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Design of Telecommunication Network for Geographic Information Systems for the Appalachian Council of Governments: A Case Study

by

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This thesis is written as a public service to increase overall networking knowledge and to aid in the solving of an actual Information Resources problem. In doing so, several technologies were investigated that would suitably satisfy the SCACOG's connectivity requirements given a funding constraint. Infrared and microwave were discounted because of their costs and/or limited range. Spread spectrum and dedicated T-1 lines from the local phone company fell within the range and price constraints.

Spread spectrum and TCP/IP, both originally developed for the military, were selected as the telecommunication service and file transfer product to fulfill the SCACOG's requirements.

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I. INTRODUCTION

A. BACKGROUND AND OBJECTIVES

To share valuable computer resources and information, one needs to implement a communication network. When the geographic scope of the communication is confined to a small area, such as an office or a building, the connection of computers and peripherals is termed a *Local Area Network (LAN).* As the demand for distributed processing among businesses increase, LANs may also be required to expand and connect to one another, to form a *Wide Area Network (WAN).* Such is the case in the Greenville, South Carolina area.

The South Carolina Appalachian Council of Governments (SCACOG) is currently investigating a means of centrally maintaining a Geographic Information Systems (GIS) database for use by five geographically separated offices in the city of Greenville. The objectives of this case study are to (1) provide an overview of networking concepts and issues, (2) provide an analysis of possible telecommunication services, (3) provide an implementation plan for the most cost effective method of internetworking, and (4) discuss the selection of the best file transfer product.

B. SCOPE

This thesis investigates the means of connecting a group of LANs in a small geographic area for the purpose of sharing geographic data. It is not meant to be a highly technical report on the nuts and bolts of electronic communications hardware and software, nor an analysis of every possible means of connecting the LANs. It is written at the "casual user's" level of understanding in the area of networks and provides a good, not necessarily the best, solution.

An implementation discussion is provided for the two most promising technologies, but this is very basic and should not be considered a step-by-step manual for achieving connectivity. The actual implementation of these products is going to vary from user to user given the circumstances, and no one is going to know how it is precisely put together until it is together and running (Schneidewind, 1993).

Connecting LANs involves the use of both hardware and software. Hardware is required to provide the physical passage of data between the LANs in the form of bridges, circuit cards, and transmission media like cables or antennae. Software is required for the protocols (sets of rules) that govern the transmission of data, as well as for the interfaces between the user and the application, and the application and the network.

In this case study, the constraints are a fixed amount of budgeted dollars available to be spent on the connectivity ($80,000), the geography of the buildings involved, and a data rate requirement to allow for the timely transfer of geographic data between the five sites. The data rate requirement was determined through the analysis of demand currently experienced at the SCACOG as well as expected future demand. Since the requirement is based highly on an infrastructure not in place at the current time, the result could be considered somewhat subjective.

This case study is also limited to the connection of homogeneous LANS, even though that is not currently the case, and doesn't necessarily have to be. Specifically, Sun Operating System version 4.1 and Open Windows version 2.0 are in place at three of the five sites. A fourth site is moving to Sun OS in the near future, and a fifth will probably never move to it. This does not mean that the telecommunication network proposed in this thesis is moot because the desired results can be obtained through the use of software.

Specific vendors for possible future use are mentioned by name in this thesis, but this should not be misconstrued as an endorsement or denouncement of any particular product. Multiple vendors exist for all of the items mentioned (except for the phone company), and those selected were done so because of the availability of literature and not because this thesis considers them to be the best in their area. They were selected as representatives of the mainstream of their field so that this case study could compare *technologies*, not necessarily vendors within each technology.

C. ORGANIZATION

This thesis is organized into five chapters and one appendix. This first chapter has discussed the objectives of the case study, as well as outlined the scope and limitations. Chapter II is the description of the requirements based on what is currently in place, the demand for geographic data, what is likely to be in place in the near future, and the estimation of the required data rate to be used for the remainder of the thesis.

The third chapter is the analysis of four networking technologies. Infrared and microwave are discussed only briefly because they fall short of the requirements. The services of the Local Exchange Carrier (LEC), Bell South, are discussed in greater detail because at least one of them can fulfill the requirements. A semi-technical discussion ensues, followed by a basic implementation plan. The chapter continues with a discussion of spread spectrum.

Chapter IV is a discussion on the Network File System software package that is used to perform the transfer of data within the network. Chapter V is the conclusion drawn based on the research performed, as well as considerations that may merit further investigation sometime in the future by Greenville.

Basic network considerations and structures are covered in the Appendix. Here the seven-layered OSI model is broken down and discussed as it pertains to the GIS personnel involved in this case study. The Appendix also discusses the principles and functions of bridges that connect homogeneous LANs together.

II. DESCRIPTION OF REQUIREMENTS

The South Carolina Appalachian Council of Governments (SCACOG) is a not-for-profit local government consulting agency. Based in Greenville, it serves the Geographic Information Services (GIS) needs for six counties and 43 municipalities throughout the northwest corner of South Carolina.

In addition to GIS, the SCACOG services include developing programs for the elderly, conducting management studies, federal and state grant administration, personnel studies and administration, community and economic development and planning, and geographic information analysis. Although several of the departments may benefit from computer networking, GIS is the only one currently exploring networking strategies and implementation options.

The demand for networking their GIS assets has recently been driven by plans of Bavarian Motor Works (BMW) to proceed with locating their first foreign manufacturing facility near the Greenville - Spartanburg Airport. With the addition of 4,000 new jobs as a result of BMW's expansion, unprecedented growth is expected over the next five years that will far exceed the SCACOG's ability to provide the services expected and required. Under the present system, backlogs and unavailable services are already straining the limited throughput capabilities.

To help effectively plan for this growth, an enormous amount of spatial data must be developed, analyzed, and communicated to local policy makers. GIS technology will play a central role in this process helping design transportation systems, locate schools, implement county zoning, and plan for efficient delivery of county services. A central data repository with data distribution capabilities is required to successfully manage the expected growth. (Hanning, 1993)

The SCACOG GIS staff needs a cost effective method for distributing existing GIS databases to their clients. Making an investment in a wide area GIS network is a necessity to meet the growing demands for their services. The greatest concern is the SCACOG's ability to create and distribute geological data for use in computer generated maps using Environmental Systems Research Institute, Inc.'s (ESRI) ARC/INFO.

ARC/INFO is an integrated GIS software which is used to input, automate, manipulate, analyze, display and report on geographic data. Cartographic data managed by ARC/INFO is explicitly linked to tabular data that is stored and maintained using commercially available relational database management systems such as ORACLE, INGRES, SYBASE, and INFORMIX. In addition to supporting external DBMSs, the open and flexible design of ARC/INFO allows the integration of scanning, Computer Aided Design (CAD), map publishing, image management and other related technologies. (Kasunich, 1993)

ARC/INFO is present on all of the concerned LANs in the SCACOG's area of responsibility. Yet the majority of data management and map making is performed by the GIS specialist at the SCACOG with the help of two local college student interns. Geographic data exists at some of the other sites, but at various levels of currency, completeness and accuracy causing redundancies and unuse. As long as the sparsely staffed SCACOG is maintaining their geographic data correctly, it will be the major source of cartography services, even for offices who have the infrastructure to do it on their own.

