3 – 5 years.

In many municipalities, particularly within major metropolitan areas there is a limited amount of space available in the public right of way and cities are encouraging the Joint Trench model to coordinate future infrastructure projects and to reduce the requests to open the cities streets.

Introduction

The City of Cambridge, Massachusetts proffered a Joint Trench Project due to the fact that numerous companies were trying to build conduit throughout the City. The City chose to nominate a "Lead Vendor" for the project that would then coordinate with other vendors and private enterprises that wished to participate in the build. This method provided efficiencies for both the City and the build participants. Harvard University regularly attends the pole and conduit meetings in the City of Cambridge and when the project was announced, we declared our intention to participate. The project represented an extensive build by a carrier through the Cambridge and Boston metropolitan areas.

The segments of interest to Harvard entailed opening three miles of city streets to run conduit to one of the carrier neutral collocation facilities in Cambridge. The project encompassed installing up to fifty-six 4" conduits in some sections of the build. Harvard purchased 1 ¼" conduit within a 4" conduit along the segments we were interested in. Additional laterals were engineered at our expense to tie into the carrier manhole from Harvard property to access our conduit.

Lead Company

The lead company responsibilities include interfacing with the cities and towns involved to secure the necessary permits, and provide the engineering drawings required for the proposed path. The lead company also provides the estimated costs to the Joint Trench participants, holds regular meetings to update the participants, and handles all billing to the participants. It's not uncommon for the municipality to reject a proposed path and will ask the lead vendor to present new engineering drawings on an alternative path. It is the joint trench participant's responsibility through the lead vendor to propose the path, not the municipality. Some municipalities may provide more guidance or even suggest the path.

Joint Trench Agreement

The lead vendor will require a signed agreement with the participants, which will specify the terms and conditions, the participant's percentage of participation (i.e., one or four conduits), and the estimated costs associated with the build. The agreements will also include provisions specifying that all costs are estimates and may vary depending on a number of factors including the final approved path of the build, street preservation, etc. Proposed engineering drawings of the proposed path should also be part of the agreement as an attachment. Educational institutions unfamiliar with these types of agreements should seek legal advice from their Office of General Counsel. It is also prudent to seek outside counsel with a firm that has experience in Telecommunications contracts.

Participant in the Joint Trench Project

The participant in the joint trench project should understand their objectives by participating, their one time construction costs, and the recurring operational and maintenance costs associated with those objectives. Unlike campus conduit and fiber assets, the assets acquired as part of the Joint Trench Project are in the public right of way and require set procedures for accessing the manholes. This can include police details, notifying the lead vendor or their agent and the lead vendor may require they or they're agent perform all work in the manholes along the public right of way.

Cost Allocations

Cost allocations are done with a weighted divide by N model. For example, if there are 56 conduits being placed and 18 participants then N=18. Each participant however may purchase different amounts of conduit. 1 participant buys 10 another 5, another 20, etc., A participants percentage of the overall costs is greater with 20 conduits than a participant purchasing 1-1 ¼" inch conduit with a 4" conduit. Consequently each participant's share of the ongoing operational and maintenance costs are also divided among the participants using the same method - their percentage of participation in the build.

This works to the advantage of all participants, since no single participant could afford the cost of the entire build. It allows an individual participant to increase the number of conduits they may purchase given the cost sharing arrangement.

Additional Costs

The lead vendor will charge a management fee for the project management associated with doing the build. This fee is typically 5% and billed along with the construction costs for each segment. This does not include the engineering costs associated with planning the proposed path of the build.

Co-location Costs

The additional costs of fiber builds that end in a carrier or vendor neutral (owned by a landlord and not a commercial carrier) facility can include a number of additional ongoing fees and non-recurring costs.

Note: These fees are all negotiable.

- Rack
  Leasing a rack within a co-location space can range from $800 to $1,600 per month and typically comes with a power budget of between 20-30amps. Power requirements beyond the 30amps are an additional charge.

- Cross-Connects
  Cross-connect fees within a co-location space can run between $100 - $500 per month. Typically this is a fiber jumper from a meet me location within the facility to your rack.

- Building Entry Costs
  Pulling conduit into a co-location space usually has an associated building entry fee. This is a one-time fee and can range from $5,000 to $30,000 depending on the facility.

- Neutral Cross-Connects Permitted
  If the build ends in a carriers facility and your leasing rack space within that facility insure in contract that neutral cross-connects are permitted. This means that although your leasing a rack from carrier "A" you can cross-connect to carrier "B" that also leases space within the same facility.

- Fiber Termination Costs
  The cost of terminating a large fiber cable in a co-location facility can be an unexpected cost for a large cable. Termination can range from $200 - $500 per strand end. Multiply this by a 288-fiber strand cable and it's a significant one-time expense.

Risk Assessment and Mitigation

It's possible given contention in some parts of the right of way that the participants may have to reduce the number of total conduits in the build in order to place the conduit within that particular part of the right of way. If a participant is purchasing four conduits can they get by with two?

If one or two participants in the Joint Trench Project drop out and the costs are re-allocated among the remaining participants can you absorb the cost increase? The Joint Trench agreement should outline the participants and their percentage of the overall project and each participant's costs. Given these numbers you can and should calculate the costs based on two or more participants dropping out of the project to assess your risk. If you're a small percentage of the overall build this provides some risk mitigation. The participants with the larger percentages of the project will bear the greater burden should participants drop out of the project.

These projects can run into many types of delays. Northern municipalities may have moratoriums on street openings, typically between November and March. A proposed path for the build may not be approved and a new path will need to be engineered. Once the path is approved and the street opened utilities may have to be replaced. Much of this can be anticipated with proper planning and engineering, but typically these projects take longer than anticipated.

Title/Ownership

Once the Joint Trench construction is complete and all costs have been paid to the lead vendor, the lead vendor will provide a letter stating the build is complete and the conduit is available to have fiber pulled. The participant should make sure they have all of the final engineering drawings for the build and include them in University GIS systems if available. At this time the lead vendor and the Joint Trench participants should have agreed on the ongoing operational procedures and costs.

On-going Operations and Maintenance

The cost does not end when the title is in hand. There are ongoing operations and maintenance expenses associated with the build. These tend not to be excessive and when assigned as part of a joint build agreement are shared among the "participants" on the same weighted divide by N model as the original build. These fees do not include any charges levied by the municipality for the use of the right of way.

Working with City/Town Government

- **Street Preservation Offset Fees (SPOF Fees)**

  Most major metropolitan cities and towns have established guidelines for the collection of fees associated with street openings. These can include permit applications, permit fees, dig safe, police detail costs, and street preservation offset fees. These fees and the algorithms used to calculate them can vary greatly between cities and towns and for larger projects can sometimes be negotiated. You can find yourself paying for things not anticipated including streetlights, sidewalks, and paving of the roadway to restore it after the build.

  The "Lead Vendor" or engineering firm hired by the Lead Vendor should outline all the anticipated costs including the ones in this section. This estimated fees should also include the ongoing fees charged by the city or town for the use of the right of way.

- **Pole & Conduit Commissions/Department of Public Works**

  Larger Universities may have Wire & Cable groups on campus that work with the local government's pole & conduit commissions. These may be part of the Department of Public Works, the Cable Commission etc. It varies from city to city. It is always in the best interest of the "Participant" to be familiar with the local government's requirements, whose attending those meetings, and more importantly what infrastructure are commercial carriers, cable companies, and other private or public entities proposing or building. Joint Trench Projects offer the opportunity to secure infrastructure to off-site locations and carrier facilities using a cost-sharing model that makes the project financially feasible to an individual participant.

NCREN3: An Option for the Future

Contact: Mark Johnson, MJ@NCREN.NET

Executive Summary

NCREN3 is a concept and planning proposal for a next generation networking architecture to address the emerging requirements for transforming higher education to meet the challenges of our twenty-first century society - it represents a beginning point and an evolution path, not an end point. To succeed NCREN3 must evolve and the evolutionary process must take place in the context of a larger worldview. While the NCREN3 proposal could stand-alone as a separate network, it is envisioned that it will evolve in collaboration with other networking initiatives to better serve the networking requirements of North Carolina's educational and governmental entities.

NCREN3 is based upon the following guiding principles:

- Meet the rapidly escalating demand for reliable and dependable network services and capabilities
- Exploit the value of collaborative development activities and sharing of resources
- Significantly expand the set of users to include all of education and government
- Coordinate and leverage existing network resources, capabilities and personnel
- Provide flexibility for regional variability and management

NCREN3 initiates a distributed architecture based upon Regional Points of Presence (RPoPs) that allow North Carolina's Universities, Community Colleges, Schools, as well as state and local governments, to share and leverage facilities, networks, and expertise. Co-location, shared facilities and circuits will meet both individual communities needs *and* state networking needs. Each community will develop their own networking requirements but will plan the physical networks in collaboration with other communities. It is anticipated that each community will bring strengths and resources to the statewide effort.

The current NCREN community, which includes the UNC system schools, Duke, and Wake Forest, have identified current requirements for increased bandwidth, very high levels of network redundancy and resiliency, and extensions beyond its intercampus boundaries. NCREN3 will be implemented in phases and upon its completion, will provide these and other emerging network requirements for its users. The design also takes into account the need for all members of the education community to interact and therefore includes accommodations for creating a K-20 networking environment.

