Designing and Implementing a Wide Area Network for Pabco Fluid Power Company

By

Joel Edward Harder

Submitted to
the Faculty of the Information Engineering Technology Program
in Partial Fulfillment of the Requirements for
the Degree of Bachelor of Science
in Information Engineering Technology

University of Cincinnati
College of Applied Science

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Author: Joel Edward Harder	3/7/01 Date
Faculty Project Advisor	3/7/01 Date
Department Head	3/7/01 Date

Dedication

I would like to dedicate this work to Roberto Williams and Dr. Ashraf Saad.

Roberto, thank you for the three years of mentoring that you have given me while I was employed at Pabco. You have always looked out for my best interests and have taken your own time to help me along in my career. I appreciate everything you have done for me.

Dr. Saad, thank you for taking a personal interest in my education, for always giving me good advice, and for going the extra mile for me and your other students at the University of Cincinnati.

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Abstract

Pabco Fluid Power Company has five branches throughout Ohio and Michigan. These branches have no network connectivity except through a system designed to let users access their main business software and a Remote Access System to access Cincinnati's LAN through a slow dialup connection. This lack of connectivity prohibits Pabco from effectively offering many services now common among corporate networks to these outlying branches. These services include file sharing, access to printers, E-mail, Internet access, Intranet sites, databases, and many other network applications.

This project will design and implement a Wide Area Network infrastructure that will allow users in each of Pabco's branches to access such applications. This project will eliminate the need for their obsolete network hardware and slow dialup connections. This network infrastructure should also be completely transparent to the end users.

The WAN will be composed of T1's connecting the LAN's in each branch. These T1's will be terminated by Adtran CSU/DSU's which will then pass the data to Cisco routers into the networks in each branch.

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1. Statement of Problem

1.1 Introduction to Pabco

Pabco Fluid Power Company is a manufacturer of hydraulics systems and a distributor of hydraulics components. They have been in business since 1964 and have five branches throughout Ohio and Michigan.

The Cincinnati branch is home to Pabco's corporate offices. It has a full Sales staff, Engineering department, Accounting department, and IS department as well as a complete warehouse and manufacturing facility. Pabco's computer and network operations center resides here. The Detroit branch also offers full Sales and Engineering departments as well as a complete warehouse and manufacturing facility. Pabco also has smaller sales offices with a skeleton stock located in Dayton, Columbus, and Saginaw, MI. The two larger branches consist of approximately 40 employees each and the smaller sales offices consist of 5 to 10 employees each.

1.2 Pabco's Information Systems

At the start of this project Pabco's Information Systems consisted of two main components, their business software and a very limited network. They also used Internet Service Provider's for Internet and E-Mail access.

1.2.1 Business Software

Pabco is using a software package called Tribute. It is a software package that is widely used in the hydraulics industry. This package manages and tracks inventory, sales, quotes, accounting, customer contact, manufacturing, and engineering data.

This system is hosted on an IBM RS/6000 server running AIX 4.3 (a version of Unix). It was originally hosted on a Basic Four mainframe system. During the conversion to the RS/6000 system from the Basic Four System Pabco has reused peripheral equipment such as dumb terminals and line printers. All of Pabco's users have direct access to this software via permanent 56K leased lines to each of the branches. This speed is sufficient because the software is all text based and does not require a lot of bandwidth.

Pabco has plans to utilize other business software such as Goldmine for managing sales contacts, Microsoft Exchange Server for E-mail, Internet Information Server for an internal website, Microsoft SQL Server for Data Warehousing, as well as a Cold Fusion based E-Commerce server. Pabco's users will require connectivity to all of these applications, but currently users at the remote branches would have no way of accessing them except though a slow dial-up connection.

1.2.2 Network

Pabco's network consisted of a Local Area Network in the Cincinnati branch. This network allowed Cincinnati users to access each other's computers and printers, the Tribute software on the RS/6000 using terminal emulation, and a small file server where users could store their data.

The other branches were connected to Cincinnati via 56Kbps Leased Lines (DS0's) and Digiport Terminal Servers, see Figure 1. This only allowed users to access the Tribute software using terminal emulation through a connection from their comm port to the terminal server located in each branch. These computers, dumb terminals, and printers were connected to the terminal server in each branch via existing Cat 5 cabling.

The terminal servers in each branch connected directly to the RS/6000 in Cincinnati. Essentially all the computers, dumb terminals, and terminal servers were seen as devices hanging directly off the RS/6000. The computers in the branches could not see each other, share files, printers, or other devices.

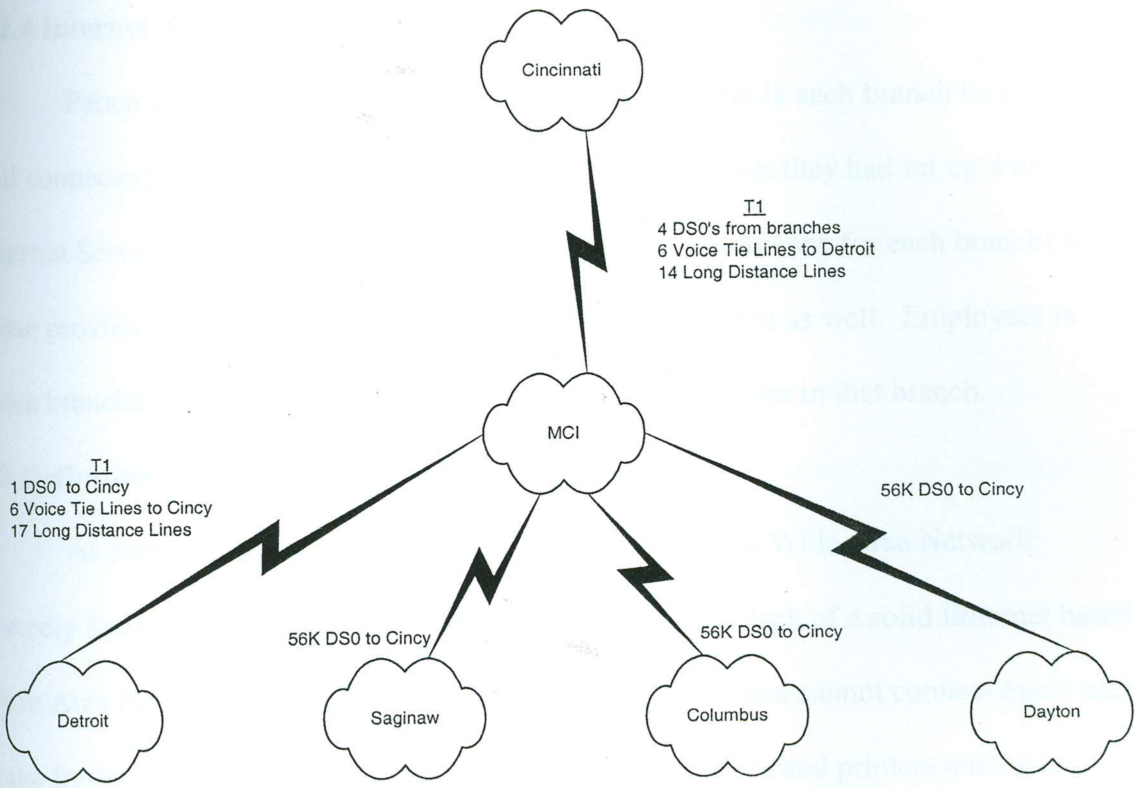

Figure 1.
Pabco's Existing WAN

If users at the remote branches needed access to any files stored in Cincinnati they could only connect to the LAN via a dialup connection on one particular PC in each branch to a Remote Access Server (RAS) in Cincinnati. This RAS server was also used to let outside salespeople connect to Tribute while on the road or at home.

1.2.3 Voice Network

Pabco has PBX's in Cincinnati and Detroit. The other branches have smaller key telephone systems. They have two T1's that are primarily used for voice services. They have one T1 in Detroit that has 17 long distance lines, 6 voice tie lines to Cincinnati's PBX, and one channel (DS0) for data traffic to Cincinnati. The other T1 goes to Cincinnati with 14 long distance lines, the 6 voice tie lines from Detroit, and the 4 data DS0's from the branches. See Figure 1.

1.2.4 Internet Access and E-mail

Pabco had no direct Internet connection. A few users in each branch had modems and connected to the Internet very rarely using dialup accounts they had set up with Internet Service Providers. They also had five email accounts (one for each branch) with those providers and connected to those via a dialup connection as well. Employees in those branches had to share one Email account among everyone in that branch.

1.3 Definition of Need

As seen through the previous discussion, the lack of a Wide Area Network severely limits the technology that Pabco can use. With the lack of a solid Ethernet based Wide Area Network infrastructure that supports TCP/IP, Pabco cannot connect every user to the Internet, give each user their own Email box, share files and printers among all users, or offer countless other possible services.

The Internet has standardized TCP/IP as the "de facto standard" for transmitting data over networks and Ethernet has become the standard platform for networking. Pabco needs a Wide Area Network that interconnects every branch, which will support these protocols.

2. Review of Literature

2.1 Networking

For the past few decades networks have been installed everywhere; in businesses, colleges, schools, government offices and even homes. They allow people to share resources, access published data, communicate more effectively and efficiently, work on documents together, and much more. Businesses are run on information regardless of the industry. Each business has information about inventory, payroll, accounts, contacts, customers, suppliers, and manufacturing. The accessibility, organization, and distribution of this information is vital for businesses to survive.

Another key element for productive business is easy and efficient communication between employees. The easier it is for employees to communicate to each other and access this data, the more efficient they will be when performing their jobs. Networking was the computer industry's solution to this problem. Networking takes individual computers from anywhere in the world and links them together. By doing so they allow individual computers to access common databases, software applications, e-mail systems, the Internet, and an endless collection of other resources.

There are several standards that have risen to the top that most networks support. The two most common standards that networks support are TCP/IP and Ethernet. The Internet has made TCP/IP and Ethernet the default standards of network communication. This allows network applications such as e-mail servers, web servers, and databases to be designed independent from the network infrastructure. Although other standards exist and are used, these standards allow different hardware platforms, operating systems, and network infrastructures to work together in one large network.

2.2 Wide Area Networking

Networks often span cities, states, and countries. These networks are called Wide Area Networks or WAN's. They connect smaller Local Area Networks (networks within one physical building or site) or LAN's together. Over the past two decades the method for connecting these LAN's together has evolved as the need for pipes of greater and greater bandwidth has increased.

The Internet is one example of a Wide Area Network. It is made up of thousands and thousands of smaller networks all woven together through a multitude of different types of connections.

