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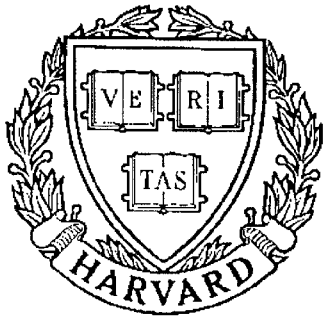

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Trade-Off Analysis of Local Area Networks

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M.S. 90-8

TRADE-OFF ANALYSIS
OF LOCAL AREA NETWORKS

by Susan M. Urban

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of the University of Maryland in partial fulfillment
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ABSTRACT

Title of Thesis: TRADE-OFF ANALYSIS OF
LOCAL AREA NETWORKS

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This thesis is a trade-off analysis of the discerning characteristics of local area networks. The operational needs are described followed by the functional, operational and physical requirements for a fabricated customer environment. The following characteristics of local area networks are examined: topology, signalling methods, cable access protocols, and transmission medium. Design issues that affect the configuration and performance of local area networks are examined. A trade-off analysis is then performed for the specified environment using weighted evaluation criteria against the discerning characteristics.

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LIST OF ACRONYMNS

bps	- bits per second
CATV	- Community Antenna Television
CSMA	- Carrier Sence Multiple Access
CSMA/CA	- Carrier Sense Multiple Access/ Collision Avoidance
CSMA/CD	- Carrier Sense Multiple Access/ Collision Detection
FAX	- facsimile
FDM	- Frequency-Division Multiplexing
IEEE	- Institute of Electrical and Electronic Engineers
ISO	- International Standards Organization
km	- kilometer
LAN	- local area network
LED	- light emitting diode
M	- mega
Mbps	- mega bits per second
OSI	- Open Systems Interconnection
PBX	- Public Branch Exchange
RAS	- Reliability, Availability, Serviceability
SE	- Systems Engineer
TDM	- Time-Division Mutiplexing

1.0 INTRODUCTION TO THE THESIS

The Master of Science degree in Systems Engineering at the University of Maryland, College Park requires the completion of a Systems Engineering thesis. This thesis is the first one to be completed in this newly approved Masters degree program. The author has volunteered to be the first student to attempt to define a structure and approach for this thesis. This particular thesis will be used as a base that will be critiqued and improved upon so that future students may benefit. Initiating and implementing the Systems Engineering program has been in itself a systems engineering process.

1.1 OBJECTIVE OF THE THESIS

The objectives of the thesis are for the student to:

1) choose a topic that relates to a current/future work assignment

2) choose a topic that introduces the student to leading edge technology

3) demonstrate the systems engineering process, techniques, and skills.

Systems Engineering as a discipline includes all knowledge, theories, and analytical methods that are required for the explanation and understanding of the interplay between all functions, operational and physical conditions, and integrated disciplines that make it possible to foresee, simulate, and evaluate all aspects of the system performance, including its cost, over its complete life cycle [1]. In this thesis some of the fundamental characteristics of local area networks (LANs) are examined and a trade-off analysis of the various characteristics is performed for varying environments.

The Systems Engineering thesis is different from other thesis papers because the Systems Engineering curriculum covers a broad spectrum of technical and management areas with emphasis on real world applications. The student is not concentrating on a narrow technical arena as other engineering disciplines do. The Systems Engineering student sometimes performs people management tasks, project coordination tasks, in-depth technical analysis, hardware design, or project review meetings. In addition, the systems engineering student is studying and refining a process of how to solve complicated real time problems. As a result, the thesis may not be at the level of detail that other degree thesis' may be. Additional time must be spent to understand the thesis topic since the student has not studied this topic in any course work. Part

of the Systems Engineering degree requires the student to pursue topics without any prior experience in that area. This experience is not atypical of the systems engineering process used in the real world. The student has refined the techniques of how to approach a complicated real world problem and design an economically optimal solution.

1.2 SYSTEMS ENGINEERING PROCESS

The systems engineering process involves many iterative steps; the "life" cycle starts with the operational needs determination for a system and ends with the retirement of the system. Each and every systems engineering process or development effort will require different steps depending on the complexity of the total project, knowledge of the development team and customer, level of technology being developed, etc. No formula or algorithm exists that identifies each and every step in the sytems engineering process in order to guarantee that a project will be designed, developed, tested, and deployed on schedule and within budget. It is the systems engineer's knowledge and experience that will determine which is the optimal method of approaching this project. If a formula did exist, the systems engineering process would be predictable and not as challenging. The goal of systems engineering is to identify processes that are similar for all, or

at least most, of the projects. Most sytems engineering projects follow the life cycle or structure outlined below [2].

1) The operational needs of the system are determined. The operational needs statement answers the question why and when is the system needed. It prevents people trying to solve a problem that does not exist or to solve the wrong problem.

2) From the operational needs, the system requirements are derived. The requirements can be subdivided by many methods or perspectives. Two common methods follow:

First Method:

- Functional requirements
- Operational requirements
- Physical requirements

Second Method:

- Functional requirements
- Performance requirements
- Recovery requirements
- Interface requirements
- Reliability, Availability, Serviceability (RAS) requirements
- Programming requirements

It is up to the Systems Engineer (SE) to determine the appropriate approach for each particular project and/or customer. Depending on the customer, the customer may write the requirements report(s). In other instances, the SE may learn about the customer's environment and write the system requirements report. In either scenario, a good systems engineer will anticipate any unidentified or unrealistic requirements. The requirements identification step is an iterative process of discussions and reviews so that both parties understand the requirements fully. Depending on the size of the project and complexity, subsystem requirements reports will also be written.

3) After understanding what the customer wants, the SE completes the conceptual design of the system. The SE will consult with other experts in the industry for specific knowledge. The conceptual design is an abstract expression of a solution to the identified requirements [3]. The SE will have to make a choice of the basic technology that will be used to solve the problem. Through this design process, multiple solutions may exist with varying costs, schedules, and risks.

4) Since multiple design solutions may exist, one design must be selected for implementation. Evaluation criteria may be

selected with corresponding weights. A trade-off analysis is then performed against each design option in order to determine the optimal design solution according to the evaluation criteria. Prototyping, simulation, and/or modeling are often performed to help in the evaluation of the design solutions. Design selection should always be based on a multi-disciplinary review process with experts from various fields, e.g., human factors, reliability, test.

5) The selected design is then developed. This development effort requires the support of multiple skills such as software development, hardware development, human factor's experts, project management, etc. It is the SE's responsibility to oversee the overall technical development and to keep the "big picture" in focus.

6) The components e.g., hardware, software, microcode, procedures, are integrated and tested to ensure that the end products do meet the requirements.

7) The system is then deployed to the customer and installed.

8) The system is maintained for the remainder of its useful life.

9) The system is retired and replaced with another system.

Throughout the SE process, continuous reviews at varying levels of detail are conducted to assess whether the optimal design solutions were chosen for the price and schedule. This iterative feedback process improves the quality of the system and future systems. This feedback process provides a database of information about systems that can be accessed in the design of future systems.

1.3 SCOPE OF THE THESIS

This thesis follows the systems engineering process identified in section 1.2 "Systems Engineering Process" from the steps, Operational Needs Determination through Trade-Off Analysis. The steps of development through system retirement are not included.

2.0 DESCRIPTION OF THE ENVIRONMENT

The following description is a completely fabricated customer environment. The customer is a small sized manufacturing company, AOA Corporation, producing widgets. The company consists of three main areas: Accounts Management, Manufacturing, and the Remote Sales Offices. Accounts Management has two main functions of Accounting and Purchase Order Management (POM). Other functions exist in the company, e.g., legal department, human resources, but their data processing needs are not part of this analysis.

The Accounting area performs the typical tasks associated with accounting. POM receives the customer orders from the remote sales offices and interacts with the manufacturing area to initiate and to determine the status of a particular order. The manufacturing area produces highly specialized widgets requiring high process control. Each customer has a different tolerance range requirement for the widgets and pays accordingly. The manufacturing of each order requires an initial setup of the manufacturing equipment. The software determines the next job to be completed due to the priority of the job, overall size of the job, and if multiple jobs can be completed in one batch. Once a job is completed in the manufacturing process, the supervisor

wants this data automatically sent to POM so that the shipping and billing can be completed. The sooner that the widgets can be shipped to the customer, the less of a storage cost incurred. Once POM receives notice of a completed job, POM works with the accounting area in completing the transaction. Therefore, POM must be able to interface to the manufacturing area, the accounting area, and the remote sales offices. Accounting and manufacturing have no requirement to communicate, but accounting does occassionally communicate with the remote sales offices. Today, these functional areas do not communicate data to other areas in an automated fashion. Each area performs its tasks and then manually, e.g., via paper or telephone, notifies the other area of its status. The manufacturing area needs to store voluminous amounts of data concerning the production of each batch of widgets, i.e., actual tolerance ranges for each batch, data of processing, and the data is stored on a mainframe system. Accounting also has the requirement for storage of large volumes of data. Accounting accesses its data frequently while the manufacturing area rarely ever accesses the production data; it is a regulation for the archival of data. Figure 2.0 depicts the AOA Company structure.

