Fieldbuses (esp. Foundation Fieldbus) as key building blocks of a working Supply Chain and E-Manufacturing solution

Abstract

The use of Fieldbus and Ethernet in process control and manufacturing systems is accelerating and this paper outlines the design of a typical industrial communications system and how it can form the basis of a working e-manufacturing and supply chain system. The discussion commences with a quick review of the operation and typical components of Fieldbus (and Devicenet); Ethernet and TCP/IP. Hereafter there is a brief review of the features for each of these standards together with areas to be wary of in the context of a process control and manufacturing system. The paper will then focus on the use of Fieldbus as a key component in a working supply chain and e-manufacturing solution and the tight direct connnection between the customer, supplier and the fully automated process control system. Finally the interface to the Internet will be described with an emphasis on security and robust design together with some suggestions on the implementaton of a working supply chain and e-manufacturing system.

1.0 Introduction

The implementation of effective supply chain and e-manufacturing systems has been a veritable graveyard over the past five years with a high level of dissatisfaction from users and in many cases dubious savings actually achieved. Most of the "action" with supply chain systems has focussed on the commercial areas (such as procurement /accounting/ suppliers/customers) and the manufacturing and process control area has been neglected in many cases. The objective in this paper is to demonstrate that these systems can be implemented successfully and one of the key building blocks is an open communications standard (such as Foundation Fieldbus and Ethernet) in the area of the often neglected factory and plant floor. And the overriding thesis of this paper is that control and instrumentation engineers have a one–off-now opportunity to apply their knowledge of industrial systems (especially that of the new open communications networks such as Foundation Fieldbus) to optimising and improving the bottom line for the entire enterprise in implementing a supply chain system – both from the commercial and industrial point of view.

E-manufacturing means many things depending on whom you are talking to and the application. But words associated with it range from e-procurement, B2B, B2C, Industrial Ethernet, Portals, TCP/IP, UDP, XML, wireless, embedded web servers to supply chain management. E-manufacturing can be simply described as the movement away from the plant operating independently from the overall enterprise, with the emphasis today on grabbing real time data from the plant floor and integrating and using it effectively as part of the complete enterprise. Without an adequate communications interface to the plant floor, the supply chain has no clue about the status of orders and materials and how to optimise the use of the enterprise's resources. Hence the new Fieldbus (and associated Ethernet) technologies are critical to the success of these systems. As we all know, anything with the letters "E" in front of it has particularly bad connotations these days due to the dot com trillion dollar stock implosion. Nonetheless there are very real benefits for the enterprise in setting up an e-manufacturing and supply chain system. In the discussions that follow the words e-manufacturing and supply chain are used interchangeably.

The real meaning of integrating corporate supply chains is arranging the manufacturing processes so that all information including forward orders and invoices is passed digitally to the suppliers at one end of the chain and to the customers at the other end of the chain. In creating a system such as this, corporations should be able to reduce the costs and stocks.

Process Control and indeed SCADA (or Supervisory Control and Data Acquisition) systems have traditionally relied on proprietary industrial communications networks to transfer data from field instruments to a Remote Terminal Unit (or RTU) or Programmable Logic Controller (PLC) or have avoided any communications system and used the 4-20mA system for example. Today the widespread use of Open networks is generally the approach espoused by both users and manufacturers of SCADA and process control systems. At the same time as the rapid increase in industrial communications networks , there has been an explosion in the use of the Internet. There are two issues where the Internet has impacted on the industrial network in the factory environment – one is the increasing popularity of TCP/IP and Ethernet in industrial networks and the other is the connection to the Internet. The connection to the Internet is not simply a matter of using a Web Browser but of integrating the complete production and process control facility into a complete interface with that of the customer and supplier. This is where e-manufacturing and supply chain systems (exchanging commercial information between computers) is growing so rapidly. One of the areas where these systems depend on for their success is the effective implementation of a sophisticated open industrial network throughout the factory and plant right down to the instrument level.

There is some debate about the best communications standard to follow, with a vigorous interchange of views between opposing camps in the Fieldbus arena ranging from Profibus, Interbus-S, ASI-bus, Foundation Fieldbus to DeviceNet. At present there is still no clear winner (if there ever will be) although Profibus is considered to have by far the largest market share. On the other hand, some proponents believe that Foundation

Fieldbus has technically the best solution. Another contender for the "Fieldbus crown" is Ethernet and the TCP/IP Protocol (derived from the Internet). Although this is a fast growing option used in the upper levels of the plant control system hierarchy it is also increasingly found at the field level but it is easily integrated with the Foundation Fieldbus H1 offering (and indeed is the basis of the HSE standard).