The concept and design of NCREN3 creates a number of advantages and capabilities:

- Regional networks are an effective way for organizations to share knowledge and resources
- Provides the opportunity to share expensive, long-haul telecommunications costs
- The distributed model allows organizations to share the funding of network personnel
- Fosters a focus on providing service to a more diverse user base
- Distance and distributed learning can work more effectively across communities
- Regional operators and communities will have the ability to negotiate arrangements and services to meet local needs

- Regional networking is the only way to extend advanced Internet technologies (like Internet2 and Abilene) to the larger education community

NCREN3: Rationale

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Why are we planning NCREN3?

Just about everyone has come to understand that the Internet has revolutionized the way we live, learn, work and play. When you connect to the Internet today, whether from your home, office, car or cell phone, you have access to resources, people, governments, businesses, schools and institutions of higher learning from around the corner to around the world (see Attachment 1). One marvels at how this comprehensive and far-reaching network evolved in less than a decade. When did this enormous global planning begin? From where did the funding for such a huge initiative come? The answers are founded in the very nature of what the Internet is all about. The Internet is not a single network, but a community of thousands of interconnected networks and computers (initially created by the higher education research community and the federal government), designed to inter-operate and to provide access to public and private resources.

Each one of the networks began with a focus on serving a particular audience or organization. Each one developed around a set of standards and applications that would allow it to expand and extend and meet the needs of its community. Each network was designed to meet local needs while providing for flexibility and adaptability. And, once these thousands of networks became interconnected, it became what is now known as the Internet. And these networks are still continuously evolving to deliver new services, new applications, more security and privacy as well as greater capabilities. NCREN is an important member of this community and NCREN3 represents the next iteration of network planning for the research and education community in North Carolina. It is also important to note that universities need advanced and high performance networks in order to stay competitive, and NCREN3 has been designed to provide that competitive edge in high performance networking. The design also takes into account the need for all of members of the education community to share resources and interact with each other, and therefore includes accommodations for K-20 networking.

Networks have become critical to sustaining and advancing educational, governmental and private sector enterprise. The networks have become so critical in fact, that economic and operational success is increasingly dependent on the quality of network access and the ability to deploy and use innovative network applications and services. Many factors have contributed to the global success of the Triangle and the state, including an established technology industry base. The factors include the state's early and visionary embrace of information technology; being located on a major north-south fiber corridor; and the intellectual capital creation and application of its research universities. Today the technology industries identify the lack of technically skilled workers as their greatest business impediment, and point out that economic resources increasingly flow to areas that can best create and attract a strong technical workforce. Higher education is clearly a key factor in the economic development equation.

Networking requirements vary across the higher education spectrum but typically exhibit considerable uniqueness stemming from the propensity toward experimentation and early adoption. This characterization is particularly pronounced for research extensive universities focused in the science, technology, and/or engineering areas. For higher education institutions, networking is much more than a utility - it is an integral and integrated part of teaching, learning, and research. In this context, resident expertise, open access, freedom of innovation, architectural flexibility, open collaboration, and competitive differentiation, are essential to meeting core mission objectives as well as larger economic development expectations.

North Carolina Schools and Community Colleges are developing networking requirements for learning applications and interactive distance learning environments and as such, have similar requirements as those for higher education. Now is the time to plan how the education community in North Carolina moves its teaching and learning capacity forward using networks to bring our students, teachers, professors and researchers together, all over the state. Indeed, only an integrated K-20 network will be able to meet the rapidly growing needs of these institutions and provide equal access to all the citizens of North Carolina.

K-12 Schools, Community Colleges, and other public sector organizations such as State Government, are also constantly evolving and working on the next iteration network needs of their communities as well. And, since all these networks are critical for sustaining and advancing all aspects of education, government and research, it is essential that each community continue to focus on their needs. Thus, NCREN3 continues to focus on University needs just as other groups (State Government, K-12, Community Colleges, Administrative Office of the Courts, Rural Internet Initiative, etc) address the needs of their respective communities. As these communities continue to focus on their particular networking requirements, they will develop their future networks based upon common planning and design criteria so that their efforts can be leveraged and interoperability can be maintained. To that end, NCREN3 initiates a distributed architecture that allows the other educational systems, state and local governments co-location and shared facilities that will meet the needs of individual user communities and statewide networking needs. And, since NCREN3 is a key partner of the NC Net Planning effort, the distributed architecture and approach to networking will be able to be leveraged by the entire K-20 community as well as State Government.

Where are we today?

Starting in 1983, the university community has been developing a network infrastructure to support their research and education needs, and it is now called the North Carolina Research and Education Network (NCREN). It physically consists of a variety of leased telecommunication lines, equipment, network services, applications and Internet access co-managed by MCNC and the Universities. Within the last several years, the country's large research universities decided that new advancements in the science of networking and the use of networking in science could no longer be done over the Internet. So, a group of these universities started Internet2 – a separate network dedicated to this research. The member universities created an organization, University Corporation for Advanced Internet Development (UCAID) to work with industry and the federal government for advanced research and funding. Currently, 5 universities in North Carolina are members of UCAID (Duke, East Carolina, NC State, UNC-Chapel Hill and Wake Forest Universities), and MCNC and UNC-General Administration are affiliate members. It is also important to note that as of October 2000, UCAID has agreed to broaden the use of the national Abilene Research network, and is now willing to provide access and use of Abilene to state networks which provide service to K-12 Schools and Community Colleges.

At the same time, Duke, NC State, UNC-Chapel Hill and MCNC created the North Carolina Networking Initiative (NCNI), which focuses on advanced networking research and applications for the next generation Internet. NCNI and UCAID membership are not connected but coexist to the advantage of all of the NCREN community. However, all North Carolina UCAID universities connect to the Internet2 research network (Abilene) through the NC GigaPop (a name based on the networking term *Point of Presence* – describing the high bandwidth connection to Internet2). The NC GigaPop was originally created by NCNI for research purposes. When NCNI moved on to new research initiatives, the GigaPop was inherited by NCREN for higher bandwidth production use. This type of technology transfer, as a result of advanced networking research demonstrates the importance of retaining independent research and education networking capability that will eventually support production use around the state.

NCREN3 meets the evolving production needs of the university community, and NCNI meets the evolving research needs of the university research community. Although it is difficult for these networks to share network infrastructure, never the less they do. The universities have chosen to intermingle "production traffic" with "research traffic" for some very compelling reasons: to use their production traffic as a testbed, to decrease costs, and increase the available bandwidth. In addition, since NCNI focuses on research and next generation Internet technologies, private industry has donated literally millions of dollars for equipment and infrastructure, which supports and benefits the larger research and education community.

What is NCREN3?

NCREN3 is a set of interconnected Regional Points of Presence (RPoP) which extends the existing NC GigaPoP to regions across the state and provides high performance networking services to the University community. The RPoP itself is a physical location where networks and users converge to share facilities, resources and exchange data traffic. The RPoP is managed at the local level by users and institutions, and interconnects to other RPoPs. The RPoPs in turn, are also interconnected to the other major state networks serving K-12 Schools, Community Colleges, State and Local Government and so forth.

NCREN3 will be accessible, flexible, and affordable, and will meet the current and emerging needs of the education and research community. It is based upon a combination of commercial, private and public facilities and infrastructure, and will be tightly coordinated with other statewide networking initiatives and services to eliminate duplication while increasing the scope and capability. For example, as the Rural Internet Initiative establishes high speed, dial and Internet access for people living in rural areas, NCREN3 will interconnect directly to that initiative and, rural citizens will have high-speed access to the university community. NCREN3 will also share circuits, routers, racks and co-location facilities with the State Government ITS network, which will provide better services, reduce duplication and be most cost effective.

So, what does this all mean?

NCREN3 has two primary objectives. The first objective is to provide the university research and education community with the high performance networking capabilities required to keep the universities competitive at the national level. The second objective is to become an integral part of the statewide networking infrastructure so that all citizens and institutions can enjoy the benefits of statewide networks and services. These two objectives ensure that NCREN3 will interoperate with both intra and interstate networks, becomes a basic building block of the statewide networking infrastructure, and is also focused on meeting the needs of the universities. The result will be seamless network which benefits all of North Carolina, and one which provides not only costs savings and efficiencies through leveraging other state networks, but continues North Carolina national leadership in advanced networking and competitiveness.

It also means that a new level of coordination, cooperation and overall governance of networks and resources is required. The rapidly increasing costs and complexity of providing network services across the entire state out-strips the ability of any single state agency or group of institutions. At the same time, it is essential that there is an on-going focus to meet the needs of each user-group. The key to success will be to maintain a balance between unique network needs and common network resources; this can only be accomplished through a constituency-based governance structure.

Given this requirement for collaboration and a commitment to cooperation and overall governance, NCREN3 is envisioned as being within the framework under development by NC Net (North Carolina's Networks Enterprise Effort). NC Net is proposed to be responsible for planning, coordinating, and integrating the network needs of government and education. NC Net (if approved by the Joint Select IT Committee and the General Assembly) will plan and facilitate the evolution of State networks. NC Net will continuously update the evolving network plans for the future, and will provide reports to the General Assembly, the IRMC, the Chief Justice, and the Governor on network usage, costs, requirements, and emerging issues. The development of NC Net is a voluntary, collaborative effort undertaken by entities with network responsibilities in the state to ensure that network planning is coordinated, that resources are appropriately leveraged, and that shared efforts are managed efficiently. The cooperation of all of the network providers in the NC Net effort and the continued commitment of all constituent entities in the state, is one of the key success factors for NCREN3 as well as for effective state networking. The mission of NC Net is to develop an integrated planning process that results in an evolving network that keeps North Carolina competitive and services the citizens of North Carolina.