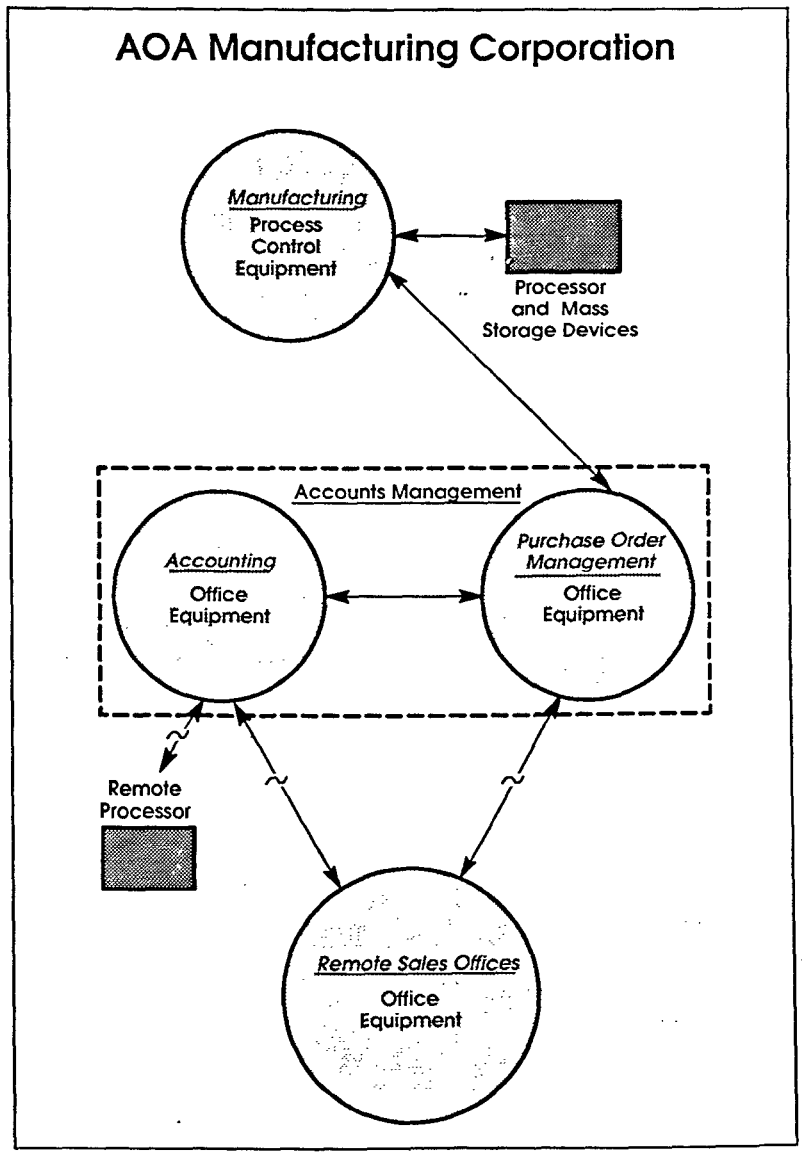

Figure 2.0 AOA Company Structure

2.1 OPERATIONAL NEEDS DETERMINATION

The operational needs statement identifies at a high level what the problem is to be solved and in what time frame. The operational needs statement is technology free and does not elaborate on how a solution will be designed or implemented. The Operational Needs Statement for AOA Corporation is: Capability to interconnect and optimize the automated functions performed by the accounting area (which consists of office related functions) and the manufacturing area (which consists of the manufacture of widgets via highly automated control processes) and the remote sales offices (which consists of office related functions.)

2.2 OFFICE ENVIRONMENT

The following three subsections further define the requirements for the office environment. The office environment was chosen due to its wide application in the real world and the diversity of the form and presentation of data. It is important to note that the long term strategy for this line of business should be understood. If a customer is planning to grow in size or function, then the immediate design for the solution should not preclude the

possibility of adding to the system. All future strategies must be considered at this point.

The complexity in this environment increases due to the different protocols used and the differing transmission speeds required. Historically, the office environment has had this great diversity which requires the SE to understand the fundamentals of the environment, identify the specific requirements, design solutions to the requirements, and test the solutions.

2.2.0 FUNCTIONAL REQUIREMENTS

Table 2.0 lists the functional requirements for the office environment.

REQUIREMENT #	DESCRIPTION OF REQUIREMENT
1	Provide the capability to support electronic mail. (An immediate transfer of the electronic message is not required for this application.)
2	Provide the capability to support a document image processing system in the future.
3	Provide the capability to support file serving.
4	Provide the capability to support print serving.
5	Provide the capability to support conferencing. (This requires support for voice and data. The solution could transmit analog or digitize the data, transmit the data, and then convert the data back to analog.)
6	Provide the capability to support video. (This includes video, data, and voice signals.)

7	Provide the capability to support immediate queries/accesses to text, data, and future image databases.
8	Provide POM and accounting the capability to communicate with the remote sales offices.
9	Provide the capability for POM and manufacturing to communicate with each other.

Table 2.0 Office Environment: Functional Requirements

2.2.1 OPERATIONAL REQUIREMENTS

Table 2.1 lists the operational requirements for the office environment.

REQUIREMENT #	DESCRIPTION OF REQUIREMENT
1	Provide the capability to add and/or remove a device without degrading or terminating operations.
2	Provide a system that requires less than two (2) hours per week maintenance for the end user community.
3	Provide a system that does not require greater than five (5) hour down time per day. The data used in the office environment is not accessed during a five (5) hour window.
4	Provide a system where the end user with technical skill level 3 can bring a personal computer, workstation, or printer online.

5	Provide a system that has error detection and error correction code.
6	Provide a system that complies with standards if economically feasible.

Table 2.1 Office Environment: Operational Requirements

2.2.2 PHYSICAL REQUIREMENTS

Table 2.2 lists the physical requirements for the office environment.

REQUIREMENT #	DESCRIPTION OF REQUIREMENT
1	Provide the capability to support forty-five (45) office devices.
2	Provide the capability to support a maximum of one hundred (100) office devices for future growth.
3	Provide the capability to interconnect "office" devices consisting of personal computers, workstations, FAX machines, direct access storage devices, optical libraries (for image data in the future), and printers.
4	Provide the capability to interconnect these devices that are physically located within a distance of two (2) kilometers.

5	Provide low interconnection costs. (Due to the decrease of the cost of peripherals, the interconnection cost should be less than the cost of the peripheral device.)
6	Provide the capability to move or reconfigure devices frequently.

Table 2.2 Office Environment: Physical Requirements

2.3 MANUFACTURING ENVIRONMENT

The following three subsections further define the requirements for the manufacturing environment.

2.3.0 FUNCTIONAL REQUIREMENTS

Table 2.3 lists the functional requirements for the manufacturing environment.

REQUIREMENT #	DESCRIPTION OF REQUIREMENT
1	Capability to transfer large volumes of data per day from the manufacturing equipment to a minicomputer.
2	Capability to transmit quality control data to another device in x seconds 95% of the initial attempts to transmit. This transmission time must have a variance of +- 0.02 seconds. (High degree of determinism)
3	Provide error detection and error correction.

Table 2.3 Manufacturing Environment: Functional Requirements

2.3.1 OPERATIONAL REQUIREMENTS

Table 2.4 lists the operational requirements for the manufacturing environment.

REQUIREMENT #	DESCRIPTION OF REQUIREMENT
1	Provide a system with 99% availability.
2	Provide a system that can be installed and maintained by an technician or engineer of skill level 14.

Table 2.4 Manufacturing Environment: Operational Requirements

2.3.2 PHYSICAL REQUIREMENTS

Table 2.5 lists the physical requirements for the manufacturing environment.

REQUIRMENT #	DESCRIPTION OF REQUIREMENT
1	Capability to operate in an environment where numerous electrical signals are emitted.
2	Provide a system where the interconnection costs are lower than the manufacturing equipment.
3	Provide the capability to support eighteen (18) devices.
4	Provide the capability to support a maximum of thirty-two devices in the future.
5	Provide the capability to interconnect the devices that are physically located within eight (8) kilometers.
6	Provide the capability to function in a hostile environment, e.g., dirt, dust.

Table 2.5 Physical Requirements: Manufacturing Environment

3.0 CONCEPTUAL DESIGN

The conceptual design of the system is an abstract expression of the solution for the requirements [3]. The conceptual design is a "paper" design and the physical hardware and/or software is not produced at this phase but in the development phase. Some prototyping, simulation, and/or modeling data may be developed in this phase, but this output may not be a part of the actual software, hardware, microcode, or procedures delivered to the customer. The basic technology to satisfy the functional, operational, and physical requirements is chosen. After review of the customer requirements described in section 2.0 to section 2.3.2, the systems engineer has determined that local area networks used in conjunction with other data processing equipment would provide the optimal solution. The remainder of this thesis concentrates on the interconnection (networking) solution and not all the software needed for the applications.

Local area networks are chosen as a part of the solution for this particular customer for the following reasons:

1) Groups within the overall organization have differing requirements. LANs allow each group's requirements to be satisfied without compromise to a detrimental end. LANs allow

the overall organization to function in a modular manner but still allow for connectivity between the modules. Each LAN or module is optimized (cost and function) for that particular group's requirements.

2) One user or node needs to frequently communicate with another node.

3) The customer requires great flexibility in interconnection capabilities. This flexibility includes the quantity of equipment, type of equipment, and the physical location of the equipment.

Due to the flexibility available with LANs, a disadvantage is the fact that the complexity of installation and maintenance increases. The advantages do outweigh this disadvantage, so LANs are a viable and desirable solution. The following sections further define LANs.

3.1 INTRODUCTION TO LOCAL AREA NETWORKS (LANs)

A local area network is a communications network that contains an interconnected collection of autonomous computers and/or associated data communicating devices capable of exchanging data

within a limited geographical area [5]. The exchange of data can be further defined as the transmission of voice, video, or digital signals in any direction between multiple devices [5]. The autonomous computers and/or data communicating devices include any device such as workstations, telephones, facsimile (FAX), image scanners, color printers, aperature card plotters, or manufacturing process control equipment that communicates over a transmission medium. A personal computer will be used throughout this thesis to mean a microcomputer that is at the lower end of capabilities and processing power. On the other hand, a workstation is a sophisticated high powered microcomputer capable of many functions e.g., integrated floating point hardware, graphics processor, 32 bit system, multi-tasking, windowing. The American Institute of Electrical and Electronic Engineers (IEEE) Committee 802 defines a LAN: "A LAN is a datacomm system allowing a number of independent devices to communicate directly with each other within a moderately sized geographical area over a physical communications channel of moderate data rates."

Local area networks have appeared on the horizon due to the decrease in price of personal computers, workstations, and peripherals with an increase in their processing power. The computer processing power no longer has to be located at the central processing unit of the mainframe. The end users have the

choice of where the processing power can be physically located and how much processing power needs to be at that particular location. More companies, government agencies, universities, and similar institutions have dispersed the computing power so that it is closer to the end user. Due to the increase in the number and types of personal computer/workstation software packages, the end user has greater discretion in the type of tools to run on his/her own personal computer or workstation. In the past, the end users were limited by the capabilities of the host mainframe computer which attempted to meet the requirements of all the users. With the processing power dispersed to the end users, the end users may have more specialized tools at their disposal without levying those same requirements on other end users. Some engineers need high processing power for complex calculations while the secretary of the department has the requirements for word processing and electronic mail. The engineer would have a scientific workstation and the secretary would use the low cost personal computer. Each user would utilize a personal computer/workstation according to his/her needs which is more cost effective. This flexibility to meet the end user's needs on a more economical basis has increased the demand to connect these independent devices and LANs can meet some or most of these needs.

Many end users work in some type of departmental group whether it be an accounting department for the government, an engineering research department at a company, or the student records deparment at a university. The LANs provide the capability to exchange the data amongst the members of the department(s). The data is exchanged directly from node to node instead of being transmitted from the origin node to mainframe to target node which reduces the overall network traffic. Computing power not only provides the capability for high powered calculations but the capability to communicate these results effectively. Much of the "cost" in real world applications involves the ability for people and computers to communicate. If a computer is able to complete millions of calculations quickly but communicates the results slowly, then the overall power(value, effectiveness) of the equipment is diminished. LANs provide the communication necessary for the data communicating devices or the people using this data.