This paper is broken down into the following sections:

- Supply Chain and E-manufacturing
- Review of Fieldbus and Ethernet (& TCP/IP)
- Ethernet and Fieldbus Applications
- E-manufacturing and Supply chain Applications
- Conclusion

2.0 Supply Chain and E-manufacturing

A good illustration of an advanced supply chain system in Australia is the fruit juice manufacturer and distributor Berri Ltd. All the company's distributors have laptops which allow them to input the sales and ordering information. This is then uploaded into the Berri supply chain system. This information then drives the production of the plant as far as type and quantity of juice required. Berri has the suppliers on the system as well so that orders can be tied into the production of the juice. A survey done by supply chain consultants Dawson Consulting (1992) show that 62% of respondents in Australia intend to increase spending on IT for the supply chain over the next 12 months.

Lockwood Greene Engineers (Spartanburg, SC, USA) have given a typical model for interfacing plant-floor systems with the enterprise and supply chain systems as in figure 1. The idea is to achieve direct database access to a production database. This database would then be accessed by supply chain management, machine maintenance, quality control and management reporting software. The use of the Internet and Intranet makes the access of the data easy across the entire enterprise. And naturally having an open Fieldbus system on the plant floor makes for a easier implementation of this system.

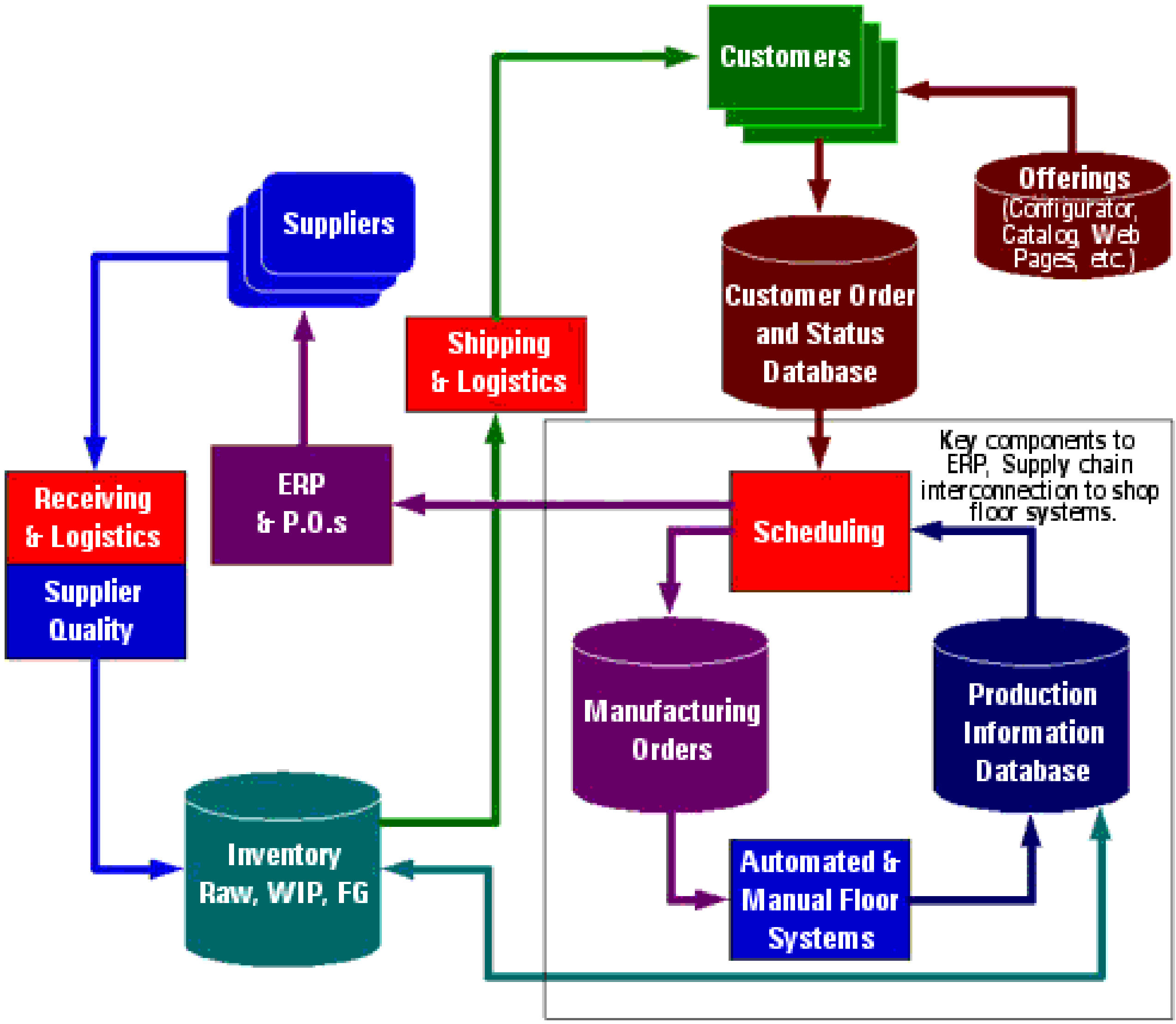


Figure 1
Typical Model for Plant Floor Interface to the Enterprise and Supply Chain Systems
(courtesy of Lockwood Greene Engineers)

3.0 Review of Fieldbus and Ethernet (& TCP/IP)

A brief review of the various alternatives for communication on the plant floor are given below. This topic has been canvassed in some depth in other papers so this will be necessarily brief.

3.1 Ethernet and TCP/IP

Introduction