What are some Funding sources?

The implementation of NCREN3 is divided into three phases over three years requiring over $17 million in capital, circuit and operational costs. Funding sources for the new NCREN3 network will include sources that result from a combination of grants, collaborations, user fees, state support and MCNC. Traditional sources of federal and private granting agencies will be leveraged to help develop applications and services. Statewide network planning and coordination, and the sharing of resources with state agencies and other network providers will significantly reduce both up-front costs and on-going operational costs. NC Net members are also addressing other funding requirements and options.

NCREN3: Current Status

NCREN has been providing Internet, data and video services to the University community for over 15 years and has developed what is recognized as one of the finest networks in the nation. Today, NCREN is a world-class inter-campus network which provides Internet access, data connectivity, and interactive video services to the 16 campuses of the UNC System plus Duke University and Wake Forest University. Internet services are also provided to 34 additional private North Carolina Colleges and Universities. NCREN services include:

- Inter-campus data communications

- Access to the Internet (Internet Gateway)
- Video services
- Network planning and engineering
- Leading edge (emerging) technologies
- Network Operations Center (NOC)
- Training
- Security and network design consulting

Although NCREN is operated by MCNC under a contract from UNC General Administration, there are a number of working groups and advisory groups providing advice (NCREN Advisory Board), strategic direction and policy development (Technical Advisory Group) and operational support (Video Managers, Video Directors, Engineering, etc).

While video usage has continued to increase each year, the bulk of the growth in usage and traffic has been on data communications. This has mirrored what has been happening at the national level. In 1996, for example, the North Carolina university community used just a little less than 4.5 Mbs of Internet gateway bandwidth; by October 2000, that bandwidth had increased to 350 Mbs of capacity. This translates into an increase of 80-fold in 4 years. Except for a $700,000 increase in the NCREN contract in 1999, this growth in services and capabilities had been accomplished without an increase in the NCREN contract since 1995. However, because of the flat budget, equipment replacement has not taken place, and just as importantly, network capacity upgrades have not occurred. The result is that NCREN now has a significantly higher risk of network failure due to aging equipment, and also has reduced performance because of network saturation and capacity limitations; this motivates the need for the NCREN3 architecture.

While looking ahead to NCREN3 implementation, a number of short-term goals must be addressed to maintain the vitality and viability of NCREN. These include:

- further increasing the reliability and capability of the network (although NCREN has very high levels of reliability, it has become mission-critical for higher education and must work toward 99.99% reliability)
- obtaining adequate capital funding for equipment repair and replacement, and
- developing network traffic management capabilities for all campuses (since network usage and cost are related, it is essential that each campus have the capability to manage traffic – this includes managing costs as well as implementing appropriate network usage policies by each campus).

Although the focus of the following plan is designing a network architecture (NCREN3) to meet the long term needs of higher education, these short term goals have been included in the planning process as they directly support the longer term strategic direction of NCREN and the future needs of the research and education community.

NCREN3: Challenges

One of the biggest challenges facing higher education in North Carolina is the lack of a plan to evolve NCREN to address the future needs of the universities and the education community.

Although NCREN currently solves inter-campus connectivity problems, it does not directly address off-campus networking issues or interconnections with Community Colleges and K-12 schools or the citizens of NC. The UNC System has identified five strategic priorities for the future and these depend upon an adequate networking infrastructure and extensive use of information technologies. These strategic priorities are:

- Access to education
- Creation and transfer of knowledge
- Human capital formation
- Support for K-16 education
- Transformation and change

While NCREN clearly has the potential to support these strategic priorities, it needs to focus beyond the immediate status quo services and begin to address these strategic priorities. It is also essential that the NCREN plan address issues relating to affordability and predictability of services as the university community establishes distance learning programs and provides services to a wide range of students and citizens across the state.

In addition, since neither the Community Colleges nor K-12 schools have integrated networks or services and depend on a variety of providers and networks for their connectivity, users face network fragmentation problems which discourage use. As a result of these fragments and multiple networks, each segment of the education community has had to develop its own network capabilities, and must negotiate multiple organizations and networks to provide services to the wide range of constituents across the state. It is ironic that although NC has some of the most advanced networking capabilities in the world serving the universities, its K-12 and Community College communities are served unevenly.

NCREN, thus needs to directly address network fragmentation issues, it must focus on providing dependable and predictable services, and must be re-purposed to address the strategic priorities of the University. With North Carolina's participation in the Internet2 Sponsored Educational Group Participants program (SEGP), a opportunity exists to extend access to advanced Internet services to the entire educational community. NCREN must also address the problems associated with the on-going rapid growth and use of the Internet as the amount of internet bandwidth continues to increase, and it is critical that this growth be managed, both financially and technically.

NCREN3: Recommended Plan

Evolve NCREN to help the University community leverage the existing NCREN network and other network providers to serve K-20 education institutions across the state. Through expansion of the North Carolina Gigapop and the establishment of Regional Points of Presence (RPoPs) across the state, the NCREN3 network would take advantage of the existing ITS state government network, the pending Rural Internet Initiative, and the many commercial providers across the state, to provide K-20 institutions across the state with a seamless network infrastructure. Multiple peering points and high speed interconnects among the RPoPs across the state, will facilitate the exchange, sharing and delivery of educational resources among K-12, Community Colleges and Universities, with the public at large, at home or at work. With the establishment of this seamless network, K-20 institutions will be able to focus on content, courses, curricula and continuing education applications rather than on the network mechanics and the underlying technologies themselves.

NC GigaPop and NCNI

The NC GigaPop has one of the finest networking infrastructures for research, education and business in the world. The NC GigaPop, which is not based at any single location, has been designed to be a distributed "GigaPop" and is currently distributed across the Triangle campuses and MCNC (initial connections include Wake Forest University in Winston Salem, and East Carolina University in Greenville). The NC GigaPop currently connects to 3 of the largest ISP providers in the world (Level3, Qwest, and Sprint); the connection to Qwest is OC12 (622 Mbs), while the connection to Level3 is GigE. The NC GigaPop has been designed to provide very high speeds (dual 2.4 Gbs links today, 10 Gbs links in 18 months) as well as highly reliable performance through redundancy and infrastructure. The NC GigaPop also connects to the Abilene Research network, which in turn interconnects major universities, research labs and other scientific and educational institutions across the nation. The current connection to the Abilene Research Network is 2.4 Gbs.

The expanded North Carolina Gigapop features RPoPs which also have a rich focus on local connectivity, participation, and services. Each RPoP become part of the larger NC GigaPop and will be located in key regions across the state. These locations will be connected by high speed, reliable interconnects to the statewide NC Gigapop providing both institutions and individual citizens with an unparalleled services and capabilities. The new NCREN3 would not be a separate physical network that competes or duplicates other state networking initiatives, but would provide users with a logical network to meet their needs. Physical facilities, circuits and network components would be shared with other providers to take advantage of aggregation and network management resources.

NCREN3 would leverage the NC GigaPop infrastructure throughout North Carolina. In each case, a high-speed network IP connection (OC3, OC12, or some equivalent service) interconnects the nodes together to create the statewide NC GigaPop. Users and institutions across the state will have direct access to multiple international Internet Service Providers (ISP), high speed backbone access, very high reliability, and the national high speed research networks. Since the NC GigaPop has been designed from the outset as a distributed POP (that is, it does not exist in a single building or point) each new node and RPoP would appear as just another node along with the current connections at Duke, NC State, UNC-Chapel Hill, ECU, WFU and MCNC.

The NCREN3 initiative will also be able to leverage over $25M of existing infrastructure and have access to high speed networks and services that have been established by the North Carolina Networking Initiative (NCNI). Through partnerships with RBOC's, CLEC's, cable companies and others, this direct connection will be easy to implement and has been engineered to a very high level of reliability, redundancy and service. As the initiative grows, more bandwidth can be readily acquired, and more ISPs can be added as and where required.

Regional Points of Presence (RPoPs)

In many ways, each RPoP can be viewed as a free standing POP that will serve as a "neutral" ground for providers and clients. This site will have adequate power, space and a controlled environment to accommodate direct connections by users as well as by other providers. Since it is the primary point of connectivity for the region, it will also need to have UPS, diesel generator(s), redundant HVAC systems, and dual feeds for connectivity and power. One of the primary sub-goals will be to make sure that local providers (BellSouth, GTE, Cable systems, CLEC, small independent phone companies, etc) will be able to directly connect to the RPoP from their CO (Central Office) or POPs. This will not only provide high speed access to the Internet for each of their clients, but, when combined with connections to other RPoPs and the NC GigaPop, will be able to provide a level of peering which begins to approach that of a NAP (Network Access Point). Essentially this means that traffic destined for other institutions or organizations in the region (or providers) will not have to go to the public exchange points in Washington, DC or Atlanta, but will switched appropriately at local node. This not only conserves a considerable amount of bandwidth destined for the Internet gateway, but also provides much better response time and performance for local users, especially with latency-sensitive applications, such as voice/video over IP.

