ABSTRACT

Clustering Algorithm for Local Area Network Design in A CIM Environment

by
A.C. Manjunath

Communication systems have come to be regarded as being one of the most important aspects in manufacturing enterprises in recent years. It continues to offer enormous potential for improving the efficiency of manufacturing enterprises through Computer Integrated Manufacturing (CIM). It is true however that this potential cannot be realized by developments on the communications front alone. Strategic and economic considerations in installing a communications system in a manufacturing environment is of vital significance.

This thesis, at the outset attempts to bring out some of the issues in the area of communications (research), specifically in relation to CIM. A perception of prior research to some of these issues has been provided. The main focus of this thesis is placed on developing a methodology for designing an optimal flow local area network (LAN) for a CIM communications system using analytical models for resource allocation. A new representation of information flow load among the various nodes in a network is conceived which helps to determine an optimal communication traffic matrix. A decision logic to generate a system architecture based on the above information flow is designed. The various factors and variables involved in a communication network are identified. For the purpose of this study however, the most critical variables/factors of these are considered. Definitions of the various terminologies associated with these factors are provided. Experimentations are performed using the simulation approach.

The main objective of this study is to help LAN designers to suggest effective configurations of the nodes to be networked so that the installation costs and propagation delays are reduced.

CLUSTERING ALGORITHM FOR LOCAL AREA NETWORK DESIGN IN A CIM ENVIRONMENT

by
A.C. Manjunath

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APPROVAL PAGE

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by

A.C.Manjunath

Dr. Sanchoy K. Das, Thesis Adviser
Assistant Professor, Department of Mechanical & Industrial Engineering
New Jersey Institute of Technology

Dr. Golgen Bengu,
Assistant Professor, Department of Mechanical & Industrial Engineering
New Jersey Institute of Technology

Dr. Xuili Chao,
Assistant Professor, Department of Mechanical & Industrial Engineering
New Jersey Institute of Technology

BIOGRAPHICAL SKETCH

Author: A.C. Manjunath

Degree : Master of Science in Industrial Engineering

Date: May, 1992

Undergraduate and Graduate Education:

- Master of Science in Industrial Engineering, New Jersey Institute of Technology, Newark, NJ, 1992.
- Bachelor of Science in Industrial and Production Engineering, R.V. College of Engineering, Bangalore, India, 1988.

Major: Industrial Engineering

Professional Positions:

Research Assistant, September 1991- May 1992, Department of Mechanical and Industrial Engineering, New Jersey Institute of Technology.

Instructor, P.C. Distribution Program, June 1991-September 1991, New Jersey Institute of Technology.

Graduate Assistant, October 1990-May 1991, Computing Services Department, New Jersey Institute of Technology.

Production Engineer, January 1989-August 1990 Sundaram Clayton (TVS) Ltd., India.

This thesis is dedicated with love ...
to my mother and the memory of my sister Rama

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CHAPTER ONE

INTRODUCTION

1.1. INTRODUCTION

Competition in the manufacturing industry has assumed such intense proportions in recent years, that manufacturing organizations in the U.S. and elsewhere are being driven to making major changes in the area of manufacturing (processes), resources, markets and product strategies. The easy availability of sophisticated automation equipment and computer hardware/software is permitting companies to achieve significant improvements in manufacturing productivity. The bottom line is drawn and only those industries which can meet international competition by being the most productive and cost effective shall survive. Thus, within certain limitations or constraints manufacturing organizations are now forced to optimize the way in which they function in order to achieve the best possible performance. Most efforts in achieving this optimization are being implemented under the umbrella of *COMPUTER INTEGRATED MANUFACTURING (CIM)*. A CIM system is characterized by the existence of a system architecture which includes sub-architectures such as production management, data management, and communications management. However, effective communications management thru efficient communications networking may be viewed as being the most important, or key determinant of a successful computerized manufacturing system and hence to CIM.

Recently the design and planning of communication architectures for CIM design has received much attention in the research community. According to McIvor (1989), "CIM is a process of replacing the human physical and intellectual contribution to individual manufacturing operations, in any such sequence of operations, by machines, in a common electronic data base environment. From this definition of CIM it is quite clear that an (electronic) environment can only become possible when free communications between computers and people exists. In other words the key to achieving a full fledged CIM is to have an effective communications infrastructure both within a manufacturing enterprise and among its suppliers and customers (Daigle, 1989).

The primary focus of this thesis has been on developing analytical models for optimally allocating resources in a CIM communication network. The objective is to design *Optimal Flow Local Area Networks (LAN)* for CIM application. The term computer network, which conventionally refers to an interconnected collection of computers, refers throughout this thesis to a collection of nodes. These nodes could be computers, or a series of other computer controlled equipments/facilities, typically used by a manufacturing facility viz CNC machines, CNC processing equipments etc. Moreover in our study we have regarded a node to be a collection of computer controlled devices which is further indivisible if it is installed as a consolidated package coming from a single vendor.

1.2. PROBLEM DESCRIPTION

A CIM system typically consists of multiple computers and computer based equipment. The system also consists of a local area network which is responsible for transferring data between these different computer nodes in the facility. Figure 1 illustrates an example network designed for CIM application. Observe from figure 1 that a LAN is made-up of groups, and sub-groups of nodes. At the most basic level nodes communicate within groups. Beyond that communication occurs between sub-groups, and then groups. This division of the nodes at the associated interlinking mechanisms define the architecture of a LAN. Clearly then the time and cost to send a message between any two nodes, is dependent on their relative position within the architecture.

In designing a LAN a variety of options are available to the CIM engineer. These include, in addition to above discussed network architecture, a choice of protocols, communication devices, and network cables. Using these choices the engineer can literally come up with millions of possible configurations.

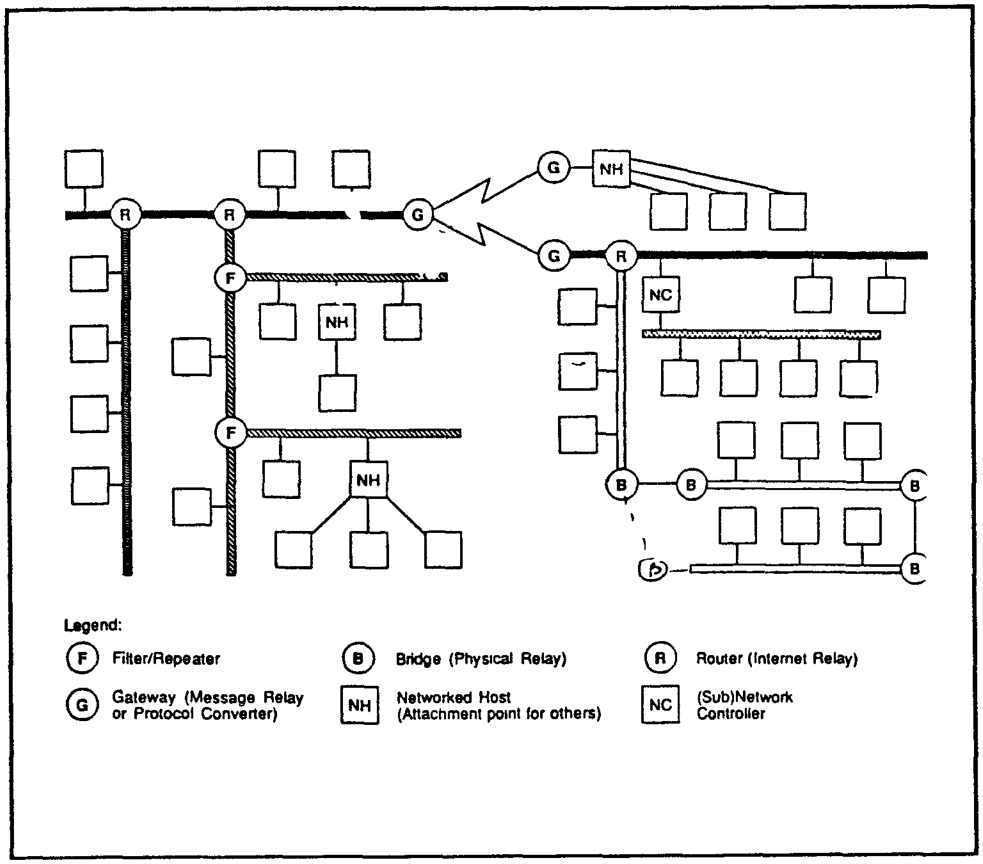


Figure 1. Generalised CIM Network

The performance of a specific network is dependent on it configuration, clearly only a subset of the possibilities are attractive to the engineer. Performance in a LAN is also a multi-dimensional entity, and is usually dependent on what the user hopes to achieve. In a CIM environment the following network performance criteria or features are usually of interest:

a) The network should be able to accept (without excessive delay), an intended transmission from a host,
b) The network should be efficient. That is no substantial part of the network should be idle for any extended period,
c) The cost of establishing, maintaining and operating the network should be kept at a minimum
d) Data arriving at a receiving host should be capable of being rapidly processed,
e) When a transmission calls for a response, the delay of this response should be minimal,
f) Resource sharing is permitted.

Almost all of the above objectives are either directly or indirectly effected by the option choices listed above. Technical labels for the above include Transmission Delay Time, Data Throughput Rate and Local Network Medium Utilization.

The LAN design problem may be viewed as a resource allocation problem, in that the capabilities of the network are being distributed among the system nodes. if we assume there is a cost associated with each allocation, then the objective is to minimize the network cost. It seems rational to assume that any allocation methodology will be based on the projected use of the network by the nodes. This projected use may be described by the communication or event intensity between each pair of nodes. The event intensity is equal to the total number of information packets sent from one node to another. Figure 2 exhibits an event intensity matrix for an example ten node problem. Figure 3 proposes several solution architectures for this example problem. For each solution the performance and cost is different, and the engineer must select the best suited solution.

	1	2	3	4	5	6	7	8	9	10
1	-	200	80	280	300	40	800	60	48	170
2		-	0	78	150	40	39	150	46	68
3			-	40	68	45	140	150	150	40
4				-	300	120	70	60	600	150
5					-	200	0	210	150	78
6						-	30	200	150	0
7							-	400	0	230
8								-	0	60
9									-	260
10										-

Figure 2 : Event intensity matrix

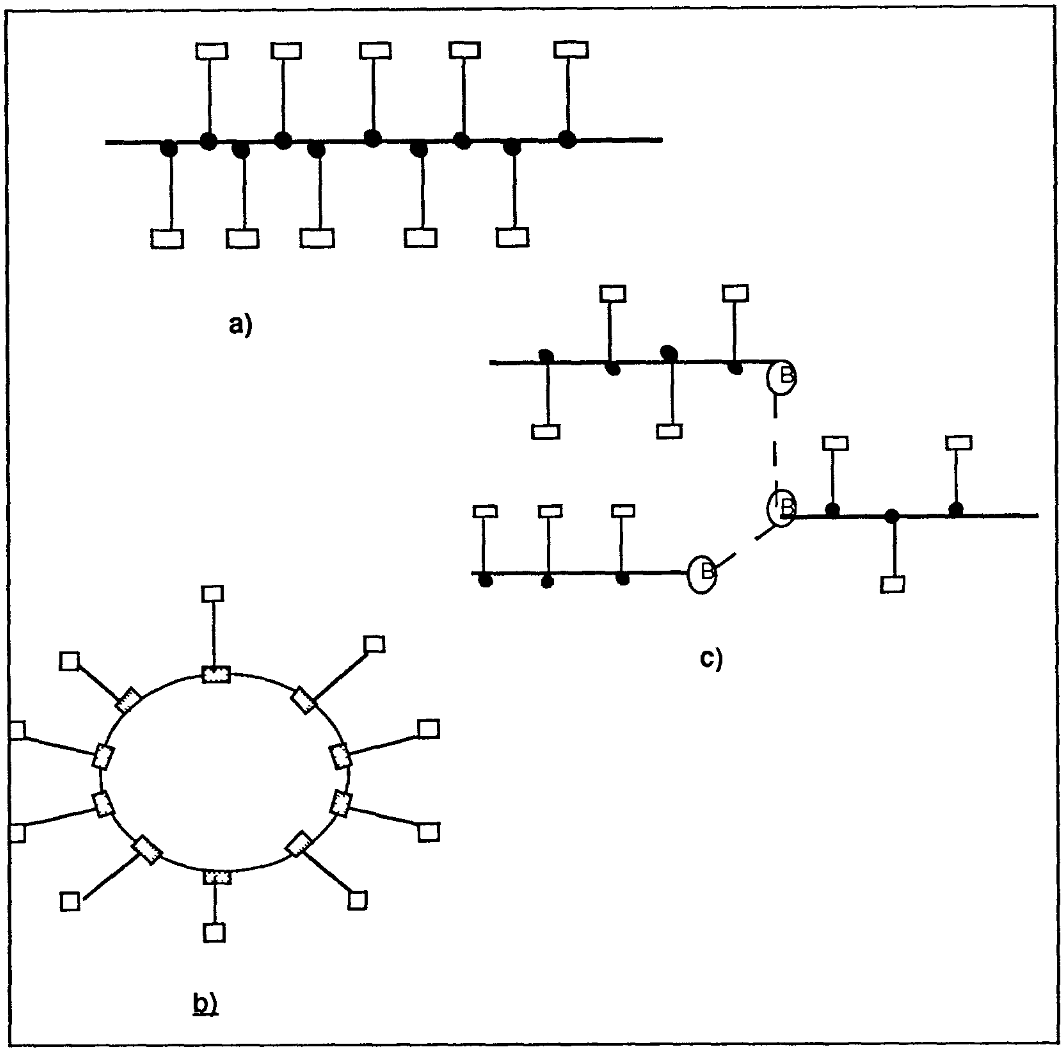


Figure 3. Different Solution Architectures Possible

1.3. PROBLEM STATEMENT

There is a need for a methodology which will first design the network architecture for a LAN to be used in CIM settings, and second select appropriate communication hardware. The network architecture must not only allocate nodes to network sub-groups, but also specify the configuration of the nodes within each sub-group.