Lastly, the geographic range of the LAN is relatively small. LANs are usually implemented in a building or campus environment. If the data must be transmitted over longer distances then the LAN can be connected to other networks.

3.2 DIFFERENCES OF A LAN FROM OTHER NETWORKS

Local area networks can be differentiated from other networks (telecommunications, long haul, wide area networks) if the communication network has most or all of the following characteristics [4]:

1) All the devices on the communication network share the same physical transmission medium e.g., cable, optical fiber.
2) The devices can operate independently of the other devices on the LAN or the transmission medium.
3) The geographical area that a LAN transverses is relatively limited and is generally less than 25 km.
4) The transmission data rate is high compared with that of telecommunication networks.
5) The occurence of transmission errors is less probable than with other networks.
6) Any device on the LAN can communicate or exchange data with any other device on the LAN provided physical/logical paths exist.
7) The LAN does not use public services or utilities. The LAN is privately owned, operated, and controlled. No

external regulations or restrictions apply to it. In contrast, the telecommunications networks have governmental regulations and restrictions applied to them.

8) The devices on the LAN are loosely coupled as opposed to being tightly coupled. The devices are capable of operating with little dependencies on other devices.

The LAN's size is in between that of the bus network in the computer and a normal telecommunications network. Figure 3.0 illustrates a bus network in a computer.

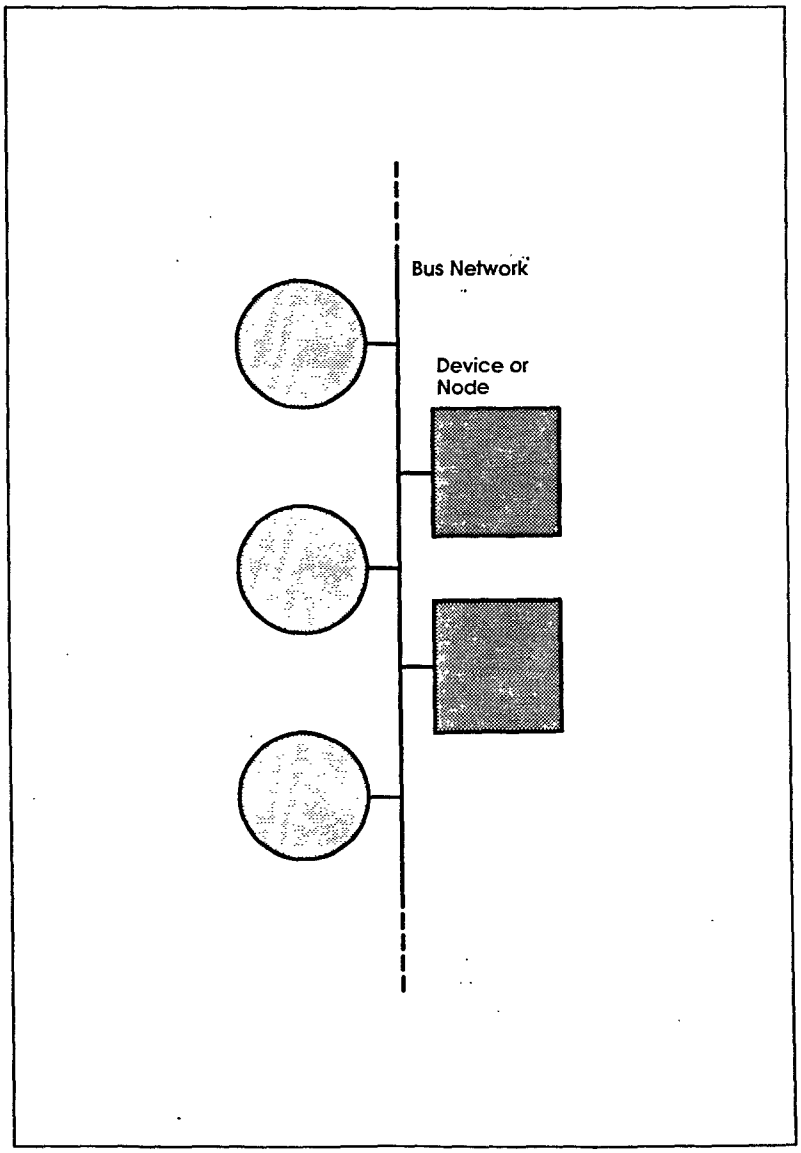

Figure 3.0 Bus Network

Figure 3.1 provides a comparison of multiprocessor systems, local networks, and long haul networks. Characteristics #3 and #8 differentiate local networks from long haul networks and multiprocessor systems. Long haul networks are needed when data must be transmitted for distances greater than 25 km. Satellites are often used in this type of transmission. LANs generally experience significantly fewer data transmission errors and significantly lower communications costs than those of long haul networks.

Multiprocessor systems are tightly coupled, usually having some central control with integrated communications functions while LANs are opposite in features. A multiprocessor system involves two or more processors configured so that communication may occur periodically, on-line in interactive mode, or in batch mode. The processors are usually located in the same room or same floor in the building. A multiprocessor system is configured with this communication capability if greater processing power is needed than can be provided by one processor, or if one or more of the processors are specialized in function or processing power, or if one processor is a backup unit in case of failure of the primary processor and recovery is required.

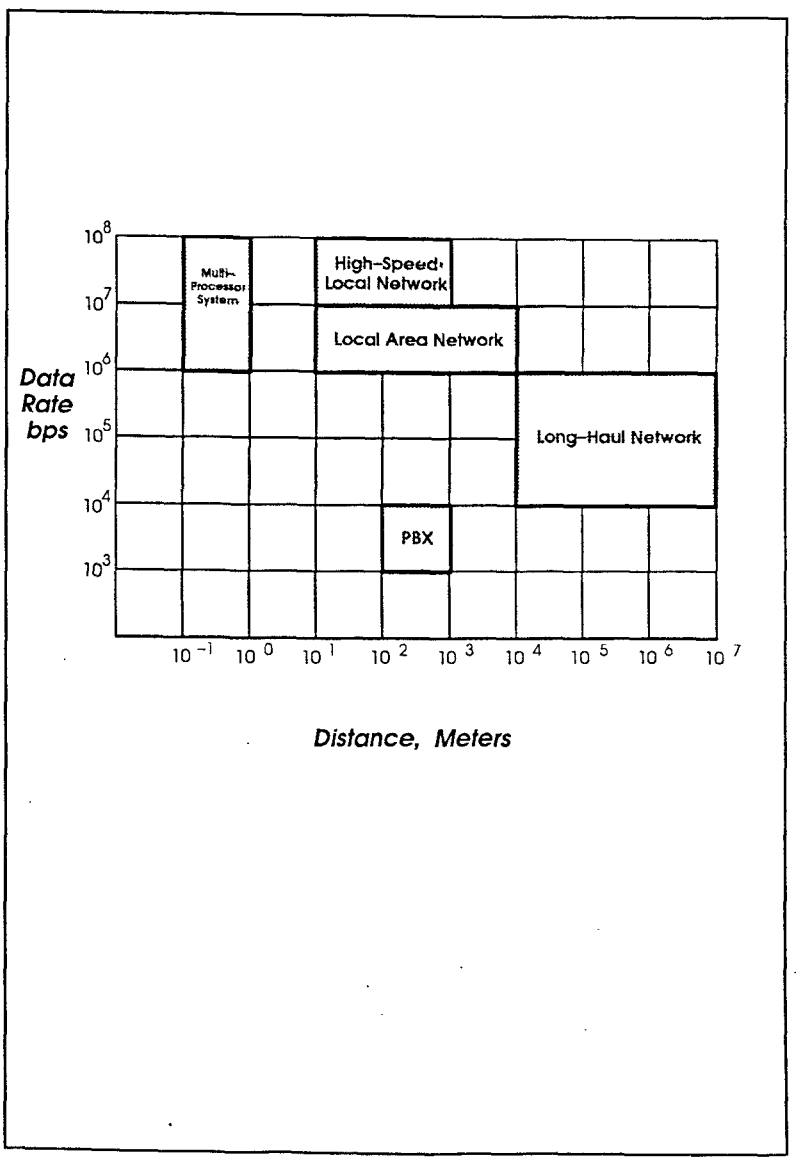

Figure 3.1 Comparison of Multiprocessor Systems, Local Networks, and Long Haul Networks [5].

3.3 ADVANTAGES AND DISADVANTAGES OF A LAN

As with any technology, advantages and disadvantages exist. The goal is to benefit from as many advantages as possible for the specified environment with minimizing the effects of the disadvantages. Local area networks are not the solution for every list of requirements. The goal is to understand when and where local area networks can be optimal and using them at that time.

Local area networks are advantageous when the customer wants to add devices slowly with minimal impact to the overall operation. LANs also allow the end users and the computer system to share expensive resources such as storage devices or printers. Each user does not have to invest in their own devices. LANs also sometimes allow devices manufactured by different vendors to exchange data with each other. Some personal computer and workstation software packages have import, export, and conversion functions contained in the products.

On the other hand, LANs can be disadvantageous when multiple users have access to a database and it is not desired. Some type of software security must be implemented to circumvent this problem. LANs may have different protocols causing interconnection difficulties. Finally, interoperability is not guaranteed between

the software and data. One device may generate data but another device on the LAN may not be able to import that data and process it.

3.4 TRANSMISSION METHOD

Transmission method involves the organization of the data that is transmitted from one node to another node in the network. Three categories exist for transmission method: circuit-switched, message-switched, and packet-switched [4]. Circuit-switched networks dedicate a complete physical connection i.e., an electrical circuit, centralized switching facility [4]. Message-switched allow a pair of nodes to have access to the transmission medium for the duration of their session. The disadvantage of the message-switched network is that the other devices on the LAN must wait for access to the transmission medium. Packet-switched networks allow a transmitting node access to the transmission medium for the time required to transmit a specified amount of data. The amount of data in this packet is determined by the operating conditions of the network. Small packets will not be efficient because the target node address and control information must be sent with each packet. Unusually large packets will increase the time that the other nodes will have to wait before the node is able to transmit. A balance must be obtained in order

to maximize performance for the application(s). Most currently available commercial LANs use packet-switching for their transmission method, even with the star topology (discussed in section 4.1.0.) Due to this committment to the packet-switching, it is assumed that LANs will continue on this path. Therefore, this thesis will assume that the LAN solution uses packet-switching.