The goal is to have a centrally maintained database for the geographic data that is accessible to all five offices. These offices have the tools and casual user training required to fulfill their own cartographic services that are now being tasked to the SCACOG, but do not fully utilize them because they often lack the data required. If they could access the data that SCACOG uses, they could make many of the maps that are currently delegated to the SCACOG. Connecting these sites in a wide area network is needed to meet the new cartographic demand as Greenville grows because the SCACOG is overtasked now.

Current hardware in place at the SCACOG is a Sun Micro-Systems 4/330 and an X-Terminal on a TCP/IP Ethernet. The addition of a SPARC 10 onto the LAN is imminent. At the

Greenville County Office, the TCP/IP Ethernet will contain a SPARC 10 with 10 gigabytes of storage and seven work stations. All are using Sun OS 4.1 and Open Windows 2.0.

The Greenville City GIS Office currently runs ARC/INFO on two VMS 3100s using DECNet, but the conversion to Sun Ethernet with four work stations is also imminent and should be considered in place for the purpose of this thesis. The E-911 Office has a single IBM PC running DOS with the PC versions of ARC/INFO and Network File System (PC NFS).

It is somewhat unclear and undecided precisely how the Greenville County Sheriff's Office will be included in the WAN. For planning purposes, their equipment will include a four station Sun Ethernet with roughly the same data transfer requirements. Figure 1 summarizes the equipment in place for the purposes of this thesis.

The SCACOG currently moves (creates and distributes) a maximum of three to four maps a day in support of the services it is contracted to provide the city and county offices. This is limited by the time it takes the GIS specialist to create the map by modifying the portions of the existing database as well as plotting, mounting and sometimes delivering the map.

SCACOG conservatively estimates that the file server sends and receives at most four files per work station per day. The total number of work stations in the proposed WAN is 19. The files average 5 to 10 Mbytes (millions of bytes) in size, giving the worst case transfer requirement of 12.16 Gbits

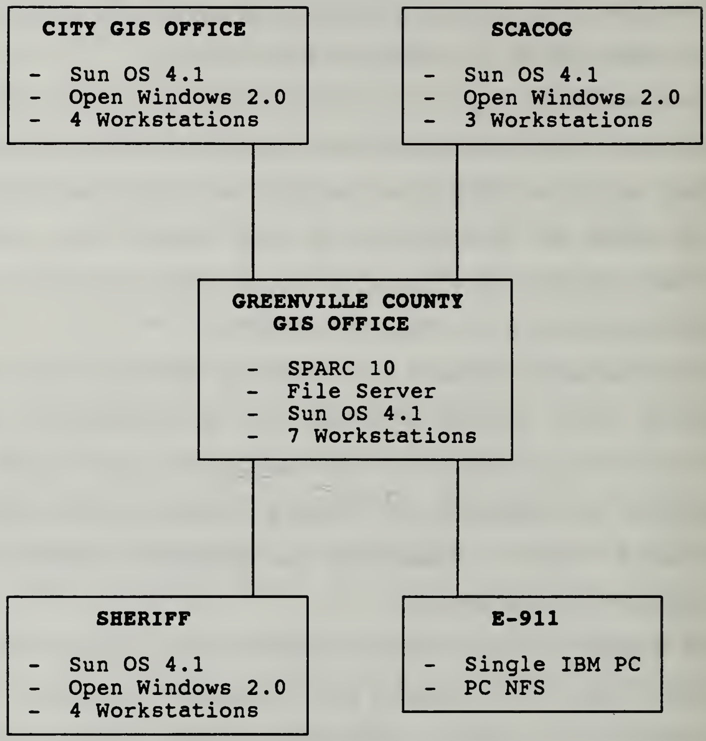

Figure 1: Current equipment in the case study area.

(billions of bits) per day if a file is to be read from the server and subsequently written back.[1] Realistically, peak periods will routinely occur near the beginning and end of the

[1] 12.16 gigabits is derived from the following: 19 workstations times 4 files times 10 megabytes per file times 8 bits per byte times (1 read plus 1 write = 2) server accesses.

day for an hour, and before and after the lunch break, for another hour.

These peak times dictate that a majority of the required file transfers will happen over the course of three hours (10,800 seconds) of the day for an exaggerated required data transfer rate of 1.126 megabits per second (Mbps).

III. OPTION CONSIDERATIONS

This chapter examines the four options of providing connectivity. The first two are microwave and infrared technologies, neither of which meet the requirements of the SCACOG because of geographic range and/or price constraints. The final two options discussed are spread spectrum radio transmission technology and the dedicated digital services provided by the local phone company, both of which meet the price and data rate requirements.

A. MICROWAVE

Microwave is an established radio frequency method of transferring high rates of data over great distances. The radio frequencies in the microwave spectrum are in the gigahertz (billions of cycles per second) range.

Microwave communications are susceptible to interference or degradation from the environment through which the waves travel. Atmospheric conditions such as rain, lightening, dust and pollution can seriously degrade reliable communication. Simply stated, the greater the intensity of the above conditions within the path of the microwaves, the greater the probability of unreliable data transfer (Freeman, 1991, p. 497). The geographic conditions in Greenville and the perceived non-urgent nature of data transmission did not deter any confidence that a microwave solution would be applicable to the GIS networking requirements.

Currently, microwave is used for satellite and terrestrial line-of-sight (LOS) communications. In both instances, LOS is required; but, with satellite communications, the signal is "bent" back to the receiving station from the satellite. Due to the relative short distances between the concerned buildings, as well as great cost, research was limited to that of terrestrial LOS. Among many companies that are capable of fulfilling GIS networking requirements with microwave bridges, only Motorola and Microwave Networks are considered here.

The Motorola system ALTAIR II is capable of transferring data above the required rate with an approximate cost of $8,000 per site. The range of the Motorola system is limited to 500 feet or approximately 150 meters, which would preclude connecting any two of the five sites. A point to consider in future considerations of this type of system is the ownership of the required frequencies by the Motorola company. This fact eliminates the need for dealing directly with the Federal Communications Commission to license the required frequencies.

Microwave Networks of Houston, Texas provides the equipment necessary to meet both the data and distance requirements. The cost of hardware is estimated at $25,000 per site and does not include licensing. This figure greatly surpasses the budgeted dollar amount.

B. INFRARED

Infrared technology involves using pulses of light outside of the visible spectrum to transmits ones and zeros (the most common household use is that of the TV remote control). Like microwave, there is a line-of-sight requirement, and reliable ranges can be reduced because of environmental circumstances such as birds or rain. Also like microwave, the terrain and topography of Greenville support the consideration of this technology.

According to Flannagan, improvements in this field have yielded ranges of three to five miles with data rates up to about 45 Mbps (T-3). Also, equipment is often inexpensive, small (about 12 pounds), and does not require any FCC licensing. (Flanagan, 1990, pp. 91-92)

But research indicates that two leading companies offering infrared bridging, 3-COM and LCI, have a maximum range of one mile or less. Also, due to the high thunderstorm activity during several months of the year in the Greenville area, transmission reliability may noticeably suffer. Finally, costs are ranging between $20,000 and $25,000 per site, which exceed the budget constraint.