2.2.1 Methods of Connecting

Originally people connected to networks that were such large distances away by utilizing the existing phone system networks via modems. This system allowed transmission of data initially at very slow speeds of 300bps (bits per second) and over time as more efficient technology evolved to a maximum of 56,000bps. As it became clear that this medium was very limited in bandwidth other types of connections surfaced such as DS0's (64Kbps), DS1's or T1's (1.544Mbps), DS3's or T3's (44.736Mbps), ISDN (128Mbps), OC-x or SONET lines (fiber connections ranging from 51.85Mbps across an OC-1 to 13.27Gbps across an OC-256) and most recently DSL lines ranging from 1.5Mbps to 9Mbps downstream (to the subscriber) and 16Kbps to 800Kbps upstream (from the subscriber).

Each technology has different physical requirements such as the type of line (copper or fiber) and the number of those lines (2 pair of copper lines, 4 pair, 8 pair, etc). Lines that can use existing copper lines are less expensive than those that new fiber lines.

As the distance between the networks increases the cost to connect them increases as well. Also as the amount of bandwidth increases the cost increases. You must analyze the networking scenario carefully so that you choose the correct type of line. Most important in that analysis is how much bandwidth the applications using those lines will require.

2.2.2 Protocols

Once the type of line is chosen, depending on the type of line, you will have to choose what protocol will be used. For example with T1's you can use Point-to-Point or Frame Relay. Each protocol offers different advantages. Point-to-Point offers a set amount of bandwidth. Frame Relay allows you to set a minimum bandwidth and allows you to "burst" up to a set higher bandwidth as the telecommunication carriers network has slower traffic. This allows telecommunication carriers to let more customers use a minimum amount of bandwidth and share the rest of the bandwidth with each other for a reduced price. Some lines such as ADSL do not offer you a choice of protocols.

Once a protocol is chosen, sometimes a "sub protocol" is chosen that determines how the line will be used. For example in a Point-to-Point T1 you can control how the data is transmitted by choosing the framing and coding formats.

There are two main framing formats for Point-to-Point T1's, Super Frame (SF otherwise known as D4, traditionally used by all of the Bell telephone companies) and Extended Super Frame (ESF). They just control the way the data is transmitted and like many protocols, one has evolved from the other but with increased efficiency or offers new benefits that the other doesn't.

There are three types of line code formats associated with T1 lines. The AMI line code format can be used with voice or data. Voice channels use the full 64Kbps of bandwidth and data channels are restricted to 56Kbps of bandwidth. The B7 line code format is used in voice only applications. The Bipolar 8 Zero Substitution (B8ZS) line code format allows 64Kbps to be used for either voice or data.

2.3 Hardware

In order to use different types of communication lines you must have the proper hardware to terminate the lines at the site. For example if you chose to use a T1 to connect your networks you will need a Channel Service Unit/ Data Service Unit (CSU/DSU) and a router.

The purpose of the CSU/DSU is to terminate and condition the line. It also allows you to multiplex a combination of different signals for different services (such as voice, video, or data) into one T1 line. A multiplexor formats (or merges) the data to allow 2 or more signals to pass over one communications circuit at the same time. The CSU/DSU provides access to the digital channels that make up the T1 and perform functions similar to modems. They take data from the network, encode it, and then send it down the pipe. The receiving end has another CSU/DSU to receive the signal, filter it, and decode it.

The purpose of the router is to direct or "route" the network traffic to the network that the traffic is intended for. When there are many networks the router has to decide which one the traffic is supposed to go to.

3. Description of the Solution

3.1 Solution

The solution consists of creating a Wide Area Network to each branch using Point-to-Point fractional T1's. There will be a T1 to each branch and they will be cross connected by the telecommunications carrier into one T1 in Cincinnati, as shown in Figure 2.

Each of the branches will have 6 of the 24 channels dedicated to the data circuit to Cincinnati's LAN for a total of 24 channels (4 T1's times 6 channels) coming into Cincinnati (see Appendix A for a specific channel by channel breakout). We must also accommodate for the existing voice services via the existing T1's.

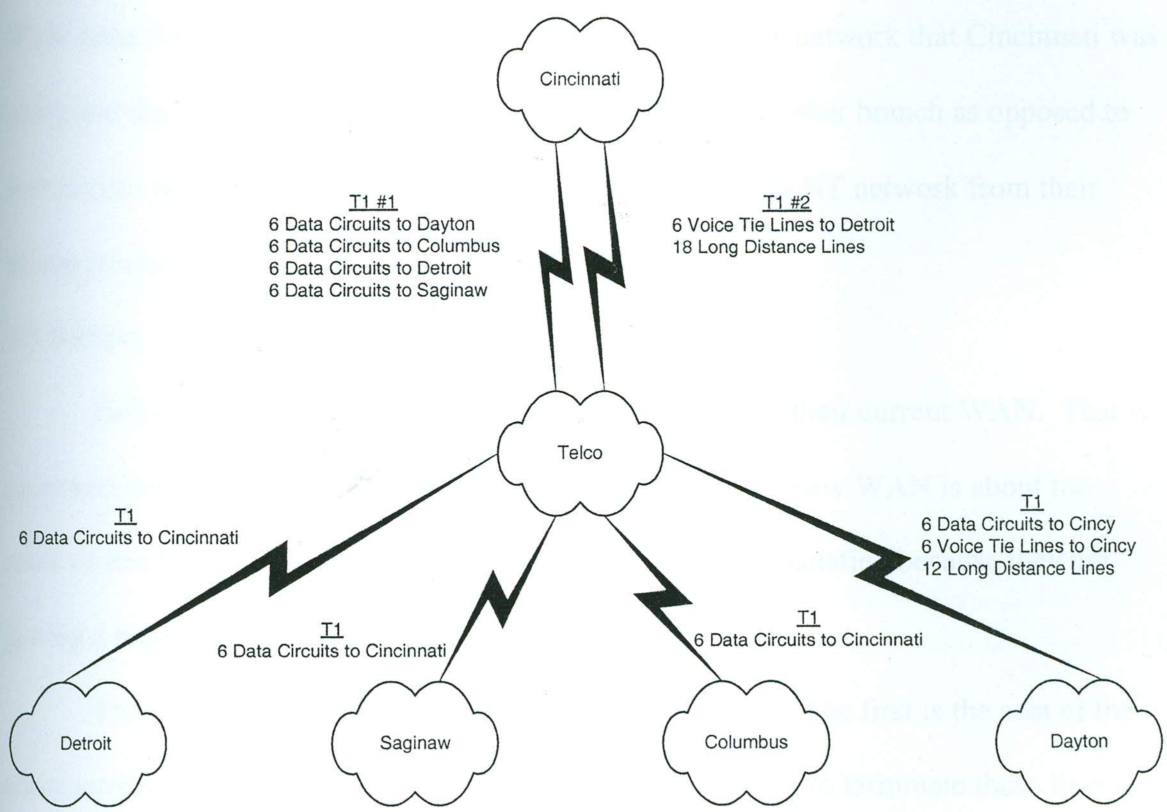

Figure 2.
Pabco's New WAN

The T1's will be terminated in each branch by a CSU/DSU. The CSU/DSU will pass the voice channels to the PBX's in Cincinnati and Detroit and pass the data channels to the routers in each branch.

These routers will allow communication between the Local Area Networks that will be set up in each branch. Each branch will have their own subnet and their own LAN. Each PC will be connected to the LAN by a hub or a switch.

3.2 User Profile

The WAN should be completely transparent to the end users in each branch. Once their PC has been correctly configured it should appear as if the five separate networks are one large network. End users should not have to know anything about the Wide Area Network except how to log into the Windows NT network that Cincinnati was using and that it takes a little bit longer to transmit data to another branch as opposed to within their branch. The users are familiar with the Windows NT network from their dialup connections. The login process only changes slightly.

3.3 Budget

Pabco is currently paying about $8,600 per month for their current WAN. That is approximately $103,000 per year. As long as the cost for the new WAN is about the same or less than the cost of the current WAN then Pabco is satisfied because they are getting a better WAN for the same price or less.

There are two areas where this project will incur cost. The first is the cost of the telecommunications lines. The second is the hardware needed to terminate these lines and to network the branches together.

3.3.1 Telecommunications

Pabco currently has two T1's, one in Cincinnati and one in Detroit. They also have 3 DS0's to the smaller branches. In Figure 3 you will see a table that breaks out the current telecommunications costs.

Each DS0 and DS1 has two types of charges. The first charge is the local loop. The local loop is just the local connection to the telco point of presence (POP). The second is the long haul. This is the fee for the distance between the POP's. You will also notice a column for the channel service charge. This is a charge for the data service across the channels of the T1's. The voice tie lines are treated like data lines in this circumstance because they are seen as data lines between the PBX's.

Branch	Local Loop MRC	Channel Service	Long Haul MRC	Total MRC
DS1 Cincinnati	$ 249.75		$ 419.37	$ 669.12
Data Channel to Detroit		$ 460.64		$ 460.64
Data Channel to Saginaw		$ 460.64		$ 460.64
Data Channel to Columbus		$ 460.64		$ 460.64
Data Channel to Dayton		$ 460.64		$ 460.64
Tie Lines to Detroit (x6)		$ 230.32		$ 1,381.92
DS1 Detroit	$ 262.36		$ 451.25	$ 713.61
Data Channel to Cincinnati		$ 460.64		$ 460.64
Tie Lines to Cincy (x6)		$ 230.32		$ 1,381.92
DS0 Saginaw	$ 273.08	$ 50.00	$ 468.34	$ 791.42
DS0 Columbus	$ 199.49	$ 50.00	$ 409.86	$ 659.35
DS0 Dayton	$ 258.05	$ 50.00	$ 393.31	$ 701.36
Monthly Totals:	$ 1,242.73	$ 2,913.84	$ 2,142.13	$ 8,601.90
Yearly Total:				$ 103,222.80

Figure 3.
Pabco's Old Telecommunications Charges

As you can see the yearly total is quite expensive. With the drop in telecommunications charges over the past few years we were expecting these numbers to drop significantly and they did. This is part of the reason why we were able to install

T1's instead of DS0's at each branch. This yearly total is the driving force in our budget. Our overall costs must stay below this number.

3.3.2 Hardware

When trying to establish a hardware budget for this project we must look at how long it would take to see a return on our investment. Looking strictly on cost savings, rather than the benefits this network would offer, we would like to see a return on investment in hardware equipment within one years. For example, if we cut the yearly telecommunications total by $20,000, then we would be able to spend $20,000 on hardware.

Using a return on investment method is an effective way of justifying the spending of capital on equipment. This method lets us calculate the time it would take to pay off the investment in equipment from the savings that this project will produce. Telecommunications carriers usually look for a return on investment in equipment in under a year, sometimes in as little as three to six months.

We were anticipating a cut in the telecommunications cost by about $40,000 to $50,000. However, we did want to show an immediate cost savings so we would like to only spend $20,000 to $25,000 on hardware. This amount should be sufficient to cover the costs of such hardware, but we do have some flexibility if we cannot quite meet that budget.