4.0 CLASSIFICATION OF LANS

LANs can be classified according to a multitude of criteria. This trade-off analysis uses the following classification criteria: topology, cable access protocols, signalling methods, and transmission medium. Other criteria can be used but these were chosen because they provide the greatest discerning factors in determining the optimal LAN in comparison to the requirements of the environment.

4.1 TOPOLOGY

Topology is the physical/logical interconnection pattern for the attachment of the devices in order to support the exchange of data. Three basic topologies exist: star, ring, and bus [6]. All other topologies are derivations from these fundamental three.

Of interest is the manner in which the network utilizes the topology to transmit data. Networks can be classified either as sequential or broadcast networks. In a sequential network, a signal is sent from one node to the next consecutive node. Sequential networks require each node to receive the signal, read the signal, recreate the signal, and retransmit the signal to the next node in sequence. Broadcast networks transmit the signal to

all nodes simultaneously. Each node must decide which signal to process or not to process according to the address. The following subsections describe various topologies.

4.1.0 STAR

The star topology was the first to gain recognition in the arena of local area networks. The topology evolved from the concept of the computer system as the controlling entity of the devices that are slave to this master. Figure 4.2 depicts the star topology with the centrally located computer giving authority to the outlying nodes.

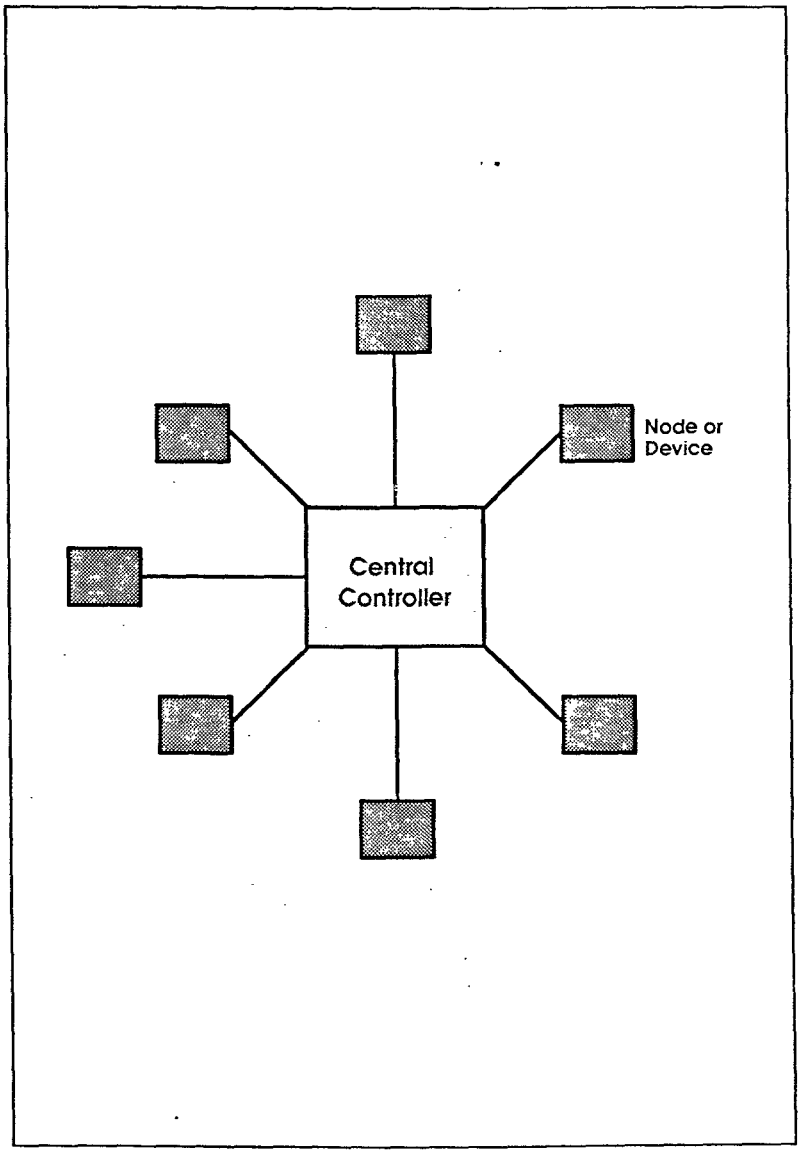

Figure 4.0 Star Topology

When a node wants to transmit data, the source node sends a request to the central controller requesting a connection to a target node. Once the circuit is set up, data is exchanged between the source node and the target node as a dedicated point-to-point connection.

The central hub is the one and only intelligent resource with command functions. It performs all logic and switching functions that may be required. It is interesting to note the first application of this topology. It is a result of the telephone industry's reorganization in 1934 when Congress adopted the Communications Act [6]. AT & T had a complete monopoly over the telecommunications industry. It had distributed networks where there was wiring between individual homes with one centralized exchange. When a telephone call was made there was no decision as to the path the data would make since there was only one path. If there was a disturbance in that one path, then the reliability of the system was in jeopardy since no backup path existed. The star network is important because private telephone exchange (PBX) systems may be already installed where LANs are needed. If a LAN could be based on the existing PBX, then installation costs would be drastically reduced.

The performance of the network is related to the performance of the central controller. The network is able to process only as fast as the central controller since all data has to be passed through the central controller. If the central controller failed, then the entire telecommunications network failed. A disadvantage of the star network is that each node requires a separate link to the hub. The materials and labor costs can be very high even though expansion is flexible.

Another variation on the star topology is to have a device in the place of the central hub which broadcasts the message to all the devices in the star topology network. This is a crude version of a bus network in a star topology. This configuration requires that each node then have the intelligence to recognize its own messages and to be able to respond to them.

Finally, the addition, removal, or failure of one of the outlying nodes has minimal impact on the overall performance or availability of the network system. Broadcast networks are more reliable since all the nodes will have to fail in order to fail the network. According to the characteristics of LANs in comparisons to other communication networks given in section 3.3, the star topology is not a thoroughbred LAN. The shared resource is the central controller and not the transmission medium.

4.1.1 RING TOPOLOGY

In the ring topology the controller or the "intelligence" is a device in the ring like any other device at a node. Figure 4.3 illustrates a ring topology.

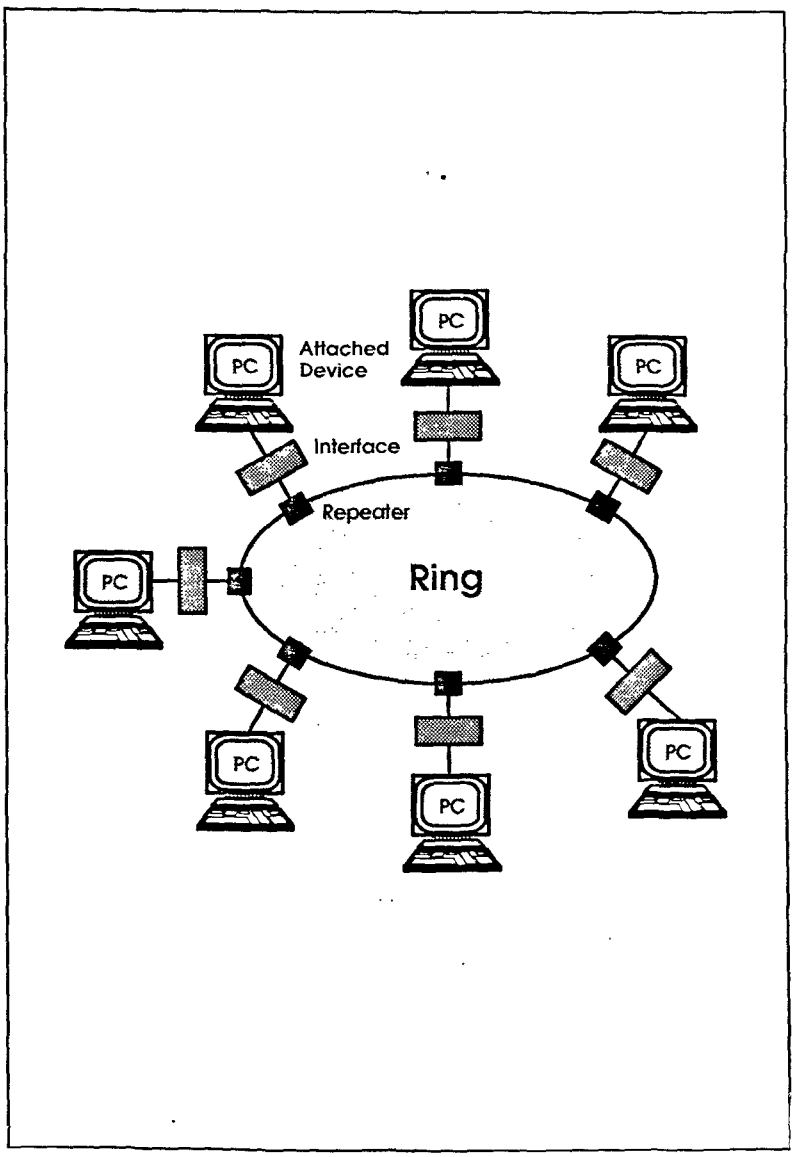

Figure 4.1 Ring Topology

The control functions consists of the communications tasks and performance monitoring. The control function can be performed by a dedicated device (then it is called a loop) or each device can participate/support this control function. The ring topology is a sequential network where the devices in the LAN are a series of nodes. The address and actual data are transmitted sequentially to every node until there is a match in the address. If there is a match then the device processes the data. If there is not a match then the device regenerates the message and passes it to the next node. The flow is usually unidirectional with no routing decisions.

The ring topology introduces the possibility of a degredation in the data integrity since the address and data are regenerated many times. To offset this, the message can return to the originator for verification or have an acknowledgement sent.

If there is a break in the ring, then the entire system has failed. In order to circumvent this scenario, each node has a relay with a circuit. When the circuit is de-energized, it shorts the two together. Also, redundant cabling can be used or secondary cables between alternate nodes can be installed. A switching function can be used to bypass the failed node so that a subset of the original ring can go on processing. This switching

function must constantly test to determine if the next node in the ring is functioning properly. Implementing a bidirectional ring would also alleviate this problem. Once the data encounters the failed device, the data flow in the ring could be reversed. A new ring would then be implemented.

In a ring topology the devices are not attached directly to the transmission medium. Each node has a device called a repeater that receives the transmitted data and retransmits the data to the next node [4]. This configuration avoids problems when the device e.g., personal computer, has failed. The repeater is powered separately and continues to receive and retransmit the messages whether or not the attached device is functioning properly. Sometimes there is another device used to interface the repeater to the attached device. This interface component performs the function of data buffering and ring access functions [4]. This allows the repeater to perform the receive/transmit functions with little responsibility in the arena of error checking which speeds up the overall repeater performance.