1.4. RESEARCH OBJECTIVES

1. Identify and define various network parameters, variables.
2. Discuss the analytical treatments offered to LAN design, specially in CIM environments.
3. Identify factors affecting LAN performance and costs.
4. Develop the application of algorithms for optimizing communications network' performance, while reducing costs.
5. Test / Experiment the optimizing algorithms.
6. Define the LAN design methodology for the final architecture.
7. Provide recent trends in the field and other related technological advancements.
8. Suggest guidelines for future research.

CHAPTER TWO

LITERATURE REVIEW

Information flow and computer networks design has received much attention in the research literature. Specifically, communication network in the context of a manufacturing system has been an area of active and enthusiastic research. Some researchers have provided heuristics to determine optimal design parameter values of a CIM communications network, while others have discussed issues related to designing principal architectures for CIM communications. This chapter discusses in detail, previous research which relates to this field.

2.1. CIM AND COMMUNICATION NETWORKS

Snyder (1991) in describing CIM states that "the basis for the CIM concept is the combination or the integration of various technologies and functional areas of the organization. The integration of technologies such as computer aided design and computer aided manufacturing (CAD/CAM), robotics, automated materials handling. materials planning requirement (MRP), flexible manufacturing systems (FMS), and automatic identification, with the just in time (JIT) philosophy results in CIM. This broad enterprise view of CIM provides the means for achieving strategic and competitive advantages in manufacturing".

Snyder, further quotes Freeman (1989) according to whom "CIM implies tying various 'islands' of computing such as MRP, quality systems, process automation systems etc., together in an integrated rather than just an interconnected manner". Freeman's definition of CIM attempts to validate the notion that while networking is the key to integrated manufacturing, it is also of high significance that the various technologies that are interlinked to obtain a CIM, match with one another in terms of consistency of purpose. This will ensure that the diverse technologies are orchestrated to achieve common production goals. It also opens up an argument which proposes that there exist better ways via which the various islands of computing can be linked.

Ranky (1985), in his discussion on tool management system architecture states that "one should recognize the need for systematic modularity, compatibility and a generic approach when designing (such) information management support systems in a CIM environment where networks link information sources and processing nodes together for the sake of increased efficiency, speed reliability, quality and other less important reasons." McIvor (1989) defines CIM as "a process of replacing the human physical and intellectual contribution to individual manufacturing operations, in any such sequence of operations by machines in a common electronic database environment". From this definition the significance of effective communication among computers (including computer controlled machines) and people is evident. Further (Daigle et al, 1989) say that "the key to achieving a full fledged CIM is to have an effective communications infrastructure, both within a manufacturing enterprise and among suppliers and customers".

Mitchell (1990), states that "CIM involves the design and redesign of an entire manufacturing enterprise, so that all aspects of the system work together effectively". Mitchell contends that CIM is a strategy of attaining the enterprise objectives and is characterized by the use of computers to achieve an integrated flow of manufacturing activities based on the integrated information flow that links together all organizational activities". Das (1991) in his attempt to 'Classifications in CIM', states that CIM is usually defined in the context of what is relevant to a particular project. Thus CIM is defined by many as either a LAN, a common database, a single production facility, a bar coding system, a MRP II system. or in other words anything that creates a unity in the system". In our study we place focus on the concept of creating a unity among the elements of a manufacturing system through a LAN.

There have been many definitions of CIM in literature, diverse in their description and some controversial in nature, but there has been a striking unanimity in their acceptance of the fact that effective communications networking is the key to achieving CIM. Unfortunately the networking that is so essential to CIM implementation is not an easy task to achieve. The networking solution for CIM may be considered to be a part of the total organization's establishment of a rational and effective network architecture

2.2. ISSUES IN THE DESIGN AND IMPLEMENTATION OF A CIM SYSTEM ARCHITECTURE

An architecture is a special plan for the proposed system which identifies internal and external elements, and their inter-relationships. Figure 4 depicts the various external and internal elements that form a system architecture of a CIM plant. We have been stressing that a good communication networking is one of the most important aspects for the successful implementation of CIM. However, it is important to note there are other issues to be considered while designing a system architecture.

Jones et al. (1989), feel that "a system architecture must include three separate but related architectures for production management, data management and communications management. Production management includes all of the functions related to the order, design, fabrication and inspection of parts. Data management includes all functions related to the delivery of accurate and timely information to the production management processes. Communication management includes those functions required for the reliable transmission of messages between computer programs". They discuss the following three sub-architectures at length in their paper. These may be summarized as follows:

A. Production Management:

Production management in a CIM environment includes : (1) automating each production function to the extent possible; (2) developing an architecture which can be used to integrate them; and (3) providing uniform data structures for all shared information. The NIST (National Institute of Standards and Technology) architecture in CIM is a typical production management architecture and the various functions involved in such an architecture are as depicted in Figure 5.

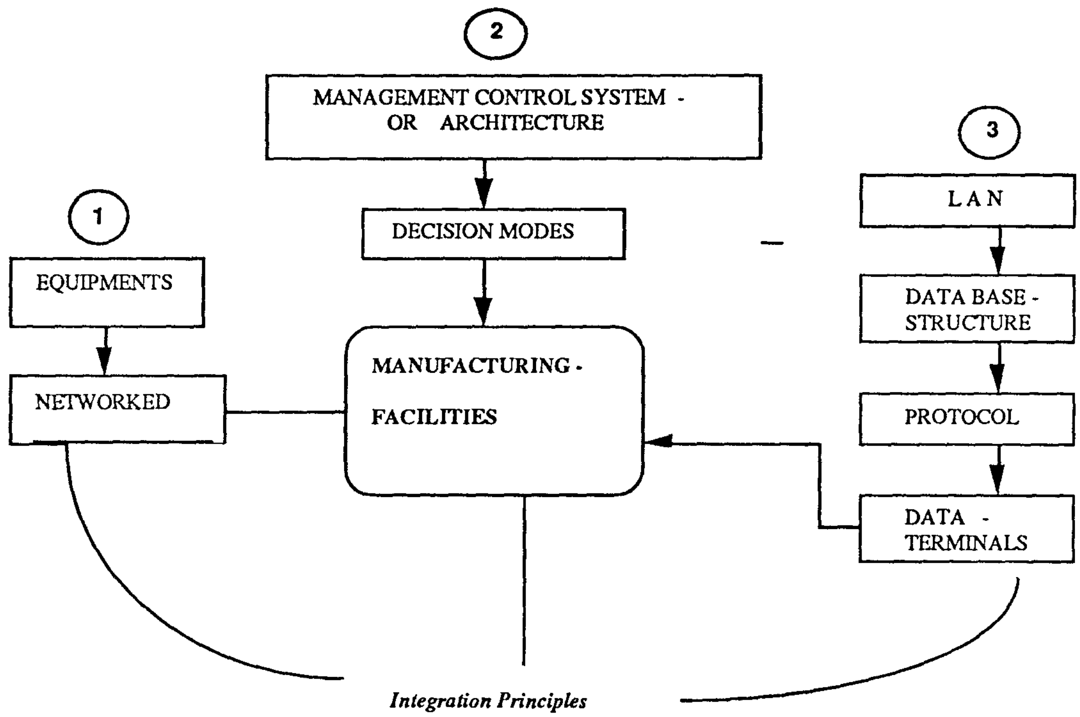


Figure 4 : Elements of a CIM System Architecture

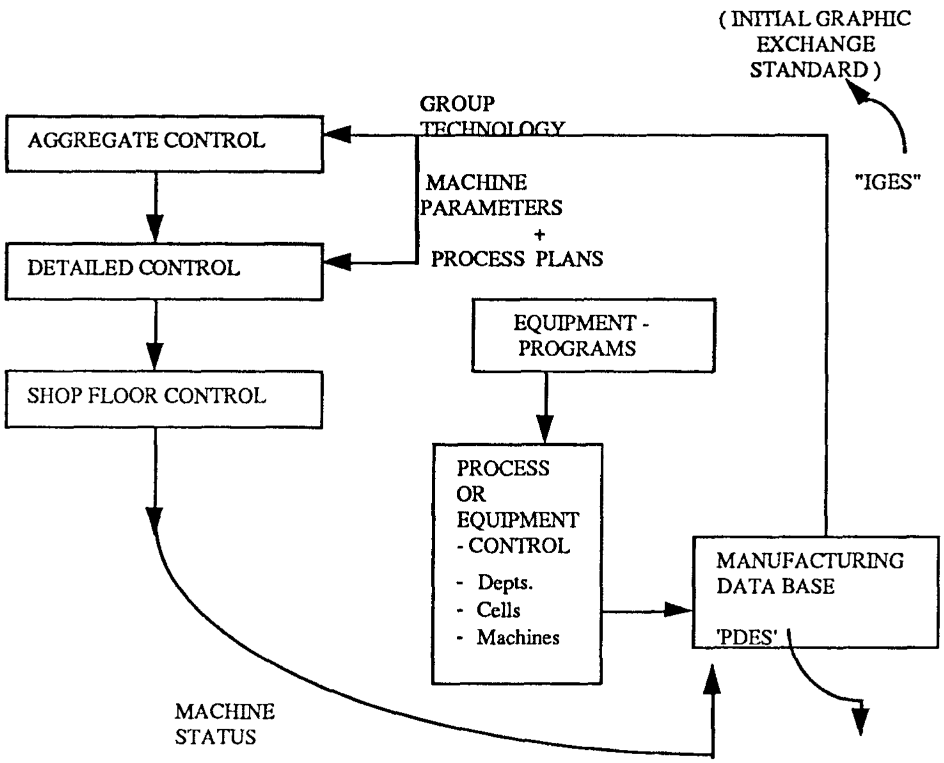


Figure 5 : The NIST CIM Architecture

B. Data Management

The main function of a data management system in a CIM environment is to support functions in the production management architecture with timely access to all essential data. It is essential to design and implement a data management architecture which is separate from but integrated with the production management architecture. It allows the two structures to be developed independently, with proper understanding of their inter relationships. Figure 6 shows a canonical architecture for a distributed data system with distributed control consisting of local data management systems which process locally originated and locally satisfiable requests and negotiate with each other to process all other requests.

C. Communications Management

The CIM communications system provides those functions needed to transmit messages between computer programs executing production and data management tasks.

In planning an integrated CIM network, there are therefore three ideas that are fundamental :

(1) production management and data management programs themselves use one common connection service specification for communication with other programs, regardless of function or location;

(2) the physical networks are transparently interconnected, so that any program could conceivably communicate with any related program anywhere in the CIM complex; and

(3) the technology and topology of sub-networks are chosen to provide optimal communications responsiveness for the primary functions.

The third idea may be deemed to be representative of the objective of our study wherein we try to provide a means to optimally allocate the CIM resources into manageable clusters so that the communication network that is resulted from the physical interconnection of these resources attains optimal responsiveness in terms of both performance and cost.