Infrared is best suited for intra-office networking, or for wireless LANs within the same close geographical area, and cannot at this time meet the requirements.

C. LEC DATA SERVICES

There are a variety of services that are offered by LECs, and they can be categorized as either dedicated or switched. One of the dedicated services is called Digital Data Service (DDS) that provides up to 56 Kbps of dedicated bandwidth. This is obviously not enough to satisfy the SCACOG's requirement.

A second form of dedicated service is T-1, which offers 1.544 Mbps. In order to grasp the extent of 1.544 Mbps, consider that a single T-1 line carries as much information per unit time as 160 computer ports using 9,600 bps modems (Flanagan, 1990, p. 1). This is enough throughput to satisfy the requirement.

Switched services go by many different names for many different data rates, but they all come down to 56 or 64 Kbps (thousands of bps) multiplied by *n*, where *n* varies from 1 to 24. Most common rates are switched 64, 128, 384 and 1,536 for *n* equal to one, two, six or 24, respectively. The future will provide switched broadband services of 1.5 Mbps and above; but, for the present, Bell South's switched services support only 56 Kbps channels. Switched services are often accessed through ISDN.

ISDN can take two forms, both of which are offered by Bell South. The first is Basic Rate Interface (BRI) which consists of two 64 Kbps channels for voice or data. The second is

Primary Rate Interface (PRI) which consists of 23 64 Kbps channels for voice or data.[2]

Bell South's switched 56 Kbps channels can be inverse-multiplexed to achieve switched connectivity at higher than 56 Kbps data rates. However, the number of switched 56 Kbps channels that can be inverse-multiplexed is practically limited by the number of ports available in inverse multiplexers. For example, Ascend LAN Service Units and Cisco Inverse Multiplexers support up to 8 ports, allowing at most eight 56 Kbps channels to be bundled with an aggregate switched data rate of 438 Kbps. This falls short of the SCACOG requirement for data rate.

Furthermore, the need for an inverse multiplexer at each of the five sites brings the total hardware cost well above the budget. The costs for inverse multiplexers, per site, include roughly $1,200 for installation and $15,000 for hardware. This leaves dedicated T-1 service as the only feasible solution offered by LEC.

T-1 is transparent to the users, and its maintenance and monitoring are the responsibilities of the phone company, as are the CSUs (which prepare the data for transmission along the phone line). Redundancy is not provided for free from the local phone company like it often is by long haul carriers,

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[2] A second PRI line will be able to provide 24 channels of 64 Kbps.

but the purchase of a parallel system is not necessary because of the high expense and the low mission criticalness.

To further describe T-1 connectivity in Greenville, the subnetworks at each of the four remote sites will be attached with a T-1 bridge for approximately $3,300. The bridge will then be connected to the CSU on site, which is connected to the T-1 line in the wall (see Figure 2). The CSUs and T-1 installation costs are an initial $20,859, plus an additional $1,326 per month in line leasing costs.

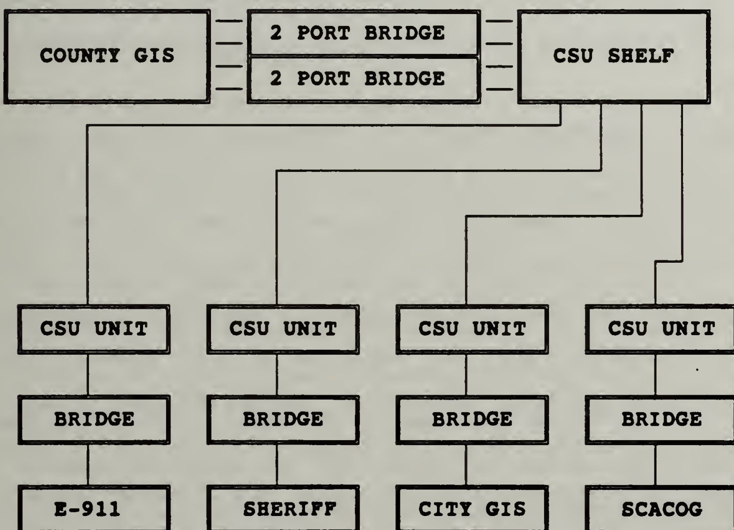

Figure 2: T-1 Schematic

At the Greenville County Offices, four incoming T-1 lines will be connected to four CSUs which in turn are connected to a bridging rack capable of handling four lines. The most economical way of handling this is by the use of two separate 2-port bridges at a cost of $4,850 each.

The total costs of installing the T-1 method are $43,759 up front and an additional $1,326 to the monthly phone bill.

D. SPREAD SPECTRUM

Spread spectrum modulation techniques originated over forty years ago to support the military where concerns for "hardened" communications were paramount. Spread spectrum provides for anti-jam and low probability of intercept properties allowing secure and reliable battlefield communications.

Spread spectrum modulation techniques widen the radio frequency bandwidth of a signal. This results in the transmitted signal's bandwidth being much wider than would be necessary for transmitting the information signal alone. This is achieved by modulating the carrier signal with a spreading code. Spreading codes are sequences of code elements that appear to be randomly generated. While the code elements generated by a spreading code appear to follow no apparent pattern, an identical code generator can generate the same sequence. Therefore, systems utilizing this modulation technique must have their respective transmitters and receivers equipped with identical code generators.

The more common methods of spread spectrum modulation include Direct Sequence, Frequency Hopping, and Stacked

Carrier (NSA, 1979, p. 2.1). Wireless LANs use the direct sequence spread spectrum modulation technique.

1. Direct Sequence

Most communications systems are concerned with the efficient utilization of bandwidth and signal energy. Spread spectrum DS signals have several advantages over conventional signal types (NSA, 1979, pp. 3.1-3.2). These include:

1. Processing gain
2. Jamming and interference resistance
3. Security[3]
4. Low probability of intercept
5. Selective addressing

Other advantages given by Schilling are low cost and low volume of the equipment (Schilling, and others, 1991, p. 78).

If one was to view a direct sequence signal through a spectrum analyzer it would appear to consist of only noise with no visible trace of a carrier signal. The carrier is directly modulated (phase-shift keyed) by the near-random spreading code. The purpose of modulating the carrier with a spreading code is to widen the bandwidth of the signal. Since the transmitted power of the signal is spread out over a larger bandwidth, the signal to noise ratio is much lower than what would be required for reliable transmission using other

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[3] Schilling argues this point, saying "Spread spectrum is not secure. To insure that a communication is secure, standard encryption algorithms must be employed." (Schilling and others, 1991, p. 68)

radio frequency communications techniques. It is this low signal to noise ratio that provides for what the military desires and defines as low probability of intercept. (Pickholtz, and others, 1982, p. 859)

At the other end, the receiver demodulates the signal using a spreading code identical to the one used by the transmitter. It is imperative that the spreading code be synchronized to the received signal. The timing code must be such that the code elements match the phase shifts in the received signal. A special synchronization circuit is used to adjust the timing of the spreading code and to track the frequency of the received signal. (Pickholtz, and others, 1982, p. 860)

During the demodulation process the phase shifts generated by spreading codes in the transmitter are removed from the carrier signal. The intended receiver, by concentrating the signal to its baseband information, will now "see" much less noise and will therefore achieve a much higher signal-to-noise ratio (SNR). (NSA, 1979, p. 2.8)

Interfering signals (any signal the receiver picks up other than the desired signal) will have their power effectively reduced since they will be spread across the bandwidth generated by the DS encoding. Therefore the SNR for the desired signal compared to the SNR of any undesired signal will be greater when the DS encoding is used. This will enable the intended receiver to interpret the original information.