A Local Area Network (or LAN) is defined as a communications path between one or more computers, file servers, terminal, workstations and various intelligent devices. A LAN allows access to devices to be shared by several users, with full connectivity between all stations on the network.

In a LAN the software that controls the transfer of messages among the devices on the network must deal with the problem of sharing the common resources of the network without conflict or corruption of data. Since many users can access the network at the same time, some rules must be established as to which devices can access the network, when and under what conditions.

These rules are covered under the general subject of access control. The rules that apply depend on the structure and type of the network eg. A star, ring or bus topology and a token passing or CSMA/CD (Carrier Sensing Multiple Access/Collision Detection), to be discussed later.

A typical SCADA system using a Local Area Network is shown in the figure 2 below. The traditional approach is for Ethernet to be used at the inter-PLC/PC level with a Fieldbus from the instrument to the PLC or indeed totally replacing the PLC with a direct interface to the Operator stations.

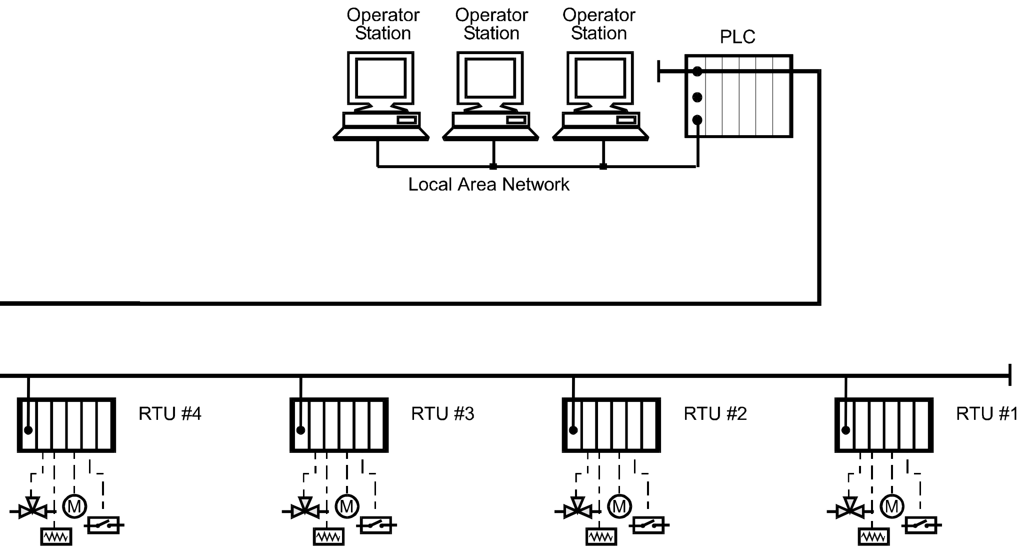


Figure 2
Typical Structure of SCADA System

As can be seen there are three requirements indicated in this figure:

- Instrument Level Data to be transferred to the PLC (or RTU) and
- Inter-PLC data to be transferred and
- PLC data to be transferred to the SCADA system

The Fieldbus systems target the instrument-to-PLC communications network as it was believed that Ethernet would not be suitable here.

Open Systems

One of the strong movements in the SCADA world has been the embracing of an Open Model for communications which all vendors have to comply with. Application of an Open System approach means that the more flexible open connectivity from various vendors displaces older proprietary communications standards where communication is difficult (and expensive). The theoretical structure of the International Standards Organisation Open Systems Interconnection Model (or simply OSI) is indicated in figure 3 below.