There are a number of advantages and capabilities of RPoP's, which form the basis of NCREN3. These advantages include:

- *Regional Networks are a way for organizations to meet together to share knowledge and resources*. One of the most important aspects of an RPoP is that technical professionals and leaders from higher-ed, K-12 and community meet on a regular basis. As a result of the WinstonNet partnership for example, Wake Forest University and the Winston-Salem/Forsyth County Schools have received grants and federal appropriations in excess of $800,000 to foster connectivity and technology transfer in education. Numerous other grants have been written and submitted via collaborations between other members and non-members of WinstonNet, including Wake Forest, Winston-Salem State University, Public Schools, Salem College and Forsyth Tech. These opportunities only came about because of the synergy and framework of cooperation that WinstonNet created.

- *Regional networking provides the opportunity to share expensive, long haul telecommunications costs*. In the WinstonNet model, the members share the cost of maintaining the local network and contribute to the cost of the combined Internet access. WinstonNet also serves as a major recruiting tool to attract businesses to the Winston-Salem/ Forsyth County area.

- *The RPOP model allows organizations to share the cost of funding network support personnel*. It is very difficult for each individual organization to be able to find and fund top quality network engineers. Pooling funds and sharing the expertise is the best way to overcome this hurdle.

- *The RPOP model fosters a focus on providing service to a more diverse user base.* Local non-profits, social service organizations, museums, etc, that have traditionally been left out of statewide networking can now be served through the local RPOP. Many of these organizations will have to be funded through grants, gifts and other non-traditional means. The RPOPS will be best able to facilitate that process.

- *Distance and distributed learning can work effectively inside a community.* Through RPoPs, programs can be created that involve K-12 and Community colleges as well as the universities. This is a very effective way to help cross the digital divide, and involves community centers, libraries and public housing. It is only through community and regional networks that this can be effectively accomplished.

- *Allows communities to negotiate with local Internet Service Providers for network peering arrangements*. RPoPs can minimize the bandwidth and complexity of local networks by working out agreements with local service providers for direct connectivity to their networks. It also allows for significantly enhanced negotiation power through aggregated purchases.

- *Regional Networking is the only way to extend advanced Internet technologies (like Internet2) beyond the research intensive Universities.*

Deployment Plan

This draft plan has been developed to make NCREN3 a viable resource for the campuses and to provide affordable and predicable services into the future. The plan includes the deployment and implementation schedule for the RPoPs, the expanded NC Gigapop and includes the associated costs of equipment, circuits and operations. The deployment plan will be closely coordinated with the NC Net plans to eliminate duplication and to ensure that network resources and capabilities are effectively leveraged and shared. The first phase of the plan is to:

- expand the North Carolina GigaPop
- establish Regional Points of Presence (RPoPS) at
    - Charlotte (OC12 link)
    - Greensboro (OC3 link)
    - Greenville (OC3 link)
    - Winston Salem (OC3 link)
- upgrade the CORE NCREN3 backbone to accommodate these new connections
- implement a self-healing ring architecture to improve network resiliency
- replace old network routers and switches
- install four (4) H.323 gateways for distance learning plus 40 codecs for campus use, and
- establish network management software and capabilities for NCREN3 backbone
- establish traffic measurement software and capabilities for NCREN3 campuses (18 campuses)

Staffing Summary

Minimal staffing requirements

Integral to the expansion of the NC Gigapop architecture is significantly improved network resiliency and performance. The plan to use more localized network administration (such as consulting, educating, training, coordination) minimizes the need to increase staff to support the network. However, minimal staffing for the expanded network is as follows: phase 1 will require three additional personnel; Phase 2 will require a second video technician; Phase 3 will require one additional network engineer.

The satisfactory experiences with MPEGII over IP plus the emerging use of H.323 video, point to a looming reduction in the percentage of video sessions requiring manual scheduling, testing, monitoring, switching, and evaluating. As this forecasted change occurs, NCREN will also shift those technicians involved and the resources required toward additional IP networking functionality, thereby helping to reduce costs while providing enhanced services. Shepherding the evolution in video services can be accomplished with redirection of the existing video services staff; however, moving forward with video-over-IP to support distance learning will require additional staff to manage gateway requirements.

Acquiring and understanding the details associated with all the traffic flows of the NCREN3 network is an essential step toward enabling appropriate controls and management techniques to be applied. The volumes, origins, destinations, and patterns of data flows are quite voluminous, and as such, pose significant challenge in the storage and analysis of network statistics. Since much of the associated data is directly attributable to particular users and user groups, access and security become paramount issues. In addition to challenges in collection, security, and analysis of networking data, there are many potentially workable management approaches or tools that might possibly be utilized to implement policy or exercise controls on network traffic. Exploring the plethora of available systems, approaches, tools, and techniques is an essential early step that can help frame the foundation for policy-making efforts. Once the capabilities are well understood and communicated, and policy or control decisions are made, then implementation or application of policy and controls also requires coordination and resources. The continuing rapid growth of network requirements, the on-going changes in network applications, the complexity of network traffic, and the need to effectively monitor and manage traffic to manage financial and policy constraints, requires focus and support. On-going traffic management and measurement characterization activities will require a dedicated network engineer which has been included in Phase 1 minimal staffing plan.

Optional staffing requirements

Today, the NCREN NOC is available to all official users on a 24x7 basis for maintenance coordination services via on-call pager. All NOC staff members who are involved in delivering this service have access to high-speed Internet access services at their residence to facilitate remote diagnosis, actions, and trouble clearance. Only those problems requiring someone to physically visit an NCREN community premises actually require a staff member to be on hand. However, a 24x7 NOC staff coverage could shorten the response time associated with maintenance and emergencies. The round-the-clock staff could accomplish both provisioning and routine maintenance while on NOC duty. To provide a 24x7 staffed NOC would require four (4) additional staff positions.

Middleware is the essential glue that enables a new platform of shared educational resources to be universally available to students, faculty, and administration at all locations throughout the state. Detailed discovery and research are required in order to properly design focused middleware systems providing vital services such as campus and system wide directories and the ability to authenticate and authorize users across campus boundaries. With proper attention to middleware, UNC-GA can be assured that all courseware is universally available, with precise crediting, and accurate associated billing. Middleware can be defined as those services necessary for applications to function in a network environment. Middleware is often not used directly by end-users but invoked on the user's behalf by a user's applications. Since middleware can be invisible to the user it is often overlooked. Nevertheless middleware plays a key role.

Throughout the nation, this key area is receiving close attention from the wide university community as well as the much narrower Internet2 community. New concepts are being explored continuously and are a major part of the ongoing research outlined in Internet2 meetings and publications. In order to take advantage of new breakthroughs, it is necessary that the University be well established with this initiative and poised to implement the most efficient and effective solutions as these become available. Implementation of a Network-wide Directory Service structure will probably require a Directory Services Manager

Gateway Internet Access History

Recent History

Year	Bandwidth in Mbs	Total Cost	$/mbps
1996	4.5	$152,750	$101,833*
1997	45	$204,000	$4,533*
1998	45	$189,980	$4,221*
1999	79	$581,771	$7,364
2000	180	$1,357,708	$7,543
2000 (Dec.)	350	$1,357,708	$3,879

* Numbers reflect impact of NSF grants

Potential Growth of Internet Gateway bandwidth in Mbs at 25%, 50%, 75% and 100% per year

Year	25%	50%	75%	100%
2001	438	525	613	700
2002	548	788	1073	1400
2003	685	1182	1878	2800
2004	856	1773	3287	5600

Historical trends indicate that Internet gateway usage doubles every 18 months, and the cost per Mb decreases about 20% per year. Based on these trends, the amount of Internet Gateway Bandwidth required by July 2002 would be 700 Mbs or $1.9M; in December 2003 it would be 1400 Mbs or $2.7M. Note that as of the time of this publication in the fall of 2002, available subscribed Internet Gateway bandwidth from the two OC12 single GigE links was approximately 1400Mbps, with expansion to 2200Mbps on the same set of circuits; indeed bandwidth increased more quickly than predicted and costs were contained.

Glossary

RPoP – Regional Point of Presence

The RPoP is a physical location where networks and users converge to share facilities, resources and exchange traffic. The RPoP is managed at the local level by users and institutions, and interconnects to other RPoPs to extend the NC GigaPop across the state. The RPoP also is used to aggregate traffic, circuits, and users to save costs and provide better service.

> Example: Several of the 16 UNC Universities act as Points Of Presences for other intuitions in their local area. For example, UNC-Asheville has a high-speed connection back to the Internet via MCNC in RTP. Mars Hill College and many other institutions in the Asheville area connect to the Point of Presence at UNC-Asheville

Circuits

Circuits refer to the communication links between various sites (campuses, RPoPs, schools, agencies, etc) which enable users to receive and transmit data with other users across the state. Circuits can be shared by multiple users for efficiency, performance and cost savings.

> Example: Each UNC Universities use circuits connecting their network equipment to their Internet service provider and the greater Internet

Co-location Facility

Co-location facility is a physical location where network providers and service providers, as well campuses and agencies, place equipment in a shared space which has highly reliable electrical power, cooling, redundant power (UPS and generators), physical security and so forth. Since the cost to provide highly reliable facilities is expensive, it is very cost effective for multiple users to share the same facilities.

> Example: MCNC co-locates equipment at the Point Of Presence at Qwest (in Raleigh) in order to facilitate better and more efficient Internet access

Gateways

Gateways essentially provide two types of capabilities for users: access and translation. The Internet gateway is the portal and connection point between the user and the international Internet, and provides users with direct access to the Internet. A video gateway provides a connection point for users with different video formats and technologies to interoperate and communicate with each other; the gateway essentially converts or translates one type of video technology so it can be received by another video technology.