3.3 Timeline

This project was scheduled to be completed by June of 2000. All the branches must have their LAN's set up and be a part of the wide area network by this time. There will be four main phases to this project as shown on the gantt chart in Appendix B.

Those phases include the analysis of the problem, researching a solution to the problem, designing the solution, and implementing the design.

In analyzing the problem we must first determine exactly what the problem is. By knowing the problem we can then determine the requirements of solution, the timeline that we have to implement the solution, and a budget for the solution.

The second phase is researching the solution. This consists of research to determine possible alternatives for the solution, the cost of those alternatives, a broad plan for each possible alternative, and the advantages and disadvantages of each solution. This phase will be concluded by chosing one of the possible solutions. Usually the choice of this solution is made easier as you investigate the different solutions and costs. Your research will usually make one particular solution rise above the rest.

The third phase consists of designing the solution. In this case this includes designing the network, choosing the hardware and hardware configurations, determining the amount of bandwidth required, negotiating pricing on both hardware and telecommunications lines, and comparing that pricing to our budget to assess budget feasibility.

The last phase consists of implementing the solution. This includes chosing a telecommunications carrier, writing and signing a service contract, procuring, configuring, and testing equipment, and installing the lines and equipment at the branches. This phase concludes with configuring the PC's and servers for the new network, testing the network, and educating the users about the new network.

4. Objectives

The new WAN expansion must meet the following criteria:

1) Give every branch access to each other's networks.
2) The WAN must be completely transparent to end users.
3) The design must support Ethernet and TCP/IP based applications such as:
    i. Microsoft Exchange
    ii. Microsoft SQL Server
    iii. Internet Information Server
    iv. Windows NT 4.0 and 2000
    v. Other networking protocols, specifically DHCP, WINS, and DNS.
4) A permanent Internet connection must be able to be easily integrated into the WAN.
5) The need for dial up access from the branches must be eliminated.
6) Old multiplexing and terminal server equipment must be phased out completely.
7) The WAN must be designed in such a way as to support IP based telephony and Voice Over IP based communication in the future.
8) WAN outages must be easily detectable and any problems must be pinpointed easily.
9) Until the conversion to the new WAN is completed, tested, and proven functional and free of problems, the old WAN must remain in place and fully functional.
10) This WAN design must set the standard for all future Wide Area Network expansions for Pabco.

5. Design and Implementation

The design of this project includes two main areas, the LAN's in each branch and the WAN connecting them. The design of the LAN's is fairly simple and will be discussed in section 5.1. The design of the WAN is more complex and will be discussed in section 5.2. A summary of all the resources needed will be discussed in section 5.3. Also in section 5.4 the steps for implementation will be covered.

5.1 Local Area Networks

There are three main components to Pabco's LAN's; the PC's that will be connected, the cabling that connects them to the hub, and the hub and/or switches that connect the individual PC's together.

5.1.1 PC's

Fortunately Pabco already owns all the PC's that we will need. They use them to connect to the RS/6000 in Cincinnati via terminal emulation. The only modification that will be needed is to add a network card to those that do not have one and configure the PC to use TCP/IP, log into the network, and use DHCP to obtain the correct network settings from the servers in Cincinnati.

The network cards that we will be using are 3Com network cards. We chose 3Com for a couple reasons. First, they are on of the top network card manufacturers. They are known for their quality and support. Second, drivers for them are often included in the operating systems driver library and they are compatible with most client operating systems, Windows, Linux, etc.

The network cards we chose also have a light indicator on the back that indicates if there is a good network connection. This is essential for trying to remotely walk an end user through troubleshooting a network issue.

5.1.2 Cabling

Every computer that is connected to the network must be connected to a hub or a switch in each branch. Again fortunately for Pabco they were using Cat 5 cabling to connect each PC to the terminal servers in each branch. This Cat 5 cabling is capable of supporting an Ethernet based network.

5.1.3 Hubs & Switches

Each branch will have their own hub or switch. The branches have the following number of end users and need the following number of ports:

Branch	Number of End Users	Ports
Cincinnati	30	96
Detroit	20	36
Columbus	8	24
Saginaw	6	12
Dayton	5	12

Figure 4.
Pabco's End Users By Branch

As you can see in Figure 4 Cincinnati has enough ports for about triple the number of end users. Cincinnati will have more servers and network devices (such as printers and networking equipment) than any other branch. Cincinnati also has several extra network connections throughout the rest of the building that are used for things such as training classes and employees that travel down to Cincinnati.

The other branches will need enough ports for the end users, a couple networked printers, network equipment, and a server or two. When designing a network you must accommodate for future growth. If you cannot access the potential for growth, it is a good rule of thumb to have about a third of your ports reserved for future growth.

5.1.4 IP Addressing Scheme

Each LAN will have its own subnet and IP address range. Cincinnati's current LAN uses the IP addresses in the 10.1.0.0 range with a class B subnet mask (255.255.0.0). It would be a good idea to follow a similar convention with the other branches but if we were to change their address range now would be the time to do it.

Lets look at the advantages and disadvantages of that specific IP address range. The only big disadvantage is that that address range is non-routable on the Internet. This means that those computers cannot directly connect to the Internet. They would have to go through a secondary server or router that translates their IP address for them, such as a Proxy server or a router running Network Address Translation (NAT). This could limit what applications can be accessed on those PC's or servers.

However non-routable IP addresses is not necessarily a disadvantage. First, you would have to buy a block of IP addresses from an ISP that would have enough addresses for all those PC's and servers. Second, it is much more secure to use non-routable IP addresses and hide them behind a firewall or router.

Also, it might be a little confusing to some people because the 10.1.0.0 addresses are Class A IP addresses (any IP address beginning with 1 to 126) and would normally have a Class A subnet mask (255.0.0.0). However, Pabco is currently using a Class A address with a Class B subnet mask.

Again this is not really a disadvantage, and in fact it actually a well thought out idea. If you look at the table in Figure 5 you will see the different Private IP Address ranges. To the right of those ranges you will see the common subnet masks used with each class and the total number of networks and hosts that combination will give. As you can see the number of networks versus hosts is not that great. You can have either one network with millions of hosts, up to 15 networks with a couple thousand hosts, or up to 254 networks with only 254 hosts each. What if you need 16 networks with more than 254 hosts on one of them? It is impossible without modifying the subnet mask.

Class	Range	Mask	Networks	Hosts/Network
A	10.0.0.0 – 10.255.255.255	255.0.0.0	1	16,777,214
B	172.16.0.0 - 172.31.255.255	255.255.0.0	15	16,382
C	192.168.0.0 - 192.168.255.255	255.255.255.0	254	254
Pabco	10.0.0.0 – 10.255.255.255	255.255.0.0	254	16,382

Figure 5.
Private IP Address Ranges

Below the normal ranges and masks, you will see Pabco's current IP address range. Notice how if you modify the subnet mask to add one more octet to the network portion of the address range you will see that the number of networks and number of hosts per network is more optimal. This leaves Pabco enough networks to accommodate any future growth, but still leaves more than enough room for clients on each network.

Currently the only subnet that Pabco uses is 10.1.0.0 with a subnet mask of 255.255.0.0. This subnet is for the Cincinnati LAN. This scheme is perfect for what we want to do. We can easily add more subnets and not have to change the existing IP addressing scheme as well as all the PC's, servers, and other hardware using IP addresses. We are going to need four more subnets for the branches. As shown in Figure 6 we will just increase the number in the second octet by one for each subnet.

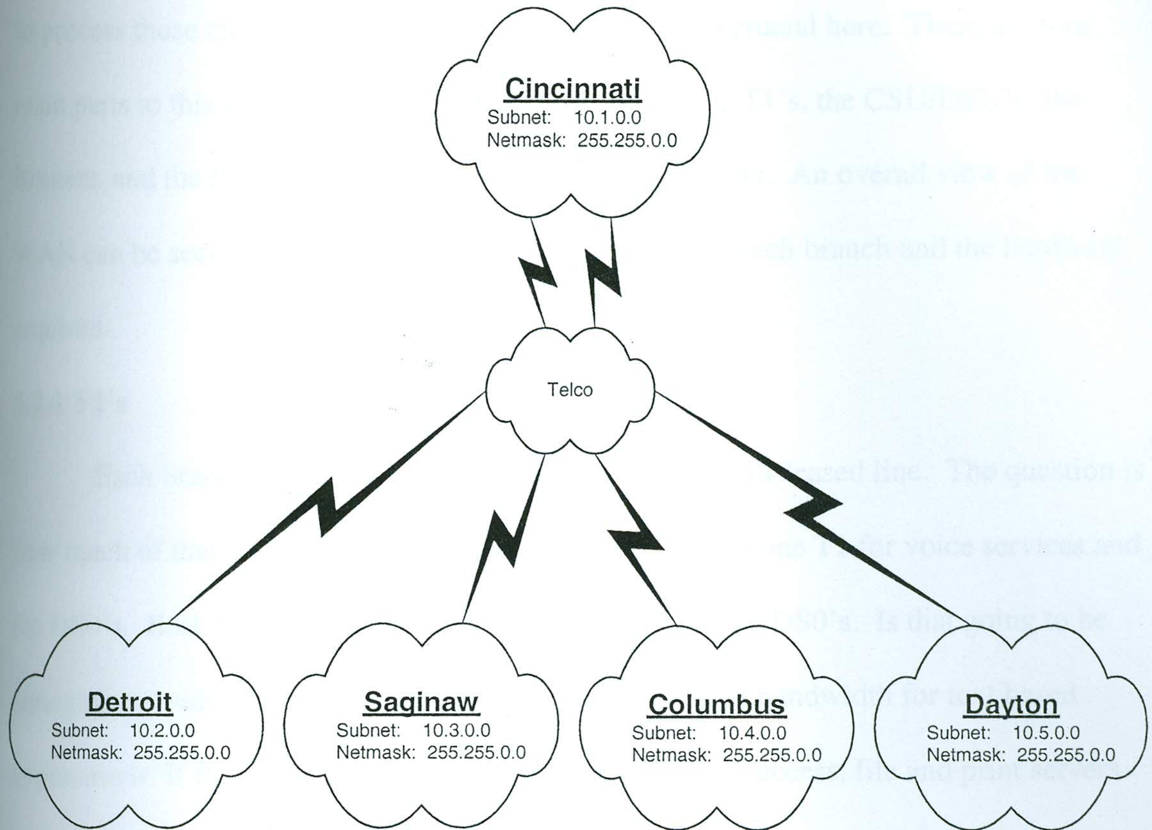

Figure 6.
LAN IP Subnetting Scheme

Each subnet will use the address range 10.x.0.1 – 10.x.0.255. In order for administrators to easily identify the type of equipment we will use specific ranges within that range for specific types of hosts. For example, in each subnet the users PC's will fall between 10.x.0.100 and 10.x.0.200. In Appendix C you will find the breakouts for the IP addresses in each specific subnet.