4.1.2 BUS OR UNROOTED TREE

The bus network is based on the concept of networking used in the internal architecture of computer systems where the transmission

medium between devices is a single shared resource. The bus network was the last topology to emerge becasue the implementation required that each node participate in the management of the network requiring the nodes to be more complex. The topology was dependent on the development of the microprocessor chip to provide the intelligence at each node. The bus network is the most basic of all the LAN topologies. The bus has great configuration flexibility due to the distributed control intelligence. Data is sent to every device on the bus and only the intended receiver pays attention to the data. Only one data packet may be sent on the bus at a time. All the power for the entire transmission is provided by the originating node. Figure 3.0 depicts a simple bus network. Since the non-originating nodes are passive listeners for the messages, if a failed node is connected to the bus, this failed node does not affect the performance or the capability to perform of the entire bus. The remainder of the devices on the bus can continue transmitting data. Also, additional nodes may be added to the bus with minimal impact to the operation of the bus. This expansion may require the bus to have extra length, but a repeater can be installed that will read the message and retransmit it in order to have the same strenth. The bus network inherently allows for ease of installation. It is easier and cheaper to install a single cable throughout a building than to install many radiating lines for the star network or to have a

return line for the ring topology. The costs in cabling could be significant.

Another situation that can occur with bus networks is when one device on the bus continuously transmits data and has taken control over the network not allowing other devices access to the network. Since there is not a central intelligence or a monitoring device, this phenomena could be disasterous until the failed device is removed from the network.

Another variation on the bus network is the tree topology. The tree topology is an extension of the bus in which several buses are joined together. This joining of multiple buses produces the branching effect. There are two types of trees, rooted and unrooted. Unrooted trees take the basic form as the bus network but their branching is random. Failure of a single branch other than the main bus does not normally disrupt the network. Rooted trees have a unique control point at which some critical device is located. This critical device approves/disapproves communication with other branches. Figure 4.4 depicts a rooted tree bus topology.

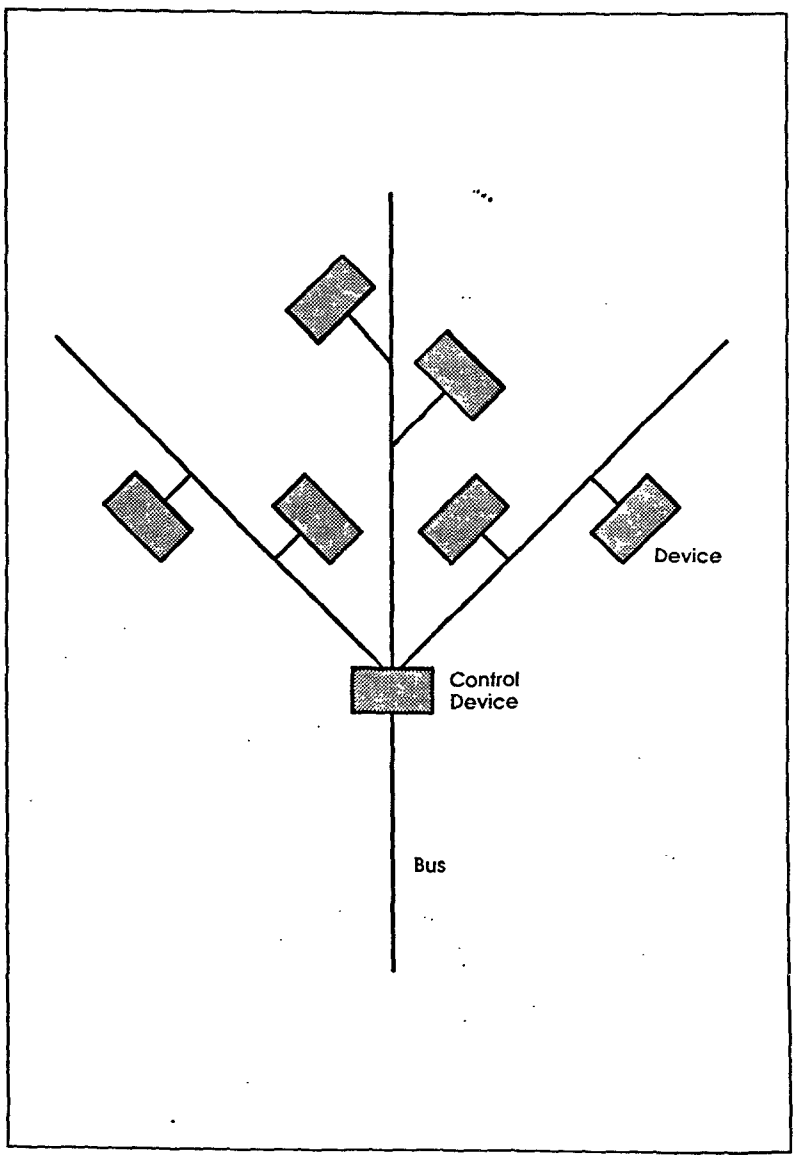

Figure 4.2 Rooted Tree Bus Topology

4.2 SIGNALLING METHOD

In order for a network to operate, data must be transmitted to its destined device reliably. Two categories of signalling methods have evolved to perform this function: baseband and broadband.

4.2.0 BASEBAND

Baseband signalling methods include those where data is introduced to the transmission medium directly without any modification or modulation of the data [4]. Since no modulation occurs, baseband transmitters and receivers (transceivers) are technically simple to contruct and are therefore inexpensive; due to this low cost, baseband is popular. The bandwidth of the system is that of the originating datastream [4]. The data is introduced to the medium as a series of 1's and 0's, represented by voltage levels or light pulses depending on the medium. Baseband networks function by allocating a designated time period for each device to transmit the data. If no data is to be transmitted then the time period is not used by another node. Baseband multiplexes the signals that the devices can transmit in time or Time Division Multiplexing (TDM).

The drawbacks of baseband include the fact that only one device can introduce a signal to the transmission medium at a time.

4.2.1 BROADBAND

Broadband evolved from Community Antenna Television (CATV), or cable television. The data signal, introduced to the transmission medium, is modulated to a carrier wave of fixed frequency [4]. This carrier is transmitted on the transmission medium until it reaches the destined device where it is demodulated at the receiver to recover the original data. Since the carrier can have any frequency theorethically, it is named broadband. Numerous signals are transmitted at the same time but at different frequencies or Frequency-Division Mutiplexing (FDM).

The difference between baseband and broadband is that baseband is multiplexed on time while broadband is multiplexed on frequency.

Each broadband installation must have a radio frequency transmitter and receiver at each node in the LAN. Each node will transmit or modulate the data and then at another time receive the data or demodulate it. The requirement for the modems can be limiting factor from a cost perspective.

4.3 CABLE ACCESS PROTOCOLS

One of the characteristics of LANs identified in section 3.3 was that all the devices on the communications network share the same transmission medium. In a ring and bus topology, the same transmission medium is shared by all the devices in the transmission of the data. This is not true for a star topology. The only part of the transmission medium used by a node in the transmission of data to another node is the direct path through the central controller (this does not include the broadcast star topology.) Since the star topology does not share the same transmission medium, like the bus and ring topologies, protocol techniques for access to the medium are not needed. Bus and ring LANs, on the other hand, have multiple nodes trying to transmit data on the same medium. Some set of rules or protocols must be enforced to guarantee the optimal use of the LAN equipment with each device's requirements optimized, if possible. The following protocols involve some variation in the timing of access to the transmission medium. Due to the Time-Division Multiplexing (TDM), these protocols relate to baseband networks that have bus or ring topologies.

4.3.0 CSMA

In the bus topology, the data is transmitted or broadcast to all devices attached to the bus. When multiple devices are attached, the problem arises when multiple devices broadcast simultaneously. The data becomes corrupted and no data is effectively transmitted. A method is for each device to have an assigned priority and is given approval to transmit before doing so. Also, a protocol can exist where each node is given an opportunity to transmit in an equally based order. Each node will have the same number of chances to transmit but by following a specified order. While in the prioritization protocol, some nodes may have a greater number of chances to access the medium.

Out of this need, Carrier Sense Multiple Access with Collision Detection (CSMA/CD) was developed where all devices "listen" to the bus and if a device is in the process of transmitting then the device waits. If the device does not hear any data being transmitted, then the device transmit the data. It is possible that two or more devices simultaneously initiate transmission causing multiple data packets to be on the bus at any one time. Collision detection senses that simultaneous transmission is occurring and the multiple devices stop transmitting. After a random amount of time, the devices attempt to transmit again.

CSMA/CD is an outgrowth of CSMA. When collision detection was not performed, the entire data packets of the multiple devices transmitting simultaneously would be transmitted. It was not until the target node returned a message acknowledging transmission error that the collision was detected. Since the collision is identified earlier, the performance of the bus is improved.

A combination of the contention and ordering protocols is shown in the CSMA/CA (CSMA/ Collision Avoidance). After data has completed transmission, this protocol allocates a fixed time for each node to transmit. If the node does not need to transmit any data, the time period is left unused. If no nodes transmit after all have had the opportunity to transmit then the protocol reverts to CSMA/CD until the next transmission takes place. This variation allows for a prioritization of nodes where the transmission delay times are critical. The advantages of CSMA and its variants is that it orders and optimizes the access to the bus network. It does have the following disadvantages [4]:

1) The data packet minimum size is dependent on the size of the network. Assume the network is relatively large and the data packets are small. Due to the propagation delay for a large network, different devices on the network will detect a collision

at different times. The data packet size and network size must be balanced so that all devices detect a collision at the same time in the network.

2) Due to the random order of access to the medium, some devices will have unpredictable, undue delay. It is just a matter of chance that a device gains access to the medium and another device may have a prolonged wait. For environments requiring a fixed response time, this protocol would be undesirable.

3) If the data is corrupted due to another reason other than collision, then the originating device will not be able to know this reason. The originating device will get a message indicating corrupted data and it is assumed in this environment to be due to collision. Collisions on multiple attempts could be probable due to the amount of network traffic. The real reason for data corruption would not be detected nor solved.

4.3.1 TOKEN PASSING

Token passing involves a specific data packet or token that is transmitted in the bus or ring network. Receipt of this token by a device gives the device the opportunity to transmit data. Only one token is available in the network and so only one device is transmitting at any one time. Determination of which node gets the token can either be sequential or prioritized.

Token passing allows for a greater predictability in the timing of when a device can transmit data. The disadvantages of token passing is that a failed node can destroy the token or generate additional tokens causing chaos. Additional procedures must be instituted to safeguard against these scenarios. One device might provide a primary monitoring function. If the monitoring device fails, some other device must determine that the primary monitoring device has failed and take over the monitoring function.