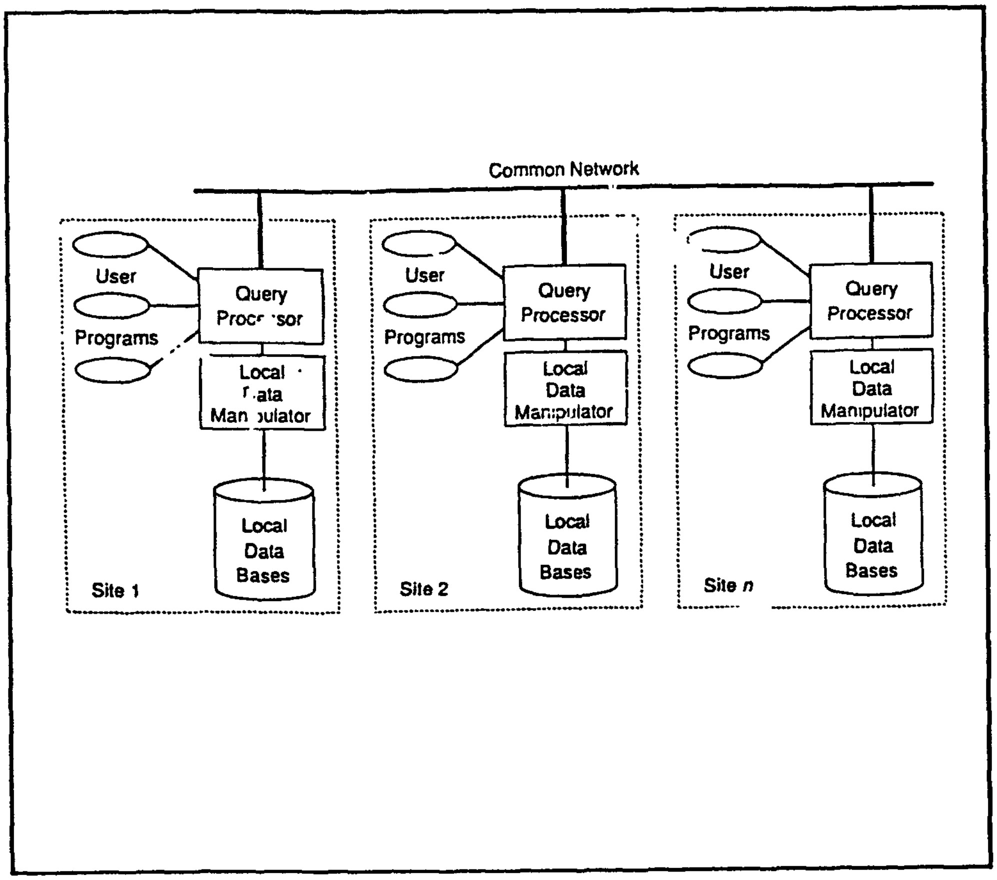


Figure 3. Distributed Data System with Distributed Control

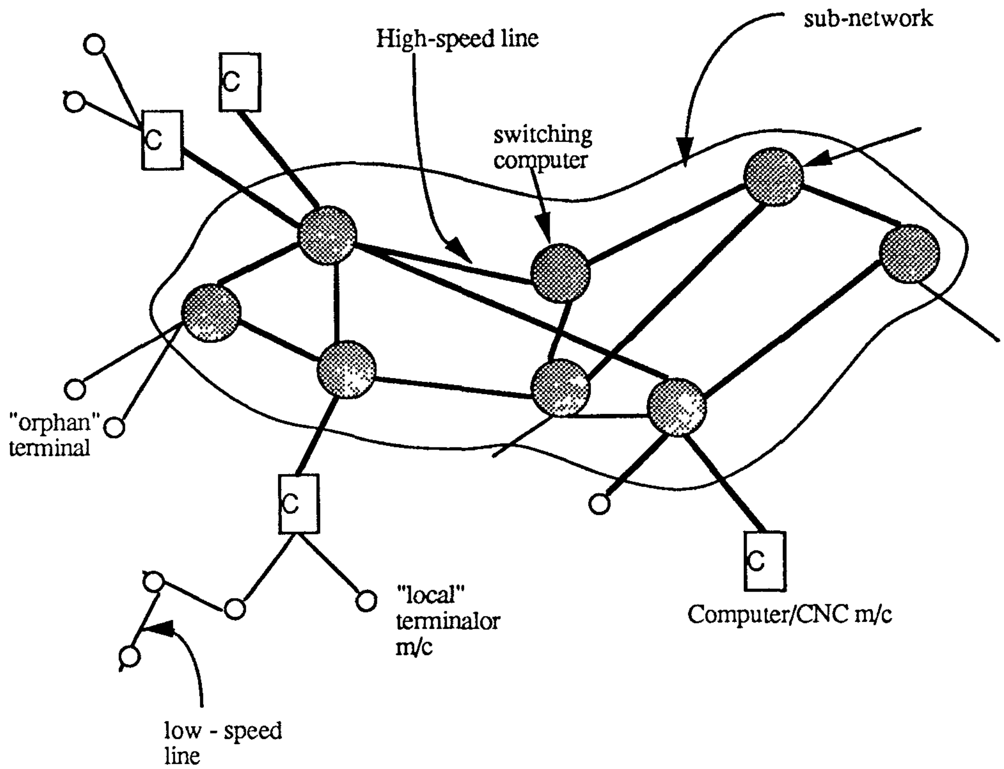


Figure 7. Communication Network Representation

2.3. COMMUNICATION NETWORKS IN A MANUFACTURING ENVIRONMENT

When an array of computers is interconnected, the hardware and facilities located at each facility is referred to as a host while the resources devoted to providing the inter-host communication is referred to as a communication network (Schilling, 1987). Certainly, the following are features which are to be desired in such a network.

(1) The network should be able to accept promptly (without excessive delay) an intended transmission from a host,

(2) The network should be *efficient* , i.e., no substantial part of the network should be idle for any extended period,

(3) Data arriving at a receiving host should be capable of being rapidly processed,

(4) When a transmission calls for a response, the delay of this response should be minimal,

(5) The cost of establishing, maintaining and operating the network should be kept at a minimum.

Figure 7 represents a communication network. The square boxes are the automated equipments/computers. The small open circles are terminals, while the larger shaded circles are the switching centers which provide the switching facility needed to make the connection as required. These switching centers are themselves sophisticated, specialized computers, and are hence appropriately referred to as switching computers. Some computers serve a number of terminals and some of the lines connecting terminals to their local computer serve more than one terminal. Generally lines joining terminals to a local computer need not be required to transmit at high data rates (and therefore a relatively modest band width is adequate). These lines are known as "low speed" lines. High speed lines are used to inter-connect switching centers.Some terminals have no associated local computers and are instead connected directly to a switching center. Similarly some computers have no directly connected terminals and are associated with the network only through their connection to a switching center. The communication system encompassing all the switching computers is referred to as a "sub-network".

Communication network in a CIM plant is a necessity. A good communication network within the factory, between factories of the plant and perhaps between the factories and the corporate office, is inevitable. It is also important to collect various information on a real time basis, make decisions, and make available these decisions to the various nodes (viz systems, equipments and related departments). Sakakibara and Matsumoto (1991), highlight the importance of a communication network for a CIM plant and state that " the information communication network (LAN) forms the foundation to realize this (CIM). We think LAN is one of the basic components of the plant just like electricity, air and water". They feel that LAN enables simpler, cheaper wiring between nodes by using taps on the ceiling. Since starting the operation (i.e. implementing the LAN), there has been a 50% movement of the equipments by layout changes and the merits of this arrangement, they say is appreciable. This shows that a good, well thought out communication network design yields an economic operation of a CIM unit.

In our study we extend this logic and are interested in demonstrating that, given situation where a LAN has to be implemented, how can we arrange the nodes and propose generic guidelines for a LAN architecture that incurs the least expensive wire routing methods and also improves the performance of the network and hence the CIM plant itself.

2.3.1. LAN Definition

A Local Area Network (LAN) is a communication network that provides interconnection of a variety of data communicating devices within a small area (Stallings , 1990). It is a communication network to facilitate data transfer from one attached device, called a node to another. The data communicating devices include those devices that communicates over a transmission medium. (Stallings, 1990) listed some of the examples of communicating devices as 1) computers, 2) terminals, 3) peripheral devices, 4) sensors (temperature, humidity, alarm, sensors), 5) Telephones, 6) Television transmitter, 7) Facsimile. However in a CIM situation, computers are typically meant to include in addition to computer workstations, most processing equipments and machining centers and a host of field devices.

2.3.2. Computer Control Systems Using LAN

Saleno (1989) of the Timken company describes how the company elected to build an automated steel plant with its various manufacturing facilities integrated by a LAN. He describes the facility as one using extensive computer control systems which were incorporated into the design of the plant. the backbone of the computer control system would be the ethernet based LAN that connects all of the individual control systems together. This venture culminated into a LAN that had a hierarchic computer control system consisting of fourteen DEC - PDP-11 / 44s, two 11 /750s, and two VAX 11 / 780s. The architecture of the LAN was based on a hierarchical computer control system with each higher layer or level controlling its subsequent lower layer of machines or nodes. This LAN serves as a means to making a variety of network connections throughout the HCCS. These connections may link any level in the hierarchy to any other level. The primary function of the LAN however is to connect the control and information systems together for intra system communication. Typically intra system communication would involve alarm and event notification, and routing, plant scheduling, historical data collection and general information sharing.

In our study however the hierarchical approach is not used for generating the network system architecture. On the other hand the network design will be based on communication intensities between the various interacting nodes. This may sometimes lead to conflicting physical layouts of machines or nodes with reference to the available space, though for the most part the physical layout derived from such a network design will logically link the various machines and equipments. In such situations compromises have to be made to suit available space at the plant in the best possible way.

Jafari (1992) identifies three basic elements in designing LANs in industrial settings, that can be considered to be governing factors. For example, if we consider a shop floor control system, the architecture of the network would be governed by, among other features, :

1. The physical structure and operation of the controlled system (viz the arrangement of machines into cellular layout etc.).
2. The physical structure or hierarchy of the controllers themselves.
3. The logical structure of the controller that deals with the databases at a cell controller and the coding and structuring of relevant data.

Our study aims at achieving the best possible combination of factors one and two. In addition it must be noted that there are different requirements to the communication scenarios presented by different plants. The clustering algorithm proposed in the thesis provides one such basis for enabling custom building of Local area networks.

2.4. NETWORK RELATED VARIABLES AND PARAMETERS

There are many variable factors that either affect or reflect the performance characteristics of a communications network and in our instance a LAN. These are and defined as follows :

1. Event Intensity : " It may be defined as the total number or percentage of (packets, data packets, data bytes) of information exchange that takes place between a source node and destination node". This is typically recorded as a *communication matrix*. It concerns questions as to whether traffic is evenly distributed among the network users or are there source - destination pairs with unusually heavy traffic.

2. Packet Size : " It is defined as the total length of the units of data that may be transmitted between a source node and a destination node at a time". A typical maximum length is 1000 to a few thousand bits. If the messages are above the maximum length, they are divided into smaller units and sent out one at a time. Note the these packet sizes are applicable to packet switched systems which accommodate larger messages and are called message switching systems.

3. Inter arrival Time: "It is defined as the time between consecutive carrier (network busy) signals". In other words it is the time between two events at a node.

4. Communication/Packet Delay : "It is the time a packet or a frame is ready for transmission from a node and the completion of a successful transmission".

5. Source: "the total number of nodes that offer load to the communication network". The total offered load 'G' to the network, i.e., the total rate of data presented to the network for transmission is a function of the total number of users or nodes.

CHAPTER THREE

LOCAL AREA NETWORK TECHNOLOGY

Almost all LANs have a technology that essentially comprises topology, transmission medium, and the medium access control technique. This chapter discusses the structured manner in which the communication process occurs. Some common topologies, transmission media, and LAN protocols for medium access control are described.

3.1. THE OPEN SYSTEMS INTERCONNECTION

In a manufacturing scenario which involves more than one computer or computer controlled system is doing the intended work, additional elements in the form of hardware and software are needed in order to support the communication between or among the systems. The communications hardware itself is relatively standard and poses relatively few problems. However when communications is sought among heterogeneous machines, the software development effort can be a major challenge. The pattern of events or communication between the various nodes or machines becomes complex. Different vendors use different data formats and data exchange conventions. Thus a one-at-a time special purpose approach to communications software development becomes too costly and unacceptable. Also the task of of communications in a truly co operative way between applications on different computers (machines) is too complex to be handled as a unit. The problem must be decomposed into manageable parts. Hence before one can develop standards, there should be a *Structure* that defines the communications task. Thus the International Standards Organization (ISO), developed a model called the *Open systems Interconnect (OSI)*, which provides such a structured way to think about communications. It defines standards for linking heterogeneous computers. The term *open* denotes the ability of any two systems conforming to the reference model and the associated standards to connect. The complexity experienced in the application of the model places a tough task for the information systems designer. Decisions made regarding these aspects of systems design must involve a continuous and active involvement by the planning group.

In the OSI model a "system" consists of a computer, all of its software, and any peripheral devices attached to it, including terminals. A distributed application is any activity that involves the exchange of information between two open systems. Examples of such systems include situations wherein :

- A user at a terminal on one computer is logged onto an application on another computer.
- A file management program on one computer transfers a file to a file management program on another computer.
- A user sends an electronic mail message to a user on another computer.
- A process control program sends a control signal to a robot.

OSI is concerned with the exchange of information between open systems and not with the internal functioning of each individual system. Specifically, it is concerned with the capability of systems to co-operate in the exchange of information and in the accomplishment of tasks.

3.1.1. The Model

The OSI is a layered model of the individual activities that are involved in message exchange among computers. The communications functions are partitioned into a hierarchical set of layers. Each layer performs a related subset of functions. It relies on the next lower layer to perform more primitive functions and to conceal the details of those functions. It provides service to the next higher layer. Ideally the layers should be defined so that the changes in one layer do not warrant a change in the other layers. Thus one large problem is decomposed into a number of more manageable sub-problems. Table 1 defines the different layers in terms of their functions. The two users who wish to communicate have the same set of layered functions in their respective systems. Communication is achieved by having the corresponding ("peer") layers in the two systems communicate. The peer

Layer	Definition
1. Physical	Concerned with transmission of unstructured bit stream over physical link; parameters include signal voltage swing and bit duration; deals with the mechanical, electrical and procedural characteristics to establish, maintain, and deactivate the physical link (RS-232-C, X.21).
2. Data link	Provides for the reliable transfer of data across the physical link; sends blocks of data (frames) with the necessary synchronization, error control, and flowcontrol (HDLC, SDLC, BiSync)
3. Network	Provides upper layers with independence from the data transmission and switching technologies used to connect system; responsible for establishing, maintaining, and terminating connections(X.25, layer3)
4. Transport	Provides reliable, transparent transfer of data between end points; provides end-to-end recovery and flow control
5. Session	Provides the control structure for communication between applications; establishes, manages and terminates connections (sessions) between cooperating applications
6. Presentation	Performs generally useful transformations on data to provide a standardized application interface and to provide common communications services; examples:encryption, text compression, reformating
7. Application	Provides services to the users of the OS I environment; examples: transaction server, file transfer protocol, network management

Table 1. The OSI Layers (Stallings , 1990)

layers communicate by means of a set of rules, or conventions, known as a protocol. The key elements of a protocol are :

- Syntax: The form in which information is exchanged (format, coding)
- Semantics: The interpretation of control information for co-ordination and error handling.
- Timing: The sequence in which control events occur.

Each computer controlled unit (node) contains the seven layers. With reference to figure 8, if user 1 wishes to send a message to user 2, it invokes the application layer (layer 7). Layer 7 establishes a peer relationship with layer 7 of the target computer, using a layer 7 protocol (application protocol). This protocol requires services from layer 6, so the two layer 6 entities use a protocol of their own, and so on down to the physical layer, which actually transmits bits over a transmission medium.