5.2 Wide Area Network

The Wide Area Network configuration is more complex and requires more planning. When a telecommunications provider is used it takes at least 15 to 30 days to determine the pricing and process the paper work before the T1 can be ordered. It takes another 30 to 45 days to install and test the T1. Once in place this part of the network will hardly ever change except for the addition of new branches because it takes so long to process those changes. That is why the planning is so crucial here. There are four main parts to this component of the project. They are the T1's, the CSU/DSU's, the Routers, and the IP Addressing Scheme between the routers. An overall view of the WAN can be seen in Figure 7 on the next page. It shows each branch and the hardware required.

5.2.1 T1's

Each branch will be connected to Cincinnati via a T1 leased line. The question is how much of that T1 will we use? Cincinnati already uses one T1 for voice services and the DS0's. Each branch already has a 56Kbps pipe through DS0's. Is that going to be enough bandwidth? Currently that 56Kbps pipe is enough bandwidth for text based applications. If Pabco is going to be adding email, Internet access, file and print servers we better increase the bandwidth, but how much? If we only want to add one more T1 to Cincinnati because they are so expensive (between $600 and $900 a month) then we are limited to 24 64Kbps channels in Cincinnati. To avoid adding another T1 to Detroit we are going to steal some long distance channels since a report from the PBX showed they are hardly ever completely used at one time. We decided to divide those 24 channels equally among all the branches leaving 6 channels per branch. With 6 channels per branch and 64Kbps per channel this gives us a 384Kbps pipe to each branch.

Every T1 can use different types of framing and coding as discussed in section 2.2.2. In this application we are going to use ESF and B8ZS. We are using ESF because it uses the bandwidth more efficiently and B8ZS so that we can have both voice and data channels using 64Kbps instead of just 56Kbps per channel.

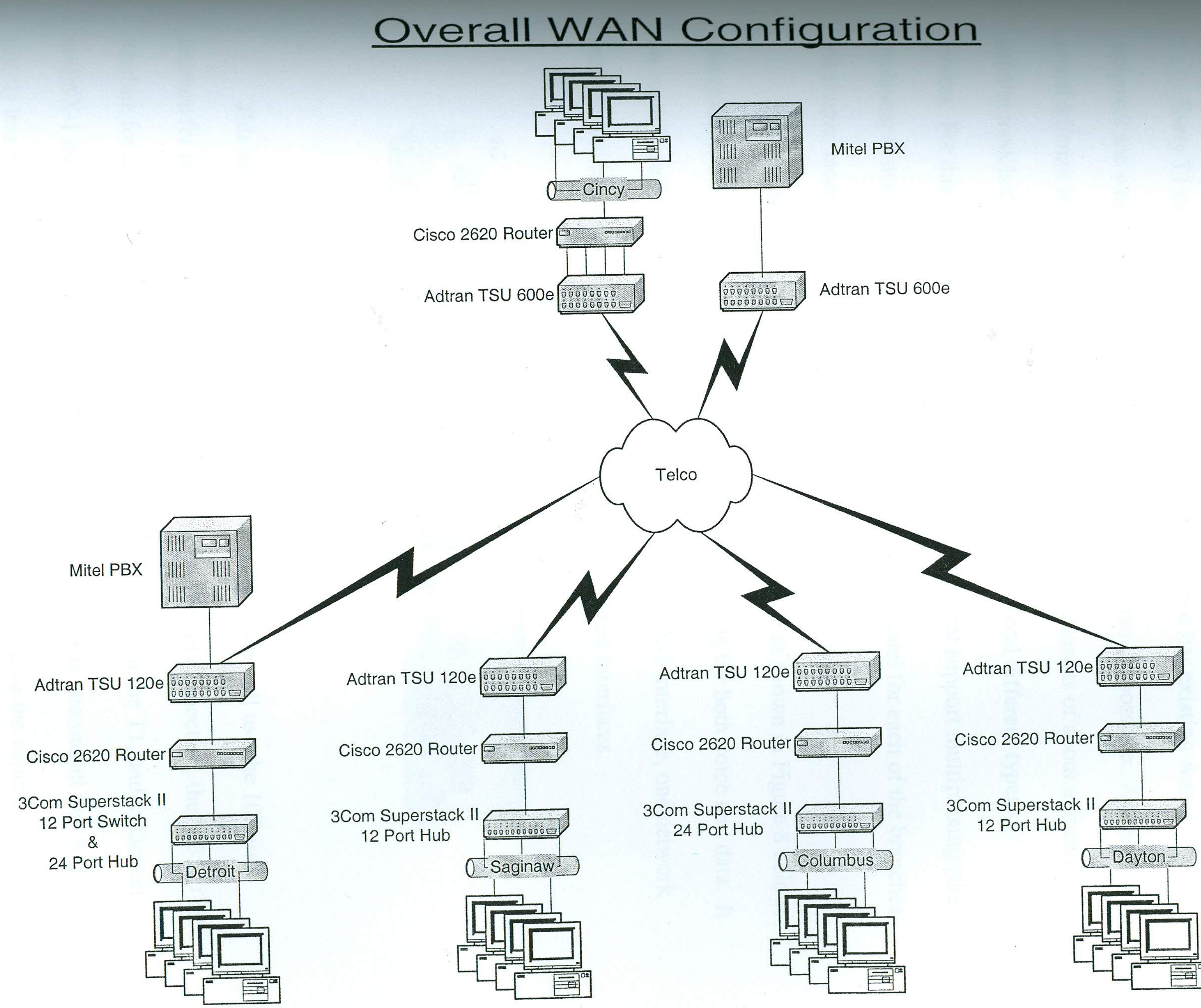

Figure 7.
Overall WAN Configuration

5.2.2 CSU/DSU's

Every T1 must be terminated by a CSU/DSU. Pabco has existing Adran equipment and would like to continue to use Adtran equipment if possible. Adtran offers several different levels of CSU/DSU's. Their product line consists of about a dozen different models that have ports and expansion slots for several different types of services. For this network we chose two different models that support multiplexing (the combining of multiple services across one line), a smaller model for each of the branches and a larger, more robust one for Cincinnati.

The first model we are using is the Adtran TSU 120e as shown in Figure 8 below. This model is the most basic model that supports multiplexing for both voice and data. It has one 10BaseT interface, one V.35 DTE interface, one DSX-1 interface, one network interface, and one expansion slot that supports up to four more interfaces.

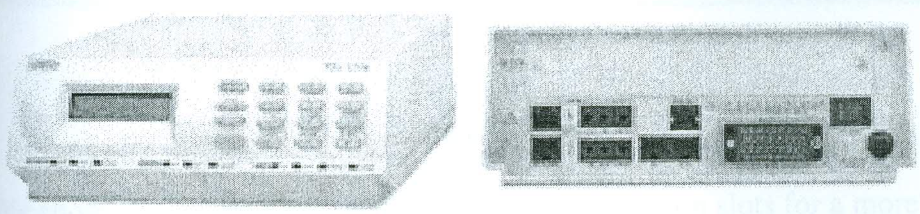

Figure 8.
The Adtran TSU 120e

This model will be used in all the remote branches. We will use the 10BaseT interface for remote access across the network through a telnet connection, the V.35 DTE interface for a connection to the router, the network interface for the T1, and in Detroit the DSX-1 interface to pass voice lines to their PBX. There was one model that was slightly less expensive without the DSX-1 interface however since the capital investment is so expensive and the difference is not, they would like the DSX-1 interface in all of the remote branches in case they add PBX's in the branches later. With all capital investments such as this is in your best interest to anticipate future changes so that you do not have to purchase new equipment later. You have to weigh the additional cost for future upgrades and changes and the probability of the change versus the overall cost of the equipment. In this case it was to their advantage to get the next model up with the built in DSX-1 port.

The second model that we will use is the Adtran TSU 600e as shown in Figure 9 below. This model will be used in Cincinnati because it offers more expansion slots for different ports that we will need. It has one 10BaseT interface, one network interface, and six expansion slots that support up to four more interfaces each.

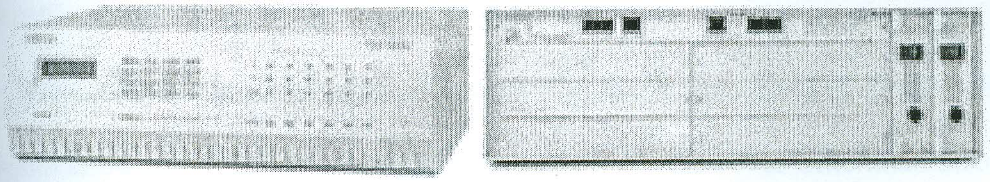

Figure 9.
The Adtran TSU 600e

We chose this model because it offered more expansion slots for a more robust configuration. In these slots we can use cards for up to four interfaces each. These cards include interfaces for additional T1's, DSX-1 ports to pass voice lines to a PBX, V.35 DTE ports to pass data lines to a router, and analog phone lines to pass to a telephone, fax machine, or modem.

Cincinnati will have two of these units. In the first unit we will terminate the T1 that handles Pabco's existing voice services. We will need a DSX-1 card (which can only be used in slot 6) to pass the long distance and voice tie lines from the first T1 to the

PBX. The telco passes the T1 to Pabco using framing and coding of ESF/B8ZS and this unit will be responsible for converting it into the D4/AMI framing and coding that is required by the PBX.

The second unit will terminate the T1 that will handle the data circuits for each branch. We will need a Dual Nx56/64 Plug In Module with a Dual Nx56/64 Plug On Module. A "Plug In" module is the normal card that you would insert into an expansion slot. The "Plug On" module is a card that you can combine with the "Plug On" module into one card. The "Dual Nx56/64" modules have two V.35 DTE ports that can pass data circuits to a router. By using the "Plug On" module you have four of these ports in one slot instead of just two. This saves the other slots for other services or future expansions. These four ports will pass the four data circuits (6 channels each) from the branches into Cincinnati's router.

We could have just added an additional "Drop & Insert Module" into the first unit that would allow us to terminate both T1's into one unit. However Cincinnati also uses a T1 for 24 local voice lines that they want to terminate into one of these units. They have very small CSU/DSU that terminates that T1 and does not offer as many features as these units do. Also by having two units, if one malfunctions we can quickly switch the data circuits and local lines to the functioning unit and use the local lines for long distance service. The long distance calls will cost slightly more over the local lines, but it is better than having no long distance at all. This gives the Cincinnati branch some redundancy and fault tolerance in case anything malfunctions.