4.3.2 SLOT METHOD

The slot method involves a specified number of fixed length data packets that continuously circulate around the ring network. The data packet consists of one or more slots and corresponding header(s). The header(s) indicates if the slot is empty or full. When the data packets are transmitted around the ring, the device reads the header to determine if the slot is empty. If empty, the data is transmitted in one or more slots until all the data is transmitted. When the receiving node has received the data, the header is changed to empty.

4.3.3 BUFFER INSERTION

Buffer insertion is another method of cable access protocols for the ring topology. When a node needs to transmit data, the repeater of the node determines the end of a packet, and then switches the buffer containing the data for transmission into the ring circuit [4]. The buffer effectively becomes part of the ring and the ring size is increased by the length of the buffer. The data is serially transmitted onto the ring and incoming data is received in the buffer. Once the data is transmitted around the ring, the data is returned to the originating device. The originating device detects this and removes the data from the ring. At this time, the buffer is removed from the ring. Buffer insertion allows for larger packet sizes and the size of the packet is limited by the size of the buffer.

4.4 TRANSMISSION MEDIUM

The transmission medium is the physical materials used to physically connect the data communicating devices. Unusual, expensive, or theoretical media may be used but this project is dealing with real world applications and the type of media will continue in the same intent. The transmission media used for LANs

consist of various forms of electrical conductors and fiber optics. Electrical conductors have been on the scene longer than fiber optics, therefore the electrical conductors have been used throughout industry much more frequently. Due to the advancement in fiber optics and the reduction in price, a greater number of customers are converting or using it for their initial LAN installation. There are three types of electrical conductors commonly available today: twisted pair, ribbon/multicore cable, and coaxial cable. Each type will be described briefly.

4.4.0 TWISTED PAIR

The twisted pair is a pair of single insulated conductors twisted together in order to minimize the amount of noise absorbed from the environment. Twisted pair cable has been used for numerous years for the transmission of analog voice traffic in telephone networks. It is an advantage that almost all buildings have been wired with twisted pair cable for the existing telephone system. Since twisted pair cable is established, twisted pair cable is inexpensive and easily installed.

The disadvantages of twisted pair include the fact that the cable was designed for the transmission of analog signals. It cannot support high data rates over a long distance. The high frequency

signals are degraded over long distances requiring the addition of repeaters. Twisted pair also emits a considerable amount of energy and is susceptible to external noise. This may pose a problem where electrically sensitive equipment is installed or where security of the data is important.

4.4.1 RIBBON/MULTICORE CABLE

Ribbon and multicore cables are distinct but they exemplify similar advantages and disadvantages, so they will be described in the same manner and be taken to be the same. Ribbon cables are flat but wide cables, like a ribbon with stripes, where a number of separate conductors allow the separation of control, data, and synchronization signals within the overall signal. This simplifies the level of complexity of the network interfaces which reduces the overall cost per node. Ribbon cables exhibit high attentuation like twisted pair cables and therefore repeaters are required for high data rates over long distances. The advantage of ribbon cables over twisted pair is the effective data rate. The signals are sent over multiple parallel conductors which effectively allows for a significant improvement in the amount of data allowed to be transmitted. Ribbon/multicore cable is described for informational purposes but is not an option per the customer's direction.

4.4.2 COAXIAL CABLE

The third type of electrical conductor is coaxial cable and it is the most popular in commercial installations. Coaxial cable consists of a central conductor surrounded by an insulating dielectric material (braided wire shield) and covered with a conducting screen which forms the signal return path [4]. The cable has a protective insulating sheath on the outside. Coaxial cable prevents the noise from entering the transmission medium in the network therefore eliminating the need to remove the noise from the network. The inner and outer braided conductors carry the desired signals, with the outer shield going to ground [4]. With the outer conductor grounded, any noise encountered is intercepted and return to earth before it interferes with the desired signal. Generally, the smaller the physical diameter of the cable, the narrower the bandwidth.

4.4.3 FIBER OPTIC

Fiber optic media is an extremely high performance media that consists of a single thread of glass. As described by [6], at one end of the flexible glass rod is a light source, like a laser or light-emitting diode (LED); at the other end is an optical

detector. Light passes through this thread of glass. Information is transmitted over this beam through modulation of the light source.

Fiber optics has high bandwidth that can be twenty-five times as great as coaxial cable. Also, since fiber optics uses light and not electricity, the transmission is not affected at all by electrical interference or "noise." Fiber optics is also immune to illegal tapping of the fiber preserving the security of data. It is almost impossible to tap into the fiber without it being detected.

Fiber optics is a relatively young technology and therefore equipment such as connectors are expensive and obtaining technicians is sometimes difficult. According to [7], costs for fiber network equipment could drop up to 42% by 1994, due to the increased competition for the increased demand.

5.0 CONFIGURATION OPTIONS

Various options exist for the physical configuration of the equipment and the transmission medium. These options grew out of the requirements or demand of connecting multiple networks or networks with differing characteristics. Two groups may be physically distant but the groups still need to communicate with each other. Since these departments are physically distant, each department will have its own local area network since one local area network could not cover this entire geographical area with acceptable response time.

5.1 BRIDGES

In order for the two local area networks to communicate to each other, a bridge is installed. A bridge is a communicating device that selectively passes data from one network to another [6]. A bridge consists of three components that help in the accomplishment of this function: interface, filter, and buffer. The bridge is usually one personal computer that is attached to each local area network via cabling. Thus the bridge is a node in each network with its own address. The interface is usually a network adapter card that is installed in the personal computer. Two adapter cards are required because cabling must run from each adapter card to each local area network. This interface often

provides for amplification of the signals so that the signal can transmit accurately for a longer distance. The filter provides the function of determining whether a packet of data should be sent over the bridge to the other LAN or to be transmitted/processed on the current LAN. Since the bridge is a node in both networks, data packets may be destined to either LAN. This filter function is usually performed in software running in the bridge personal computer. Finally, the buffer provides the memory storage for data packets. If the two LANs are operating at different transmission speeds or the bridge node is not able to get immediate access to the receiving LAN, then the bridge stores the data packet in memory until the opportunity for transmission arises. It is assumed that the two networks have a similar protocol but different data rates.

The bridge is beneficial in the scenario where two networks have different requirements e.g., data transmission rates, and each network can be tailored for those two specific requirements without the other network sacraficing in its own requirements or having increased costs.

5.2 MODEMS

If the distance between the two networks is too great for twisted pair or coaxial cable, then a modem (MOdulator-DEModulator) can be

used. Usually the long distance data link is a leased telephone line due to its easy accessibility and low cost. A modem is a device that translates the digital signal to a carrier frequency to be transmitted over a leased telephone line and then at the receiving modem, it is translated back to a digital signal. Since leased telephone lines are usually used, there is an increased error rate. To eliveate this high error rate, the receiving modem "echoes" data back to the sending modem for verfication. Modems can be sending and receiving at the same time in order to increase overall throughput. An alternative to the modem is dedicated equipment that support the transmission of packet data.

5.3 BACKBONES

Multiple LANs may need to be interconnected for the transmission of data. One rudimentary method would be to connect the multiple LANs via bridges. This would increase the network traffic for LANs in the "path" and are not the source or target LANs. To alleviate this additional network traffic, a backbone network is installed. The backbone network has all the LANs connected directly to it. When one LAN wants to communicate to another LAN the originating node of LAN #1 sends the data to the backbone network and the backbone network transmits the data to the target node on LAN #X.

5.4 GATEWAYS

Two networks may need to be able to communicate with each other but the networks may different and incompatible protocols. A gateway provides the function of protocol translation or conversion. The gateway can take the form of a bridge or a modem. Protocol conversion involves the process of restructuring the addresses, error control, and flow control of data packets. The complications can be imagined from converting from a broadcast LAN to a sequential LAN in the structuring of the addresses. Usage of the standards (discussed in section 6.0) can help in this protocol conversion since the hierarchical layers isolate the functions and differences experienced at each layer.

5.5 LAN TO HOST MAINFRAME

An end user may need access to a host mainframe system and need the local processing power of a minicomputer. The minicomputer can contain an emulation hardware adapter and emulation software. The emulation equipment provides a method of one device appearing as if it were another device. The personal computer or workstation appears to be a terminal to the host mainframe. This is accomplished through protocol conversion or language (commands,

messages, and codes) translation.

6.0 STANDARDS

Due to the advantages of the local area networks, the number of users and manufacturers of local area technology and equipment has drastically increased. Due to this development, the need for standards has come into focus. Standards are the rules and regulations governing the physical design of a LAN and the protocols control the data flow in the LAN [4].

Numerous advantages exist for the support and implementation of standards. If all vendors implemented the standards, then it would be possible for the interoperability of multiple vendors' equipment. A consumer could purchase the products needed from each particular vendor. Since standards are not followed by many vendors today, a consumer is often "locked-in" to a vendor. After a consumer initially decides on a vendor to purchase products, it is often difficult or even impossible to change to another vendor. The vendor has a proprietory protocol in which few or even no other vendors support or interface to. If this primary vendor does not provide the products to solve a problem, the consumer has the choice of either waiting for the vendor to develop the product, to develop the product/function itself, or to have an integrator provide the development work. If all the vendors followed the standards, then there would be greater competition, development, and service in the market. This is one of the

reasons why the vendors have not followed the standards sooner. Many have a niche or customer base that they are not willing to risk to lose to high competition. Standards would provide greater overall reliability since more attention would be given to solving one set of problems instead of every vendor trying to solve its own problems. On the other hand, the technology used to support LANs may be considered to still be young. It may be difficult to standarize the protocols when the LAN requirements are not fully understood or researched. Various organizations have started the process of establishing standards. The following subsections identify the organizations and their progress.

6.1 OPEN SYSTEMS INTERCONNECTIONS

A predominant system for interconnection is the Open Systems Interconnections (OSI) model proposed by the International Standards Organization (ISO). The following overview information has been extracted from reference [4] to identify the progress and methodical approach used in the OSI model. The model involves the interchange of data between computers and peripherals. The model is not limited to the rules and regulations affecting LANs. The model consists of a seven layer architecture of protocols that enables two data communicating devices to communicate. The seven layers consist of protocols for interfacing hardware and software

at the various levels. The model was architected with multiple levels so that changes/improvements in one level does not affect the other levels. The changes are isolated from other software and hardware which will decrease the overall cost to the customer. The seven layers are as follows:

Layer 1: Physical medium: The physical medium is the actual hardware that is used to transmit the data from one device/location to another. Examples include the adapter cards in personal computers or the coaxial cable.