User 1 transfers the intended data to an application layer module. That module appends an application header to the data. This header file contains the control information needed by the peer layer on the other side. The two together, i.e., the original data and the header are referred to as the protocol data unit (PDU). This is passed as a single unit to layer 6. The presentation module treats the whole unit as data, and appends its own header. This process continues down through layer 2, which adds both a header and a trailer. This layer-2 PDU, usually called a *frame* , is then transmitted by the physical layer onto the transmission medium. When the frame is received by the target computer, the reverse process occurs. As we ascend the layers, each layer strips off the outermost header, acts on the protocol information contained therein, and passes the remainder up to the next layer. Because of the additional (control) information in the form of header and trailer files, each packet of information to be transferred (in the case of packet- switched networks) includes not only data but also (at least) an address. Note also that there is no direct communication between peer layers except at the physical layer.

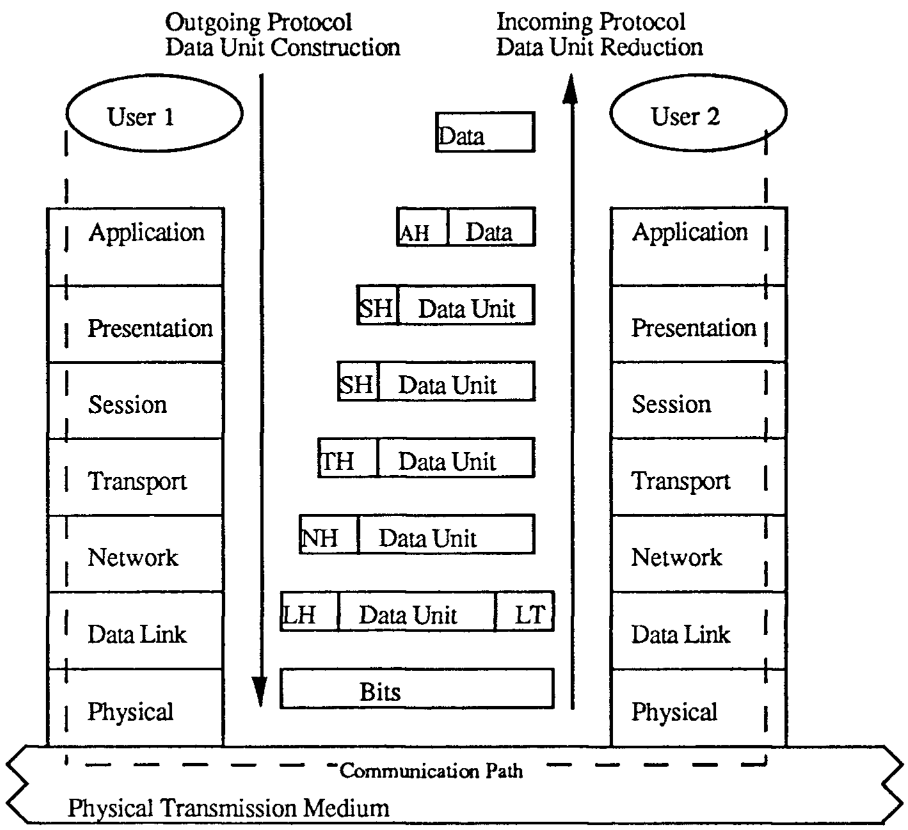


Figure 8. The OSI Environment

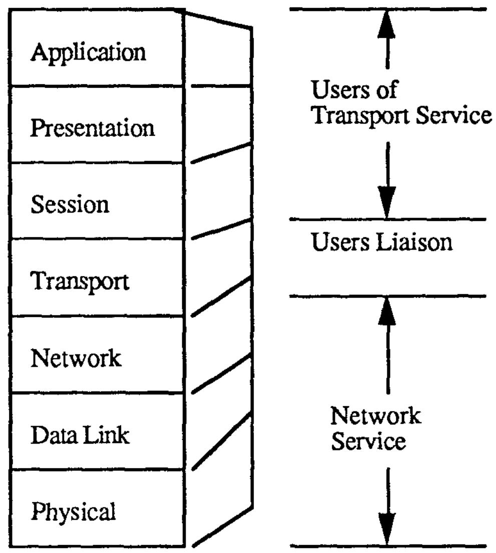


Figure 9. : A Perspective on OSI Architecture

<table>
<tr><th>OSI</th><th>CCITT</th><th>ISO</th><th>DOD</th><th>IEEE 802</th><th>ANS X3T9.5</th></tr>
<tr><td>7. Application</td><td rowspan="4"></td><td rowspan="2">Various</td><td rowspan="2">Various</td><td rowspan="5"></td><td rowspan="5"></td></tr>
<tr><td>6. Presentation</td></tr>
<tr><td>5. Session</td><td>Session</td><td rowspan="2">TCP</td></tr>
<tr><td>4. Transport</td><td>Transport (TP)</td></tr>
<tr><td>3. Network</td><td>X.25</td><td>Internet Sublayer</td><td>IP</td></tr>
<tr><td>2. Link</td><td>LAP-B</td><td rowspan="3"></td><td rowspan="3"></td><td>Logical Link Control</td><td>Data Link</td></tr>
<tr><td rowspan="2">1. Physical</td><td rowspan="2">X.21</td><td>Medium access control</td><td rowspan="2">Physical</td></tr>
<tr><td>Physical</td></tr>
</table>

Table 2. Commercially Known Layers/Protocols.

The main advantage of the OSI model is that it makes heterogeneous computer communications possible. Two systems, no matter how different, can communicate effectively if they have the following commonalties :

- They implement the same set of communications functions.
- These functions are organized into the same set of layers. Peer layers should perform the same functions, though it is not necessary that they do it in the same way.
- Peer layers must share a common protocol.

The OSI upholds the above by defining the 7-layer architecture in terms of the functions and services to be provided by each layer. However it should be noted that the OSI layers are not by themselves standards. They merely stipulate a framework for building standards. Thus there are many well known, important standards. Table 2 gives a listing of some of these protocols and their relationship to to the layers in the OSI model.

To sum up the OSI model, it can be perceived as comprising three parts. The lower three layers contain the logic for a computer to interact with a network. The host is attached physically to the network, uses a data link protocol to reliably communicate with the network, and uses a network protocol to request data exchange with another device on the network and to request network services. The transport layer provides a reliable end-to- end service regardless of the intervening facility; it is the user's liaison to the communications facility. Finally the upper three layers, taken together, are involved in the exchange of data between end user, making use of a transport service for reliable data transfer. A perspective of this composition of the OSI is provided in figure 9.

3.2. TOPOLOGIES

Topology is one of the three factors that characterize the features of a LAN. The other two being transmission medium and medium access control technique. They characterize the type of data that may be transmitted, the speed and efficiency , and the type of applications that a LAN may support. According to Stallings (1990), "the term topology, in the context of a communications network, refers to the way in which the end points or stations of the network are interconnected. It is defined by the layout of communications links and switching elements, and it determines the data paths that may be used between any pair of stations."

The need for different topologies arises because of the fact that it is infeasible to provide direct connections to all the pairs of devices that form a network. This is because, with *N* devices we would require N(N-1) links and each device would require N-1 input/output ports. Thus the cost of the system would grow with the square of the number of devices. This setback which is also referred to as *mesh topology* is depicted in figure 10. There are four most common topologies that are used to form LANs. They may be used in various combinations to form more complex networks. These topologies are: bus, tree, ring, and star. These are shown in figure 11 and discussed below.

The Star Topology

In the *star topology* , each station is connected by a point-to-point link to a common central switch as shown in figure 11. Communication between any two stations is via circuit switching. For a station to transmit data, it must first send a request to the central switch, asking for a connection to some destination station. Once the circuit is set up, data may be exchanged between the two stations as if they were connected by a dedicated point - to - point link. All communications are controlled by a central switch , which must set up and maintain a number of concurrent data paths. However the communications processing burden on the stations is minimal. Other than some rudimentary logic for requesting and accepting connections, the stations need only be concerned with the simple communications requirements of a point-to-point link.

The Ring Topology

In the *ring topology* (refer to figure 11), the network consists of a set of repeaters joined by point-to-point links in a closed loop. Hence each repeater participates in two links. The repeater is a comparatively simple device, capable of receiving data on one link and transmitting it, bit by bit, on the

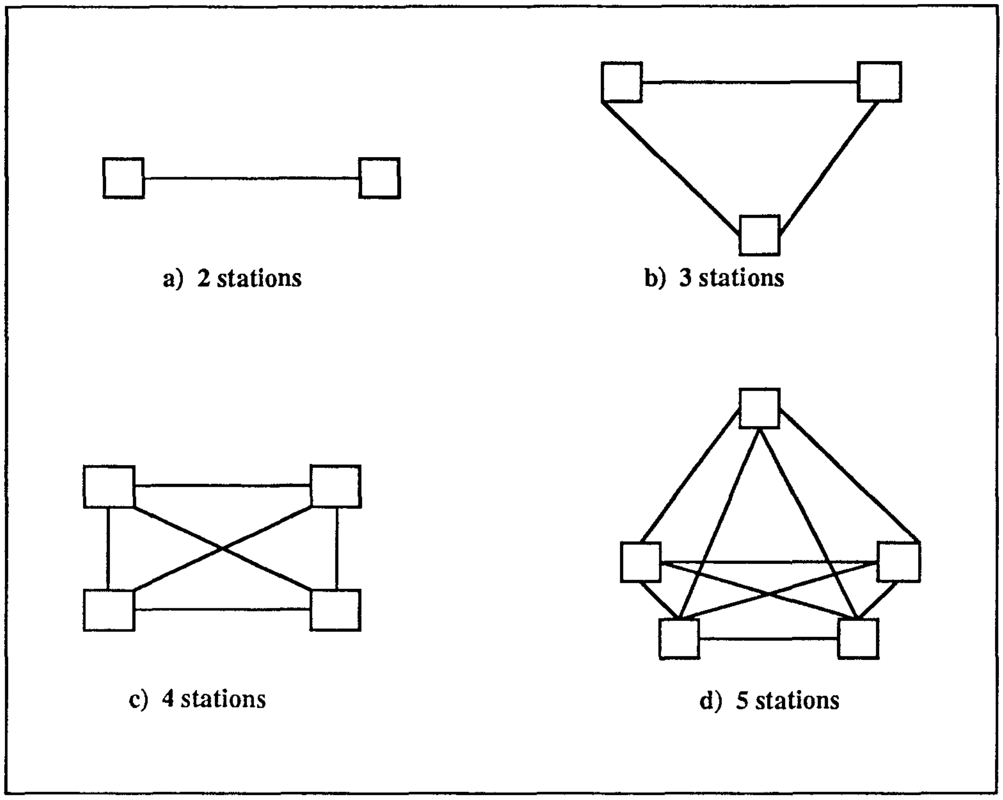


Figure 10. The Mesh Topology

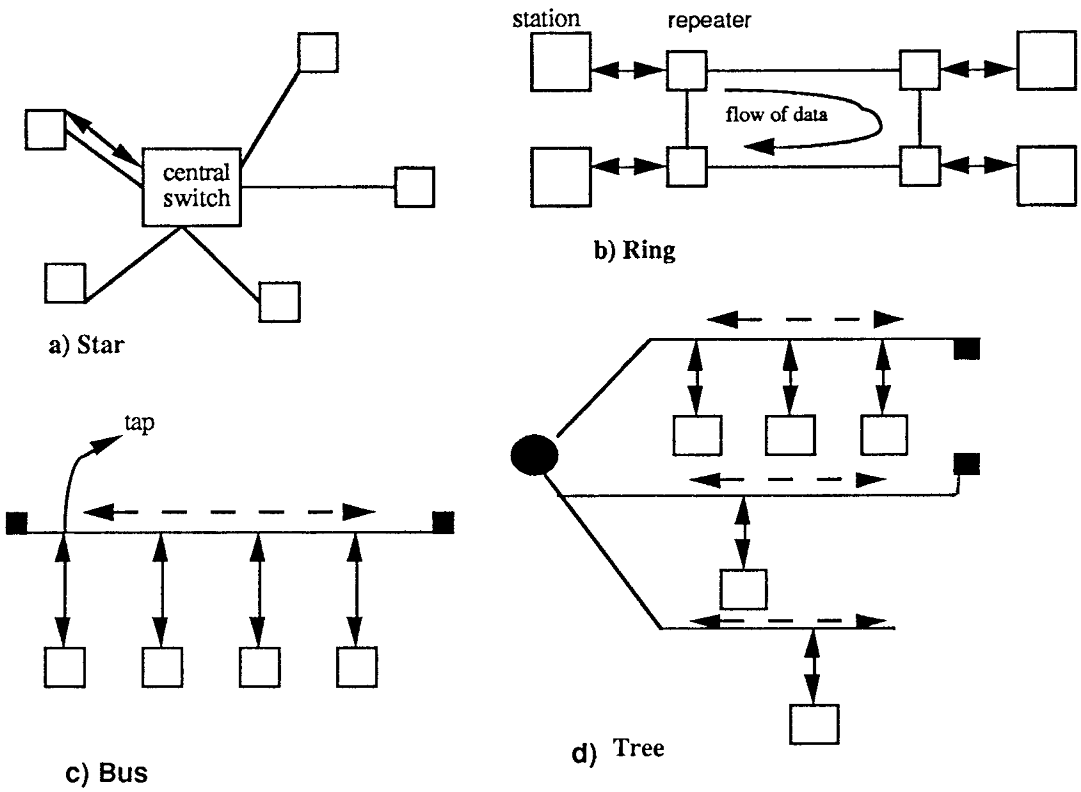


Figure 11. Local Network Topologies

other link as fast as it is receive, with no buffering at the repeater. The links are unidirectional; that is, data are transmitted in one direction only, and all oriented in the same way. Thus data circulate around the ring in one direction (clockwise or counter-clockwise). Each station attaches to the network at a repeater. Each station contains access logic that controls transmission and reception (through and from a repeater).

