CHAPTER 1 INTRODUCTION TO FIELDBUS SYSTEMS

1.1 Preface

In industrial operations, it has long been an issue as to how to gather process data, how to analyze it, and how to implement systems to control advanced automatic systems. Over time, many types of control systems have developed; some common contemporary systems are DCS (Distributed Control System), PLC (Programmable Logic Controller and SCADA (Supervisory Control and Data Acquisition) [1].

At the lowest level of communication, before the Fieldbus era, a lot of standards reigned, for example, the 4-20 mA standard for analog sensors or the 0 – 24 V for digital inputs, etc. These standards led to a cabling of 2 wires for each analog point and one wire for each Boolean point (true, false), or each binary digit in a number. The result was the need for a great number of cables in the factories. The design and installation of the wiring were expensive. The operation and maintenance or evolution was difficult. This was one of the reasons why end-users requested a solution for simplifying these operations: the Fieldbus was an answer to this request [2].

1.2 The Definition of a Fieldbus

The Fieldbus is the serial digital communication network which is able to communicate in real time between automatic control systems like (PLCs, DCS,...) and field devices like (Instruments, Actuators, Gateways,...)

The Fieldbus technology was developed in the mid 1980's when it was needed to organize the signal transmission system of communication networks which used digital technology. The Fieldbus transfers, in most cases, the information in small-sized packets in a serial manner. Choosing the serial transmission has many merits in comparison with other kinds of transmission like parallel transmission. For instance, the sequential or serial transmission reduces the total required number of the connecting lines over greater distances than that of the point-to-point or even parallel transmissions.

A set of rules must be defined in order to accomplish data transfer between the units along the bus. This set of rules is called Communication Protocol or just the Protocol. This is unlike the case of the ordinary point-to-point transmission where any two connected entities send and receive data from each other whenever the data is available. The protocol is responsible for two important rules on the bus, the mechanism that any unit can acquire or seize the bus (from the network terminology this means the way of Medium Access), and the synchronization between those multi-units on the bus.

The medium access protocol choosing is a vital step in designing the DCS. This is because of the odd nature of the bursty traffic of such control systems. So the existing LAN (Local Area Network) protocols such as the token ring or the CSMA (Carrier Sense Multiple Access) are not appropriate for the control applications. For the token ring case, the more nodes are added, the longer the time each node will wait till it can transmit its data. Needless to say that the CSMA protocols, which are contention based protocols, will add randomness to the overall response time. This term is the elapsed time interval between sending the data from the producer node, and the receiving of that data at the consumer node. This came from the way that the CSMA allows only one node to transmit data if and only if no other node is seizing the medium. The randomness occurs when a collision happens. Collision happens when two or more nodes try to transmit at the same time on the network. The nodes which encountered the collision will have to wait to for a random time before it start again transmitting.

In general, there are three main issues that must be considered when designing the Fieldbus system which are:

1) The communication protocol used
2) The interoperability (compatibility) of the units
3) The topology of the network used

Although almost any type of topology that is used with the ordinary LAN can be fit with the Fieldbus system requirements, but there are two other factors that affect the selection of such topology. These factors are the medium access method used and the medium used in the DCS (twisted pair, coaxial cables, optical fibers … etc.). Other more specific factors are used to select the topology; like the cost and ease of wiring installation and the reliability [1].

1.2.1 Fieldbus Advantages

The advantages of using a Fieldbus in comparison to the point-to-point method are many but here we will list some of the most general:

1) The data transmission is done in a standard form to suit the special demands of the factory communications.
2) The data exchange along the bus is available easily to all the nodes at the same time (i.e. no need for extra cable to connect certain node to another one).
3) The ability to connect new units on the bus becomes more flexible. This means that the network extension also becomes easier to achieve [1].
4) The distances that can be covered by the Fieldbus are greater than that of the old point-to- point system.
5) The Fieldbus can save the expenditure of wiring compared with an existing point-to-point communication method by using a single transmission medium.
6) Unlike the analog signal, the digital Fieldbus signal is not affected by noise or distortion. The digital Fieldbus signal does not require the conversion of analog to digital or digital to analog.