5.2.3 Routers

Once the T1 has been formatted and terminated by the CSU/DSU, it is then passed to a router in each branch. There are several manufacturers of routers including 3Com, Allied Telesyn, Cabletron, D-Link, Intel, Lucent, Nortel however Cisco seems to be the dominating manufacturer of routers in the past few years. They are known for their stability, robust product lines, and superb technical support. Pabco chose to use Cisco routers throughout their network.

The function of the router is to take network traffic from the local LAN that is destined for another network and "route" it there. For example, if a PC on Detroit's LAN connects to the E-mail server on Cincinnati's LAN it will send the traffic to its default gateway, or Detroit's router. Detroit's router will then forward the traffic to Cincinnati's router where it will be forwarded to Cincinnati's LAN where the hubs and switches are responsible for getting the traffic to the E-mail server. There are several different types of protocols that routers can support such as Appletalk, IPX/SPX, or DECnet however the only protocol that we will need to support is the Internet Protocol (IP).

Again, when designing such an expensive network it is necessary to look into the future and anticipate change. We see one of the next major changes in the networking industry to be voice over IP. As soon as the technology can support the same level of quality of service that the current phone systems can, then more and more people will switch to using voice over IP because the costs will be significantly reduced.

Therefore when choosing the routers we will use, we will require those routers to support voice over IP and Quality of Service. Initially we were planning on purchasing Cisco 1720 routers but after talking with a Cisco Network Engineer we decided to purchase routers one step up that supported voice over IP, Cisco 2620 routers. Each branch would need one 2620, a 1 port WAN Interface Card (WIC), and a male V.35 DTE cable. Cincinnati's router would require two 2 port WIC cards (a total of four ports, one for each branch), 4 male V.35 DTE cables, and additional memory to handle four connections. Each router would also need a Cisco Internetwork Operating System (IOS) that controls how the router functions. By default every Cisco router ships with a base IOS, as you require more features you must purchase the IOS that includes them In our case, we want to support voice over IP, therefore we must purchase the Cisco IP Plus Feature pack.

Each router will have three ports, a console port that is used to configure the router, an Ethernet port which is connected directly to the LAN via a hub or switch, and a serial V.35 port which will be connected to the CSU/DSU. The Ethernet and serial ports must be assigned an IP address as discussed in the next section.

5.2.4 IP Addressing Scheme

There is a separate IP addressing scheme for the wide area network. Between each router is another subnet. The purpose of this subnet is strictly for communication between the two routers. The only devices on these subnets are the two routers, one on each side of the WAN. In Figure 10 you will see the IP addressing scheme for these subnets. We chose the subnets 10.100.0.0 to 10.103.0.0 because they were out of the way of our other IP address ranges, yet still in the private 10.x.x.x address range. This leaves us room from 10.6.0.0 to 10.99.0.0 to grow if we need to add other branches.

Also, each router must be configured with an IP address on each LAN. This is what the Ethernet port on the router is used for. This will be the "default gateway" for all the PC's on the network. Basically, all that means is that when the IP address that a PC is looking for cannot be found on the LAN it is send there, the default gateway. The default gateway for each subnet should understand how to get the traffic where it needs to go. In our case, the default gateway for each subnet is 10.x.0.1, replacing x with the second octet from the corresponding subnet. The DHCP server will have to have separate address ranges for each subnet and be configured to give out the correct default gateway to each subnet. When a PC sends out data packets that are destined for another subnet that they PC does not know about, they are sent to the default gateway and the gateway is responsible for routing the packets where they need to go.

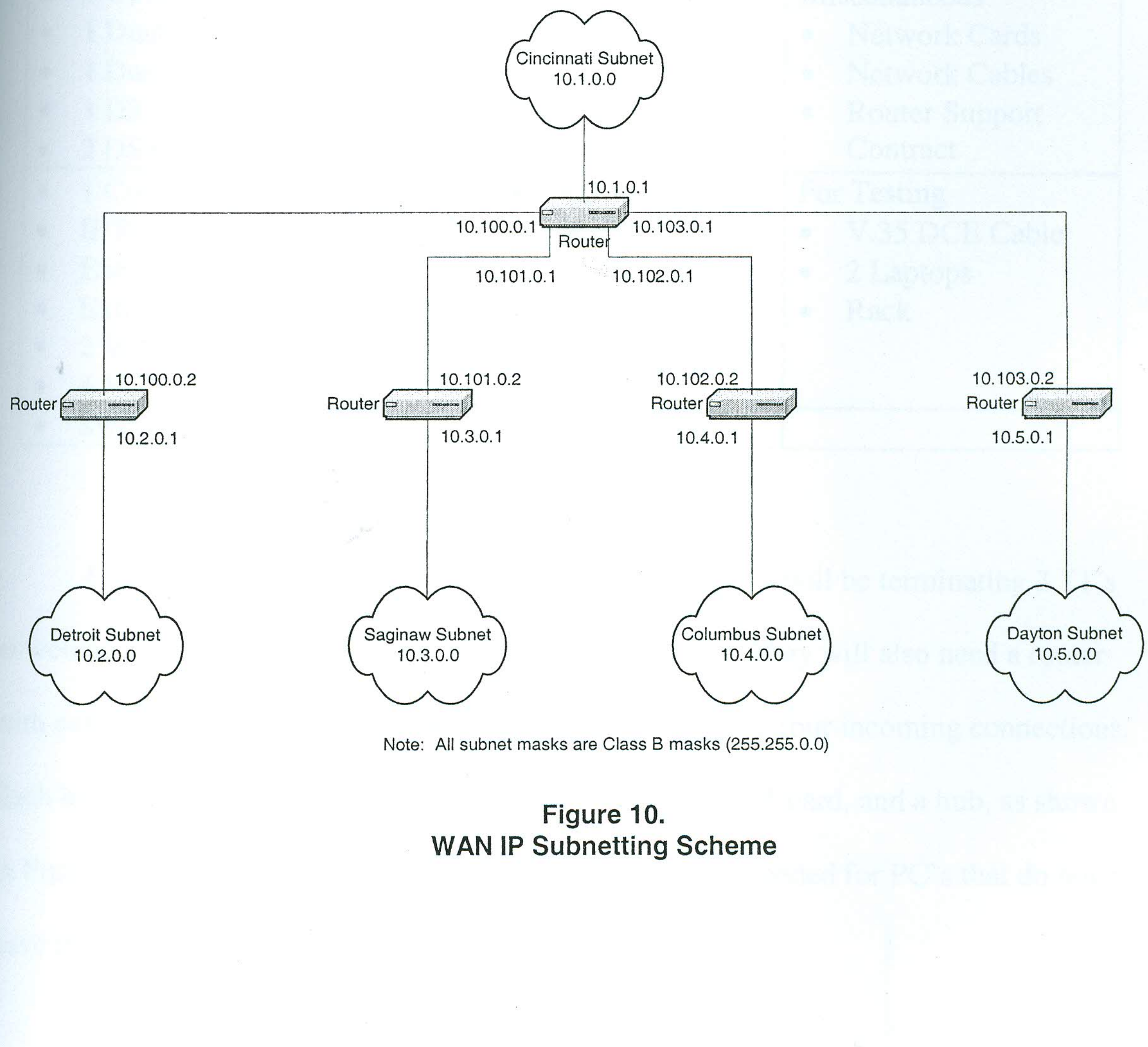

Figure 10.
WAN IP Subnetting Scheme

5.3 Resources

Now that we have laid out the design, lets look at the resources that Pabco will need. Other than the T1 leased lines, Pabco will need to purchase the required hardware for the network. All the software needed Pabco already owns or is included with the hardware. Also, lets review the resources needed and refine our estimated budget.

5.3.1 Hardware

Included in Appendix D is a table with the complete list of all the hardware needed for this project. The summary of hardware required is as follows:

Headquarters	Branches (4)	Other
• 2 CSU/DSU's • 1 Dual Nx56/64 Plug-In Card • 1 Dual Nx56/64 Plug-On Card • 1 DS-1 Plug-In Card • 2 DSX-1 Plug-On Cards	• CSU/DSU	Miscellaneous • Network Cards • Network Cables • Router Support Contract
• 1 Cisco 2620 Router • IP Plus Feature Pack (IOS) • Extra Flash Memory • Extra NVRAM • 2 WIC-2T Cards • 4 V.35 DTE Cables	• Router • WIC-1T Card	For Testing • V.35 DCE Cable • 2 Laptops • Rack
• Switches and Hubs	• Hub	

Figure 11.
Required Hardware Summary

Headquarters will need two CSU/DSU's because they will be terminating 3 T1's as well as the corresponding cards, as shown in Figure 12. They will also need a router with extra memory and the corresponding cards to handle the four incoming connections. Each branch will need a CSU/DSU, a router with the WIC-1T card, and a hub, as shown in Figure 13. Some extra network cards and cables will be needed for PC's that do not have them.