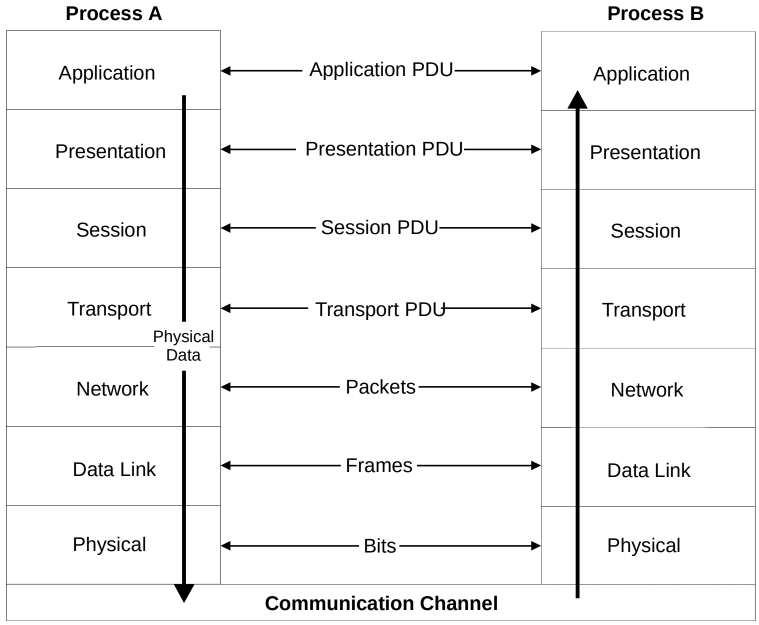


Figure 3
The OSI Model

The concept of an Open Standard has been widely supported by both standard Ethernet and TCP/IP LAN's and Fieldbus systems and forms the framework for their designs.

CSMA/CD Ethernet

The Ethernet philosophy essentially describes the Physical and Data Link Layer of the OSI Model and is based on the CSMA/CD (Carrier Sense Multiple Access/Collision Detection). This is a simple but effective protocol where the node that wants to transmit listens for any transmission that may be occurring on the bus. If this node does not hear any other station transmitting, it transmits its message. If during the transmission of its message it detects a collision (or another node transmitting at the same time), it stops its transmission for a random length of time before retrying to transmit. This is indicated schematically in the diagram below.

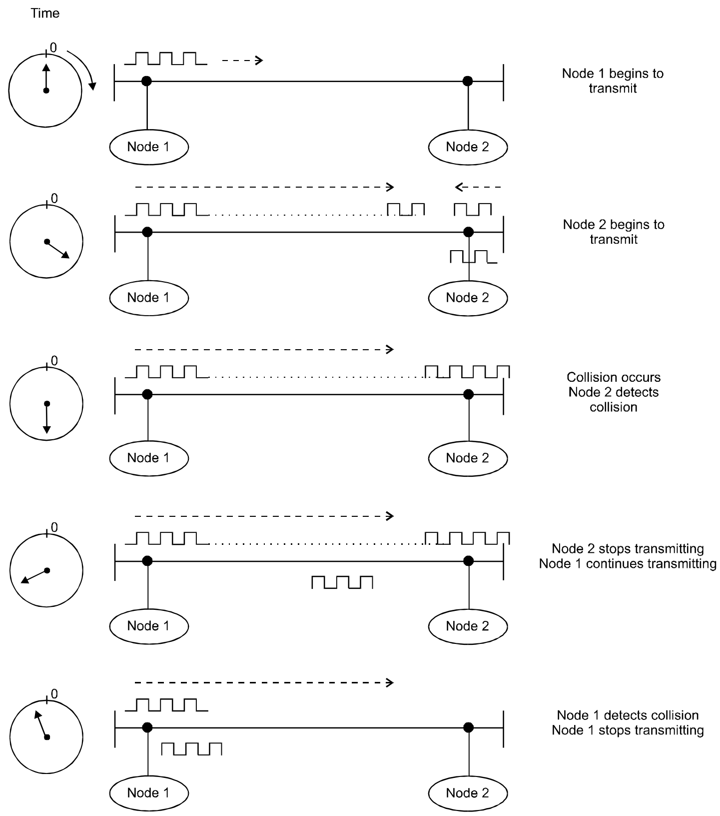


Figure 4
Operation of CSMA/CD

The problem with the CSMA/CD approach is that theoretically it is possible for a data transmission to be delayed a considerable time. Important messages may end up being transmitted before trivial messages on the bus – not a pleasant thought for critical alarm messages. But the advantage with the CSMA/CD Ethernet philosophy is that it is simple and low cost because of the massive installed base of systems worldwide.