7) The installation and operation of the Fieldbus and their associative devices become easier.
8) The Fieldbus is capable of bidirectional communication between devices. The bidirectional communication devices provide cost savings in operation and maintenance by monitoring and calibration automatically through the network.
9) Possibility to connect products from different manufacturers. This is known as the interoperability (compatibility) of the Fieldbus [3].

1.3 An Introduction to Industrial Systems Communication

In general the industry can be divided in two categories; which are the Process, and the Manufacturing. The process industry, deals with processes, continuous, or discontinuous, which have very large material flows and often have strict safety requirements (e.g. power generation, cement kilns, petrochemical production). While the manufacturing industry, is concerned with the production of discrete objects. Achieving the maximum throughput of produced goods is, normally, a very important aspect in the industrial systems.

The industrial systems faced the needs of enhancement in production monitoring and quality control and in the same time maintaining the costs of all this as low as possible. This happened in the last few decades due to growing social needs, which in turn enforce the industrial systems to grow to match up with these needs. So any operation that runs manually had to be replaced with a faster, and more reliable automated operation. This also provides both the factories and the plants with necessary monitoring which they both sought for better supervision and quality control.

Introducing all this number of automated units into the factories needed an efficient method to connect them together, to communicate with each other, and to transfer the various supervisory data to the monitors. This leads to the introduction of the communication networks into the factories. We now will present two subsections that briefly describe the history of communication development in the industrial processes [1].

1.3.1 Process Industry Communication: a Historical Background

The process industry communication developed in the last four decades in four main steps. Each step introduced a nearer control to the field devices or more distribution of the many tasks of control and/or supervision. The first step was a star topology that connects the Field Devices (FDs) to a single mainframe computer in the control room.

This mainframe computer had to make all the control and supervisory tasks. To accomplish these tasks, the mainframe computer had to transfer the required data from and to the field devices using the traditional point-to-point methodology. Star topology used in the architecture of Process Control Figure 1-1 gives an example of this configuration. This configuration is called the centralized configuration. This same configuration was famous at the 60's of the last century.

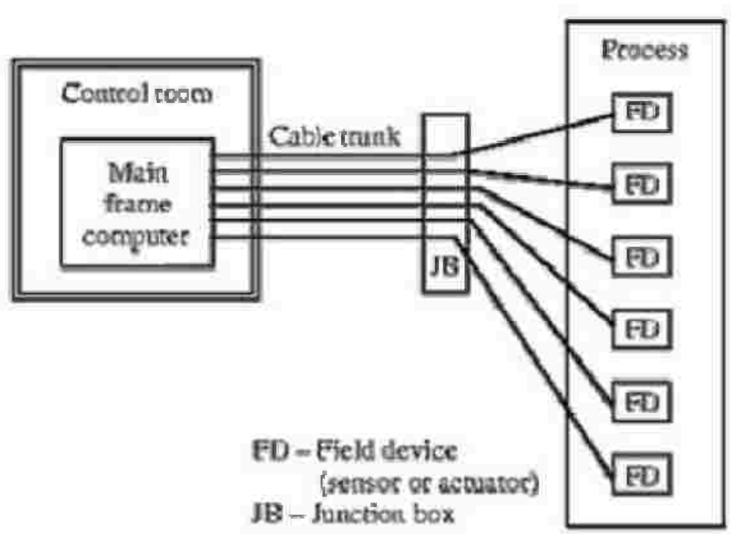

Figure 1-1 Star topology used in the architecture of Process Control

There are several disadvantages associated with such a centralized system:

1) The complexity of the wiring was so high and difficult to be re-installed, and above this they were expensive.
2) The high cost of the mainframes that are doing the control tasks.
3) The mainframe failure represented a much higher risk to the system as it can lead toward the collapsing of the whole system.
4) The lack of standards leads to the impossibility of interchanging some elements with faster or more reliable ones.

The second step of the process industry communication development was the division of the supervisory and the control tasks between two or more controllers. Each controller had its own field devices attached to it using the old point-to-point way. Figure 1-2 depicts a hierarchical architecture.