Layer 2: Physical layer: The physical layer provides and controls the physical connections between two devices in a network. It provides the control mechanism for the transfer of data on the physical medium.

Layer 3: Data link layer: The data link layer provides control for reliable transfer of blocks of data. This protocol is responsible for error detection and recovery.

Layer 4: Network layer: The network layer controls the transfer of data in an intermediate system if the data is destined to another system.

Layer 5: Transport layer: The transport layer controls the end-to-end transmission of data. This protocol is responsible for optimizing the utilization of the resources involved with the transmission.

Layer 6: Session layer: The session layer provides session control between two devices. A session is the agreement or handshake between two devices that they are in concert with how the conversation (transmission of data) will occur.

Layer 7: Presentation layer: The presentation layer controls the data formats and codes.

Layer 8: Application layer: The application layer communicates directly with the end-user's application program. Examples of application programs are a banking program for the deposit and withdrawal of money, an program used in the tracking of patients' bills in a hospital. Application programs are not part of the operating system for the computer.

6.2 IEEE 802

The American Institute of Electrical and Electronic Engineers (IEEE) organized a committee (the committee was given number 802

and hence the LAN standard is called IEEE 802) to produce LAN standards. The IEEE 802 standard has legitimized the protocols that were already developed by the computer or electrical industry. These include three types: contention using CSMA/CD, token bus, and token-ring.

7.0 TRADE-OFF ANALYSIS CRITERIA

To objectively determine the optimal design solution, weighted evaluation criteria are used. Evaluation criteria effectively "force" the SE to determine the key decision factors. It is assumed that the SE has been objective in determining the evaluation factors. To be realistic, price should always be a factor. It is worthwhile to do a price/performance analysis to determine if the increase in price is worth or proportional at an acceptable rate to the additional function or performance.

For the AOA customer, the evaluation criteria include:

1) Cost for office solution and cost for manufacturing solution. AOA completed a cost benefit analysis. Due to the costs of the natural resources, the manufacturing processing equipment, and the pay level of personnel operating the manufacturing equipment, AOA concluded that greater cost reductions could be realized if the manufacturing equipment was fully automated and optimized. Therefore, greater money is allocated to the manufacturing area. On the other hand, the office area has a greater labor market and lower salary. It is better to optimize the productivity of the limited personnel skills in the manufacturing area. If the manufacturing and office areas have conflicting requirements and one area must compromise

then it will be the office area.

2) Ability of the solution to meet the requirements. If a requirement cannot be met immediately either due to the lack of development of technology or stifling costs, it is possible to "phase" the project where some functions are available early and later deliveries provide the other functions. The solution design will not preclude the future addition of function or equipment. It must be noted that risks are associated with this process.

It can be very subjective and nebulous in the determination of the level that a solution meets the requirements. One person's view of how well a solution meets the requirements may be dramatically different from another person's view of the same solution. It depends on the person's expectations of a solution and past experience. In order to minimize this subjectivity, the key requirements to be met and how they are to be met must somehow be quantified. The customer requirements have been mapped to the areas of topology, protocol access method, and transmission media. Within each of these areas the key evaluation criteria are identified with the corresponding weighting factor. The goal is to optimize (maximize) the overall result or score.

EVALUATION CRITERIA AND

CORRESPONDING WEIGHTS

MANUFACTURING ENVIRONMENT

Scale: 0, 1, 2, 3

where 0 = unimportant, not required
3 = important and/or required

Topology:

Factor	Weight
Low cost	1.0
Complexity at Interface	2.5
Flexibility/ Expandibility after Installation	1.0
Reliability	3.0

Cable Access Protocols:

Factor	Weight
Bandwidth	3.0
Number of Nodes	1.0
Distance	1.9
Low Delay	3.0
Cost/Node	1.0

Transmission Medium:

Factor	Weight
Bandwidth	3.0
Ease of Connection	1.0
Distance	1.9
Ease of Installation	1.0
Noise Immunity	3.0
Cost	1.0

Table 7.1 Evaluation Criteria and Corresponding Weights for Manufacturing Environment

8.0 TRADE-OFF ANALYSIS

Using the trade-off analysis evaluation criteria, a comparison is made of the requirements to the key evaluation criteria. The following categories of LAN characteristics are addressed, i.e., topology, cable access protocol, and transmission medium.

Table 8.0 provides a summarization of each topology's compliance with the evaluation criteria [4].

TOPOLOGY	KEY EVALUATION CRITERIA FOR TOPOLOGIES			
	Cost	Complexity at Interface	Flexibility/ Expandibility after Installation	Reliability
Bus	Low/Med (4)	Medium (3)	High (5)	High (1)
Ring	Medium (3)	Low (5)	Medium (3)	High (1)
Star	High (1)	Low (5)	Low (1)	Medium (3)

Table 8.0 Comparison of Topologies Against Key Evaluation Criteria

Five levels of compliance exist for each category (topology, cable access protocols, and transmission media) against the key evaluation criteria. The five levels of compliance are:

Low
Low/Medium
Medium
Medium/High
High.

It is possible that a level of compliance of "Low" is desirable in one scenario and undesirable in another scenario. Therefore, the numbers in parenthesis are added where a rating of 1 is

undesirable and a rating of 5 is desirable.

Table 8.1 provides the calculation of the weights and compliance to the key evaluation criteria for the topologies in the office environment.

TOPOLOGY	CHARACTERISTICS AND CORRESPONDING WEIGHTS				
	Cost	Complexity at Interface	Flexibility/ Extendibility after Installation	Rel.	
Weights	3.0	2.1	2.8	2.1	Total Score
Bus	4 (12.0)	3 (6.3)	5 (14.0)	1 (2.1)	34.4
Ring	3 (9.0)	5 (10.5)	3 (8.4)	1 (2.1)	30.0
Star	1 (3.0)	5 (10.5)	1 (2.8)	3 (6.3)	22.6

Table 8.1 Calculation of Weights and Compliance to Key Evaluation Criteria for Topologies - Office Environment

Table 8.2 provides the calculation of the weights and the compliance to the key evaluation criteria for the topologies in the manufacturing environment.

TOPOLOGY CHARACTERISTICS AND CORRESPONDING WEIGHTS

	Cost	Complexity at Interface	Flexibility/ Expandibility after Installation	Rel.	
Weights	1.0	2.5	1.0	3.0	TOTAL SCORE
Bus	4 (4.0)	3 (7.5)	5 (5.0)	1 (3.0)	19.5
Ring	3 (3.0)	5 (12.5)	3 (3.0)	1 (3.0)	21.5
Star	1 (1.0)	5 (12.5)	1 (1.0)	3 (9.0)	23.5

Table 8.2 Calculations of Weights and Compliance to Key Evaluation Criteria for Topologies - Manufacturing Environment.

Table 8.3 provides a summarization of each cable access protocol's compliance with the evaluation criteria [4].

CABLE ACCESS PROTOCOLS	KEY EVALUATION CRITERIA				
	Bandwidth	No. of Nodes	Distance	Delay	Cost/ Node
CSMA/CD	High (5)	Medium (3)	Medium (3)	High (1)	High (1)
Token Passing	Medium (3)	High (5)	High (5)	Low (5)	Medium (3)
Buffer Insertion	Medium/Low (2)	High (5)	High (5)	Med/Low (4)	Low (5)
Empty Slot	Medium (3)	High (5)	High (5)	Low (5)	Medium (3)

* Deterministic

Table 8.3 Comparison of Cable Access Protocols Against Key Evaluation Criteria.

CABLE ACCESS PROTOCOLS	KEY EVALUATION CRITERIA					
	Band-width	No. of Nodes	Distance	Delay	Cost/ Node	
Weights	3.0	0.8	1.0	1.8	3.0	TOTAL SCORE
CSMA/CD	5 (15.0)	3 (2.4)	3 (3.0)	1 (1.8)	1 (3.0)	25.2
Token Passing	3 (9.0)	5 (4.0)	5 (5.0)	5 (9.0)	3 (9.0)	36.0
Buffer Insertion	2 (6.0)	5 (4.0)	5 (5.0)	4 (7.2)	5 (15.0)	37.2
Empty Slot	3 (9.0)	5 (4.0)	5 (5.0)	5 (9.0)	3 (9.0)	36.0

Table 8.4 Calculation of Weights and Compliance to Key Evaluation Criteria for Cable Access Protocols - Office Environment.

Table 8.5 provides the calculation of the weights and compliance to the key evaluation criteria for the cable access protocols in the manufacturing environment.

CABLE ACCESS PROTOCOLS	KEY EVALUATION CRITERIA					
	Band-width	No. of Nodes	Distance	Delay	Cost/ Node	
Weights	3.0	1.0	1.9	3.0	0.5	TOTAL SCORE
CSMA/CD	5 (15.0)	3 (3.0)	3 (5.7)	1 (3.0)	1 (1.0)	27.7
Token Passing	3 (9.0)	5 (5.0)	5 (9.5)	5 (15.0)	3 (3.0)	41.5
Buffer Insertion	2 (6.0)	5 (5.0)	5 (9.5)	4 (12.0)	5 (5.0)	37.5
Empty Slot	3 (9.0)	5 (5.0)	5 (9.5)	5 (15.0)	3 (3.0)	41.5

Table 8.5 Calculation of Weights and Compliance to Key Evaluation Criteria for Cable Access Protocols - Manufacturing Environment.

Table 8.6 provides a summarization of each transmission medium's compliance with the evaluation criteria [4].

TRANSMISSION MEDIUM	CHARACTERISTICS AND CORRESPONDING WEIGHTS					
	Band-width	Ease of Con-nection	Distance	Ease of Instal-lation	Noise Immun-ity	Cost
Twisted Pair	Low (1)	Med/High (4)	Low (1)	Medium (3)	Low (1)	Low (5)
Baseband Coaxial	Med. (3)	Med/High (4)	Medium (3)	Med/High (4)	Med (3)	Med. (3)
Broadband Coaxial	Med/High (4)	Med/High (4)	Med/High (4)	Med/High (4)	Med/High (4)	Med (3)
Optical Fiber	High (5)	Low (1)	High (5)	Medium (3)	High (5)	High (1)

Table 8.6 Comparison of Transmission Media Against Key Evaluation Criteria.

Table 8.7 provides the calculation of the weights and compliance to the key evaluation criteria for the transmission media in the office environment.