The Bus and Tree Topologies

With the *bus topology* (refer figure 11), the communications network is simply the transmission medium , without the switches and the repeaters. All stations attach, through appropriate hardware interfacing, directly to a linear transmission medium, or *bus*. A transmission from any station propagates the length of the medium and can be received by all other stations. It may be noted that a LAN is typically characterized as having a bus/tree topology as there are more than two nodes or machines connected to and capable of transmitting on the medium. A LAN may also be configured into a hybrid topology by incorporating the star and ring topologies within the main bus/tree structure.

The tree topology is a generalization of the bus topology. The transmission medium is a branching cable with no closed loops. The tree layout begins at a point known as the *headend*. One or more cables start at the headend, and each of these may further branch out. These branches may have additional branches to allow quite complex layouts. The transmission propagation is similar to that in the bus topology and in either case the processing burden on the attached stations is of roughly the same order of magnitude as for the ring attachment.

For both the bus and the tree topologies the medium is referred to as multi point. In both cases, as the all the nodes share a common transmission link, only one station can transmit at a time some form of access control is therefore to determine which station may transmit next. The choice of topology depends on factors such as the reliability, expandability and performance standards desired. The bus/tree topology is the most flexible, with the ability to handle a wide range of devices, in terms of their numbers, data rates, and data types. It has a high bandwidth range. There are however, practical limitations to these abilities. The star topology, using circuit switching, readily integrates voice with data traffic. It lends itself well to low data rate ($\leq$ 64 kbps) devices. The star topology is good for terminal-intensive requirements because of the minimal processing burden that it imposes on the attached devices. An evaluation of the network topologies is given in table 3.

3.3. TRANSMISSION MEDIA

Transmission media refers to the physical path between transmitter and receiver in a communication network. Figure 12 shows the basic elements of a transmission system. The most common configuration is a point-to-point link between two transmitting/receiving devices. Some intermediate devices may be used to compensate for attenuation or other transmission impairments. Transmission media may be either guided or unguided. In both cases, communication is in the form of electromagnetic waves. With *guided media* , the waves are guided along a physical path. Examples of guided media are twisted pair, coaxial cable, and optical fiber, all of which are use in LANs. The atmosphere and outer space are examples of unguided media, which provide a means for transmitting electromagnetic waves but do not guide them. Various forms of transmission through the atmosphere are employed for building-to-building connections. Finally one must be reminded that one of the most common ways to transport data from one computer to another is to write them onto magnetic tape or floppy disks, physically transport the tape or the disks to the destination machines. Though not sophisticated and delay characteristics are poor, it is often much more cost effective.

Twisted Pair Cable

The twisted pair is the oldest and the most common transmission medium, for both digital and analog data. A twisted pair consists of two insulated copper wire, typically about 1 mm thick, twisted together in a helical pattern. The twisted form helps to reduce electrical interference to similar pairs close by. Such a medium is most commonly used in the telephone systems.

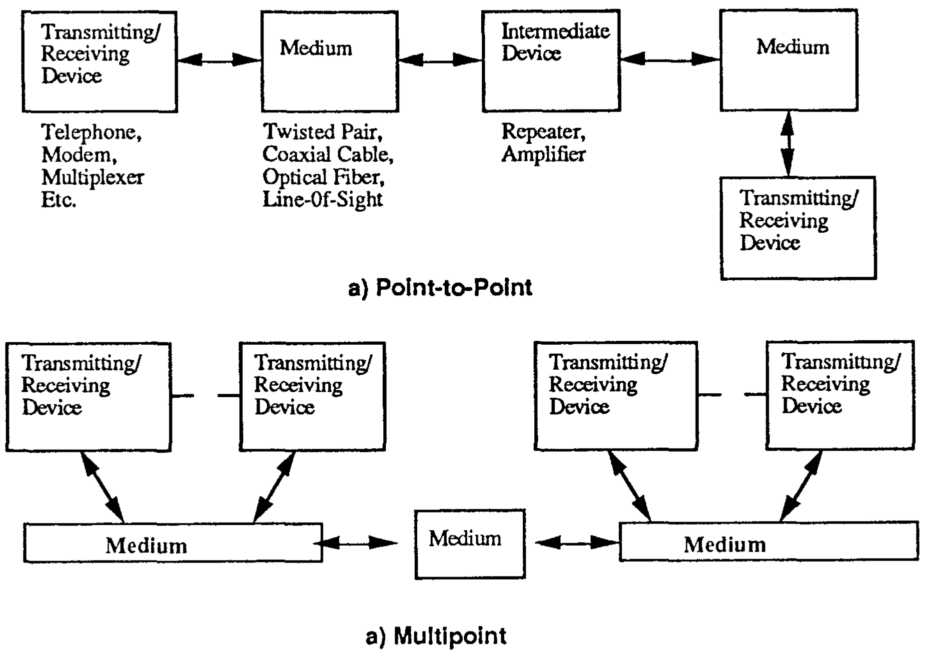


Figure 12. Transmission System Block Diagram

Criteria	Star	Bus	Ring
Most Appropriate Data Serivice Requirement	frequent node-processor data transmissions	short, frequent data transmissions	data transmissions to sequential nodes or processes
Reliability	dependent on proper functioning of central processor	high-can function despite failure	high provided bypassing of malfunctioning nodes allowed
Ex[andability	easy, provided ports are available	easy	difficult without system disruption
Transmission Speed	declines with cable length	declines with cable length	declines with number of nodes

Table 3. : Evaluation of Network Topology

Although it is inexpensive and easy to install, it has two disadvantages with respect to signal transmission:

a. A limited channel bandwidth which reduces the rate at which the signal can be transferred.

b. Signal degenerates with wire length and, thus, necessitates the use of regenerating devices called repeaters. However for the most part their performance is adequate and the cost is low and therefore is widely used.

Coaxial Cable

This is the most versatile transmission medium for LANs. Coaxial cable, like the twisted pair, consists of two conductors, but constructed differently to permit operation over a wide range of frequencies. A hollow outer cylindrical conductor surrounds a single inner wire conductor. The inner conductor can be either solid or stranded.; the outer conductor can be either solid or braided. The inner conductor is held in place by either regularly spaced insulating rings or a solid dielectric material. The outer conductor is covered with a jacket or shield. A single coaxial cable has a diameter of 0.4 to 1.0 inch.
The two types of coaxial cable are :

a. Broadband Coaxial Cable: Systems with broadband cables permit multiple stations to transmit messages simultaneously. These systems are normally divided into multiple channels, frequently 6-Mhz channels In addition to having larger channel capacity,each channel may transmit different types of transmissions such as data, voice, graphics and images. The disadvantage in using a broadband system is the need for expensive interface units called radio-frequency modems which convert digital signals to analog and back again.

b. Baseband Coaxial Cable: These are systems with limited channel capacity. They are limited to carrying a single signal through the channel at a time. They are also usually limited to one form of transmission, usually data.

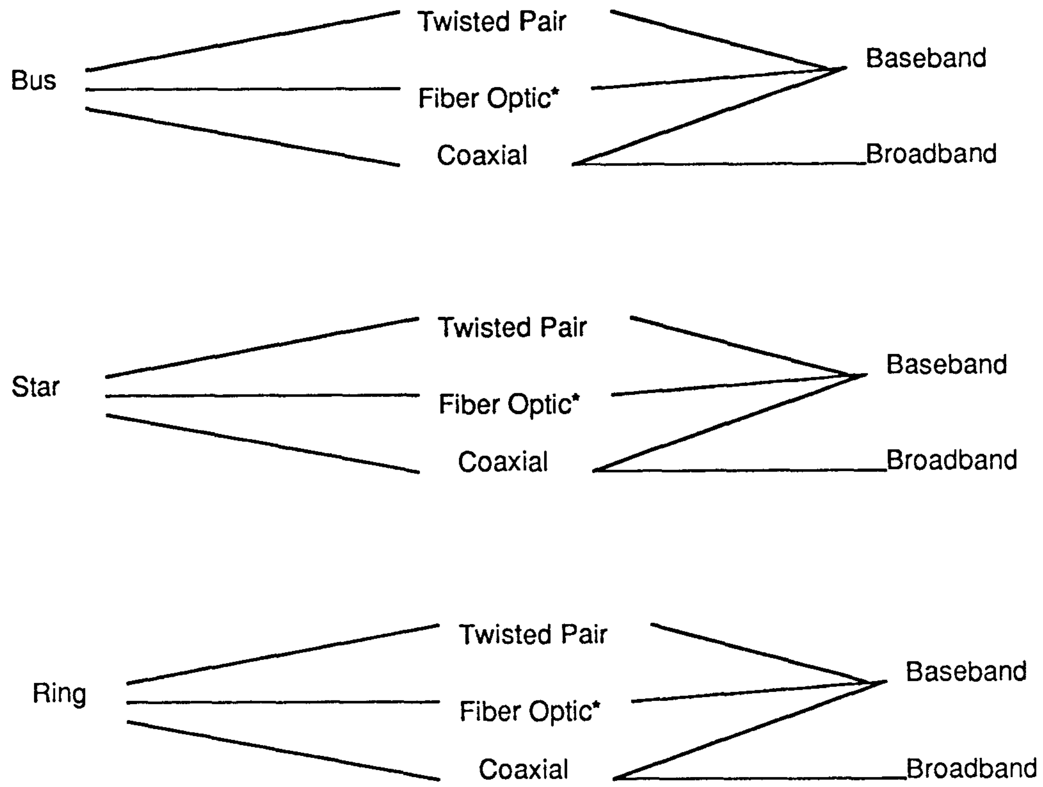
Fiber Optic Cable

Fiber optic cable is the most recent development in transmission media. It has the advantages of being extremely easy to install because of its flexibility, its light weight and its high resistance to electrical interference. It also achieves the highest transmission speeds because of its greater bandwidth. Until recently, fiber optic cable could only be used in ring networks, but new developments in fiber optic technology, not yet commercially available, now enable it to be used for any network configuration. Figure 13 shows the various technology combinations available in single network design.

3.4. RELATIONSHIP BETWEEN MEDIUM AND TOPOLOGY

The choices of transmission medium and topology are not independent. The preferred combinations are as shown in table 4. Twisted pair wire, baseband coaxial cable, and optical cable, and optical cable can all be used to provide point-to-point links typically required in the case of ring topology.(between repeaters). Broadband coaxials would not be suitable as each repeater would have to be capable of receiving and transmitting data simultaneously on multiple channels. The use of such repeaters could probably not be justified. For the bus topology, twisted pair and both baseband and broadband coaxial cable are suitable. Tree topology is best employed in combination with the broadband coaxial cable. The unidirectional nature of broadband signalling allows the construction of a tree architecture. Table 5 summarizes representative parameters for commercially available bus and tree LANs.

It may be noted that the performance for a given medium is considerably better for the ring topology compared with the bus/tree topology. In the bus/tree topology, each station is attached to the medium by a tap, and each tap introduces some attenuation and distortion to the signal as it passes by. Where as in the case of the ring, each station is attached to the medium by a repeater, and each repeater generates a new signal to compensate for the effects of attenuation and distortion. The star topology requires a singlepoint-to-point link between each device and the central switch. Twisted pair is suited for this task.



* : Fiber Optic broad band cables are highly experimental and are yet to become commercially available.

Figure : 13 Technology Combinations Available in a Single Network Design

Medium	Topology			
	Bus	Tree	Ring	Star
Twisted pair	X		X	X
Baseband coaxial cable				
	X		X	
Broadband coaxial		X		
Optical fiber	X			
			X	

Table 4. Preferred Combinations of Topology and Medium

Transmission Medium	Data Rate (Mbps)	Range (Km)	Number of Taps
Unshielded Twisted Pair	1 - 2	<2	10's
Baseband Coaxial Cable	10/70	<3/<1	100's/10's
Broadband Coaxial Cable	20 per - channel	<30	100's-1000's

Table 5. Performance Characteristics for Transmission Media for LANs

3.4.1. Layout

When some of the requirements that dictate the layout of the installed cable are considered, it is obvious that it is important to minimize cost while providing the required capacity. Though it is true that medium itself is an important determinant of cost, it is often the case, that the installation costs, which are primarily labour costs, far exceed the cost of the materials. This is particularly true in existing buildings which may present difficulties in finding pathways for new cable. In new buildings therefore, the problems and costs can be minimized if the cable layout for the LAN or for that matter any communication network can be designed ahead of time. The cable can then be installed during construction. Further the layout should accommodate equipment relocation and network growth. This is because, with the continued proliferation and technological advancements of computers and computer controlled machines, any LAN can be expected to grow.

It may be noted that this particular aspect of LAN design is very crucial to reduce total cost of the network, and is directly affected by the approach taken in this thesis to the design of LANs in CIM.

3.4.2. Choice of Transmission Medium

The choice of transmission medium is part of the overall task of designing a LAN. It is a function of a number of factors. It is for a good part directed by the topology that is employed. However there are other factors that are to be considered. These are :

a. *Capacity:* to support the expected local network traffic.
b. *Reliability:* to meet available requirements.
c. *Types:* of data supported: tailored to the application.
d. *Environmental scope:* to provide service over the range of environments required.