> Examples: Each University and organization has some sort of gateway at their site to connect to the Internet; likewise, each institution has some sort of video gateway to participate in videoconferences, classes and meetings.

Peering

Peering simply means sharing; peering within the RPoP means that users from different networks are interconnected so that it appears as though the users are all on the same network. It is important to note that although the Internet consists of thousands of “peered” networks, at the local and state level, peering does not typically take place among providers. For example, traffic from a user on network A must first travel to a major peering point such as Washington DC, to get to network B. The traffic then flows from Washington, DC, back to user B who may quite literally be located next door to the first user. If these two networks peered at the local level, the traffic would flow directly to the local user without leaving the state; peering thus saves considerable costs in terms of out-of-state bandwidth, and as importantly, also provides more reliable and better performance.

> Example: A user who has an account on Mindspring can directly access a web site such as WRAL, which is hosted by InterPath without traversing state boundaries. At the time of this writing, major peering partners are RoadRunner and BellSouth.net. The benefits of peering are quite substantial. Typical hop counts from Roadrunner to local campus networks would be 6 hops to the campus demarcation router.

Virginia Tech's eCorridors Program

Contact: John Nichols, John.Nichols@vt.edu

Overview

Access to advanced communications and network infrastructure has become critical for ensuring economic competitiveness in today's global economy. Beyond standard telephone systems and basic Internet access, communities are suddenly finding that businesses and other stakeholders are making specific demands for access to fiber optic infrastructure with very explicit route diversity and fiber specification requirements. Communities with advanced fiber, wireless, and "next generation" Internet infrastructure will have a distinct competitive advantage. Those without such infrastructure will fall behind in ways that may not be recoverable over a period of decades (such as difficulty attracting and retaining sustainable job creation opportunities).

The objective of Virginia Tech's eCorridors Program is to work with communities, private-sector, and municipal partners to facilitate rapid development of advanced, fiber optic, wireless, and "next generation" Internet infrastructure across the Southern region of Virginia, and expanding into the eastern and northern regions. Through multiple community and regional based initiatives, this program proposes to put the world's most advanced communications infrastructure within reach of every community in Virginia within 10 years. See http://www.ecorridors.vt.edu/ for the latest update on the eCorridors Program.

The overriding goal of the program is to serve as a catalyst for the deployment of affordable access to fiber optic network infrastructure that is needed to create economic and educational opportunities for citizens and businesses. Fiber optic network infrastructure is needed to support current high-speed (10/100/1000 Mbps) data access for a range of business and community applications and for future higher speed applications. Fiber may also be needed to support both analog and digital applications. The infrastructure should be open to all service providers and private sector based. It can enable the emergence of a new economy and network industry in Virginia. This new industry, in its infancy, combines high capacity optical and wireless technologies with the Internet protocol and Ethernet to enable an extraordinary advantage in cost and communications power.

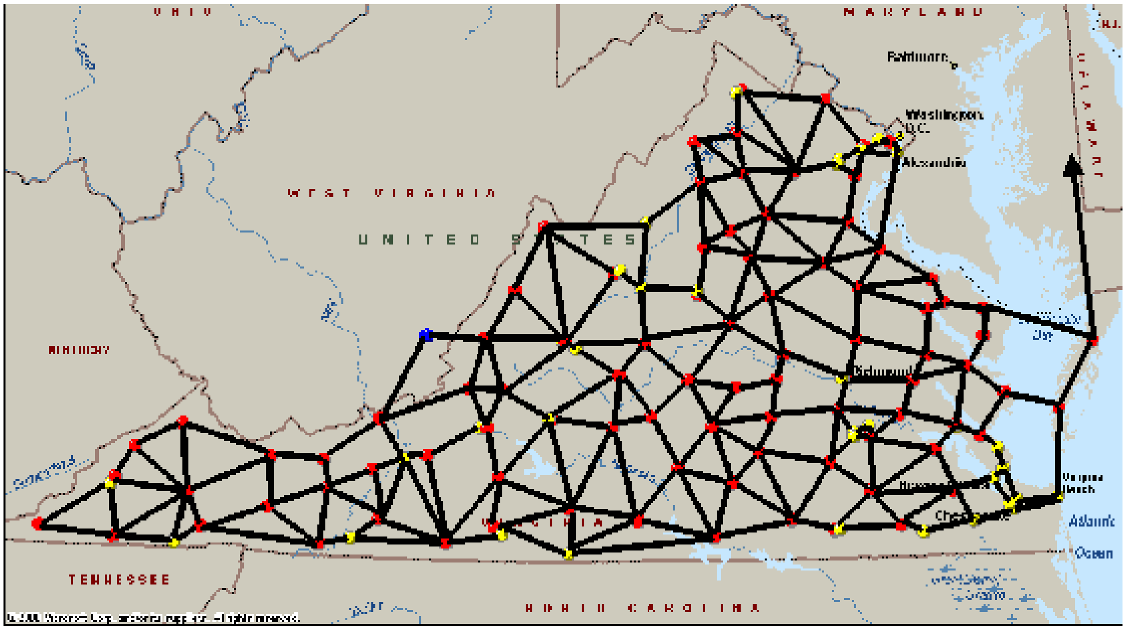
The eCorridors Program also serves educational communities. It enables research and development of network technologies and solutions for business, education, and other programs on a 'real world,' large-scale network. For the past 15 years, Virginia Tech has developed network infrastructure strategies aimed at dramatically lowering the cost of broadband network access (see http://www.networkvirginia.net/). The proposed large-scale community oriented network combines the resources and expertise of education, private sector partners, municipalities, and non-profit entities to provide a unique opportunity for all involved. The program has created significant and widespread interest from municipal leaders and legislators. This level of visibility helps build long-term relationships. Another benefit is the provision of a statewide, truly high-speed network over a diverse route infrastructure that otherwise would not be affordable. A network infrastructure is needed for the economic opportunity and the viability of communities as they develop networked economies.

eCorridors Strategy

The eCorridors strategy is to provide knowledge information to communities to enable an understanding of what communications infrastructure is needed to compete in the information age and how to leverage it for economic development and the benefit of citizens. It requires a new approach to networking on a local and regional scale. This approach leverages current infrastructure, new network technologies, efficient construction methods, combinations of optical and broadband wireless media, and innovative organizational and market structures, to extend access to scalable, high-speed data services throughout Virginia. Goals include, 1) minimum cost, 2) true bandwidth capacity, 3) scalable capacity for future needs, 4) high performance, 5) high reliability through diversity, 6) leverage Internet protocols, 7) open access for services, and 8) effective management.

The typical network infrastructure being deployed today, such as cable modems and digital subscriber lines are restrictive and do not adequately meet future needs. Optical fiber to the user is needed to support high-speed 10/100/1000 Mbps, symmetrical, data services, which is the current state-of-the art. Higher speeds are needed for backbone networks. Fiber optic circuits can support today's needs and higher speeds in the future. Today, fiber is often deployed to reach large business customers and to interconnect carrier centers, but not for the great majority of users who are left out. Long haul fiber is deployed between relatively sparse metropolitan areas and is not typically accessible at affordable prices to rural communities through which it passes. Fiber that has been deployed is generally monopolized by carriers for their business purposes and not made available to deliver minimum cost, high-speed, services to users. Since carrier business models do not enable them to deliver the affordable services needed, communities must find other ways to make services available. Also, some communities are not served by diverse route, network facilities, which have resulted in total loss of all wire-line and wireless communications in a county wide region after a fiber cut—mobile phones typically interconnect over cable facilities. Diverse alternate fiber network infrastructure is needed for reliability and for the potential need of disaster recovery.

The eCorridors Program will provide the knowledge and specifications to enable communities and partners to design and build a fiber optic network infrastructure to deliver reliable, diverse route, interconnectivity between all communities in a region. By keeping the infrastructure open to all service providers, it creates opportunities for new business ventures and services. Ultimately, the network will interconnect access nodes for all communities within a target area with fully meshed, fiber optic facilities. Each community would be served by fiber connecting it to at least two other communities for increased reliability. The fiber optic architecture is called a "Geodesic Network Mesh"--a representation is illustrated below. The mesh will interconnect multimedia services access points (MSAPs) throughout regions to form an open access, intercommunity network infrastructure. A key strategy for successful implementation is that the fiber optic mesh network should be owned and operated by a provider-neutral entity. The eCorridors Program and partners are exploring a number of business models to facilitate this strategy.



A great deal more is needed for economic development and improved quality of life in a region in than communications infrastructure. Advanced fiber optic infrastructure is needed along with roads, work space, electricity, water, sewer, and other facilities. Also, it is essential to provide education and training to the populace for how to use the network infrastructure to be producers, not just consumers. There is a "chicken and egg" problem in that advanced communications infrastructure is needed in order to compete and to create new business opportunities but the infrastructure does not exist, or is prohibitively expensive. There are not enough subscribers that can pay the relatively high prices to current providers to justify deployment given their established business models. It is critical for community economic development that the optical network infrastructure and training be available along with other facilities to lay the foundations needed. In addition to training and educational programs from schools, colleges and universities, the eCorridors Program offers training through Virginia Tech's Electronic Villages Program (http://www.bev.net/). The eCorridors and Electronic Village programs work with communities to encourage and develop workforce training and apprenticeship programs to provide opportunities for an array of people.