In turn, and as we see from the same Figure 1-2 these controllers are attached to one computer called the management information system. These controllers were placed in the same old control room with the management information system computer. The period which witnessed the prosperity of such architecture was the early 70's of the twentieth century. One thing is sure that is the fault tolerance became more lenient with this hierarchy.

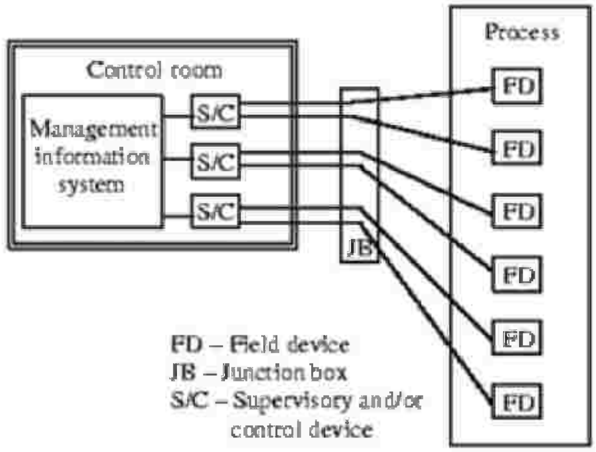

Figure 1-2 The hierarchical architecture

The great revolution of the Integrated Circuits (IC's) made the next third step of the process industry communications became true. This revolution made it possible for more distribution of the tasks. More over the performance got better and the total cost reduced a lot. The controllers communicated with each other via serial digital network. Furthermore the controllers were placed nearer to the field devices, which reduced the complexity and the cost of wiring, as the length of the cables are shortened. This happened during the mid of the 70's of the last century.

Unfortunately, the field devices were still point-to-point wired to the controllers. These controllers are called the local controllers to differentiate between them and the other controllers that might be in the control room. Also, the control room contained two independent units; one is the Operator Console, and the other is the Supervisory Computer. These two units are attached to each other via the same serial digital network that allows them to communicate with local controllers as shown in Figure 1-3.

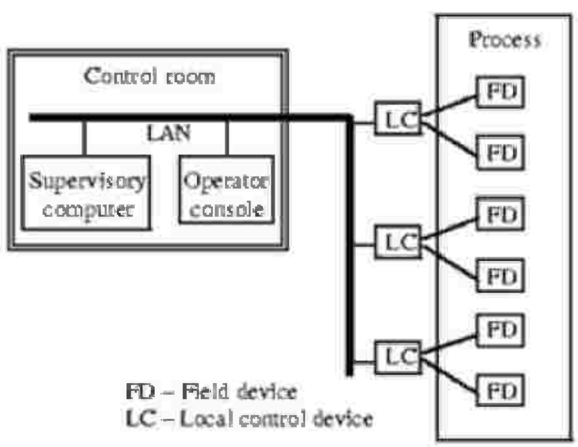

Figure 1-3 The distributed architecture in Process Control Systems

As an example of the first distributed system of this kind for process control was the (TDC® 2000 system) introduced in 1975 by Honeywell. The semi-final stage of the industrial process took place in the early 1980's. By then, the number of field devices was growing incredibly. This made the system designers to connect these devices via serial digital network. Figure 1-4 shows an example of this modern architecture. The introduction of digital network simplified the cabling and wiring of the system leading to ease of maintenance. The network that connects these field devices is called FieldBus.