CHAPTER FOUR

DEVELOPMENT OF A METHODOLOGY FOR LOCAL AREA NETWORK DESIGN

The following chapter describes the development of the CIM network design methodology. In the first section, the different measures of network performance are defined and the various factors that affect performance are described. The relationship between the total load offered to the network and the total number of nodes in the network are discussed. It will be seen from these discussions that there is a need to organize the network into manageable clusters, thereby increasing the throughput of the network, while reducing the propagation delays. It is also shown that this brings down the data rates (R) employed, to controllable proportions and reduces the distance (d) of the communication paths between nodes. According to Stallings (1990) these two are the most important parameters for determining the performance of a LAN. It is induced from these discussions that clustering or grouping of the nodes has a positive effect on network performance.

The second section projects an overview of the developed four step CIM network design methodology. Subsequent sections are devoted to detailed treatment of the methodology steps. It may be noted here that although a considerable amount of work has been done on developing detailed analytic and simulation models of the performance of various LANs (protocols), they provide a level of resolution not needed by the LAN designer.

4.1. NETWORK PERFORMANCE

The following notation is used to model the performance of a CIM LAN:

D the delay that occurs between the time a packet or frame is ready for transmission from a node, and the completion of successful transmission.

Π the throughput of the LAN, which is the total rate of data being transmitted between nodes (carried load). Π is expressed as a fraction of capacity. For example if the channel capacity is 10 Mbps (mega bytes per sec) and if over a period of 1 sec, the sum of the successful data transfers between the communicating nodes is 1Mb (mega byte), then $\Pi = 0.1$.

g the actual load or traffic demand presented to the LAN. In addition to Π, g includes the time to process tokens and account for collisions.

R the requested rate of data transfer between two nodes.

d the linear distance between two nodes measured in meters.

V the propagation velocity or the velocity at which the message travels on the network (typically, V=2 E08 m/s)

T_{idle} the time for which the network is idle, that is no message transfer is occurring.

T_{msg} time required to transmit a message after access to the network is achieved.

4.1.1. Network Related Performance Measures

The performance of a LAN is usually measured by D, Π, and g. These measures will vary with time because: (a) there is a shared access medium, (b) requires a medium access control protocol, and (c) packet switching is used. Consider figure 14 which plots the Ideal Channel Utilization. The more traffic competing for transmission time, the longer the delay for any individual transmission. Therefore Π increases with g up to a saturation point, beyond which the network cannot handle more load. Any overhead or inefficiency will cause performance to fall short of the goal. Thus it is necessary to control the load offered to the network. An effective way of doing this is by grouping the various communicating nodes into clusters based on their event intensities and forming a tree of nodes. The traffic within this cluster can now be organized by identifying those nodes that contribute most to the traffic. The maximum spanning tree and the spine among these nodes is determined. Appropriate additional devices can then be placed along the maximum spanning tree so that the outgoing traffic from the cluster and into the main bus will be kept at controllable levels as compared to a situation where all the nodes are hooked to a common bus.

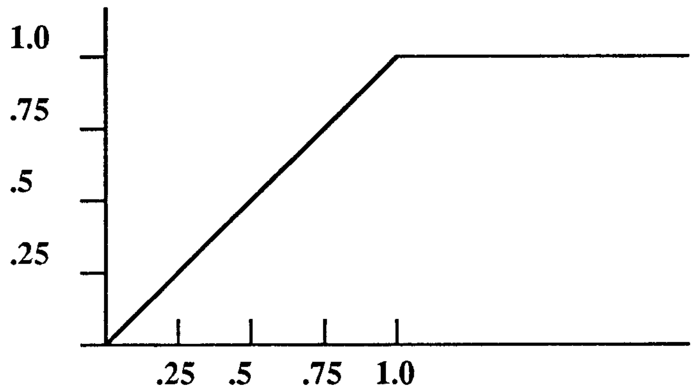


Figure 14. Ideal Channel Utilization

Another important parameter in determining network performance is the ratio (Rd)/V. A dimensional analysis of this formula shows it to be equal to the length of the transmission medium in bits, i.e., the number of bits that may be in transit between two nodes at any one time. Also d/V is the propagation time on the medium (worst case). Given that the propagation velocity remains the same, the propagation time has to be controlled by keeping the communication path length as short as possible. One way of achieving this would be to cluster the communicating nodes based on their event intensities so that the cable length running between any two given nodes in the cluster will be kept at the minimum.

4.1.2. Factors Affecting Performance

The above discussed performance measures are affected by the following list of factors:

- Capacity
- Propagation Delay
- Number of bits per frame
- Offered load
- Number of stations

We are concerned in this study with those factors that are independent of the attached devices - that is those which are exclusively under the control of the network designer. The first three factors are concerned with and are used too determine the value of 'a' which stands for the ratio -

$$a = \frac{propagation\ time}{transmission\ time}$$

These three factors can be thought of as characterizing the network; they are generally treated as givens. The local network protocol is the focus of the design effort. A technology choice that must be made.The last two factors mentioned above, offered load and the number of stations, are generally treated as independent variables. The analyst is concerned with determining performance as a function of these two variables. The clustering algorithm proposed in the study helps to achieve this.

A relationship that gives the break point between the upper and lower bounds of performance is given by the expression:

$$\frac{N}{T_{idle} + T_{msg}} = \frac{1}{T_{msg}}$$

This break point defines two regions of operation. With the number of stations below the break point, the system is not generating enough load to utilize fully the system capacity. However, above the break point, the system is fully utilized and is not able to satisfy the demands of the attached stations. This equation provides a basis for planning the number of stations.

4.2. NETWORK DESIGN METHODOLOGY

In the preceding section the need to form clusters was outlined. The following is the step by step procedure or methodology proposed in the study, for the design of an optimal flow LAN :

Step 1 - Cluster Formation

Cluster formation refers to the arrangement of the various nodes to be networked into groups called "clusters" based on the information flow pattern maintained by the various nodes. The algorithms used for this purpose is called the Single-Linkage Clustering algorithm (SLCA), and the Average-Linkage Clustering Algorithm (discussed later). Once the cluster formations are complete it will be noticed that some nodes of the system are still unassigned to any cluster. These nodes called the "Residuals" will be assigned as described in step 4.

Step 2 - Sub Network Creation

Once the clusters are formed, it is necessary to define an architecture within each cluster of nodes. It is most beneficial if the nodes in each cluster are arranged along a spine which is comprised of those nodes that have a highly intense pattern of communication with other nodes in the cluster and possibly with other nodes in the LAN. Such nodes representing the spine have a very high value of event intensity. The (Maximum) Spanning Tree Algorithm is adopted to accomplish such an architecture. Optionally the sub network creation can be done by an iterating procedure based on the functional relationship between any two nodes. An important assumption in this step is that all the nodes in any given cluster use the same hardware option with respect to the cable and band width types. Also every sub-bus in the cluster uses the same protocol and any disparity in the protocol usage between interacting sub-buses is countered by the use of gateways

Step 3 - Residuals

Residuals are resulted when a node from a cluster communicates with a node in another cluster. Such nodes either could be retained within the respective clusters with bridge connection between them.

Step 4 - Technology Choice and Cost Evaluation

Given a cluster and the architecture within the cluster, the next step involves the selection of the appropriate hardware such as Transmission Media [twisted pair, co-axial and Channel Capacity [base band, broad band] and associated interfacing equipments [transceivers, modems etc]. The total cost of installation for a given combination of hardware for all the sub networks/sub buses within a cluster and the communication costs owing to the various Event Intensities is evaluated for every option from which the optimal technology selection can be determined.

In the development of the our step method the following notation is used to represent variables and parameters:

$i \in N$ the nodes in the local are network. At times 'i' is replaced with $j \in N$.

$k \in M$ the node clusters in the network.

U_k number of nodes belonging to cluster k.

$(i,j) \in P$ possible node pairs in the upper triangular matrix defining node links. $P = \{ (i,j) \mid i=1, \ldots, N-1 \text{ and } j=i+1, \ldots, N\}$.

$A_{i,j}$ the number of messages transmitted between node 'i' and 'j' per unit time. In this study we assume that all message are approximately of the same size, therefore no attempt to differentiate between messages on the basis of size is made. Defined for $(i,j) \in P$. Also called the event intensity matrix.

B_i the total number of messages transmitted between node 'i' and all other nodes. $B_i = \Sigma_{(i,j) \in P} A_{i,j} + \Sigma_{(j,i) \in P} A_{j,i}$.

$S_{i,j}$ the similarity coefficient between the pair of nodes 'i' and 'j'. Indicates what percentage of the total message volume passing through these nodes, is $A_{i,j}$. Defined for $(i,j) \in P$.

Ψ threshold similarity coefficient level below which nodes are not open to clustering.

4.3. STEP 1 - CLUSTER FORMATION

4.3.1. The Single Linkage Clustering Algorithm For Multiple Network Formation (SLCA)

The SLCA was originally introduced by McAuley (1988) to form part groups which is used here to form multiple network communication groups or clusters. A similarity coefficient is calculated for all pairs of nodes. This similarity coefficient gives us a measure of how significant the information flow or the event intensity is, between any two interacting nodes. It is calculated as follows:

$$S_{i,j} = \left[\frac{A_{i,j}}{B_i + B_j - A_{i,j}} \right] \quad (1)$$

Using $S_{i,j}$ a modified SLCA algorithm was developed for creating LAN clusters. This algorithm is described by the following five steps:

1. Similarity coefficient is calculated for each pair of interacting nodes. These coefficients could be tabulated into a similarity matrix. A threshold value for the S_{ij} is defined for the particular LAN problem say Ψ. Also a cut off value for the maximum number of nodes allowed per cluster say N_{max} is defined as another constraint.)

2. The similarity coefficient is then scanned to locate the largest similarity coefficient. This designates the two interacting nodes to form the initial cluster. (It should be noted that nodes are assigned to clusters if and only if the similarity coefficient $S_{ij} \geq \Psi$ and the number of nodes in the cluster is $U_k \leq N_{max}$).

3. The similarity matrix is then scanned to locate the largest remaining coefficient. The associated nodes are grouped together if both the above constraints are satisfied.

4. Residuals are dealt with as described in step-4 of the design methodology, discussed earlier.

5. Steps 2, 3, 4 are repeated for all the elements in the similarity matrix. The similarity coefficients of those pairs of nodes that do not satisfy the similarity constraint are assigned within the network based on some acceptable logic taking into account their relationship with the rest of the nodes in the network.

The algorithm is terminated when all the nodes are assigned within the network.

Example :

Consider the following event intensity matrix for a network with six nodes:

$$[A_{i,j}] = \begin{bmatrix} - & 1 & 1 & 2 & 0 & 1 \\ & - & 2 & 1 & 1 & 0 \\ & & - & 1 & 2 & 2 \\ & & & - & 1 & 1 \\ & & & & - & 0 \\ & & & & & - \end{bmatrix}$$

For this example B_1=5, B_2=5, B_3=8, B_4=6, B_5=4, and B_6=4. Example similarity coefficients are S_{14} = (2/(5+6-2)) = 0.222, and S_{34} = 0.100. A more detailed illustration involving specific values of data rates that are transferred between the various nodes is presented in the chapter involving experimentation and analysis of the linkage algorithm.

4.3.2. The Average Linkage Clustering Algorithm

It may be seen from the clustering arrangement that there is a potential for the SLCA to combine all the nodes into one single cluster. This symptom is called CHAINING. This is not desirable since we are interested in isolating groups of nodes which have high intensities among them. This can be reduced by the Average Linkage Clustering Algorithm (ALCA). In this type of algorithm the, similarity coefficient is based on the average similarity of all pairs involved.Of the many ways that an average similarity coefficient can be computed, one is the method proposed by Sokal and Michner (1988). The algorithm is explained in the experimental section later. In this case the Similarity Coefficient between two interacting groups of nodes, k1 and k2, is given by:

$$\text{Similarity}\left[k1 \,\&\, k2\right] = \frac{\sum_{(i,j)\in P}\left(S_{i,j} \mid i\in k1, j\in k2\right)}{U_{k1} + U_{k2}} \quad (2)$$

4.4. STEP 2 - SUB NETWORK CREATION

4.4.1. Maximum Spanning Tree (MST) Approach

Having formed clusters based on the event intensity matrices and using the (ALCA), it is now necessary to organize the nodes of each cluster into a structured subnet or tree. The Maximum Spanning Tree approach is used for this purpose. The aim here is to determine the SPINE or the 'Dominant Bus' having the set of the most busy communicating nodes.

A graph is said to be *connected* if there is a path or flow between any two nodes in it. A *tree* is a connected graph without any cycle. The primary concern here is with the problem of finding the maximum flows between all pairs of nodes when each of these flows is to be sent through the sub net, G(V, E, c, f), separately, and the corresponding synthesis problem of constructing a net to satisfy all the flow requirements individually. Such a system known as a *communication net* , occurs naturally in practice. G(V, E, *c*, *f*) represents a network within a cluster and is a weighted directed graph $G(V, E)$ in which each arc (i, j) is assigned a weight $c(i, j)$ called the *capacity* of the arc between nodes i and j . For the sake of convenience, in this study, infinite arc capacities is assumed i.e., there is no upper bound on the amount of communication that can occur between the nodes forming the arc. '*f* ' *is the* flow in arc (i, j) in X packets/Mbytes of information per shift of plant operation. *V and E* are the node and the arc sets respectively. The flow along the arc or *edge* as it is also called can be positive, negative or zero. Further the net G(V, E, c, f) is undirected and therefore $(i, j) = (j, i)$. We can find a MST in $O(n^2)$ time where $n = |V|$ is the number of nodes. The following are the steps in the algorithm:

Step 1 -Set T = ϕ and chose any node i Define S = $\{i\}$.
Step 2 -Multiply all the flow values of the net G(V, E, c, f) by '-1', ($f = -f$).
Step 3 -Find an arc $e = (i, j)$ such that e is the shortest among all the arcs with one end point in S. Set T = T $\cup \{e\}$ and S = S $\cup \{i\}$.
Step 4 -Stop if $|T| = |V| - 1$, otherwise go to step 3.