2. The Ethernet Remote Bridge

Persoft's Intersect Remote Bridge offers a wireless solution to the connectivity challenge. This turnkey operation offers two versions, and supports all network operating systems. The Ethernet version of concern is fully IEEE 802.3, and 802.1d (spanning tree protocol) compliant. The Intersect Remote Bridge connects two or more physically separated LAN segments by using spread spectrum modulation technology. The Ethernet version supports thick, thin, and twisted-pair media (Levine, 1993).

In this specific case, one bridge is needed for each site. That is, five Intersect Remote Bridge-Ethernet (single unit's) are required, or two pairs and a single unit. One pair is exactly equivalent to two single units.

A single unit includes all the hardware, software, and documentation to move data from the Ethernet to the airwaves, from where it can be retrieved by an identical receiving unit. A single unit as described in Marty Levine's "Portable Connectivity" includes an omnidirectional antenna with five-foot coaxial cable, a directional antenna with 33-foot extension cable, RangeFinder software for optimizing antenna alignment, an Intersect Remote Bridge user manual, and the bridge itself (386SX PC, 640KB base memory and 256KB of extended memory).

On the back of each system are a serial port, two parallel ports (unused), a female F connector for the radio antenna, a 2400 baud modem, a monochrome CRT port, and connectors to join the built-in network interface to the three types of Ethernet media.

The bridge unit comes with a 1.44 Mbyte floppy drive for running the bridge software. Persoft does not include a hard drive, nor do they need one. This 386 PC is designed to act as the network front-end, and nothing more. (Levine, 1993)

3. Data Rates

Persoft advertises a maximum throughput of 2 Mbps, which is well above T-1 and the requirement set forth by the SCACOG. However, it will not be faster than the networks in place, and one test published indicates a 40.8% degradation in rate from that of the LANs.

In tests performed by Levine, a file transfer was timed over the normal network using FTP's PC/TCP on two DOS based machines. A 1.5 Mbyte file was transferred in 32 seconds, providing a data rate of 375 Kbps. Performing the same transfer across the Persoft bridge through the directional antennae, the 1.5 Mbyte file was transferred between two buildings 300 feet apart in 54 seconds. This provides a data rate of 222 Kbps, or 59.2% of a non-bridged network's throughput. (Levine, 1993)

Effective data rates across the Intersect Remote Bridge varies nonlinearly with the actual throughput of a non-bridged LAN, much like Figure 3, up to a maximum of 2 Mbps.

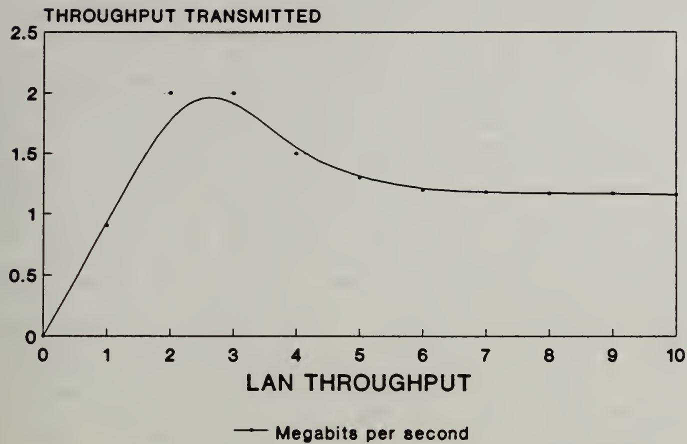

Figure 3: Depiction of expected throughputs across the remote bridges as a function of current LAN throughput. These values are approximations.

As explained by Mark Collins of Persoft, the percentage of throughput rises and falls on a near-bell-shaped (Collins, 1993).

In a LAN where throughput may reach 6 Mbps, Collins says throughput across the Intersect Remote Bridge will fall to the right of center in an area providing only about 1.2 Mbps (20% of LAN's throughput). The center of the curve is not precisely defined because, according to Collins, it is dependant upon the applications being utilized and the protocols in place, but it falls roughly around 2 Mbps. (Collins, 1993)

It would be unwise to automatically assume that Persoft is going to be able to provide all of its advertised 2 Mbps. They are, in fact, vendors given to making a sale. But how much is likely to be available, especially when already installed cases researched are well below 1 Mbps?

Research was therefore performed at the SCACOG (after receiving throughput data from Persoft) to determine the actual data rate in their Ethernet. Using the Network File System (NFS) that is in place, a 1.391 Mbyte file was transferred from a RAM drive on the host machine to the RAM on the receiving machine. The average time of transfer was 5.05 seconds, indicating a throughput of 2.2036 Mbps.[4]

Referring to Figure 3 on page 23, 2.2 Mbps falls on the near-bell-shaped curve almost at the top. Although the exact top is not precisely known due to variations in software, it is almost a certainty that the data rate across the remote bridges will exceed 1.5 Mbps. In Apopka, Florida, Persoft has successfully achieved 2 Mbps throughput while also weathering the city's severe lightening season (Dryden, 1993).

4. System Installation

A directional antenna will be required at each site. Also, lightning arrestors at each site are recommended for

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[4] RAM and RAM drive were used to prevent the added time of disk access, reading and writing. This added time, measured in seconds, would have significantly deflated the actual throughput results. The accuracy of the timing (to the hundredth of a second) is a result of the time of transfer being provided by the computer, not a user with a stopwatch.

outdoor antenna installations. Installation is described by Levine as relatively easy ("plug-and-play"); challenges could include cable access to the roof for attachment to the antenna and the antenna connection itself. 33 foot antenna extension cables are available, however, more than three extensions in series are not recommended without additional power boosting.

Persoft will complete the installation if desired at additional cost. An additional benefit of a Persoft installation is that they will walk the customer through the software setup after the expected system usage is described. This will allow the wireless network to be set up most efficiently depending on expected traffic.

Antenna setup is accomplished manually and tested for directivity through the use of the RangeFinder software provided. Line-of-sight is required between any two sites, and all five sites must be able to be "daisy-chained" to provide end-to-end connectivity (see Figure 4 at end of chapter). Persoft will assist in creating the most effective antenna pattern layout given building distances, building heights for each of the five sites, and the heights of any buildings in the direct line-of-site between two connections.

Troubleshooting of the system, should problems arise, is accomplished on-line. Once a failed bridge is located, it can be removed and replaced. Persoft will send a replacement upon word that the failed unit has been placed in the mail, thus minimizing any downtime.