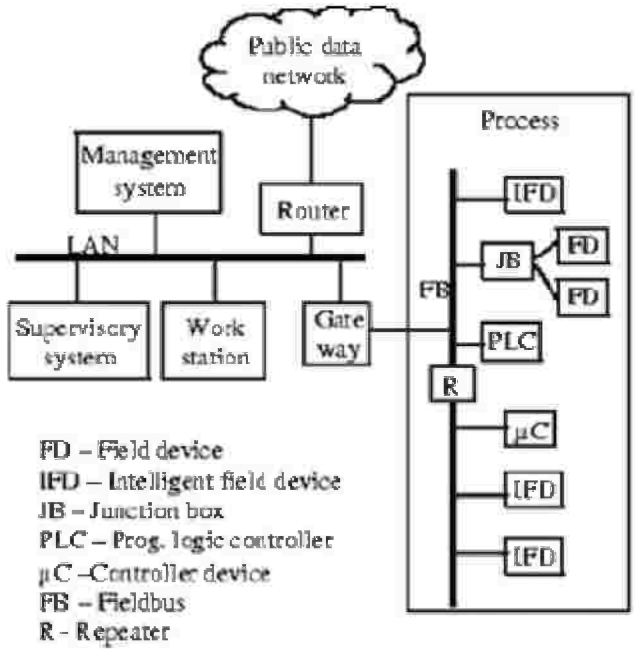

Figure 1-4 The fully distributed architecture, based on a Fieldbus, found in modern industrial automation systems

1.3.2 Manufacturing Industry: a Historical Background

After we talked about the process industry and its communication, we now move to the second category of the industry, that is the Manufacturing industry and its relevant communications. The manufacturing industry and its communication developed significantly in the last four decades along with the process industry. The development of both was motivated by the need of lower production cost while maintaining high performance and good quality control. From the 50's to the early 70's of the last twentieth century, the manufacturing plants consisted of many isolated production units called cells. During this period, the automation development was limited to these cells only as independent islands.

By the mid 70's of the last century, the need to improve the production monitoring and the miscellaneous control functions leaded the way to connect the production islands with each other. This means that the manufacturing industry like the process industry adopted the distributed architecture. Figure 1-5 shows the fully modern distributed manufacturing architecture. This hierarchy also is known as the Computer Integrated Manufacturing (CIM). We will present the definition of the term CIM shortly in this section. The CIM is defined by at least three levels of interconnection as depicted in Figure 1-5. Those levels are:

1) Field Level: The lowest level of the automation hierarchy is the field level, which includes the field devices such as actuators and sensors. The elementary field devices are sometimes classified as the element sublevel. The task of the devices in the field level is to transfer data between the manufactured product and the technical process. The data may be both digital and analogue. Measured values may be available for a short period of time or over a long period of time. For the field level communication, parallel, multiwire cables, and serial interfaces such as the 20mA current loop has been widely used from the past. The serial communication standards such as RS232C, RS422, and RS485 are most commonly used protocols together with the parallel communication standard IEEE488. Those point-to-point communications methods have evolved to the bus communication network to cope with the cabling cost and to achieve a high quality communication.

2) Control Level: We typically use control-level networks for peer-to-peer networks between controllers such as PLCs, DCS, and computer systems used for human machine interface (HMI), historical archiving, and supervisory control. We use control buses to coordinate and synchronize control between production units and manufacturing cells. Typically, PROFIBUS-DP and Ethernet with TCP/IP are the most industrial networks used to connect upper-level control devices and computers.

3) Information Level: The information level is the top level of a plant or an industrial automation system. The plant level controller gathers the management information from the control level, and manages the whole automation system. At the information level there exist large scale networks, e.g. Ethernet WANs for factory planning and management information exchange. We can use Ethernet networks as a gateway to connect other industrial networks [4].