4.4.2. Iterative Heuristics

Once the clusters are formed, it is necessary to define an architecture within each cluster of nodes, iteratively based on the functional relationship between any two nodes i and j. Let L_i be the level number of node i, and H_i the immediate higher level node to node i.

i	L_i	H_i	$\gamma_i(L,H)$	Sub Bus (b_x)	Node(H_i)	Prev(H_i)
1	3	0	$\gamma_i(3,0)$	b_1	b_1	0
2	3	0	'	'	'	'
3	'	'	'	'	'	'
4	2	1	$\gamma_4(2,1)$	'	b_2	'
4	'	'	'	'	'	'
5	'	'	'	'	'	'

The nodes in the network are considered one at a time and each time the following decision logic is applied. Thus when all the nodes are exhausted they are all assigned to various sub buses. These sub buses containing the various nodes are then connected with the use of appropriate devices.

Logic for assigning nodes into sub buses:

Let
b_x = Sub bus number, x
x = 1
Define a sub-bus bx; Assign node 1 to sub bus 1 (b_x=b_1)
for i = 2 to i_n (last i),
    If γ_i(L,H) = Previous γ_i(L,H);
        assign i to sub bus b_x (previous γ_i(L,H))
            else increment x.
        define sub bus b_x
        assign node i to bx
    end if.
if i = previous (H_i),
    assign node i to bus (previous (H_i))
End for.

4.5 . TECHNOLOGY CHOICE AND COST EVALUATION

Having formed clusters and sub-networks within the clusters the appropriate hardware is now opted for. For example the spine or the bus within a cluster can may require a transmission media of higher channel capacity. The rest of the nodes in the cluster may be linked to the main spine or bus with wires having lesser band widths etc. Such a selection of transmission media channel capacity etc., are a matter of choice on the part of the designer who could opt for the relevant hardware from a large variety of options taking into account the cost effectiveness of the choice as the chief criterion.

CHAPTER FIVE

EXPERIMENTATION AND ANALYSIS OF LAN DESIGN METHODOLOGY

This chapter applies the LAN design methodology, proposed in the previous chapter by considering a scenario involving a generic CIM where the different facilities or nodes of the enterprise are to be interconnected with one another by a computer network. Experiments using the SLCA and the ALCA are conducted. Clusters of nodes formed by applying ALCA are further analyzed to determine the MST and the SPINE. This stage of the design provides the basis for deciding appropriate hardware for the communication network. This hardware is now a matter of choice on the part of the LAN designer from a variety of options available. The methodology step involving technology choice and cost evaluation merits treatment as a separate issue and is not dealt with in detail in our study.

5.1. EXPERIMENTATION FOR CLUSTER FORMATION USING SLCA

Consider a manufacturing unit comprising of 15 different facilities (nodes) which are to be (computer) networked in order to facilitate an effective communications system to obtain a CIM. These nodes are simply denoted by the numbers 1 thru 15.

Table 6 shows the communication traffic between the various nodes in this example network. This is referred to as the event intensity between the respective nodes and is expressed in terms of packets per unit time (1 packet = 64 Kbits of instruction). Then the similarity coefficient between the interacting nodes i=1, j=2 is:

$$S_{1,2} = \frac{200}{200 + (200+80+280+\ldots+75)+(0+78+\ldots+750+200)} = 0.0359$$

Similarly the entire matrix is generated as shown in table 7. Based on the similarity matrix, the node clusters are formed.

5.2 RESULTS AND ANALYSIS OF SLCA

The results of applying the SLCA to the experimental communication traffic matrix can be seen from table 8. It shows the clusters formed and the various nodes belonging to them. The dendogram which provides a pictorial representation of the cluster formation is shown in figure 15. It provides a more descriptive means of showing the results. The abscissa of the dendogram has no special meaning; in the example it denotes nodes or groups of nodes. The similarity coefficient scale usually having a range of 0 to 1.0, is represented on the ordinate. The dendogram in figure 15 depicts the same results as table 8. In the figure each branch at the lowest level represents a node. Moving towards the top of the dendogram, the branches merge into new branches representing clusters of communicating nodes. The value of the similarity coefficient at which this occurs is denoted on the left scale of the dendogram.

With reference to the dendogram, a lower value of $S_{i,j}$ indicates a high order interaction between the communicating nodes or clusters (if an inter cluster communication occurs). It may be seen from the dendogram that at a similarity value of 0.16 nodes 3, and 13 are grouped. and at a value of 0.15 node 2 is clustered with nodes 15. Now consider the node clusters (3, 13), (2,15) and (1,7,14). Node 13 interacts with 14 at an $S_{i,j}$ of 0.11 and with 15 at an $S_{i,j}$ value of 0.15. This leads to a cumulative cluster having nodes 3,13,2,15,1,7,and 14 in it. Thus all the nodes in the net get clustered into one group as the similarity coefficient approaches the lower values in the communication net. This symptom of a single group formation is termed Chaining, as described earlier. In the example considered, the chaining of nodes into one single cluster occurs at an S_{ij} value of 0.04.

In order to avoid chaining or to be more accurate, reduce it, an adapted version of the Average Linkage Clustering Algorithm (ALCA) is proposed for the cluster formation of the communicating nodes. The Similarity Coefficient

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	200	80	280	300	40	800	60	48	170	40	220	230	700	75
2		-	0	78	150	40	39	150	46	68	169	78	240	250	750
3			-	40	68	45	140	150	150	40	170	210	700	150	39
4				-	300	120	70	60	600	150	78	170	200	70	600
5					-	200	0	210	150	78	68	158	65	68	40
6						-	30	200	150	0	180	0	0	65	45
7							-	400	0	230	250	230	70	71	47
8								-	0	60	270	240	58	59	68
9									-	260	65	65	70	75	0
10										-	78	150	155	170	200
11											-	100	0	40	45
12												-	0	40	45
13													-	0	60
14														-	0
15															-

Table 6. Communication Traffic Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	-	.04	.02	.04	.06	.01	.13	.01	.01	.03	.01	.04	.04	.12	.02
2		-	0	.02	.04	.01	.01	.04	.01	.02	.04	.02	.06	.06	.15
3			-	.01	.02	.02	.03	.04	.04	.01	.05	.05	.16	.04	.01
4				-	.06	.03	.01	.01	.12	.03	.02	.04	.04	.02	.11
5					-	.06	0	.05	.04	.02	.02	.04	.02	.02	.01
6						-	.01	.06	.05	0	.06	0	0	.02	.02
7							-	.01	0	.05	.06	.05	.02	.02	.01
8								-	0	.02	.07	.06	.02	.02	.02
9									-	.07	.02	.02	.02	.02	0
10										-	.02	.04	.04	.05	.05
11											-	.03	0	.01	.01
12												-	0	.01	.01
13													-	0	.02
14														-	0
15															0

Table 7. The Similarity Matrix

CLUSTER #	NODES	SIMILARITY COEFF..
1	(3,13)	0.16
2	(2,15)	0.15
3	(1,7)	0.13
4.	(1,7,)14	0.12
5.	(4,9)	0.12
6.	(2,4,15,9)	0.11
7.	(8,11)	0.07
8.	(2,13,14)[1,3,7,9]	0.06
9.	(3,11,12)[1,2,9,7,13,14,15]	0.06
10	(7,11)[1,2,3,9,12,13,14,15]	0.06
11	(8,12)[1,2,3,7,9,11,,13,14,15]	0.06
12	(1,5)[2,3,7,8,9,11,12,13,14,15]	0.06
13	(6,10,12)[1,2,3,5,7,8,9,11,13,14,15]	.05
14.	(1,2,4,12,13)[3,5,6,7,8,9,10,11,14,15]	.04

{1,2,3,4,5,6,7,8,9,10,11,12,13,14,15}......0.04

Table 8. Cluster Formation using SLCA

is determined using the sum of the pair wise similarity coefficients between all members of the two communicating groups of nodes i, j. For example let the node group i comprise nodes $n1$ and $n2$, and node group j consist of nodes $n3$, $n4$, and $n5$. Then the similarity coefficient S is computed using equation (2). The example used for the SLCA will be used to illustrate an ALCA. Also let us suppose that a similarity coefficient of .06 is the cut off value in the example. Then the clustering iterations are stopped at this S_{ij} value. Any previously unassigned nodes are treated as residuals.

The ALCA is composed of the following steps (the first two steps are the same as for SLCA) :

1. Similarity coefficient is calculated for each pair of interacting nodes. These coefficients could be tabulated into a similarity matrix as shown in figure below. (A threshold value for the S_{ij} is defined for the particular LAN problem say x. Also a cut off value for the maximum number of nodes allowed per cluster say y is defined as another constraint).

2. The similarity coefficient is then scanned to locate the largest similarity coefficient. This designates the two interacting nodes to form the initial cluster. (It should be noted that nodes are assigned to clusters if and only if the similarity coefficient $S_{ij} >= x$ and the number of nodes in the cluster is $<= y$).

3. The average similarity coefficients between the initial cluster of nodes and the remaining nodes are calculated. The similarity matrix is then revised using these new values and and the new group / cluster.

4. The revised similarity matrix is then scanned to locate the largest coefficient. The associated nodes are grouped together into a new cluster of nodes.

5. Steps 3 and 4 are repeated until all the nodes in the network are exhausted i.e until all the clusters of nodes are grouped. Now we see

that this is a group containing very distinct clusters of nodes as against one single cluster seen in the application of the SLCA. Each individual cluster is now ready to be structured further into trees to result in a total architecture of the network nodes.

5.3. EXPERIMENTATION FOR CLUSTER FORMATION USING ALCA

The same example used in SLCA is considered here. (Cut off Sij value is .06).

Step 1 : The similarity matrix is generated as shown in table 7.

Step 2 : The initial cluster consists of nodes 3 and 13 with the highest S_{ij} value.

Steps 3, 4, 5 are carried out as described earlier. For example step 3 would be executed by considering nodes 3, and 13 as a single entity and a new similarity matrix is calculated which is as shown in table 9. From the matrix it is seen that a new cluster is formed comprising of nodes 12 and 14. Now these two nodes are represented as a single entity in the next iteration of $S_{i,j}$ matrix calculation. This procedure is considered until all the nodes are assigned. (Iterations are stopped at an $S_{i,j}$ value of 0.05.). The resulting list of clusters is shown in table 10. The Dendogram for the above cluster formation is as shown in figure 16.

5.4. MST DETERMINATION

Now, in order to construct the maximum spanning tree, a cluster of nodes is considered. Since in the example the size of the various clusters are very small, nodes of clusters 1 & 2 are pooled. We will now have a single larger cluster consisting of nodes (1,7,4) and (2,3,13,14). For this set of nodes a spanning graph is drawn as shown in the figure 17. The maximum spanning tree for the the graph is constructed and will appear as shown in figure 18 and 19.