As the eCorridors Program takes root and expands, participating regions can become focal points for the world's most advanced communications infrastructure designed to enable users to be *producers*, not just consumers of network content and services. Full development of the envisioned infrastructure has the potential to create an integrated economic engine for merging regions, currently among the nation's poorest, from Virginia's Tidewater to the Appalachians and other areas, to form a new economy along eCorridors. It will create the critical mass of subscribers and resources needed to support economic development. The initiative will yield large economic benefits at a fraction of the cost of traditional infrastructure (such as highways) through multiple public/private partnerships. It will create competitive advantage for about 2.5 million citizens in the Route 58 region and for the region's businesses.

The Role of Communities

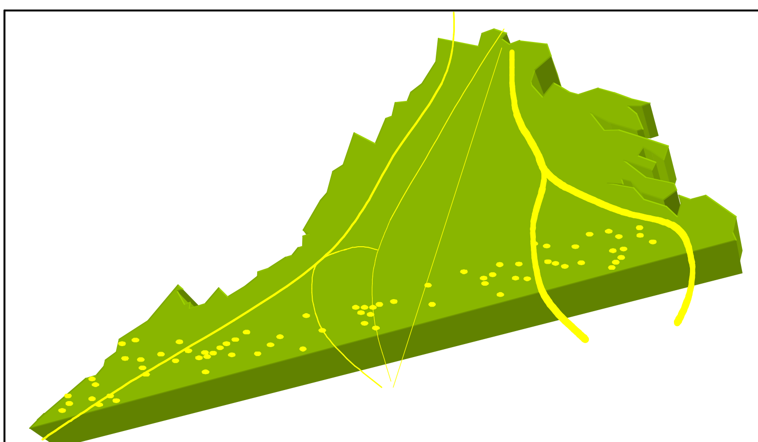
Virginia Tech, as a land-grant university, has a legacy of public service and outreach in addition to its mission of education and research. However, *the university is NOT going into the* *telecommunications business*! Virginia Tech's eCorridors Program serves as a catalyst to bring together the right mix of community resources, private sector expertise, and other economic development entities to assist communities that are interested in their economic future. By aggregating the needs and assets of communities on a region-by-region basis, the program is able to leverage municipally-owned resources, such as rights of way and other utilities infrastructure, to maximize regional impact and competitiveness.

The eCorridors Program will work with communities that initiate a relationship with Virginia Tech for the purpose of facilitating the development of advanced network infrastructure. Communities need to find a local 'champion' interested in pursuing the possibilities for public-private partnerships that will yield the right blend of expertise, resources, and business case options. Communities need to foster and support the deployment of fiber optic infrastructure within the municipal leadership committees, councils, and utilities operations. The community must make available space and rights-of-way for MSAPs and the fiber optic infrastructure. Support from municipal leadership is critical to the ongoing success of an infrastructure development endeavor. eCorridors offers to help educate communities about applications, technologies, planning, engineering, management and other issues with respect to deployment of advanced telecommunications infrastructure.

Finally, communities wishing to participate in the eCorridors Program must encourage and promote regional development. Rural communities, in particular, often find that they must compete with nearby communities for economic development advantages. However, telecommunications infrastructure gains value as it gains connectivity to subscribers over an ever-expanding geographic area that interconnects all users, including business and residential. In addition, significant benefits in terms of reducing costs and building an aggregate market for attracting high technology industry and service providers are enhanced if communities collaborate regionally.

"E-58": An eCorridors Prototype

Like many states, Virginia has a large number of rural communities that are left out of the network economy due to lack of affordable access. In many areas, the only access is dial-up modems. In Virginia, virtually all available fiber paths run north-south and none travel along the east-west border of the southern part of the state coinciding with Highway 58. This entire region comprises communities that have been the hardest hit economically and are desperately struggling for survival against such high tech regions as Northern Virginia, Hampton Roads, and Research Triangle Park. In addition, these 100 communities are situated within the tobacco-growing regions of the Commonwealth and are seeing their agricultural livelihoods and manufacturing industries rapidly deteriorating. Unemployment and brain drain are very real threats to these communities. For this reason, the

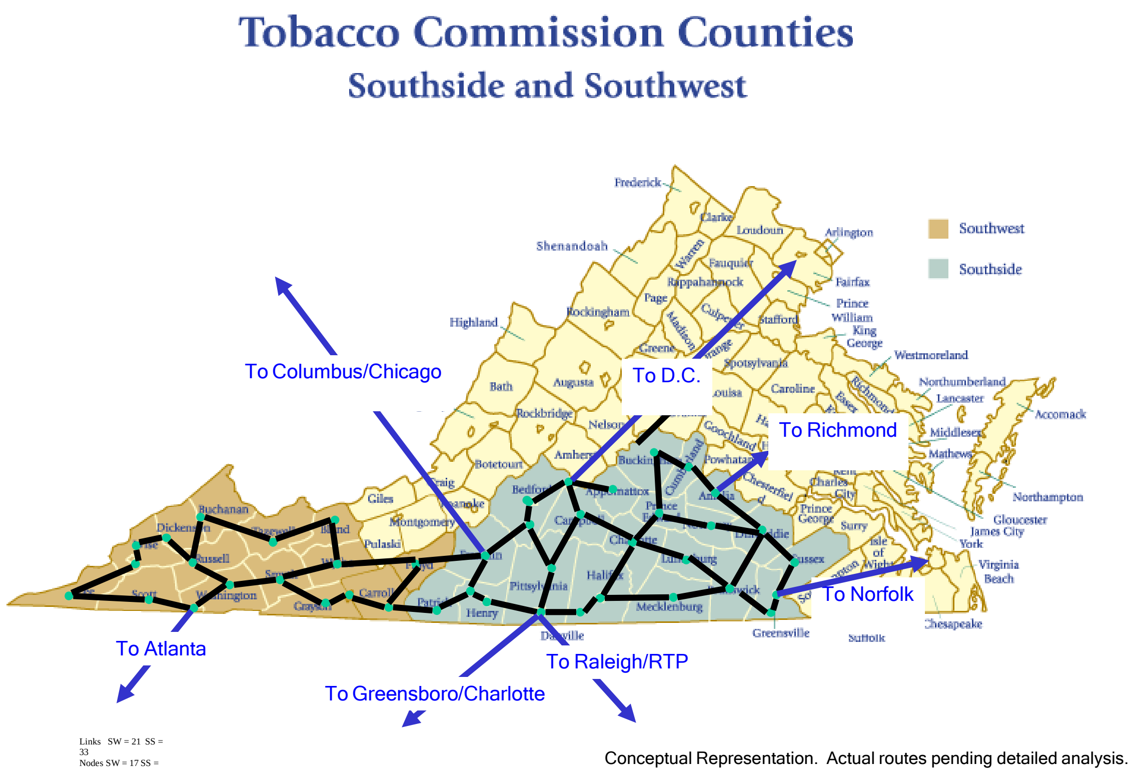


Currently along Highway 58 in Virginia, all existing fiber runs north-south, leaving nearly 100 communities (yellow dots) unserved.

eCorridors Program, along with the Virginia Tobacco Indemnification and Community Revitalization Commission chose the Highway 58 corridor as its prototype region for implementation. With the enthusiastic support and leadership of people in the Danville/Pittsylvania County area, the eCorridors Program began aggressively promoting the concept of an "E-58 Corridor."

The Virginia Tobacco Indemnification and Community Revitalization Commission endorses e58 as an effective economic development strategy and established an e58 Task Force. That Task Force conducted an evaluation of the proposed telecommunications corridor and issued a Vision Statement and Program Announcement (see http://www.vatobaccocommission.org/e58vision_form.html). In collaboration with Virginia Tech's eCorridors Program, the Tobacco Commission envisions funding a number of proposals each year that contribute infrastructure, leadership, equipment, expertise, municipal assets, etc. to the overall regional effort.

The objective is to develop *coordinated* community efforts and public-private partnerships for the creation of an east-west, dark fiber, mesh backbone with on-ramps in every community along the way.



Each community needs to build a "multimedia services access point" to provide a local peering point for access to services and to inter-community transport. It serves to keep local traffic local and improve performance while reducing costs to participating service providers.

A goal of e58 is to demonstrate: 1) how to funnel and shape regional public funding support for economic revitalization initiatives; plus, 2) influence private investments in advanced network infrastructure, services, and applications, so that *any* community in the tobacco growing region, if they choose, can participate and compete in the information economy.

Danville/Pittsylvania County - A Prototype eCorridors Community

As mentioned, a key to success for an eCorridors region is the active participation and endorsement of local community leaders with a local 'champion' that is positioned to move the effort forward. Danville and Pittsylvania County, located on the southern border of Virginia, just above the North Carolina Research Triangle, provided the impetus for the eCorridors pilot project with the help of a local non-profit organization called the Future of the Piedmont Foundation. This Foundation is made up of business leaders from the city and county -- representing the interests of both equally. The Foundation approached Virginia Tech and requested the university's assistance in developing a plan to create a competitive advantage for the Dan River region. Several initiatives were proposed by the university, one of which was the creation of an advanced network infrastructure--an 'eCorridor'. The Foundation worked with the eCorridors group to propose deployment of regional fiber optic infrastructure to the Virginia Tobacco Indemnification and Community Revitalization Commission. That proposal was funded (a copy is available on www.ecorridors. vt.edu "working paper #4") for $2 million over two years.