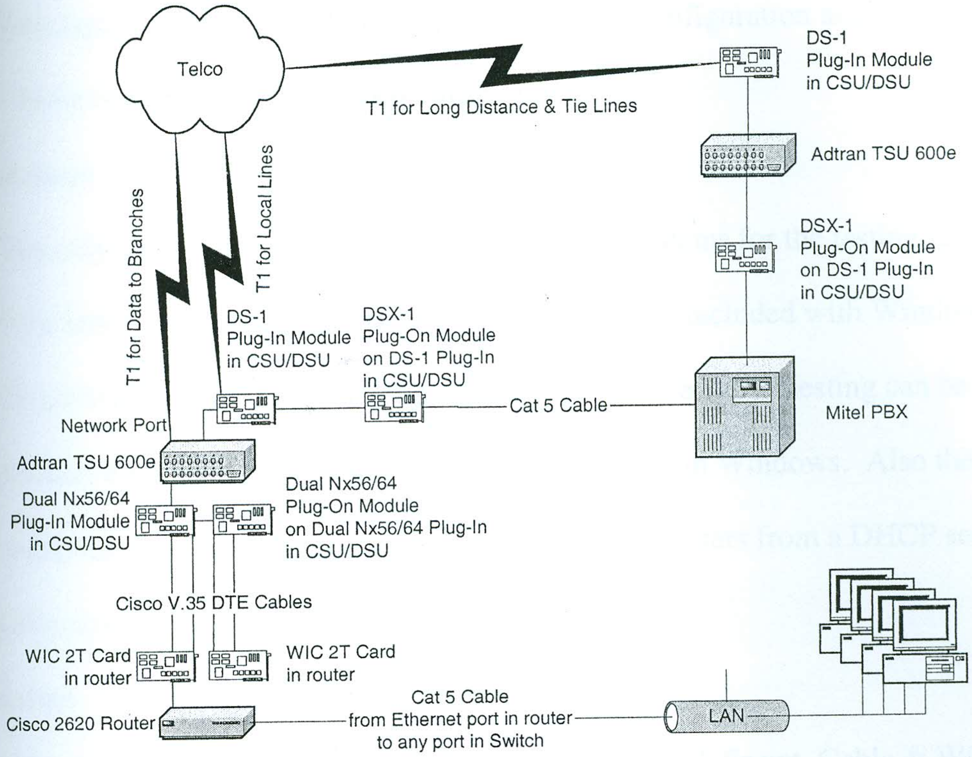

Figure 12.
Headquarters Hardware Configuration

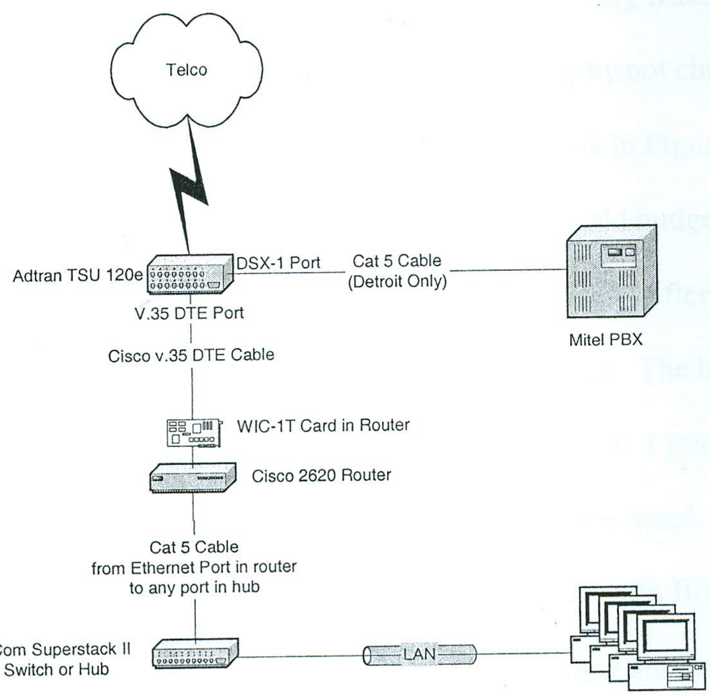

Figure 13.
Branch Hardware Configuration

Two laptops are also required temporarily for the configuration and testing of the routers. Some of this equipment Pabco already owns.

5.3.2 Software

The only software required will be the operating systems for the testing laptops, software for telnet sessions into the router and CSU/DSU's (included with Windows), and TFTP software to back up the configurations of the routers. All testing can be done from the router command prompt and the command prompt in Windows. Also the clients will be receiving their IP addresses and other network parameters from a DHCP server running Windows NT.

5.3.3 Budget

After negotiating with the major carriers, AT&T, MCI, Sprint, Cable & Wireless, and Intermedia we found that the best pricing came from the newly formed carrier, Broadwing. They were a merger of the local Cincinnati Bell Long Distance and IXC Communications of Austin, Texas. They undercut everybody by not charging any of the "channel service" fees shown in Pabco's old budget in the table in Figure 3. If you calculate the percentage of these "channel service" fees in the old budget, they were about 50% and Broadwing was not charging us any of these fees. After comparing pricing, this beat everybody else out by at least $20,000 per year. The breakdown of their pricing is shown below in Figure 14. The new pricing at $44,000 a year compared to the old pricing at $103,000 per year saves Pabco almost $60,000 per year!

Incidentally, almost a year after Pabco's initial contract with Broadwing, Pabco is adding three more T1's for new branches and they can no longer get that deal. Pabco must have caught Broadwing at a time of confusion during the merger and a time when they wanted as much new business as possible. Now they must pay those "channel service" fees for those new T1's. Fortunately, Pabco's contract was for a one year period with the option to renew at the same price for up to three years, so they are guaranteed that pricing for 2 more years.

Branch	Local Loop MRC	Long Haul MRC	Total MRC
DS1 Cincinnati #1	$ 296.87	$ 149.79	$ 446.66
DS1 Cincinnati #2	$ 296.87	$ 149.79	$ 446.66
DS1 Detroit	$ 343.65	$ 570.50	$ 914.15
DS1 Saginaw	$ 278.36	$ 132.08	$ 410.44
DS1 Columbus	$ 336.98	$ 503.38	$ 840.36
DS1 Dayton	$ 284.71	$ 336.73	$ 621.44
Monthly Totals:	$ 1,837.44	$ 1,842.27	$ 3,679.71
Yearly Total:			$ 44,156.52

Figure 14.
New Telecommunications Charges

In Appendix D there is a complete breakout of every piece of hardware required along with the manufacturer, part number, designated branch, quantity required, and cost. After getting quotes from 3 different vendors, CDW, Keller Hewitt, and Microcenter we found that the local consulting company, Keller Hewitt, offered the best pricing. The total cost for this equipment is approximately $20,000. If you compare $20,000 in capital investment with a savings of $60,000 per year, you see a return on your investment in only 4 months, plus Pabco owns all the hardware as well. This means that in the first year Pabco will save $40,000. Pabco was willing to see a return on their investment in a year or two. Therefore, the hardware budget was not a factor because there was such a tremendous savings in the telecommunications budget. We could have spent at least $60,000 if we needed too.

5.4 Implementation

After we have designed the network and procured the equipment we are put to the true test, making everything work. Since we do not want to be caught out in the field at these remote branches not being able to make it work, I came up with a better idea. The idea was to set up everything in Cincinnati and simulate a Wide Area Network.

5.4.1 Configuring Hardware

The one problem with setting the entire WAN up in Cincinnati was, how do we trick the routers into thinking there was a T1 between it? After doing a little research and playing around with the hardware I discovered two things. First, the routers could be connected directly together using a female V.35 DCE cable and a male V.35 cable. Normally, in the WAN you would connect the router to the CSU/DSU via a male V.35 DTE cable and the CSU/DSU to the remote CSU/DSU via the T1 (a RJ-48 connection on both ends, just like a Cat 5 cable). After you add the WIC (WAN interface cards) to the router, you can connect the first router to the second router by plugging the male DTE cable into the female DCE cable and the other end of both cables into the routers WIC cards, as shown in Figure 15. You can then change the network timing to allow one router to initiate the timing and the other one to go along with it. Normally the routers would just go along with the network timing passed down to it.

Figure 15.
Setup for Configuring the Routers

Now using the cable shipped with the router we can plug the console port of the router into a comm. port on one of our testing laptops. By using HyperTerminal, a program included in Windows, we can boot the router for the first time and bring up a command line in the router. From this command line we can configure the entire router.

The router configuration consists of a few steps. When the router is booted for the first time it walks you through most of the configuration. It involves giving the router a hostname, setting the passwords, configuring different protocols (in our case we only need IP), and then configuring the different interfaces with their parameters, such as their IP address and subnet mask. Copies of the configurations can be found in Appendix E. Once the Ethernet interface has an IP address and subnet mask the router can be connected to by using telnet from a PC configured with an IP address on the same subnet. Keep in mind that if you are connecting the router directly to a network card in the laptop you must use a Cat 5 Crossover cable. You cannot use a normal straight-through Cat 5 network cable to connect two Ethernet network cards together.

The next step is to configure the router on the other end. In this case I chose Cincinnati's router. You repeat the same process except you have to add one more thing. On one of the routers you must set up the network timing so that one router initiates the timing and the other one follows. Since we are going to have to configure all 4 routers to connect to Cincinnati's, if we set this up on Cincinnati's we only have to do it once. Now that you have the routers configured with the correct IP addresses and protocols you can connect a laptop to the Ethernet port on each router, configure their IP addresses to be on each routers subnet, and test the connection. There are several ways to test the connection and they will be covered in section 5.4.3.

You repeat this process for each branch router. In fact, we had enough V.35 DCE cables to connect all four branch routers to Cincinnati's at the same time. Once the routers are completely configured and the testing has shown that everything is functioning correctly you have to configure the CSU/DSU's.

How do we configure the Adtran CSU/DSU's if we do not have a T1? This is where I made my second discovery. I looked at the pinouts on the network ports of the CSU/DSU's. There was one pair (two lines of the eight lines) of lines for sending data (lets call them S1 and S2), and one pair for receiving (lets call them R1 and R2). One sending line and one receiving line (S1 and R1) make one loop and the second set (S2 and R2) make a second loop. A loop being one physical circuit with a send and receive, just like a phone line. Logic would dictate that if you made the S1 on the first CSU/DSU go to the R1 on the second CSU/DSU, S2 on the first to R2 on the second, R1 on the first to S1 on the second, and R2 on the first to S2 on the second (as shown in Figure 16 below) we would be able to simulate a T1.

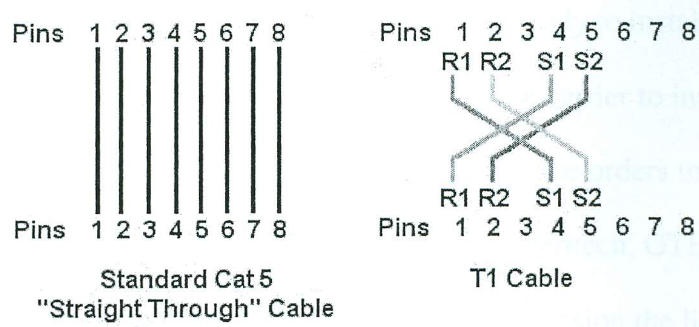

Figure 16.
Cable Pinouts

Now just connect the network (T1) port from one CSU/DSU to the network port of the other and the T1 has been simulated. Next, we need to configure the CSU/DSU's. This is done through menu display and keypad on the front the unit. The main things you have to configure here are the T1 "maps" and the T1 configuration parameters (such as framing and coding). A map is just a listing of the 24 channels of the T1 and what port on the back of the Adtran they are supposed to go to. If you remember, in Cincinnati's router we added two Dual Nx56/64 cards (for a total of four ports, one for each branch). Cincinnati's data T1 has six channels going to each port. Once you configure the maps to tell the CSU/DSU's to send channels 1-6 to the first port, 7-12 to the second, and so on, you can connect the routers to each CSU/DSU via a V.35 DTE cable. Then connect your testing laptops to each router to test the connection. Repeat this for each branch.