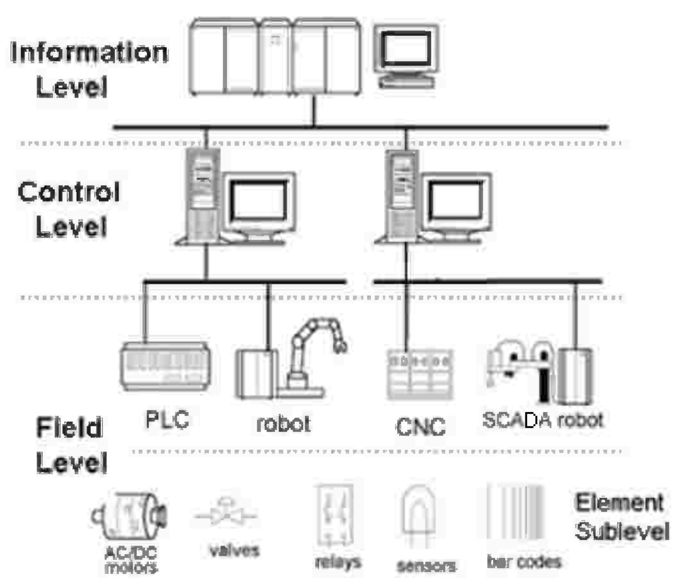

Figure 1-5 The Computer Integrated Manufacturing (CIM) architecture

A new architecture that combines all this communication protocols is needed. This new hierarchy is called the CIM or Computer Integrated Manufacturing architecture and can be seen in Figure 1-5. This architecture organizes the level of factory communication systems and was initially derived from the MAP or the Manufacturing Automation Protocol project. This project was initiated by North American industrial companies leaded by General Motors (GM) at 1980. The main target of this group was to define a new open standard for the communication in the factory that can allow the interoperability (compatibility) between many components that came from different manufacturers. There had been similar groups and attempts to standardize such protocols in Europe during the 80's of the last century. For examples, the FIP existed in France and PROFIBUS in Germany.

1.4 The Fieldbuses and the Network Reference Model

In the previous sections we have discussed Fieldbus definition and its historical origins. We mentioned that it is considered as a network that connects the field devices at the factory floor together with the controllers. Since it is a network, we have to know its relation with the famous OSI reference model. We will describe the Fieldbus in terms of the layers of the OSI model.

The OSI model organizes the protocols used and the services provided by a general communication system in a stack of layers. It is a complete layered network model in which each layer does certain communication service. One can see in Figure 1-6(a) the reference OSI model layers. How it works? From the same figure, we can see that if a node wants to send a data packet from the application, it must first call for the sending service of its application layer which in turn will call the sending functions in the next layer, and so on till the data is sent at the physical medium to the other node. This node will reverse the sequence till the received data reaches the application layer of its node then to the application which will use this data. The OSI model consists of seven layers:

1) Application layer which provides the services that are required by specific applications
2) Presentation layer which is responsible for the data interpretation, this allows for interoperability among different equipments.
3) Session layer concerned with any execution of remote actions
4) Transport layer responsible for the end-to-end communication control
5) Network layer concerned with logical addressing process of nodes and routing schemes
6) Data link layer responsible for the access to the communication medium, and for the logical transfer of the data
7) Physical layer concerned with the way that the communication is done physically

Modification to the MAP project was necessary, as the node implementation became more complex, in order to support all the services of the OSI reference model. The modification allowed the short length control data packets, which occurs at high rates, to be directly transmitted through the application layer to the data link layer. This means that we abbreviated the OSI hierarchy into a 3-layer model as can be seen in Figure 1-6(b). The resulting Fieldbus is referred to as a 3-layered architecture which is defined by IEC 61158 (Fieldbus Standardization) [3].

These layers are: the Application layer, the Data link layer, the Physical layer. One may assume that the other four layers of the OSI model that are not available in the Fieldbus hierarchy have disappeared along with their own functions and services. This is absolutely wrong, as these functions are augmented into the remaining layers. For example, the main function of the presentation layer, which was to support the interoperability between different equipments, is done now by the application layer in the Fieldbus. The assembling and disassembling of data packets which was the function of the transport layer is done now by the data link layer in the Fieldbus network. If routers to be used in some Fieldbus networks, then the routing service, which was assigned to the network layer, is mainly done by the application in the Fieldbus [1].