There are a few Ethernet standards available although all use a similar protocol. These are:

10Base-2	Thinwire co-axial cable transmitting at 10 Mbps, single cable
10Base-5	Thickwire co-axial cable transmitting at 10 Mbps, single cable
10Base-T	Unscreened twisted pair cable at 10 Mbps, twin cable bus
10Base-F	Optical fibre cables at 10 Mbps, twin fibre bus
100 Base-T	Twisted Pair at 100 Mbps (Fibre is also available)

Switches

A hardware device which is making a great impact on the use of Ethernet is the switch as indicated in the figure 5. This is changing the traditional bus form of communications outlined earlier where only one station can access the bus at a time with the ability to communicate between multiple stations in full duplex mode. This makes for a very effective system and does away with many of the previous disadvantages of Ethernet.

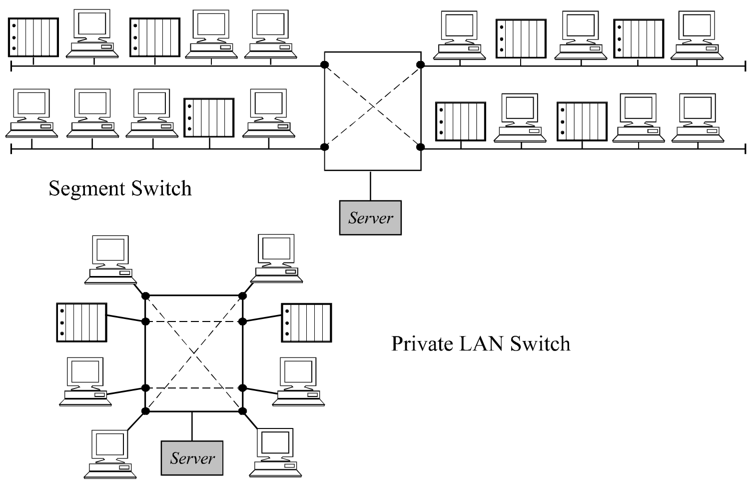


Figure 5
Use of Switches

The diagram above gives a schematic representation of multiple stations (and indeed also networks) communicating with each other simultaneously.

TCP/IP

The discussion on networks above fits into the bottom two layers of the Open Systems Model (Physical and Data Link Layers). The next two layers above these (called Network and Transport) are satisfied by an extremely popular and low cost protocol which forms the basis of the Internet called TCP/IP. Although there are other protocols around, this one is by far the most popular and probably the lowest cost as it essentially available in the public domain.

TCP/IP comprises two separate protocols:

IP Internet Protocol which handles routing of the packets around a multitude of different networks. This enables a message to be sent across many different networks (through devices called routers) using what is called IP addressing to identify all stations on the different networks.

TCP Transmission Control Protocol. This ensures that the packets do indeed get to the destination station by checking that each packet sent out does indeed arrive at the destination.

In terms of the OSI model these two protocols fit above Ethernet (described by the Network Interface section) as indicated below. In addition there is an application layer which co-ordinates file transfer and interfaces to the user program.