Persoft provides the entire system complete out of the box and will install and test the system. In addition, Persoft is available to maintain the system when problems occur over the life of the system. It is recommended that a specially priced, spare bridge be purchased should the regular system go down. This would ensure maximum up-time, should the malfunctioning bridge need to be taken off site and repaired.

To implement the Persoft system, the following items would have to be purchased (Persoft, 1993):

1. One single unit (INTR1) for $4,995
2. Two double units (INTR1) at $9,995 each

Additionally, the recommended purchase of an Intersect Remote Bridge-Ethernet (INTRS) as a spare will cost $2,995. Assorted cabling, lightning arrestors, line attenuators, etc., are estimated at $5,000. Persoft's installation charges will be approximately $1,500 to $2,000. The total purchase price of this system is approximately $34,500.

Buying individual NCR components from vendors are available for about $5,000 less than the Persoft system, but it would require assembly and installation by the inexperienced SCACOG staff. Persoft is a pre-tested, integrated gateway system. There is no need for a systems integrator, because the selling vendor is the same as the installer/maintainer. There is a standard maintenance package available through Persoft, so there is only one point of contact in case of a system malfunction.

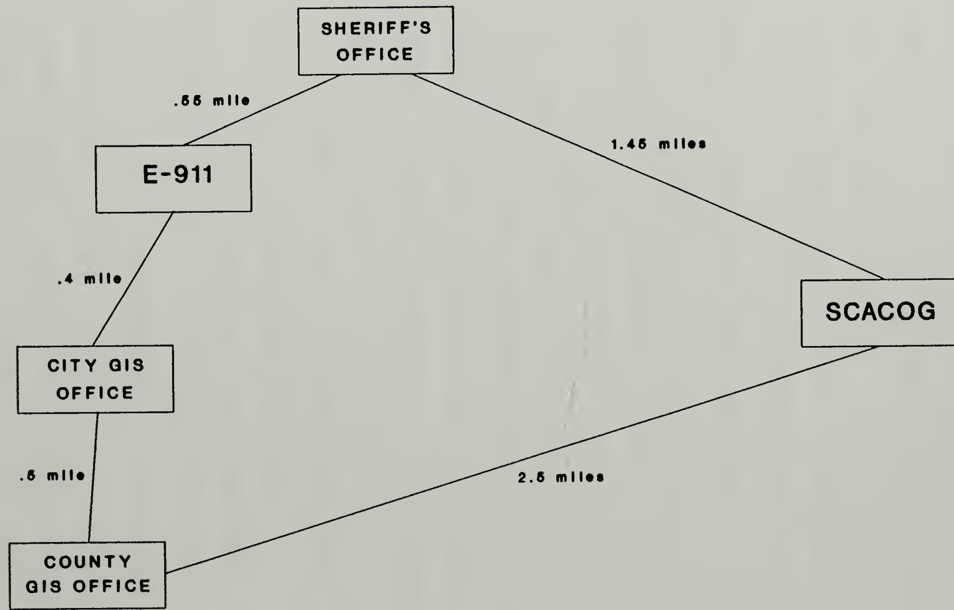

Figure 4: GIS networking sites of Greenville, South Carolina

IV. FILE TRANSFER WITH NETWORK FILE SYSTEM

A. NFS, FTP AND TELNET

Transfer of data files will be done through the use of the Network File System software resident on the LANs that make up the GIS internetwork. NFS comes installed on Sun Microsystems machines, along with unique Internet Protocol addresses and TCP to provide the basis for peer-to-peer communication in a client-server architecture (Henriksen, 1990, p.5).

NFS is both a communications protocol (rules for talking) and a collection of software using that protocol (Sun, 1988, p.3). It is always very closely associated with TCP/IP (Dryden, 1993). Alternatives to NFS include Telnet and FTP.

Telnet is terminal emulation software for remote logins to machines using different operating systems, and sometimes for machines using different varieties of UNIX (Sun, 1988, p. 16). Suffice it to say that this is not the case in Greenville unless the DEC equipment at the City GIS Office is not replaced as planned, and applications from Sun machines are needed to be used from the DECNet.

File Transfer Protocol, FTP, is a standard, generalized protocol for transferring text (and binary) data files (Henriksen, 1990, p.5). It differs from the *remote file copy* command that can be used between homogeneous UNIX machines in that it is independent of the operating system. In other words, text files can be passed from unlike operating systems (DEC versus UNIX) using FTP.[3] FTP then takes the information and passes it directly to TCP, which attaches header information and passes it further down the model (Dryden, 1993). This is all considered transparent to the user after the FTP command.

FTP or basic UNIX copy commands could be used as the means for file transfer across the internetwork while outside of the ARC/INFO application environment, but there exists a better way. NFS allows the transparent use of resources across a network. It allows users on one machine to treat a disk on another machine as if it were its own. Its use can turn the entire network into one big "disk farm" (Henriksen, 1990, p. 5).

B. BASICS OF NFS USE

Use of NFS allows users to treat other disks on the internetwork as their own by creating a *virtual drive* through the process of *mounting*. That is, machine A can access a particular directory on the server and give it the name of a drive or directory of A's choosing. For example, zoning areas are located on the server in the directory called */usr/gis/-data/zoning*, and machine A at the City GIS Office is mounted

---

[3] The use of FTP to transfer binary files must involve homogeneous operating systems. Binary differs from text in that it involves codes and instructions with regard to the operating system it was compiled under. Text is just characters that, when standardized (like ASCII), are readable in different operating systems.

to that file system under the mount point */taxes/zones*. In this scenario, machine A at the City GIS Office can work in the directory */taxes/zones* as if it were on machine A's own disk even though the actual storage is performed at the County Office in the file system called */usr/gis/data/zoning*.

This can get complicated fast as many users mount the server (or other hosts) under different mount points (virtual drives) with different accesses (read only, read and write, etc.). Administration is done by use of the Network Information Service (NIS). NIS was originally known as the Yellow Pages, but Sun encountered copyright difficulties with this name because it already has fairly definite meanings outside of NFS (Malamud, 1992, p. 133).

NIS is a distributed network database lookup service which contains files (*hosts, passswd, groups, aliases* and others) that hold information about who belongs to the network and what they can do (Sun, 1988, p.6). Simply put, NIS allows the internetwork administrator to set up user passwords and access levels to file systems as well as machine names and addresses throughout the network.

Map libraries are the spatial database component of ARC/INFO, stored in either binary or text files, that can be maintained across a network (Henriksen, 1990, p.5). This will serve Greenville well when they are able to decentralize the storage of their geographic data. A further discussion of this occurs in Chapter V.

Since the application software is already installed on the nodes, it will not be necessary to mount the application itself; only the files that need to be shared will be transmitted across the bridges.

An alternative to NFS would be to invoke FTP to *get* the desired file from the server and place it into memory where ARC/INFO can access it for use (Hanning, 1993). A disadvantage of this may be that if the transferred files are text, they must then be converted (slowly) to binary for use within the application. NFS can avoid this by using Remote Procedure Call (RPC).