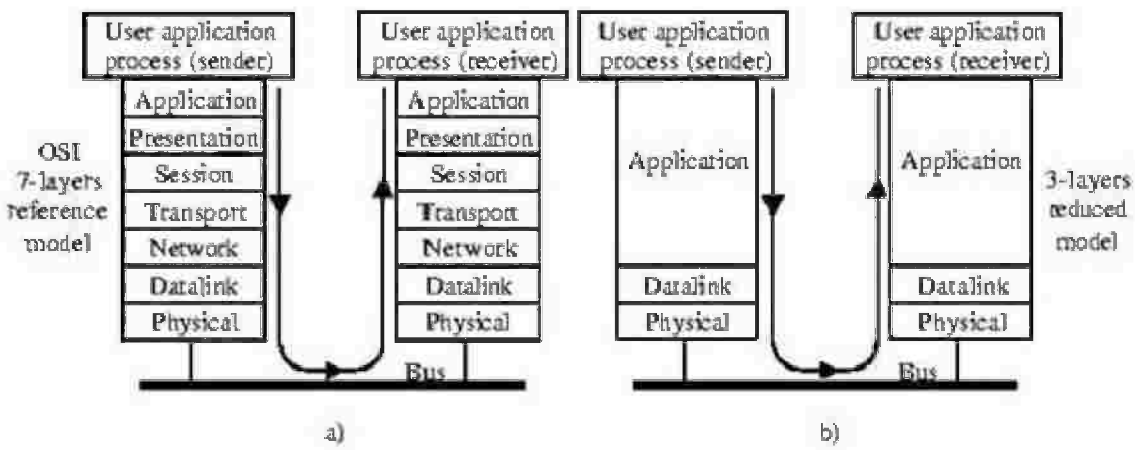

Figure 1-6 The OSI 7-layers reference model (a), and the reduced Fieldbus 3-layer structure (b)

There exist many protocols and services that are laid in the 3-layerd hierarchy of the Fieldbus network. This at the end will lead to a great difficulty in evaluating one and unique international Fieldbus standard. In fact there are many different Fieldbus protocols in the world.

There are large differences that can be found in the three layers of any Fieldbus protocol and their similar layers in another Fieldbus protocol. The requirements are varied from one situation to another. In most cases the quality of services and the system throughput in addition to the overall system performance are all common requirements for any automatic control system.

1.5 The FieldBuses and the Network Topology

An important feature of the Fieldbus is the network topology. There are five fundamental topologies: mesh, star, tree, bus, and ring. Each having its own individual characteristics, which are properly selected when designing the network. There exist combined topologies which contain more than two topologies [3].

1.5.1 Mesh Connection

Mesh topology shows the fully connected network between nodes, which has n(n-1)/2 physical line to connect n stations. For example, Figure 1-7(a) shows the network that has 5 nodes and 5(5-1)/2, 10 physical links. A mesh topology has several advantages; each link has only its own data traffic because each node has its own link between nodes. The robust point to point structure guarantees the security and privacy between stations. On the other hand, the disadvantages of mesh topology are complexity and high installation cost because of the fully connected structure.

1.5.2 Star Connection

In a star topology, the links are connected between peripheral nodes and central node. Figure 1-7(b) shows the star topology that links the peripheral stations (nodes 0 to 4) and the central hub (node 5). The nodes are not directly connected to each other. The stations can communicate with each other through only a central device, hub. Due to this structure, a star topology is less expensive than a mesh topology. However, it is not cheaper than other topologies such as tree, bus and ring, because each node requires the link between itself and the central hub.

1.5.3 Tree Connection

The basic structure of a tree topology is a star topology. Figure 1-7(c) shows the tree topology that is linked between star topologies by a hub. A tree topology has characteristics of a star topology. The advantages of a tree topology are that it makes the network range wider by using several hubs (repeaters) and allows the network to group by location or purpose.

1.5.4 Bus Connection

In a bus topology, all nodes are linked on one line. All stations in the bus topology use a common line, called a backbone. The advantages of a bus topology are lower installation cost and easier installation than other topologies. Figure 1-7(d) shows the bus topology in which all stations are connected on one line. Disadvantages of a bus topology are difficulty in adding a new device and the effect of severe damage when having the problems with the backbone.

1.5.5 Ring Connection

In a ring topology, each node is connected by an adjacent node. Figure 1-7(e) shows the ring topology that is connected by one line. Each node has a role as a repeater. Data flow through the single line that links all nodes.

1.6 Different Types of Fieldbuses

As we mention before, there are many the different types of the Fieldbuses that do exist in the international market, so standardization efforts started on the international level at the International Electro-technical Commission (IEC) to find a certain Fieldbus protocol that can fulfill all the requirements of the plant designers.