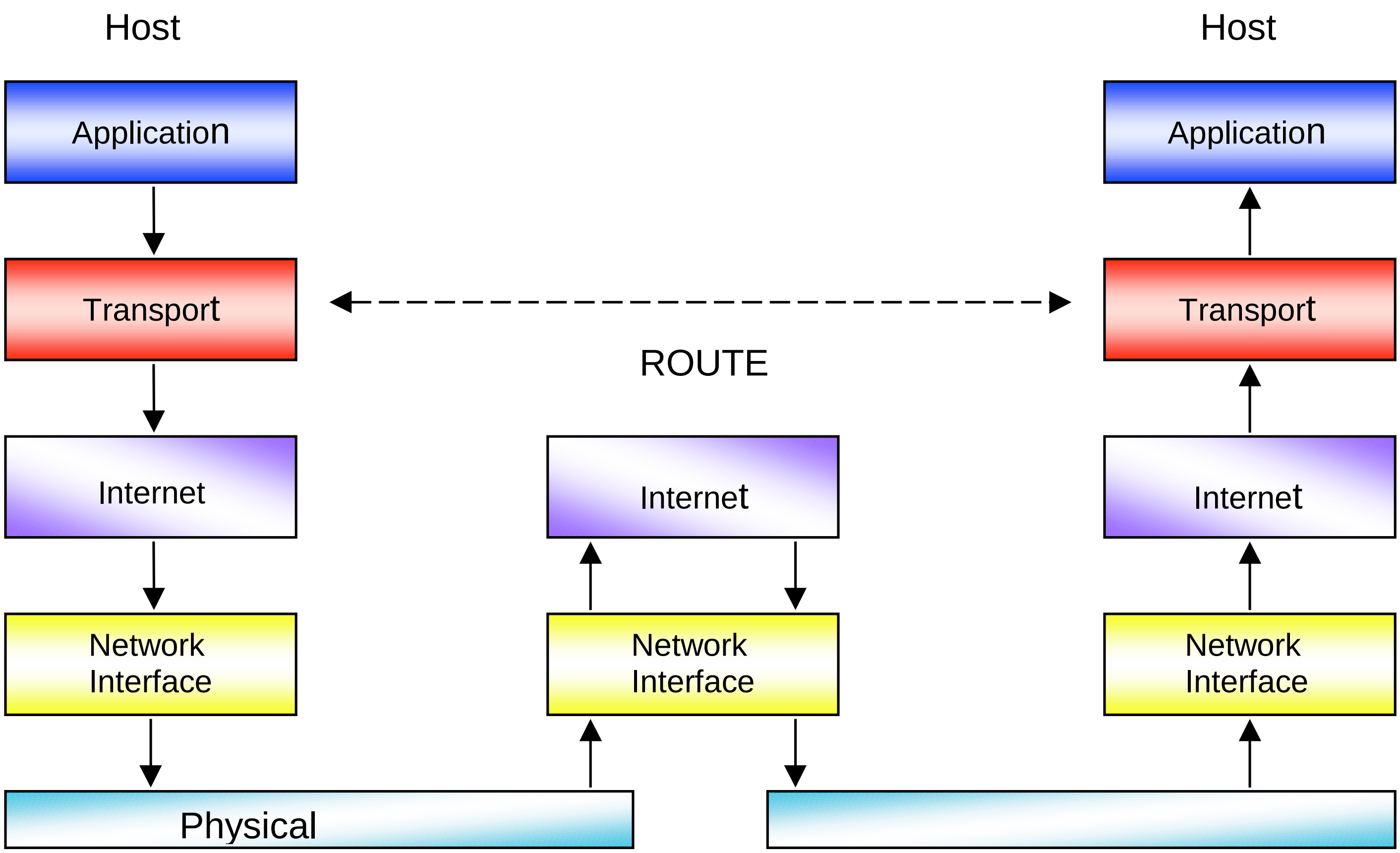


Figure 6
TCP/IP Protocol

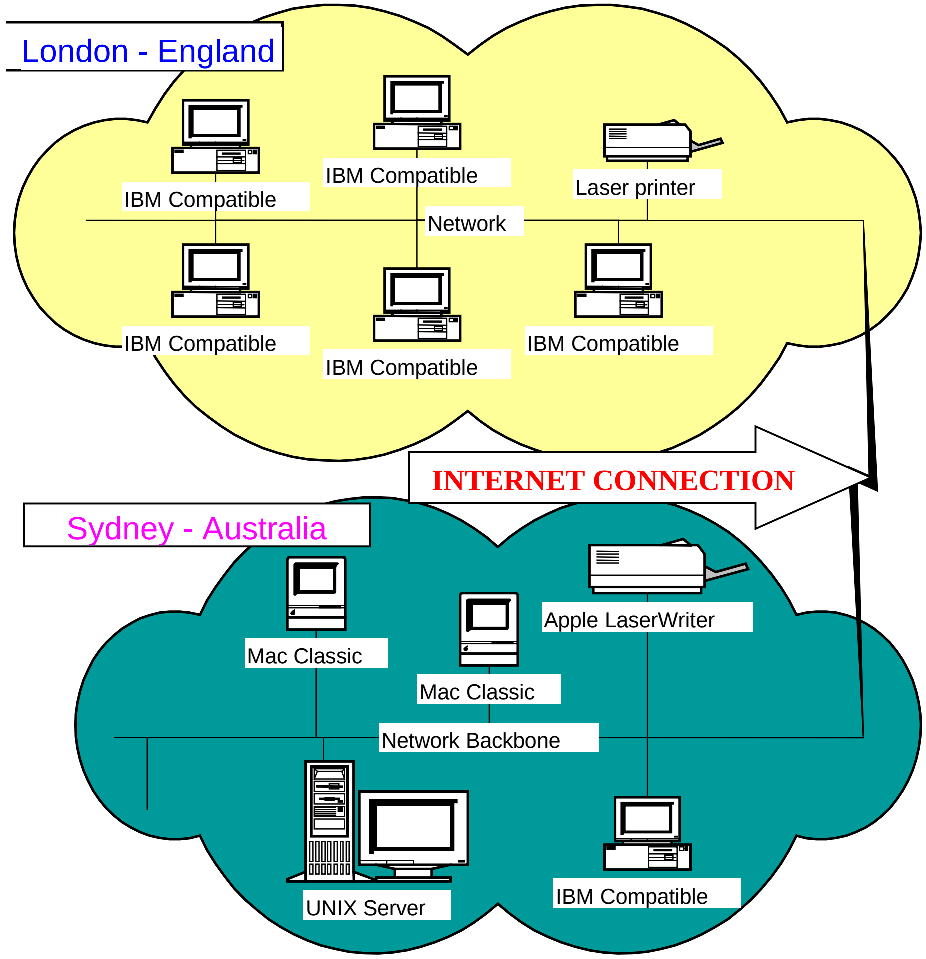


Figure 7
The Internet Connection

3.2 Review of Fieldbus and DeviceNetworks

The current approach with cabling of a typical control system is shown in figure 8. Note that each instrument is connected back to the instrument room (to a controller) with an individual pair of wires.

The strategy today is to replace this hardwired approach with a communications system which connects all the instruments and actuators together and has several advantages listed below. Each instrument and actuator now becomes an intelligent device. An intelligent device can be considered to be a computer controlled device which takes analog data (eg. a flow meter); performs an operation on it (eg. square root extraction) and sends this up a communications network to another device(s) which requires this data. Similarly an intelligent actuator can control a valve to a specific position with a data value sent down the communications network from another device. The benefits to be gained are:

- Greatly reduced wiring costs
- Reduced installation and start-up time
- Improved on-line monitoring nad diagnostics
- Easier change-out and expansion of devices
- Improved local intelligence in the devices
- Improved interoperability between manufacturers

The fieldbus approach is indicated in the diagram below.

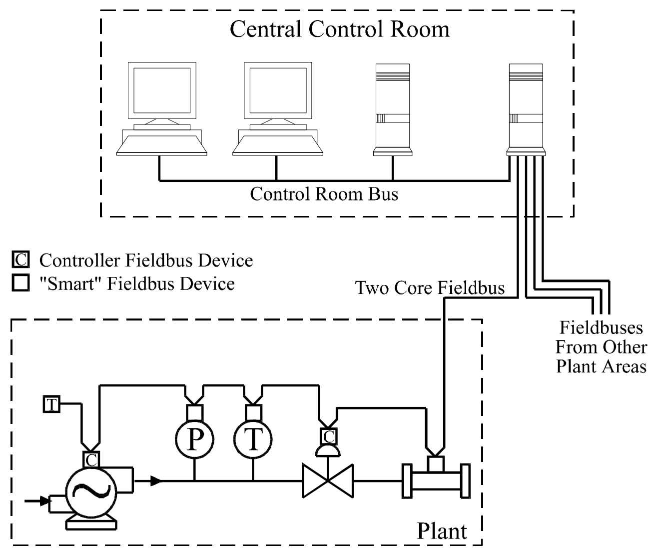


Figure 8
Fieldbus approach to cabling of a typical control system

In terms of the OSI Model discussed earlier, the Fieldbus standards generally only define the Physical, Data Link and Application Layer for reasons of simplicity and easier implementation.

The word Fieldbus generally gives the understanding of larger word message transfer especially for analogue data; whilst DeviceNet refers to the transfer of smaller byte-based messages for mainly digital data such as On-Off switches. In the discussion below the distinction between the two will be blurred and the word Fieldbus will be used.

At this stage there are three main approaches being promoted by the various groups of manufacturers:

Profibus

Profibus (FMS/DP/PA). This uses a hybrid token passing/master slave approach depending on the speed requirements of the system. The token passing approach could be used for stations such as PLC's and PC's which have fairly equal status on the system and need to have the opportunity to transmit messages regularly to each. Each station has the opportunity to transmit when it receives the token message. However if a few instruments (or actuators) are added into the network, the master nodes which pass the token to each other now have the opportunity to talk in a master-slave manner to the instruments. The instruments (referred to as slave devices) never receive the token and only "speak to when spoken to" by the master station.

Profibus FMS and DP use RS-485 as the basis of the physical wiring. This allows up to 32 devices on a pair of wires which can run over a maximum distance of 1200m.