In this manner, shown in Figure 5 on page 33, binary files can be retrieved into ARC/INFO while in the application, and in the form that can readily be used. This obviously can be done only if the client has been given proper access to the file system that the desired file is in. The call is made as discussed above using the virtual drive that has been set up in the NIS. NFS' transparency gives the illusion that the desired file is on the user's machine because once mounted, local disks are indistinguishable from remote disks. (Henriksen, 1990, p.6)

There will be one shortfall in NFS. That will be of time. Access to another remote disk, on an Ethernet or internet, will be slower than accessing the local disk. This is not the fault of NFS, but an inherent characteristic of internetworking resources at this time.

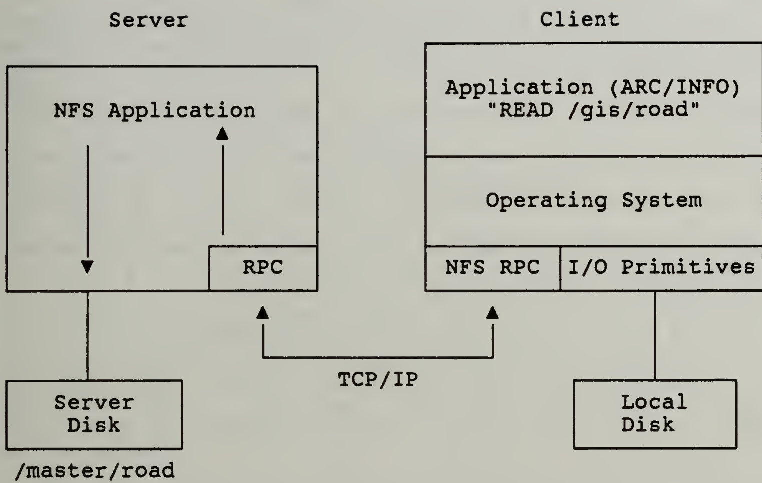

Figure 5: A client application file read request will be transparently served. In this case, the file accessed by the client refers to as */gis/road* is physically stored on the server as */master/road*. If the file is on the client's local disk, disk I/O routines will be used. But if the file is on the server, as depicted, NFS will service the request. (Henriksen, 1990, p. 6)

V. CONCLUSION

A. WHAT TO BUY NOW

In deciding which telecommunications service to recommend to the SCACOG for its GIS internetworking needs, the most important criteria are meeting the data rate requirements while staying within the budgeted amount (a non-negotiable grant from the State Government). Indeed, if it is possible to exceed the requirements and do it for about half the money allowed, then all parties are the beneficiary.

At this stage, and given the data researched, it is clear that an integrated spread spectrum system, like that of Persoft, is the best choice primarily because it gives the most bandwidth for the dollar. When compared with unintegrated systems, it is easier to buy and install, easier to maintain by nature of troubleshooting software, and easier to replace worn out components. When compared with the T-1 service provided by Bell South of Greenville, Persoft provides more bandwidth for less money, no monthly charges and no middle-man during operations. Persoft will install the internetwork for approximately $34,500, whereas it will cost the SCACOG $1,326 per month over five years ($79,560) for T-1 service, including an initial installation and equipment cost of $43,759.

Persoft is selected for several other reasons as well. The first of which is its ease of expansion. If another building is to be added to Greenville's GIS internetwork, Persoft will install the new bridge, transmitter, and antenna, as well as set up or realign any necessary equipment. The cost will be around $6,500. To add a building using T-1 will require the following:

1. Install Wiring for $1,245
2. Install Phone Co. Equipment for $3,418
3. Install Remote Bridges for $6,600

This comes to a total initial cost of $11,263. Expansion of one building will also add another $272 per month to the phone bill if the new site is as close to the Central Office as the City GIS office, or more than $442 as month if it is further than the SCACOG.

The next reason for Persoft's selection is the lack of any kind of installation delay. T-1 delays are unknown at this time, but can be as long as 18 months in some areas (Flanagan). Persoft quotes a week to arrive at the latest, and two days to install the five current sites.

The third reason is ease of maintenance. T-1 is reliable, and its maintenance from CSU to CSU is up to the Bell South. However, redundancy is not provided for free, and the limited budget and lack of urgency of the SCACOG precludes its purchasing a parallel set of T-1 lines as a backup. Persoft faults can be repaired by removing and replacing the bad equipment with either on hand spares or by calling Persoft for next day service.

The final reason for advocating Persoft's method of spread spectrum is a 30 day money back guarantee if the installed system does not fully meet the needs of the Greenville GIS internetwork. It is a safe investment in the newest of internetworking technologies, and their use as a first attempt at internetworking, given the budget and requirements, is the right choice at this time.

B. FUTURE CONSIDERATIONS

1. Use and Acceptance

There are, however, considerations that will need to be addressed other than adding a building to the internetwork in the not too distant future; perhaps as soon as installation. This is because the impact on new systems can be diverse and complex. Like this thesis, most of the emphasis has been on technical and economic factors, but side effects can be quite different from those anticipated. (Sprague, Jr. & McNurlin, 1993, p. 547)

The first of which is a rapidly growing use of the GIS internetwork for business other than GIS. Once the connectivity between buildings has been gleaned by the staffs, other business (and likely personal) related matters, such as E-mail, are sure to flourish.

This is good because it shows that the resource is being used properly and imaginatively. However, acceptance of the new system may not come as quickly as needed. To ensure the survival of this new concept, support from top management is imperative. The new internet will require top management approval and leadership throughout to keep it moving (Sprague, Jr. & McNurlin, 1993, p. 556).

Once accepted and in use, one of the best ways to reduce the traffic on the net is by using decentralized storage, as recommended by the Environmental Systems Research Institute, Inc., the developers of ARC/INFO. Since ARC/INFO utilizes a "layered" database, with maps being made by the manipulation and layering of one or several files, the office that uses a particular layer the most should be the holder and manager for that layer (file). (ESRI, 1992, p. 3)

For example, the Sheriff's Office should be the custodian of police beat and crime scene data points and vectors, while the City GIS Office should manage the layers concerned with city tax and development zones. If other offices on the internet should need this information, it will be available to them over the net, but the offices that use the information the most should keep that data on site. This will greatly reduce the traffic on the net, but only in the future. At present, the remote offices only have personnel trained as casual users of ARC/INFO, not data base administrators, so a centralized file server is the only option available until these personnel can be trained or acquired (Hanning, 1993).

2. The Internet

There also exist future targets for further advancement technologically. The first of which is the Internet. This is not an alternative to the GIS internet discussed in this thesis, but a supplement to augment the city's resources. It would be advisable for the concerned parties in Greenville to get with the closest Internet service provider, Greenville College, and initiate actions toward gaining *real* Internet addresses recognized world wide (Buddenburg, 1993). Internet's IP addresses are uniquely assigned so that traffic does not bang into itself trying to get to two different places with the same address. If the Internet makes it into the Greenville GIS internetwork, GIS will only be a small portion of the possible productivity increases because every office served in the area can benefit from being connected to the rest of the world.