The eDan proposal consisted of 5 elements:

- Inter-Community Next Generation Optical Link (Danville – Chatham)
- Gigabit Gateways
- 2 Multimedia Services Access Points (MSAPs)
- Pilot Projects: Local “1st Mile” access (e. g. LMDS, 802.11a, 802.11b, fiber to the home)
- Business Plan: Dan River Region to Tier 1 Internet Backbone

A stated objective of the Dan River Region eCorridors Pilot project is to reduce barriers to entry for new economy businesses, telecommunications providers, and local entrepreneurs. The next step after receiving funding for the project was to begin creating partnerships with local and regional private sector companies wishing to participate. The eCorridors Program aims to create economic benefit to communities and regions by encouraging local companies to begin efforts to supplement their traditional manufacturing and agricultural focus with a New Economy orientation. It was important that local companies have an early opportunity to participate in pilot projects. A second goal was to attract new businesses and service providers, so participation was invited from a wide range of participants.

The Foundation issued a Request for Collaborators, which was published in the local newspaper and sent directly to 50 companies. The request included an invitation to attend an information session in Danville to learn more about the project and how companies can get involved. The meeting was held on October 17, 2001 and was attended by about 75 companies. Seven were national companies and three were international. Several of the attendees represented new business start-ups that were looking for a location to establish their dot-com business. This was a significant turn-out that created visibility for this rural community to companies that otherwise would not have participated. The company representatives spent four hours listening to presentations about the technical elements of the project and participated in a question and answer session. Representatives of the Foundation, the eCorridors Program, and city and county officials were on hand to support the project and to answer questions and establish contacts with interested companies. The information session closed with an invitation to work together to develop proposals from either individual companies, or groups of companies, having complementary expertise and submit them to the Foundation.

The Foundation received a number of proposals from a diverse range of interested partners. With assistance from the eCorridors team, the Foundation evaluated proposals and determined funding levels. Several companies participated in local technology demonstrations to the community. The City of Danville and RACO, a local contractor, are building a 40 mile, 60-fiber route linking Danville to Chatham and Gretna. Danville is building a fiber optic backbone within the city. Access drops are planned for serving industrial parks, education, and others. Gamewood, a local ISP, is building the MSAP communication sites and will operate them for the communities. Space was provided by the communities, who also worked together to make available rights-of ways. The MSAP facilities will deliver gigabit Ethernet peering and collocation space for service providers that will provide local access to users. Task forces were created with representatives from the communities and eCorridors team to address public relations, applications, inter-community fiber build, rights-of-ways, and MSAP facilities.

The resulting private sector investments multiply the value of the initial local investment. More importantly, the participation represents extraordinary value in terms of sustainable economic development potential. Every additional company that takes a serious look at this region and begins to learn of the many advantages it can offer will add to the attractiveness of the region and will aid in building a critical mass of market demand for advanced network access and services. Over time, it will be possible to change the region’s characterization as a manufacturing and tobacco-growing region to that of a "wired", high technology region.

The eCorridors Program emphasizes an integrative approach to assisting communities in adopting new economy practices and reducing barriers to entry for new players. The network infrastructure and new, competitive, telecommunications providers will benefit the region, if its citizens and business owners understand how to effectively leverage these resources. Working with Danville Community College and Averett University, as well as the city and county K-12 public schools, Virginia Tech is developing a number of educational programs, including faculty development, to enable the community to educate its citizens and teachers. In addition, a series of ongoing hands-on technology demonstrations, open and widely promoted to the public, will aid in promoting the new technologies. It is expected that the Danville-Chatham-Gretna optical network infrastructure will be completed by the end of 2002. The region must continue to foster community-wide participation, expanded local access, networked services, and e-business training for its citizens.

Lee County, City of Norton, Wise County and Scott County Pilot Project

The LENOWISCO Planning District Commission (http://www.lenowisco.org/) proposes to put the world's most advanced communications infrastructure within reach of every business and citizen in the LENOWISCO area within 10 years or less, depending upon funding availability. The overriding goal of the project is to act as a catalyst in creating substantial economic, educational and health care improvement opportunities for citizens of the region and competitive advantage for its businesses through the development of very high speed, reliable network infrastructure at a fraction of currently available prices. This infrastructure will be private sector based as a means of ensuring its sustainability and economic viability, and will enable the emergence of the newly developing communications and network industry in southwest Virginia.

The immediate goal is to provide 125 miles of optical fiber network and extend that by an additional 100 miles for subsequent phases. The fiber would be buried alongside the planning district’s water lines using an innovative conduit that allows fiber to be blown all the way through to the end user building site. The first 125 mile phase Total Project Cost has been estimated to be $5.3 million and has already begun with installation of conduit throughout the planning district wherever water lines are in construction. Crews started laying the innovative new information pipeline June 26, 2002. in trenches alongside the water lines for the Tito and Jasper water projects. In addition, project partner Scott County Telephone Cooperative has provided use of 70 miles of fiber optic cable in that county. The underground plastic data pipeline that is being used for the first time in the nation can serve as: a conduit for massive amounts of data transmission from present and future users; developing cottage industries; educational, law enforcement and court sites; medical facilities; residential customers.

The Virginia Tobacco Indemnification Commission provided a $200,000 grant to engineer the project, and a $445,000 loan to fund the installation. LENOWISCO also plans to seek funds from other sources including Rural Utility Service and federal sources of funds.

Project Objectives

- Create a competitive marketplace
- Encourage private investment
- Reduce data and telecom costs for all
- Reduce overbuilding and redundant facilities
- Create local markets for new services

LENOWISCO does not intend to offer services through the network. Instead, private companies will be able to offer high-definition television, cable TV programming, Internet access, telephone service and other programs by leasing the network. Physicians will be able to use the broadband network to treat patients hundreds of miles away, consult with a specialist, or participate in continuing education classes. Future phases may extend into western Lee County and the Cumberland Plateau Planning District Commission's service areas, including Dickenson, Buchanan, Russell and Tazewell counties.

Southern Crossroads Metropolitan Extension

Contact: Ron Hutchins, Ron.Hutchins@oit.gatech.edu

NOTE: This example will be expanded in a future version of the Cookbook

The Southern Crossroads (SoX) is a regional GigaPoP that is operated by The Georgia Institute of Technology on behalf of the Southeastern University Research Association (SURA). SoX serves institutions across six states and traditionally aggregated all activities into the Georgia Tech. Campus. Recently SoX explored the possibility of enhancing services, capacity, and costs by creating a presence in a major downtown Atlanta carrier hotel.

Growth and demands had transitioned SoX needs for connectivity from OC3 to OC12. SoX decided to explore other opportunities beyond the existing model of purchasing circuits from the campus to the hotel. SoX implemented dark fiber from the Georgia Tech Campus into a downtown carrier hotel and transitioned through the following outcomes:

1. $16,000 per year OC3
2. $10,000 per month OC12
3. $1,200 per month dark fiber operating at OC48
4. $5,000 per month dark fiber and approximately $200,000 capital investment in optical equipment providing the following:
    a. two OC12's
    b. two OC48's
    c. one Gigabit Ethernet

In addition to the circuit savings and capacity increases, another very substantial outcome to creating a presence in a major downtown carrier hotel via fiber extension was the opportunity to interconnect and negotiate favorable prices due to proximity and ease of connectivity.

Grant County Public Utility District's Zipp Network

Contact: Sarah Morford, Smorfor@gcpud.org

Executive Summary

Grant County Public Utility District (PUD), located at the center of Washington state, serves a predominantly agricultural population with a density of less than 13 homes per square mile. In this land where portions of the county still lack basic telephone service, the possibility of advanced broadband communications seemed a futile hope at best. That's why Grant PUD began the process of installing a fiber optic network, called Zipp, for their community.

As of September 2002, the Zipp Network has achieved a 41% take rate, with more than 15 competing retail service providers offering advanced voice, video & data services over a converged, open-access Gigabit Ethernet, IP, fiber to the home network. With the launch of the Zipp Network, Grant County has seen the development of 5 new businesses and 96 new jobs resulting in over $8 million annual economic development.

Background

Prior to the launch of the Zipp Network, communication services for the people of the county were primitive. There was no competition for the local cable or telephone companies. In fact, more than 95 percent of the cable systems had less than 32 analog channels available. Three areas of the county even lacked basic telephone service and those that could access the Internet without dialing long-distance still only connected at 28.8 Kbps dial-up service. In short, there was room for improvement.

During the summer of 2000, Grant PUD launched a nine-month pilot test of its Gigabit Ethernet fiber optic project to 150 customers, offering broadband access to services including high-speed Internet and digital video. The pilot project marked the beginning process of a six year build out plan that, when complete, will form a countywide infrastructure used to read the county's 37,000 electrical meters remotely while providing customers access to competitive value added services.

Milestone Accomplishments

Following a successful pilot, Grant PUD began the process of rolling-out Zipp Network service to the county at large in March of 2001. In the 18 months following the launch, Grant PUD has strung fiber past more than 8,400 homes, businesses and farms. The success of the Zipp Network has been tremendous as 41 percent of those passed now subscribe to service.

Grant PUD attributes part of the Zipp's success to the fact that the network is Open Access. Grant has focused it's efforts on fiber network distribution and management, and has designed these Gigabit Ethernet facilities to support multiple and concurrent retail service providers offering voice, video, data, education, health care, etc.

As of September 2002, 15 independent companies offer 100Mb dedicated Internet services on the network, two provide digital television with over 280 channels, one offers telephone service with expanded calling areas and a security company has recently come on-line. By enabling competition in service and service providers, the Zipp Network is not only allowing Grant County customers a choice in the companies that provide service, but also saving them money. As companies vie for customers, they improve service and lower rates. Customers on the Zipp Network currently save more than $20 a month on high-speed Internet, digital television and telephone services as compared to those with out Zipp who pay more for lesser products.