TRANSMISSION MEDIUM	KEY EVALUATION CRITERIA						
	Bandwidth	Ease of Connection	Distance	Ease of Installation	Noise Immunity	Cost	
Weights	2.7	2.1	2.6	2.1	1.5	3.0	TOTAL
Twisted Pair	1 (2.7)	4 (8.4)	1 (2.6)	3 (6.3)	1 (1.5)	5 (15.0)	36.5
Baseband Coaxial	3 (8.1)	4 (8.4)	3 (7.8)	4 (8.4)	3 (4.5)	3 (9.0)	46.2
Broadband Coaxial	4 (10.8)	4 (8.4)	4 (10.4)	4 (8.4)	4 (6.0)	3 (9.0)	53.0
Optical Fiber	5 (13.5)	1 (2.1)	5 (13.0)	3 (6.3)	5 (7.5)	1 (3.0)	45.4

Table 8.7 Calculation of Weights and Compliance to Key Evaluation Criteria for Transmission Media - Office Environment.

Table 8.8 provides the calculation of the weights and compliance to the key evaluation criteria for the transmission media in the manufacturing environment.

TRANSMISSION MEDIUM	KEY EVALUATION CRITERIA						
	Band-width	Ease of Con-nection	Distance	Ease of Instal-lation	Noise Immun-ity	Cost	
Weights	3.0	1.0	1.9	1.0	3.0	1.0	
							TOTAL
Twisted Pair	1 (3.0)	4 (4.0)	1 (1.9)	3 (3.0)	1 (3.0)	5 (5/0)	24.9
Baseband Coaxial	3 (9.0)	4 (4.0)	3 (5.7)	4 (4.0)	3 (9.0)	3 (3.0)	34.7
Broadband Coaxial	4 (12.0)	4 (4.0)	4 (7.6)	4 (4.0)	4 (12.0)	3 (3.0)	42.6
Optical Fiber	5 (15.0)	1 (1.0)	5 (9.5)	3 (3.0)	5 (15.0)	1 (1.0)	44.5

Table 8.8 Calculation of Weights and Compliance to Key Evaluation Criteria for Transmission Media - Manufacturing Environment.

8.1 SELECTED SOLUTION

This section describes the solution for the requirements. Figure 8.0 illustrates the overall picture of the solution. The solution for the office environment was a bus topology with CSMA/CD, and broadband coaxial cable. The bus topology and broadband coaxial cable had greater advantages than the other options and it was evident in the scoring. CSMA/CD was not the top scorer for protocol access methods but was still chosen for the final solution. The conferencing and video transmission requirements determined that a broadband network was optimal. The conferencing requires that the data be transmitted without interruption and a broadband network provides for this capability since each node can have its own frequency if the bandwidth is sufficient. The video transmission requires the transmission of voice, data, and video signals. The video signal will be of poor quality if the different signal types are not separated and a high bandwidth would be required. Due to these needs, a broadband (CSMA/CD) network was chosen.

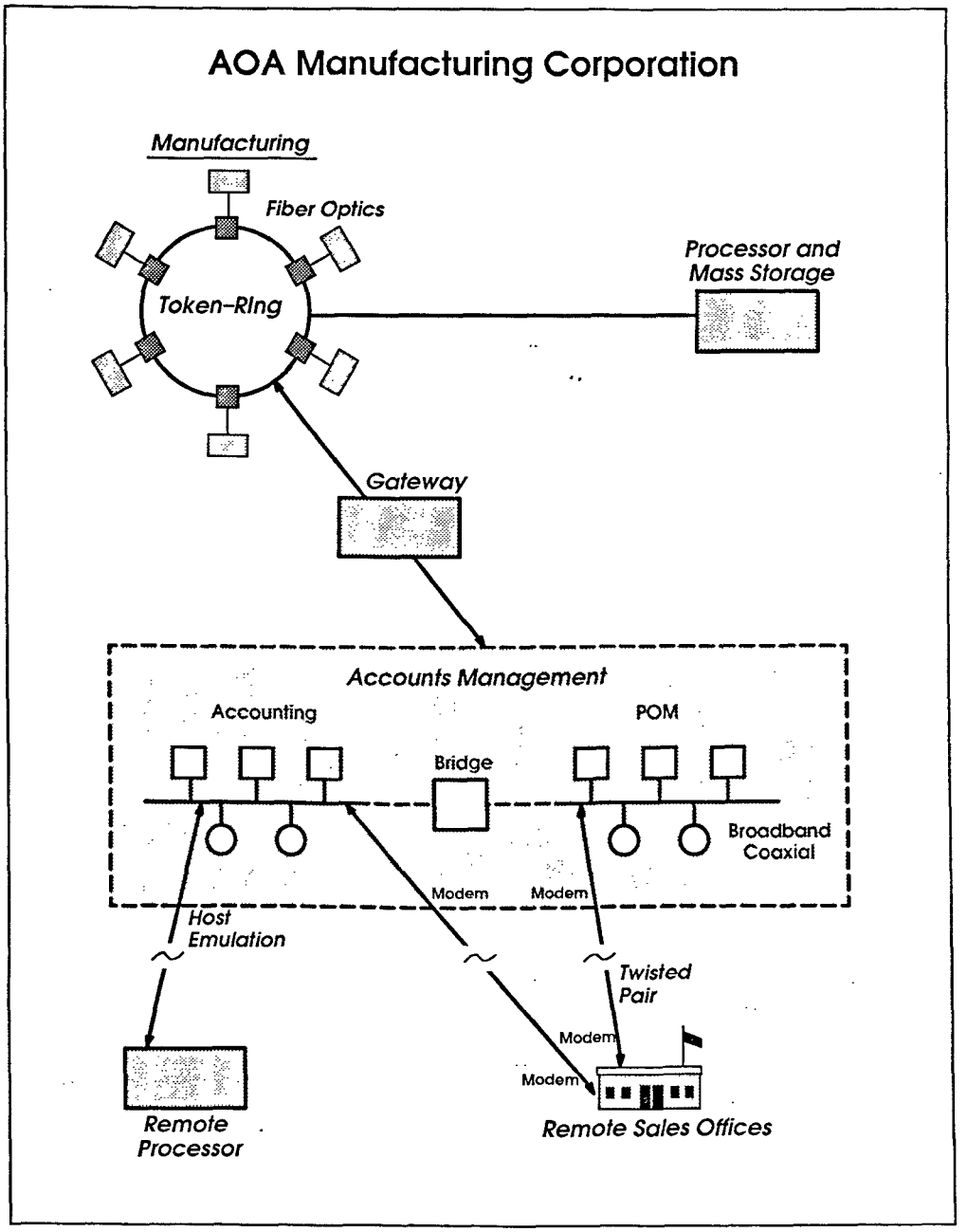

Figure 8.0 AOA Manufacturing Corporation Design Solution

For the manufacturing environment, a token-ring with fiber optic cable was chosen. The star topology did score higher in the trade-off analysis but the customer wanted a strategic solution. A strategic solution is interpretted by the customer to mean a LAN that is supported by the standards. The bus and ring (contention with CSMA/CD, token-bus, and token-ring) are supported topologies/protocols by IEEE 802. The same applies for the cable access protocols. Even though the broadband coaxial ranked close to the fiber optic media, the customer believed that the fiber optic medias would drop considerably in price in the near future.

A gateway will be installed between the manufacturing LAN and the office environment LAN due to the difference in protocols. The gateway will provide a means of transmission between the two areas. A bridge will be installed between the two office areas. Each office area has its own LAN due to the planned increase in the number of devices on the LAN and the increased network traffic attributed to the image processing. The office areas will be connected with the remote sales offices either via a modem or a FAX machine.

Table 8.9 is a traceability matrix listing the requirements for the office environment and whether the requirement was satisfied. Reference the requirements in sections 2.2 to 2.2.2.

REQUIREMENT NUMBER	SATISFACTION OF REQUIREMENT
F1	Satisfied via bus network
F2	Satisfied via bus network and host emulation
F3	Satisfied via bus network
F4	Satisfied via bus network
F5	Satisfied via broadband network
F6	Satisfied via broadband network
F7	Satisfied via bus netork and host emulation
F8	Satisfied via modem or FAX
F9	Satisfied via LANs and gateway
O1	Satisfied via bus network
O2	Indetermined, dependent on specific product used
O3	Satisfied via any network (most any commercial will satisfy this requirement.)
O4	Indetermined, dependent on specific product used
O5	Indetermined, dependedt on specific product used
P1	Indetermined, dependent on specific product used
P2	Indetermined, dependent on specific product used
P3	Satisfied via bus network
P4	Satisfied via LAN
P5	Indetermined, dependent on specific product used
P6	Satisified bus network

Table 8.9 Traceability Matrix of Requirements to Design - Office Environment

Table 8.10 is a traceability matrix listing the requirements for the manufacturing environment and whether the requirement was satisfied. Reference the requirements in sections 2.3 to 2.3.2.

REQUIREMENT NUMBER	SATISFACTION OF REQUIREMENT
F1	Satisfied via token-ring network
F2	Partially satisfied, token-ring will provide a high level of determinism or low variance. The actual transmission rates will vary by product.
F3	Indetermined, dependent on specific product used
O1	Indetermined, dependent on specific product used
O2	Indetermined, dependent on specific product used
P1	Satisfied via fiber optic media
P2	Satisfied due to low complexity at interface
P3	Satisfied via token-ring network
P4	Satisfied via token-ring network
P5	Satisfied via LAN

Table 8.10 Traceability Matrix of Requirements to Design - Manufacturing Environment

9.0 CONCLUSION

In summary, local area networks provide another option for the interconnection of data communicating devices with specific benefits for some, but not all, environments. Determining the "customer" requirements is essential for concluding whether a LAN(s) will be beneficial and how it is implemented. Local area networks have become practical and extremely useful due to the decrease in cost of microcomputers and a drastic increase in processing power. Local area networks provide great flexibility in the number and type of data communicating equipment that it can support. Due to the strong and continued growth in the microcomputer arena, local area networks will continue to grow in applications and available functions and "customers" will grow more heavily dependent on them.

10.0 REFERENCES

1 Blanchard, B. S. and Fabrycky, W. J. Systems Engineering and Analysis. Englewood Cliffs, NJ: Prentice - Hall, 1981.

2 Asbjornsen, O. A. and Budurka, B. Systems Engineering Principles. Lecture notes. University of Maryland, College Park, 1987.

3 Purtilo, J. Software Design and Development. Lecture notes. University of Maryland, College Park, 1989.

4 Bridges, Stephen P. M. Low-Cost Local Area Networks. New York: Halsted - Press, 1986.

5 Stallings, William. Local Networks, An Introduction. Second Edition. New York: MacMillan Publishing Company, 1987.

6 Byers, T. J. Guide to Local Area Networks. Englewood Cliffs, NJ: Prentice - Hall, Inc., 1984.

7 Kessler Marketing Intelligence. Lower Prices Spur Demand for Fiber Internetwork Gear. Network World, March 12, 1990.