Specifically, the Internet allows easier access to information services, such as commercial information databases that contain two terabytes of data, document search and delivery services representing millions of items of library collections, journals and newspapers, as well as a direct line to Sun Microsystems (Dern, 1993). Also, by using TCP/IP, the computers already have the protocol suite required to work on the Internet, if only they were physically connected (Henriksen, 1990, pg 5).

3. Fiber

Since planning for construction and utilities are done by the offices on the GIS net, they will be the first to know about street tearups for the purpose of laying fiber optic cable. With fiber in place between the five sites by the time the Persoft equipment is depreciated out, the growing inter-network needs will be able to slip smoothly into a Fiber Distributed Data Interface (FDDI) or Synchronous Optical Network (SONET) backbone (Buddenburg, 1993). With this technology, the data rates are be measured at 100 Mbps (Stallings, 1991, p. 427).

This was the case in Tallahassee, Florida. To support their GIS needs, the city and county governments installed a FDDI between the city hall, the county courthouse, and the city electrical department because they felt their 10 Mbps LAN could not handle the volume of data required. "From all we have heard, FDDI promises to be a very important technology, at least in the LAN backbone arena, if not for direct connection to workstation and in MANs." (Sprague, Jr. & McNurlin, 1993, p. 181)

APPENDIX

NETWORK OVERVIEW AND CONSIDERATIONS

A. WORKING WITHIN THE OSI MODEL

The International Standards Organization (ISO) has an established Open Systems Interconnect (OSI) seven layered model for networking. Starting at the bottom, these layers are the Physical, Data Link, Network, Transport, Session, Presentation, and Application. How these layers correspond to the TCP/IP used on the LANs in Greenville is shown in Table 1 (Henriksen, 1990).

1. Physical Layer

The first layer, Physical, is concerned with the conversion of data into a transmittable form of ones and zeros. In conjunction with the Transport Control Protocol/Internet Protocol (TCP/IP) and the IEEE 802.3 Ethernets being run by the concerned sites, this layer is the hardware, i.e. the Sun MicroSystems machines used by the GIS personnel for encoding geographic information into bits. The specifics (digital versus analog, and their methods) are not necessary for this discussion. It is enough to know that the Physical layer serves to transmit a bit stream of ones and zeros across a physical connection.

On the Physical layer, 802.3 offers many options, with 10BASE2 mostly in use in Greenville (10 Megabits per second

BASEband (digital) transmission and 200 (actually 185) meters maximum distance between repeaters or nodes).

2. Data Link Layer

The second layer, Data Link, ensures a reliable transfer of data, the bits, between two pieces of connected hardware by performing three functions. The first is Error Control, which is the detection of damaged, lost or duplicate data frames, and then correcting of the fault. The second is Flow Control, which prevents the sender from sending data faster than the receiver can accept it. The third is Access Control, which prevents the simultaneous access by more than one device to a shared transmission media.

Error control is done by Parity checking, Longitudinal and Vertical (2 dimensional) Redundancy checking, or Cyclic Redundancy checking. The first and most simple, Parity checking is performed by restricting data to the first seven bits of a byte with the final bit, called the parity bit, used to make the sum of all eight bits even (for Even Parity), or odd (for Odd Parity).

Longitudinal and Vertical Parity checking works on the same summing principle as Parity checking, but the bytes are stacked into a frame so that sums can be taken of a single byte longitudinally as rows, with a single parity bit appended to the end of each seven data bits, as well as columnarly. However, there is also appended a parity character (byte) to the bottom of the stack to make parity going down as well. In this way, several bytes are checked simultaneously.

Using both Vertical Redundancy (parity bit) and Longitudinal Redundancy (parity character) is still nowhere near foolproof, even though it will detect errors more than simple Parity checking by as much as two to four times (Stallings, 1991, p. 127).

The final and best method of error control is Cyclic Redundancy checking. Very complicated, it uses modular arithmetic and bit stuffing to generate a "frame check sequence" which are divided by predetermined divisors. Three such divisor are CRC-16, CRC-CCITT, and CRC-32, all have accuracy rates exceeding 99.99%. An explanation of the procedures and methods of CRC is beyond the scope of this thesis. (Suh, 1992)

Flow control is achieved by methods such as "Stop and wait" or "Sliding window." Stop and wait is slower and fails to utilize the full capabilities of the channel being transmitted upon. It consists of the first station transmitting a frame of information, and then waiting for an acknowledgement (ACK) from the receiver that the frame arrived safely. The next frame is then sent. In this method, only one frame is in transit at any time.

Sliding Window is a more efficient method of frame transmission by using numbered, sequenced frames from 0 to *n*. At the sender's "window" are a list of sequenced frames to be transmitted. This same list of sequenced frame numbers is also on the receiver's window. This allows several frames to be in transit at the same time without waiting for ACKs from the receiver.

Access control is performed by "Poll and select" or "Contention." Poll and select is used when there is one primary station and the rest are secondary stations. In this configuration, the primary station polls each of the secondary stations for information. Data is transferred only between the primary and any secondary station. After transfer from a secondary station, the primary station selects the receiving secondary station, and transfer occurs. (Stallings, 1991, pp. 153-154)

Contention is less disciplined, and is widely used in LANs. In this form of access control, there are no secondary or primary stations but only peer stations (Stallings, 1991, p. 155). All of the peers are capable of transmitting to any station at any time without having to wait for being polled. The sender attaches its address as well as the receiving address to the data and transmits. The receiver, recognizing its address, grabs the data.

Ethernet's philosophy is Carrier Sense, Multiple Access/Collision Detection (CSMA/CD), best described as "listen while talking." A computer on the network that has data for another computer transmits its information and listens to the line while it is transmitting. If a collision is detected with some other computer's transmitted data, both computers stop transmitting, wait a random (and different) amount of time (measured in microseconds), and then retransmit.

Ethernet splits the Data Link layer into the Logical Link Control (LLC) and the Medium Access Control (MAC). Remember, the Data Link layer is responsible for error, flow and access control. MAC performs the access control (CSMA/-CD), and the LLC performs the error and flow control (802.2, a superset of Ethernet).

3. Network Layer

The third layer, Network, is responsible for the interaction of devices on a network or group of networks and to handle the details of using the network. The 802.3 Ethernets that are in use operate on both this layer and on the Data Link layer as discussed above, which may be a little confusing.

As the Ethernet protocol splits itself into two different layers of the OSI model, the Network layer also splits, with IEEE 802 occupying the lower (*intra*network) portion and the Internet Protocol (IP) occupying the upper (*inter*network) portion. These splits are depicted in Table 1.

IP is a portion of the TCP/IP protocol suite originally issued and used by the Department of Defense, and is now accepted as an internetworking standard. It acts as an addressing system so that a computer on one LAN can communicate with another computer on a totally different LAN provided the hosts of each of the LANs are somehow connected. On DOD's Internet, hosts are connected in the X.25 "cloud" of transparency that is invisible to the users. In the case of Greenville's GIS needs, the cloud that connects the hosts can be determined by this thesis.