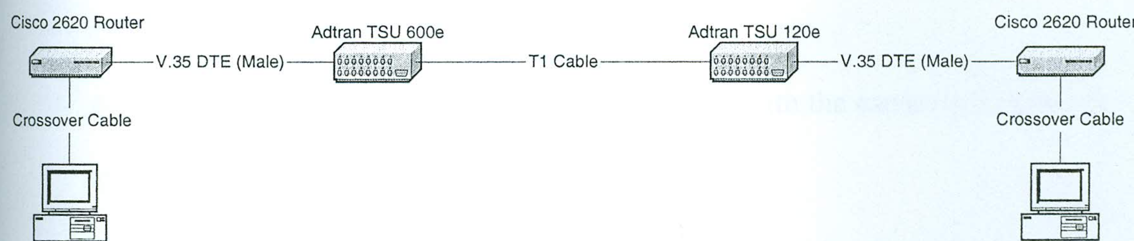

Figure 17.
Setup for Configuring the CSU/DSU's

5.4.2 Installations

Once we had configured all the hardware we were ready to install the T1's in each branch. It takes 30 to 45 days from the time of order for the carrier to install the T1. There are a few steps involved. First, the customer submits the orders to the carrier. Then, the carrier (Broadwing) contacts the local carrier (Ameritech, GTE, or Cincinnati Bell) for that city to give them the order. They both then provision the line and prepare their hardware. A technician from the local carrier installs a "smartjack" in the customers location. The carrier then tests to make sure they can see the smartjacks in each location. After they can test cleanly the T1's can be activated.

In order to activate the T1's the hardware must be installed in each branch. It is best to have someone on each end. In our case we activated the T1 to Cincinnati and the T1 to Dayton on a Thursday evening. The next day I traveled to Columbus and activated theirs. The next weekend I traveled to Saginaw and Detroit to activate theirs.

In order to activate a T1 you must follow the following steps:

1) Schedule a meeting time with the technicians at the carrier's switch sites. Usually this will be coordinated by your representative from the carrier.
2) Prior to the meeting the carrier's technicians should verify that they can connect to the smartjacks in each location.
3) Prior to the meeting the customer's technicians should set up their hardware in each location.
4) At the time of the meeting make a conference call with the carrier's technicians and the customers technicians at each site.
5) The carrier's technicians should then cross-connect the circuits at their switches.
6) The customer should then try to establish a loop across the T1 and send test data. (See section 5.4.3 – Test Procedures)
7) If the loop is successful, from one router, ping the router on the other end. (See section 5.4.3 – Test Procedures) If not, the carrier should try to put the CSU/DSU into a loop and send data to each side. Troubleshoot and fix any problems.
8) Once the loop is working and the routers can ping each other, connect up the testing laptop and try to ping something on the LAN of the other side. If it is unsuccessful troubleshoot and fix the problem.
9) If the ping is successful try to copy a file across the WAN and make sure it goes through fine.
10) If the file goes through fine the T1 is functioning properly and the installation is completed.

5.4.3 Testing

5.4.3.1 Loops

What is a loop? A loop is simply taking any line (such as a T1 or even a network cable) and connecting the sending pairs to the receiving pairs so that the data is sent straight back to the source. The loop can either be a simple device that you plug into the port or cable, or it can be created by the hardware that the cable is plugged into. A loopback plug can be created by taking an RJ-48 connector and 2 wires and crimping it so that the wires connect the sending pins to the receiving pins as shown in Figure 18.

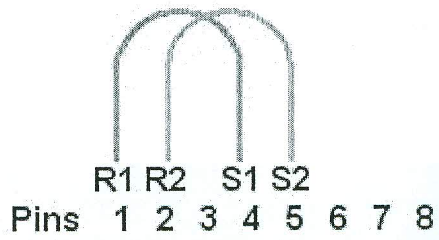

Figure 18.
Loopback Plug

What is the purpose of a loop? The purpose of a loop is to test that data that is sent goes through the line correctly. Either the data that was sent will come back or it won't. If the data does not come back we know that there is a break in the line somewhere. It works just like a continuity tester works.

How do I use a loop? The Adtran CSU/DSU's have a testing feature built in for looping. You can remotely remote put a unit into a loop (a soft loop) and send data through. The CSU/DSU will then tell you the number of failed packets and if it can synchronize with the remote unit. There should be no failed packets and you should get synchronization. If you do not, there is a problem somewhere. You can also put your unit into a loop or plug up a loopback plug (a hard loop) and let the carrier try to send data through. Carriers can usually place both the smartjack and the CSU/DSU into soft loops. They can also place the smartjacks on both ends into a loop and send the data through one, back to the other, and so on. It is the carriers responsibility to make sure that they can loop both smartjacks. If they can do that, they have provided a working circuit. If the problem lies beyond the smartjack it is the customer's problem.

5.4.3.2 Ping Tests

What is a ping test? A ping simply a PC requesting a response from another IP address. If you look at the screenshot below in Figure 19 you will see an example of a ping test. It shows you that there was a reply and that it took less than 10ms to receive each reply. It is a quick and easy test of connectivity.

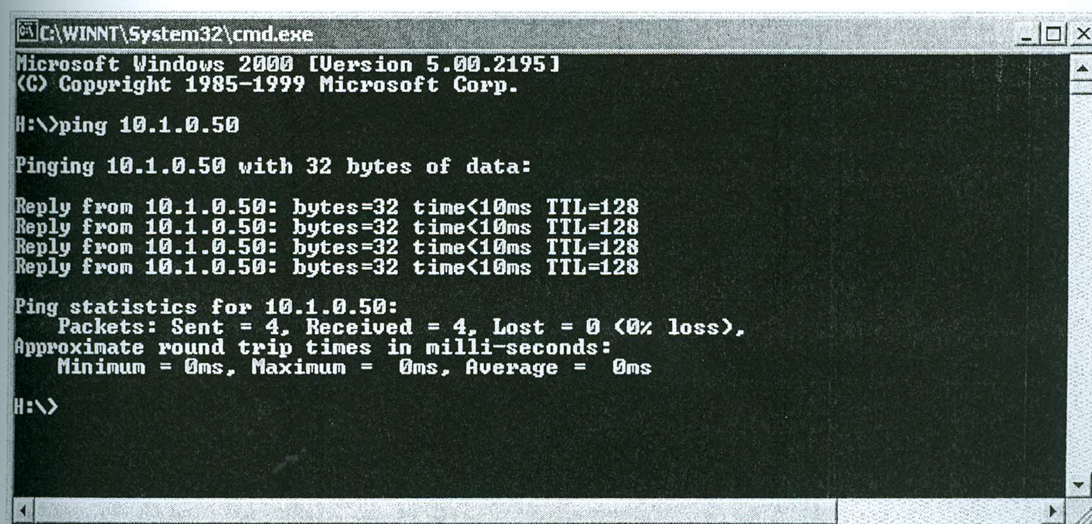

Figure 19.
Screenshot of a Successful Ping Test

What is the purpose of a ping test? A ping test ensures that you can connect to another device. If you receive a request timed out error, example shown in Figure 20, then you cannot connect to that device.

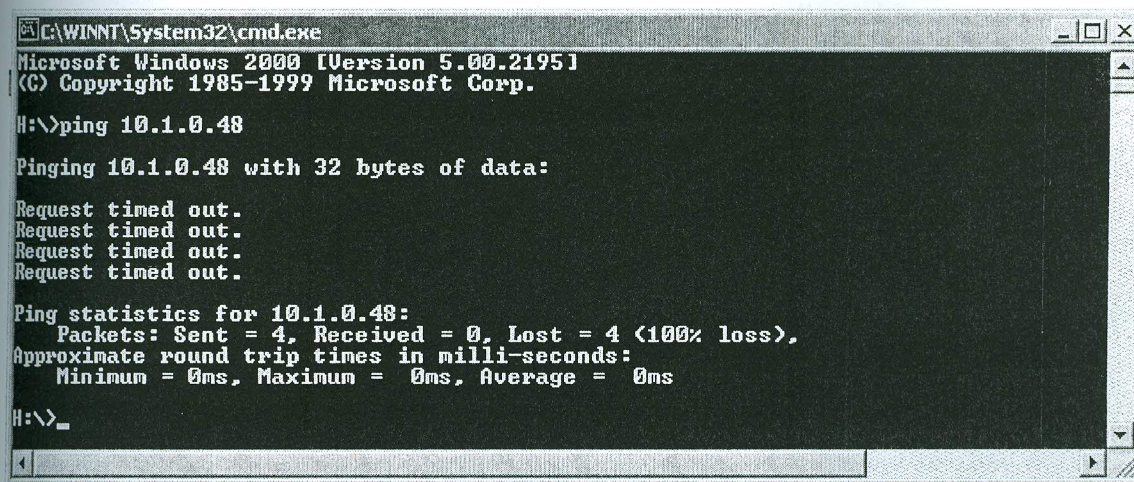

Figure 20.
Screenshot of a Failed Ping Test

How do I use a ping test? In our scenario, after the CSU/DSU's can successfully loop each other, we need to make sure that the routers can see each other. An easy way of testing connectivity is with a ping test. Also, Cisco routers have a much more customizable ping command. It allows you to specify the sending address as well as the address the packets are being sent to, the size of the packets, the amount of time to wait for a response, the number of packets to send, as well as many other options. Figure 21 shows the ping command from a Cisco router. This is one test that we used to prove that a T1 problem we had was occurring on Broadwing's network. We sent a couple hundred packets through but only about 80% would make it through. The other 20% failed to respond. Broadwing saw the T1 as being up and it was, it was just not sending every packet through and of course, like any technical support representative, if you cannot prove that it is there problem, they will not try to fix it.

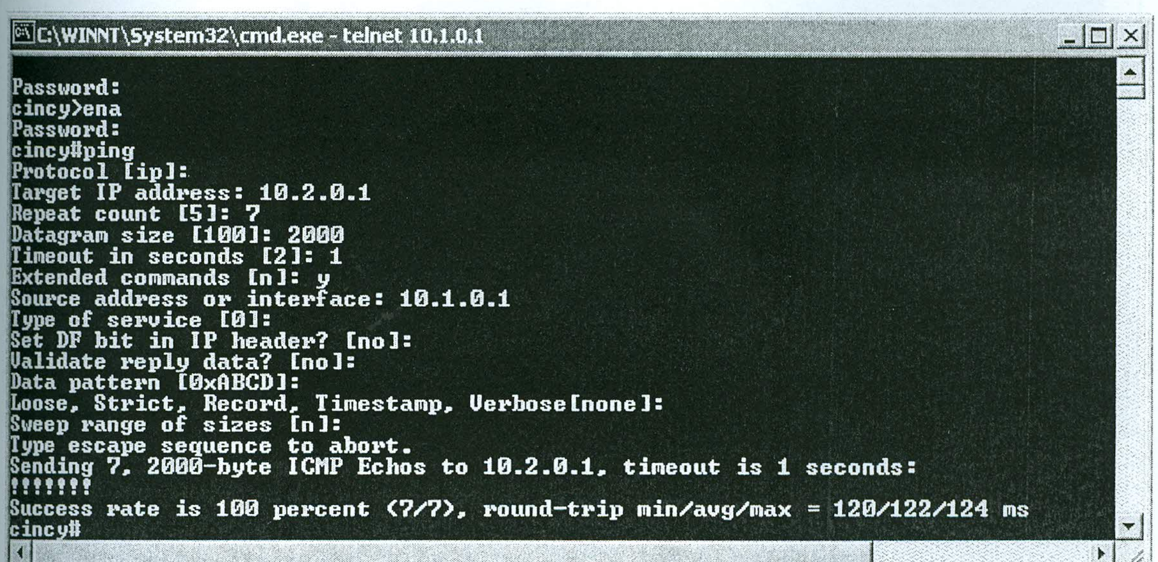

Figure 21.
Screenshot of a Ping From a Cisco Router

5.4.3.3 Traceroute

What is a Traceroute? A traceroute is much line a ping except that in a traceroute you send out a packet and you receive a response from every network device that the packet is routed through. In Figure 22 you will see an example of a traceroute from a Windows 2000 machine.