Optical Network Architecture

The Zipp Network was engineered on the beliefs that:

- Utilities work best with large, long-term infrastructure construction and management.
- Independent retail service providers are more responsive to short-term competitive change.
- Open Access and non-discriminatory pricing is essential to enable service competition.
- Everything can be accomplished over IP.
- Network topology should have maximum flexibility to mitigate obsolesce.
- Singlemode fiber optics is the only medium to support future services of unknown bandwidth.

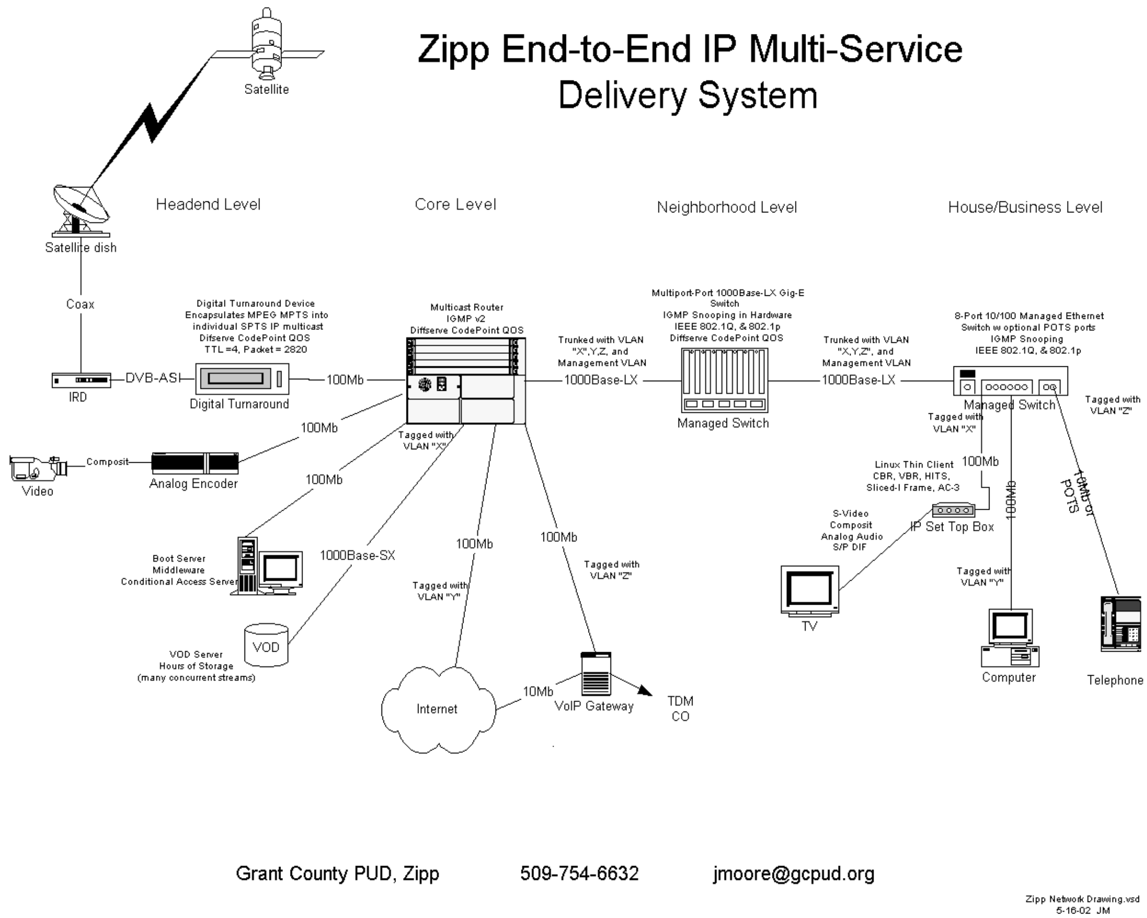
Zipp is a wholesale managed facilities network and is leased to retail service providers as an unbundled network element. Elements include dark fiber, 10/100/1000 Ethernet, SONET and a voice over IP (VoIP) gateway. The retailers bundle the Zipp Network element with their "service" or "services" and brand the product as their own to market to the public. The PUD installs, owns and maintains the leased facilities while the retailer markets, bills, collects and manages the end-user.

The Zipp Network uses dedicated point to point singlemode fiber pairs from each home, business and farm to an active curbside network aggregation device in a star topology that forms a neighborhood serving area. These serving areas encompass approximately 288 homes using Gigabit Ethernet (1000base-LX) with a reach no further than 6-8 kilometers. (During the third quarter of 2003, the density will change to 576 homes per curbside aggregation device with the use of dual-frequency (1310nm & 1550nm), single-fiber small form pluggable (SFP) optics) The active curbside device is housed in a NEMA-4 rated above ground enclosure, located within existing utility ROW, and containing HVAC, batteries, patch panels and electronics. Through the use of patch panels and fiber jumpers, any customer can have their choice of dark fiber, lit Ethernet or SONET. See curbside pictures below:

The customer fiber termination equipment, sometimes called an optical network termination (ONT), is a managed layer-2 Ethernet switch with an optical Gigabit Ethernet uplink, 6-8 RJ-45 10/100Mb copper Ethernet ports, 2 RJ-11 telephone ports, battery backup, and a utility accessible local management interface. Software features include IGMP snooping for efficient handling of IP multicast video, a VoIP gateway, and IEEE 802.1Q VLAN support. For the utility fiber-to-the-home market, the ONT is housed in an environmental enclosure and mounted outside the home, next to the telephone and electric demarcation devices. VLANs allow for network separation amongst competing retail service providers while using a shared utility fiber network. See ONT pictures below:

Zipp's use of dedicated fiber pairs to each customer and Gigabit Ethernet allows for a fully symmetric network and a non-blocking architecture. This enables anyone, anywhere to be either a network source or sink without bandwidth restriction in the first mile. Packets are marked (IEEE 802.1p) at the point of ingress and quality of service managed at the curbside aggregation device. This makes for a scalable architecture where bandwidth is managed amongst a limited number of core devices, and edge activities limited to VLAN membership assignments and link up/down status.

A high-level network diagram is shown here:



Networked Communities

As individual small rural communities, open-access broadband optical networks like Zipp are enabling access to advanced services, service competition and consumer choice. However without substantial numbers, our communities cannot attract large reputable providers. In an effort to gain access to big Internet pipes, share services amongst neighboring communities and aggregate access to end-users Grant County PUD helped form a region-wide network called the Northwest Open Access Network (NoaNet).

NoaNet

The Northwest Open Access Network (NoaNet) is a nonprofit corporation that has licensed over 1800 route miles of fiber optic cable from the Bonneville Power Administration and will license fibers from other sources and make the network available to utilities and communities in the Pacific Northwest.

NoaNet is not a traditional telecommunications company. This new network was designed and built with the future of the converging telecommunications industry in mind and focuses on deploying this network to rural areas.

The members of NoaNet are nonprofit, community-owned electric and water utilities. They use the NoaNet fiber optic system for utility purposes such as real-time metering, energy management, load control and networking among remote utility facilities. NoaNet makes excess capacity available to others on a cost-based, nondiscriminatory basis. Communities use the NoaNet system to interconnect schools, hospitals, judicial systems, libraries, and emergency services. The availability of fiber optics helps enable economically depressed communities to attract new businesses. NoaNet can be a rural communities' on-ramp to the Internet, offering access through Tier 1 providers.

NoaNet has added modern and efficient lasers to the unlit fiber it leases from BPA. Utility members and wholesale customers of NoaNet will develop and operate communication systems within their own service areas that connect with the NoaNet backbone system. Rural areas often are not economically attractive markets for investments by telecommunication companies. Since NoaNet's licensed fibers run mainly through rural areas, this new system is well suited to meet the future telecommunication needs of rural communities. By providing access to advanced broadband telecommunication facilities on an open, cost-based principle, NoaNet promises to help open a world of opportunities for utilities, wholesale customers and the rural communities they serve in the Pacific Northwest.

Economic Development

Benefits to Grant County - Providing Opportunity and Enabling Growth

Grant County is just beginning to experience the economic impact the Zipp Network is having in our area.

Population:
Grant County has experienced a 29 percent increase in population since 1990, with approximately 75,900 people now residing in the area.

Over the next several years, we anticipate future high rates of growth as the Zipp Network expands and opportunities for new growth increase.

Workforce:
While aerospace and some high-tech industries are found throughout the area, agriculture is the foundation of the county, which leads to wide swings in its economic base.

In the 2 years time that the Zipp Network has been in place, Grant County has already seen new high-tech businesses and jobs come to the area. As of September 2002, three businesses have relocated to Grant County and five new high-tech businesses have entered the area. This has resulted in more than 96 new jobs worth over $8 million in annual economic benefit to the community!

Applications areas:
- Government (courthouse, jail, city hall, police, fire, etc.)
- Educational (school internetworking, classroom networking, distance learning, etc.)
- Medical (medical imaging, doctors review scans from home after hours, database archival, etc.)
- Housing (B&B and Hotels see more business due to broadband in the rooms, apartments & houses are easier to market, real estate relocation, etc.)

- Fairgrounds (new RV business, Internet auctions, fair-tv, etc.)
- Internet gaming and web hosting. Zipp has more traffic going "to" the Internet than downloads from the Internet. The world is coming to us...