TABLE 1

THE LAYERED NETWORK MODEL

ISO OSI Reference Model		TCP/IP Protocols
Application		ARC/INFO
Presentation		Telnet/FTP
Session		...
Transport		TCP
Net-work	Inter	IP
	Intra	IEEE 802.3
Data Link		
Physical		Hardware/10BaseT

Typically, the address will take the form *x.x.x.x* where each *x* is a decimal representing four binary digits (Suh, 1992). To provide addressing, IP breaks its addresses into three classes depending on the size of the LAN. Using a 32 bit format, the address contains a prefix, the network identification, and the computer identification. The three classes dictate how many bits will be allotted for each of the three contents of the address.

The addressing formats are listed in Table 2 (Suh, 1992). The Prefix column shows what the actual address prefix is, while the identification columns contain the number of bits in that part of the address.

TABLE 2

INTERNET PROTOCOL ADDRESSES

	Prefix	Network ID	Computer ID
Class A	0	7 bits	24 bits
Class B	10	14 bits	16 bits
Class C	110	21 bits	8 bits

For example, very large (class A) networks will have only a few bits for the network identification because there are few very large networks, but will have many bits to address the computers because there will be very many of them. Conversely, small (class C) networks like the ones in use in Greenville will have many bits allotted for the network identification because there are many little networks using IP addresses, and fewer bits to identify the smaller number of individual computers within each network.

In addition to providing the standard for addressing across (or within) networks, IP also serves to define the format of the datagram (a self contained packet of information that has both "to" and "from" information) that is to pass between networks. This format will dictate variables like the version, header lengths, type of service, etc., of which the specifics are beyond the scope of this thesis.

IP could be referred to as layer 3.5 because it sits on top of the Network layer, but is also called upon by the Transport layer (Stallings, 1991, p. 454). It serves as an address and format system for one computer to address another computer across different LANS or within the same LAN (how packets move within and out of LANs is discussed later in **Bridges**). Unfortunately, the much needed error and flow control of data at that layer is not provided by the error and flow control of the Data Link layer. That function is reserved for the Transport Layer.

4. Transport Layer

The Transport layer can be either Connection-oriented Transport Service or Connectionless-oriented Transport Service. Connection-oriented is used to ensure a reliable "end-to-end" delivery through error and flow control and making sure the packets are reassembled in the correct sequence. This is performed through a logical connection that is established for the communication, is maintained throughout the transmissions, and is then terminated. TCP is used for this kind of service. (Suh, 1992)

Connectionless-oriented is supported by the UDP (User Datagram Protocol) and favors speed over reliability (Henriksen, 1990, p.5). Since the applications being run in Greenville require accuracy and reliability, the discussion of UDP is not relevant.

For end to end error and flow control across different LANs, TCP is used with IP to form TCP/IP. When the reliability and addressing functions are performed at this higher level on the model across LANs, what happens below that is transparent to the user. Therefore, the Physical and Data Link layers are of no concern to the general users of Greenville's GIS internet (Buddenburg, 1993).

The next three layers are considered the upper layers, and are the users of the network. When dealing with TCP/IP protocols and ARC/INFO, these three are all considered the Application layer (Henriksen, p. 1, 1990).

5. Session Layer

This layer manages the flow of data over the logical connection by providing and management and structuring of the exchanged data (Stallings, 1991, p. 637). It is called Session because the connection established between two application processes is referred to as a session, and it is here where messages are sent as directed and needed interruptions are inserted (Stallings, 1991, p. 455).

6. Presentation Layer

This layer presents the bottom layers to the top, Application, layer. It is concerned with the syntax used and translates data to and from the language and format used at the Application layer (Sprague & McNurlin, 1993, p 195).

Examples of presentation protocols are encryption for secure data transfer as it leaves the process, and virtual terminal protocols which allows terminals of all types to access one another.

7. Application Layer

This is the applications, like ARC/INFO, which when networking will provide functions and mechanisms to support distributed applications and data. File transfer protocols, as well as those of electronic mail are contained in this layer.

B. BRIDGES

Homogeneous LANs can most simply be internetworked through the use of an Interworking Unit (IWU) called a bridge. Homogeneous means that each of the LANs are using identical protocols for the physical and medium access layers (e.g. IEEE 802.3 Ethernet). To plainly explain the use of a bridge, the internetworking of two LANs (X and Y) will be used as an example. To connect these two LANs (referred to as subnetworks) to form an internetwork within the same building, a single bridge (B) is connected by network cabling to the two LANs: X - B - Y. This accomplishes several very important things.

The two LANs still operate just as they have in the past when they were working within their own local area, but when a station on subnetwork X has information (frames) for subnetwork Y, the bridge recognizes the address as being on the other subnetwork and the frames are passed across the bridge and into Y using the medium access control (MAC) protocol.

This is an improvement over having one large LAN because unless frames in X are destined for a station in Y, there is no need to add to the congestion in Y that they don't need. But more importantly, frames that do need to get from X to Y can now do so with a minimum of performance (speed) degradation.

Reliability in two subnetworks versus one large network is enhanced because if a network-killing fault occurs in the large network, the entire network is out. However, if X and Y are bridged, and the same fault occurs on X, Y will continue to operate as a functional LAN. (Stallings, 1991, p. 515)

In addition to the above basic functions of a bridge, there also exist some design considerations. The first of which is the bridge does not in any way modify the information it receives. The second is the bridge should have some buffering capability. This is needed because there will be peak times when frames arrive at the bridge faster than it can transmit them. The untransmitted frames need to be "held" at the bridge and then transmitted during on opening rather than be sent back to the transmitting workstation. As an analogy, consider being put on hold briefly rather than getting a busy signal and having to redial. (Stallings, 1991, p. 516)

The third consideration is the contents of the bridge. At a minimum, sufficient address information must be present so that the bridge knows whether to route the frames it receives to the other subnetworks, or keep them on the receiving side. Where cascading bridges occur as the number of subnetworks increase past two, bridges need to know what bridge to pass the frames to.

For example, if three subnetworks are internetworked in a bus format with bridges one and two, X - B1 - Y - B2 - Z, the frames transmitted in X for destinations in X are looked at by B1 but do not cross into Y. If frames in X are transmitted to Y, B1 recognizes the destination address as being in subnetwork Y and the frames are allowed over the bridge into Y for further delivery to the receiving station.

But what happens when X has information for Z? B1 has to have routing information (address tables) that give it the ability to recognize the addresses in Z as well as the ability to know to send such addressed frames to B2 for further delivery to Z.

In the case of the Greenville GIS internetwork, the subnetworks will not be connected at the MAC layer by network cabling. In the utilization of a telecommunications media like T-1 and using CSUs, the subnetworks are connected by a bridge at each site with the CSUs and T-1 communications facility in the middle.

X - B1 - {CSU ----- T-1 -----CSU} - B2 - Y

In the above point to point link, B1 will capture X's frames destined for Y at the MAC layer, append Logical Link Control (LLC) layer information (headers and trailers) to the frame, and then transmit the frame across the T-1 facility. At B1, the LLC information is stripped off, and the unmodified MAC frame is then released into Y for its destination station. (Stallings, 1991, p. 517)

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