What is the purpose of a traceroute? A traceroute tells you exactly where your packets are being routed. For example in Figure 22, we sent a packet to 10.3.0.5, it went to an address at 10.1.0.1 (which happens to be the Ethernet port on Cincinnati's router), then to 10.101.0.2 (the serial port on the router in Saginaw), then to 10.3.0.5 (Saginaw's CSU/DSU).

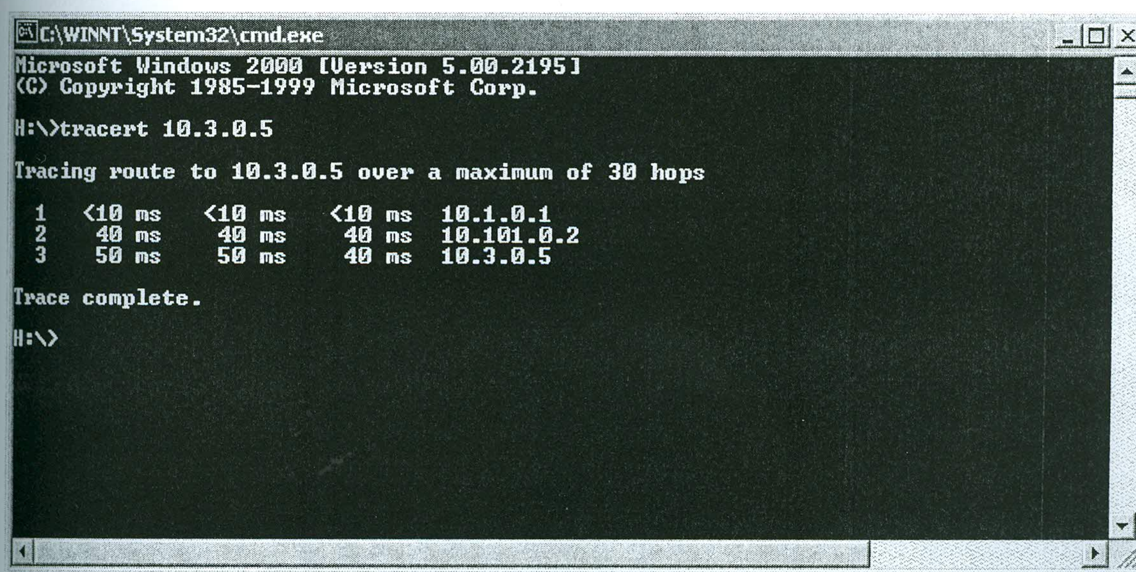

Figure 22.
Screenshot of a Traceroute

How do I use a traceroute? A traceroute will tell you if your routing tables are set up correctly. If your routing tables are not correct, data will not get to the network it was intended for. It is also useful for determining where the broken links occur. For example, if the packet stopped at 10.101.0.2, we would know that it make it to Saginaw's network, it just could not find the device.

5.4.3.4 Router Test

There is a very useful test that can be used at a command line within the Cisco routers. The command is "show cdp neighbors". CDP stands for Cisco Discovery Protocol. This protocol detects other neighboring routers and their specifications. In Figure 23 we have connected to Cincinnati's router via telnet and logged in to the command prompt. At the router command prompt we have entered the command. Notice, it shows us all of the neighboring routers and the serial interfaces that they connect to. If a router goes down you will not see it listed here. This command is useful for quickly determining which routers the host router cannot see. Sometimes you may lose two branches at the same time and this command will immediately identify which branches they are.

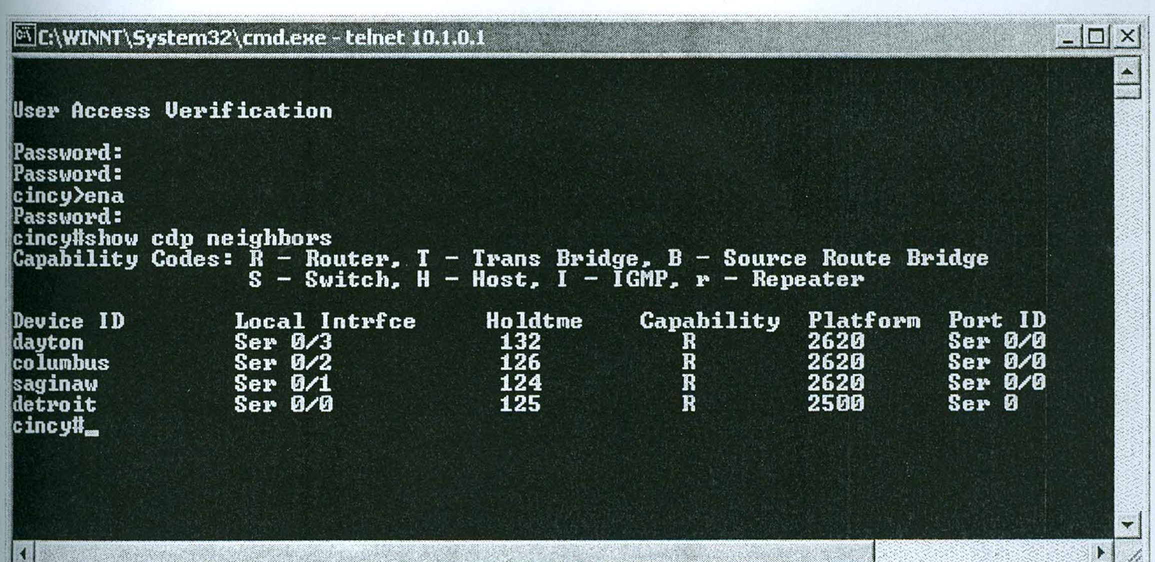

Figure 23.
Screenshot of a Router Test

6. Proof of Design

The implementation and testing of this project was completed in May of 2000. This gives us enough time to look back and effectively evaluate this project. There are three areas we must evaluate when we look at this project. First, did this project stay within budget? Second, was this project completed on time? Third, did this project meet all of the stated objectives?

6.1 Budget Analysis

The cost for telecommunications in Pabco's old WAN was approximately $103,000 (Figure 3). As you can see in Figure 14, the cost for telecommunications in Pabco's new WAN is approximately $44,000. This is a cost savings of almost $60,000 or 57 percent! That is over half of what they were previously paying!

The cost for hardware for the new WAN was approximately $20,000. That means that Pabco will see a return on investment in about 4 months! That is the same time period for a return on investment that a telecommunications carrier would aim for!

This project was so far under budget that Pabco will save about $40,000 in their first year, after the price of the required hardware!

6.2 Timeline Analysis

Although time was not a driving factor in this project, this project was completed in about half a year. One of the longest steps was negotiating telecommunications costs with carriers, writing and signing the service contract, and ordering and installing the T1's. This step took over half the time allotted for this project. However, the negotiations step resulted in a savings of almost $60,000 so it was well worth the time spent.

In a project like this it is better to design and implement the network correctly rather than rush it and risk doing something wrong. Especially when there were no circumstances requiring the network to be in place sooner.

6.3 Objectives Analysis

There were ten stated objectives that this project must meet (section 4). All ten of the stated objectives have been met.

Since the completion of this project in June of 2000 Pabco has since offered several new services to every user in every branch. These services include access to a permanent integrated Internet access connection, e-mail, and several new Windows 2000 servers for file systems and print servers. They are almost ready to release an Intranet site with a SQL server backend as well. This shows that the WAN has met the first four objectives.

Every user in every branch can now access Cincinnati's LAN through the WAN and no longer need to dial into Cincinnati's LAN through a modem connection. The RAS server has been left in place for users to access Pabco's network from home. Also, the old multiplexing and terminal server equipment has been removed, meeting the fourth and fifth objectives.

When we chose the routers we confirmed our choice with a Cisco Network Engineer. We wanted routers that would support voice over IP and he recommended a model one step up and to add more memory as well. We did this, however we have yet to use the routers for voice over IP. We also purchased the operating system (Cisco's IOS) for the routers that supports voice over IP. This cost an additional $500 per router.

After a painful, 12 hour T1 installation in Detroit that stretched out until five in the morning, the Detroit T1 went down a day later. Apparently a switch technician at Broadwing made a change to the configuration. The technician made no note in the logs of the change and when we discovered the network no longer functioned we had to prove to Broadwing that it was their fault. We did this through an “extended ping” test from the routers command line. This test sent several hundred data packets from the edge of Cincinnati’s LAN to the edge of Detroit’s LAN and showed that only about 80% of the packets being sent were actually making it through. Fortunately we still had our T1’s from MCI functional and were able to switch back to them so that users were able to access the network the following Monday morning. When Broadwing discovered the technician turned on a feature called “echo cancellers” two days later we were able to switch back to Broadwings T1. We left the DS0’s and DS1’s from MCI functional for another month until we felt confident in Broadwing’s T1’s. We were also able to immediately determine through the testing routines described in section 5.4.3 where any network outages occurred.

7. Conclusion

This project has successfully met all the stated requirements. This project was completed within the budget, on time, and met all of the stated objectives. In fact, Pabco is getting ready to add two more branches onto their wide area network in Pittsburg and in Cleveland. They will follow the same design as we did for the other 4 branches.

When designing networks it is extremely important to plan carefully. Take your time designing the network and make sure it is done right. You have to also look at what the future holds and any potential changes that you might make. By looking into Pabco's future we saw the potential to for new branches as Pabco grows. That is why we designed the network in the way that we did. The "building block" design allows us to add branches easily. All they have to do is set up LAN's in each branch with the next available subnet, order the T1's and hardware, copy the existing configurations except for minor IP addressing changes, install the WAN, and they are done. Since the process was thought through carefully the first time, the second and any future additions are very simple, just like adding another building block. The design of the block has been has been completed, now they just have to copy it to the other branches.

Wide Area Networking can be expensive, however the benefits that can be obtained from them are often very beneficial and sometimes absolutely essential. The planning that goes into the design of the network must be carefully planned out and researched. New technology emerges every day in the telecommunications industry and you must periodically evaluate your existing networks to see if they will benefit from these new changes. Pabco benefited immensely. They obtained a network that was much more functional for less than half the cost of their existing one.

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