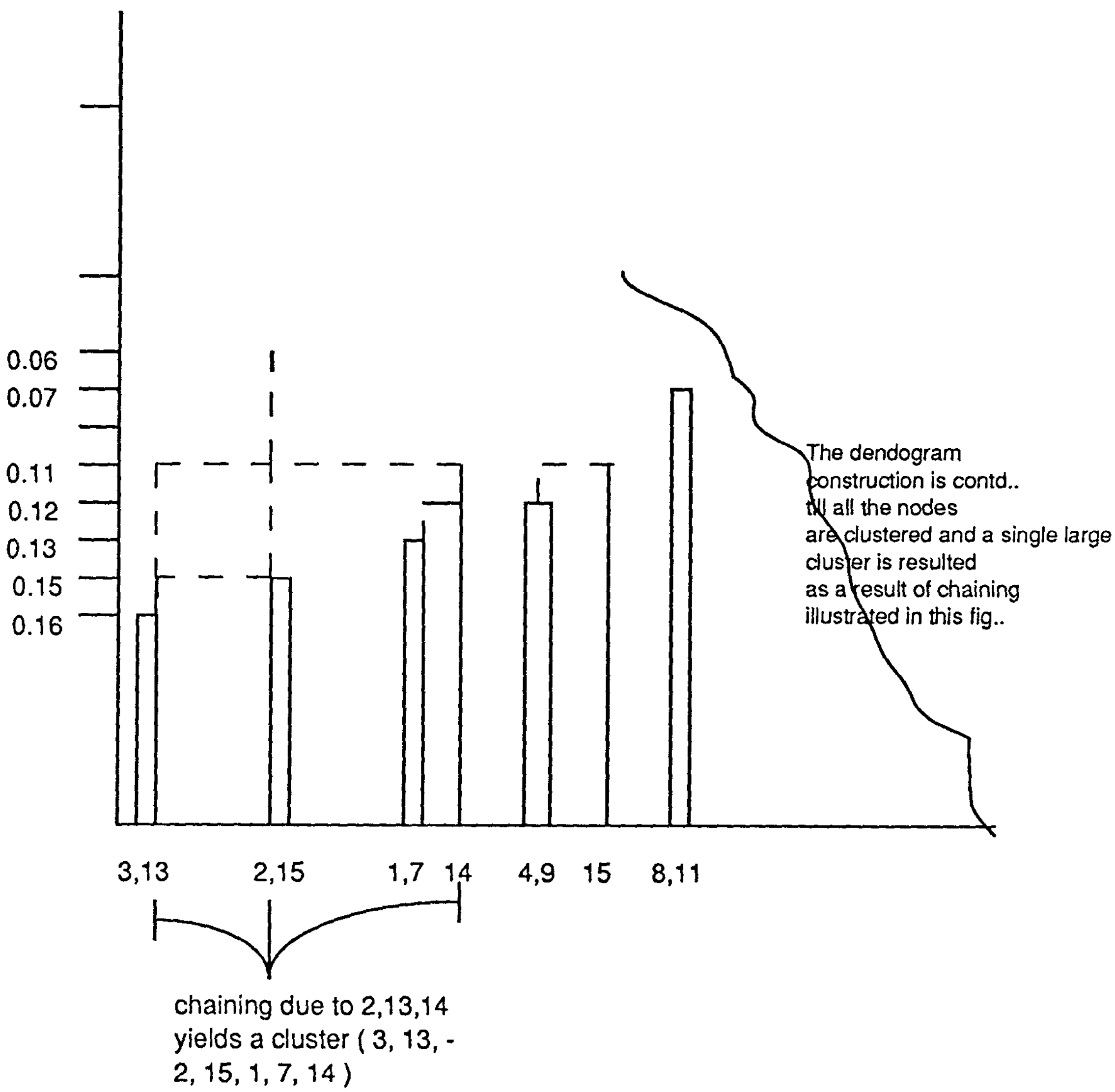


Figure 15. SLCA Dendogram

	1	2	3,13	4	5	6	7	8	9	10	11	12	14	15
1		.04	.03	02	.06	.01	.13	01	.01	.03	.01	.04	.12	.02
2			.03	.02	.04	.01	.01	.04	.01	.02	.04	.02	.06	.15
3,13				.01	.02	.02	.025	.03	.03	.025	.025	025	.02	.015
4					.06	.03	.01	.01	.12	.03	.02	.04	.02	.11
5						.06	0	.05	.04	.02	.02	04	.02	.01
6							.01	.06	.05	.0	.06	0	.02	.02
7								.01	0	.05	.06	.05	.02	.01
8									0	.02	.07	.06	.02	02
9										.07	02	.02	.02	.0
10											.02	.04	.05	05
11												.03	.01	.01
12													.01	.01
14														.02
15														0

Table 9. The Similarity Matrix

CLUSTER #	NODES	SIMILARITY COEFF
1.	1,7,14	0.07
2.	2,3,13,15	0.07
3.	8,11	0.07
4.	5,6	0.06
5.	4,9,10,12	residuals

Table 10. List of clusters due to ALCA

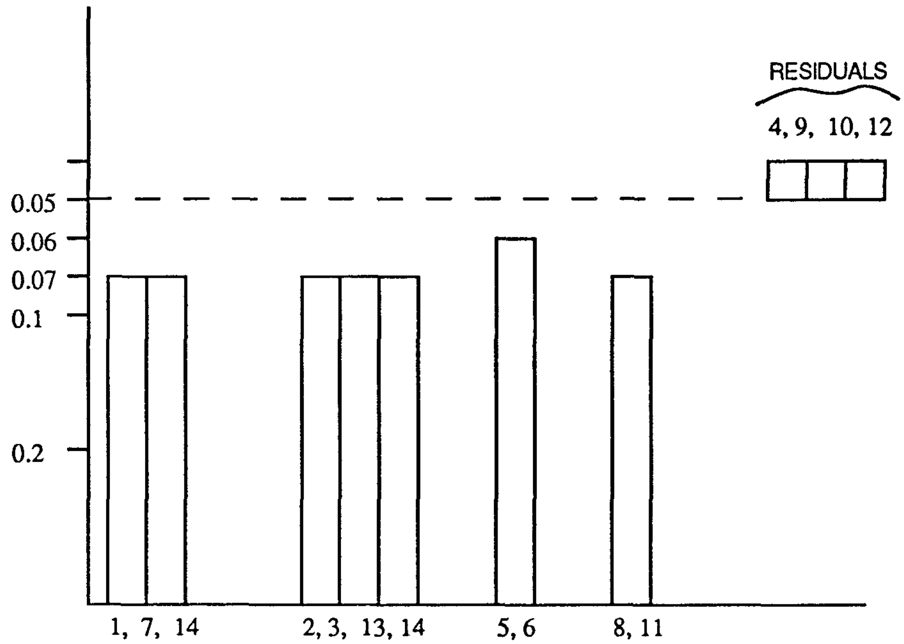


Figure 16. Dendogram for ALCA

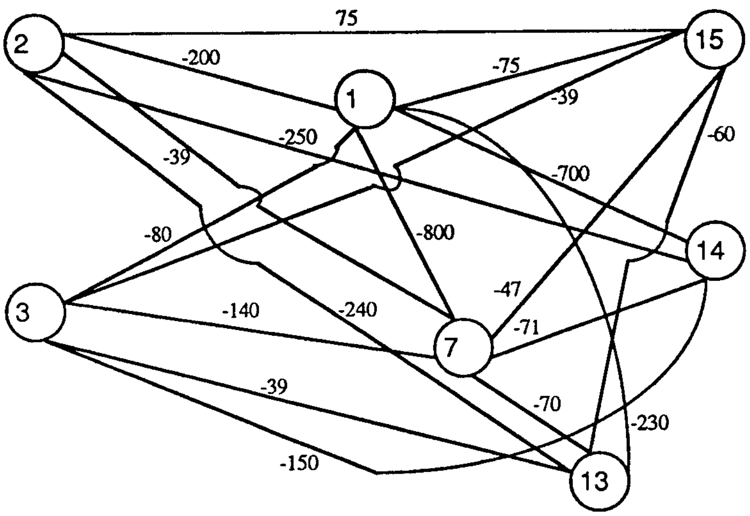


Figure 17. Spanning Tree Graph

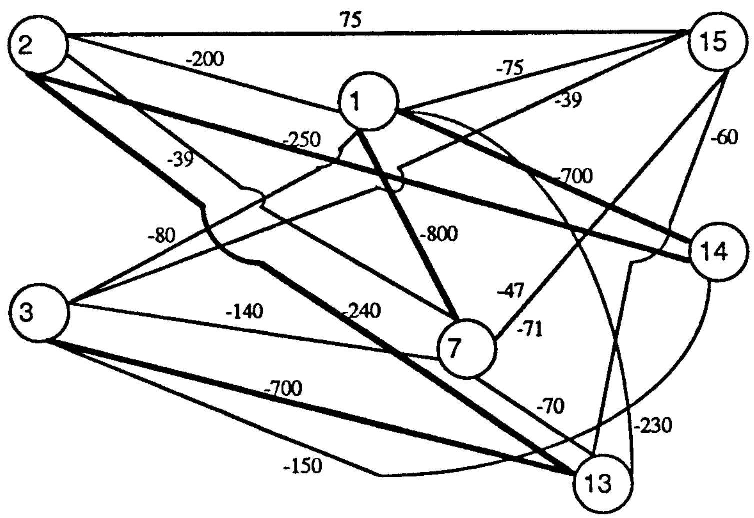


Figure 18. Maximum Spanning Tree

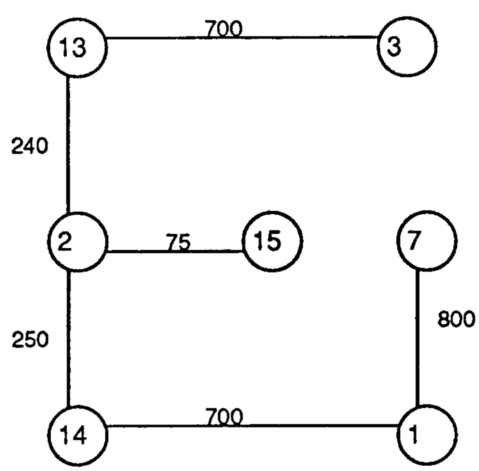


Figure 19. : Spanning Tree

Once the maximum spanning tree is determined, it is now necessary to find out which arcs of the maximum spanning tree, together form the spine of the sub-network in the cluster considered. This spine will form the basis for the choice of appropriate hardware within the cluster from a variety of commercially available options. In other words, those nodes that belong to the spine may be deemed to be the most busy in terms of communication with other nodes. These may require a hardware that can absorb a high event intensity. For this purpose it may be necessary to ensure transmission of messages among the various nodes along the spine over a wide range of frequencies. Choice of a broad band cable for physical links would be one of the typical hardware options for the spine.

5.5. SPINE DETERMINATION

The methodology for determining the spine is as follows:

1. Identify the information flow paths starting from the node which has only one arc originating from it. Let this node be i = 1 (i = 1, 2, -....n).
2. Determine the path along which the total flow is maximum among the paths identified in step 1. (M_i).
3. Increment i = i + 1.
4. Go to step 1.
5. Determine the maximum of ($M_1, M_2, \ldots, M_n$).

The above methodology is applied and the spine for the example maximum spanning tree is determined. For the example we have three nodes with only one arc originating from them, viz., nodes 3, 7, and 15. For each of these nodes, steps 1 through 4 are applied. For the node 3, we take Max [(3-13-2-15), (3-13-2-14-1-7)]. = M_1. The path M_1 is 3-13-2-14-1-7. Similarly M_2 and M_3 are determined and the Spine for the maximum spanning tree is given by the Max (M_1, M_2 and M_3). For the example the spine is the path (3-13-2-14-1-7) with a total traffic of 2690 packets per shift.

5.6. ADVANTAGES OF NODE CLUSTERING

There are many advantages to using the node clustering approach in LAN design, the primary advantages are listed below:

1. Intuitively, clustering of nodes leads to a more orderly and manageable network. Given the complexity of a CIM environment, such a grouping based on node to node interaction is reasonable as the entire manufacturing activity depends upon successful and timely communication between the related nodes.

2. Division of the total nodes into clusters (trees) leads to better utilization of the resources. That is, the average waiting time before successful transmission between two nodes in a cluster/tree would be substantially less than it would be if all the nodes were accumulated into one single huge group. This is because the average probability of access to the token for communication increases drastically.

3. For an IEEE 802.3 CSMA/CD LAN, the maximum cable length permitted is 500 meters To allow the network to extend a larger distance, multiple cables should be connected by using repeaters (devices which transmit, amplify and re-transmit in both directions). This need for repeaters can be kept at a minimum by keeping the running cable length as small as possible between the communicating nodes and this can be accomplished by grouping the various nodes into clusters.

4. Clustering permits use of thinner cables which are less expensive and easier to bend around corners rather than requiring the cable to be installed in the wall and having to provide a drop cable to the station.

5. The major issues associated with a computer network relate to :
   a. Command and control (of the various nodes)
   b. Response time
   c. Time required for data logging

d. The sensitivity of the system to failure in any of the intermediate nodes of the network

Clustering of the nodes helps to achieve the above control features easily than otherwise because the complexity of the system is reduced to more manageable proportions).

6. Clustering based on information flow provides a convenient way to relate the functional aspects of the equipment associated with layer 2, with the functional informational requirements associated with layer 4.

7. Performance : (Reduced cable length = increased performance)

Systems in which multiple users share a common channel (leading to conflicts) are called *Contention systems.* A logical arrangement (clustering) of the various communicating nodes into appropriate locations based on communication intensities causes this symptom of contention systems to be at the minimum possible level. Also,

$$\text{Channel efficiency } (\eta) = \frac{1}{1 + 2BLe/CF} \quad \text{where}$$

$2BLe/CF = x$ (B is the bandwidth of the cable).

L = running length of the cable

e = speed of transmission

C = Channel capacity

F = Frame length

When x is too large, η is low.

Therefore, the product BxL should be kept at a minimum. Thus reducing 'L' reduces BxL so that the channel efficiency is high.

CHAPTER 6

CONCLUSIONS AND FUTURE RESEARCH

6.1. CONCLUSION

This research provides a perspective of the impact of communications management on (CIM) system performance. The attempt has been to provide a conceptual model of a design methodology for developing an optimal flow LAN. The first key step in doing this is to generate clusters of communicating nodes so that there is a breakdown of the complicated interaction structure of the various communicating facilities in the CIM complex into manageable proportions. This is done using the linkage algorithms proposed in the thesis. It further investigates the need for determining the path of maximum information flow within a cluster so formed. The maximum tree algorithms are adapted to achieve this purpose. This makes it possible for the LAN designer to make appropriate hardware options so that the installed LAN will have the most efficient combination of hardware components.

In addition to the results from the experiments on the clustering and MST algorithms, some of the inferences that may be drawn from the thesis are as follows:

- Clustering of nodes leads to the development of an orderly network which can provide successful and timely communication.

- Clustering leads to a better utilization of the CIM resources especially the communication facilities because of reduced propagation delays.

- The cost of the communication network goes down drastically as the proposed LAN design methodology potentially reduces the cable lengths running between communicating nodes, as also the additional transmission devices required to retain the data integrity.

Overall it can be concluded that with the adoption of the proposed design methodology, potentially there is improvement in the way a LAN functions, given the requirements of CIM. That supplementing advancements in the electronics industry with shrewd LAN planning makes Computer Integrated Manufacturing complete.

6.2 . FUTURE RESEARCH

There are future research challenges in the development of a LAN design specifically in the context of CIM. The examples selected here are basically generic. The manufacturing scenarios however are varied with varying mix of complexities. For this reason future studies could include some typical Industrial settings and the networking requirements of these industry specific CIM systems. Studies should include in their considerations, the dynamic characteristics of industrial settings for example the changes in the information exchange structure, that may result due to changes in production requirements.

Stuidies should incorporate simulation techniques vigorously. The software Network II.5 is one tool that may be used for this purpose.

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