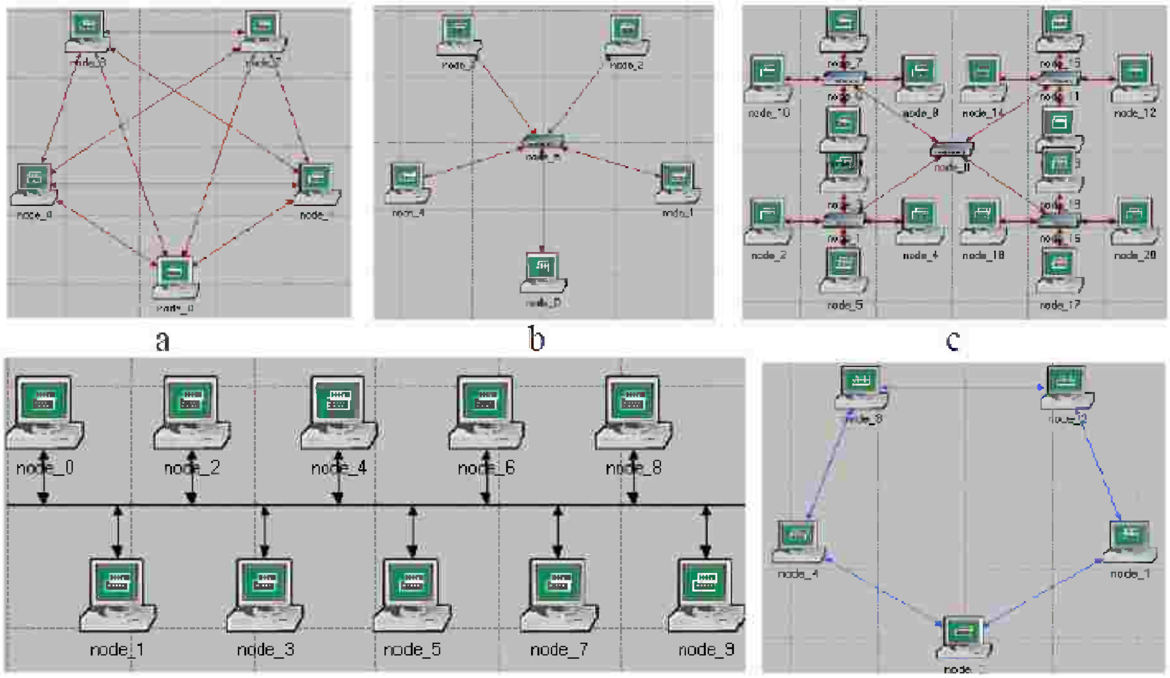

Figure 1-7 Fieldbus topologies: a) mesh b) star c) tree d) bus e) ring

The most famous Fieldbuses systems are:

1) World Factory Instrumentation Protocol (WorldFIP).
2) Process Field Bus (PROFIBUS).
3) Actuator- Sensor Interface (AS-i)

One of the most famous Fieldbuses systems is the Actuator- Sensor Interface (AS-i). It is a simplified and robust Fieldbus that enables easy and fast interfacing of sensors and actuators using logical processing functions of the automatic control.

1.7 Scope of Work in this Thesis

The purpose of this study is to investigate the Actuator- Sensor Interface (AS-i); its components, system architecture, system configuration and advantages of this Fieldbus protocols. The work in this thesis includes also a practical application set up to demonstrate the AS-i capabilities.

1.8 Thesis Layout

This thesis lies in six chapters:

Chapter 1 includes an introduction to the Fieldbus systems, their advantages, network structure, and their different types.
Chapter 2 explains the features of AS-i Fieldbus systems, advantages, architectures and their different versions.
Chapter 3 enumerates the different components that exist in the AS-i network as well as the functionality of each component.
Chapter 4 discusses the principal of operation for the AS-i network, the data packet frame structure and the profiles of the AS-i master and AS-i slaves.
Chapter 5 illustrates a practical application which is a conveyor controlled by PLC via an AS-i network and using a gateway AS-i master connected to the PLC using a PROFIBUS network.
Chapter 6 includes the conclusions derived from the work in this thesis as well as a proposal for future work.