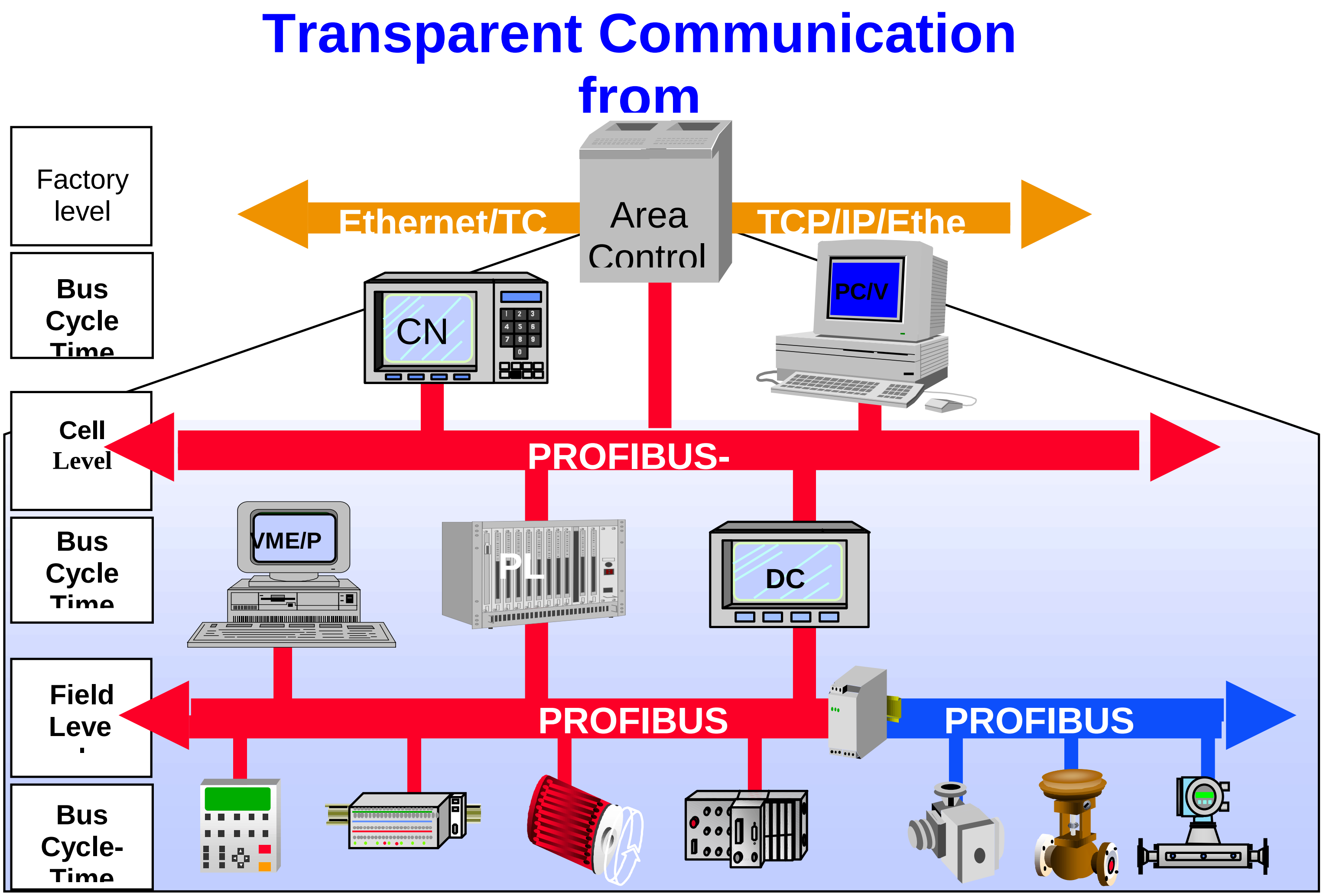


Figure 9
Typical Profibus Network
(Courtesy of Profibus International)

Foundation Fieldbus

This uses the Publisher-Subscriber approach where each parameter (eg flow rate) is broadcast at regular intervals onto the bus by the publisher device (such as a flow meter). The subscriber devices (being PLC's or PC's) will then monitor the bus and copy this value into their database. The brilliance of this approach is that it minimises the bus usage and makes for more efficient operation. The current speed is 31.25kbps and uses instrument grade cabling. This Fieldbus is designed to replace the traditional heavily analog based Distributed Control systems approach and also defines a very sophisticated User Layer where function blocks are implemented as indicated in Figure 10.

Typical parameters with H1 Foundation Fieldbus is as follows:

- 31.25kbps speed
- 2- 32 devices
- Power and communications over the same cable
- Intrinsically safe
- Twisted Pair
- 1900 m length

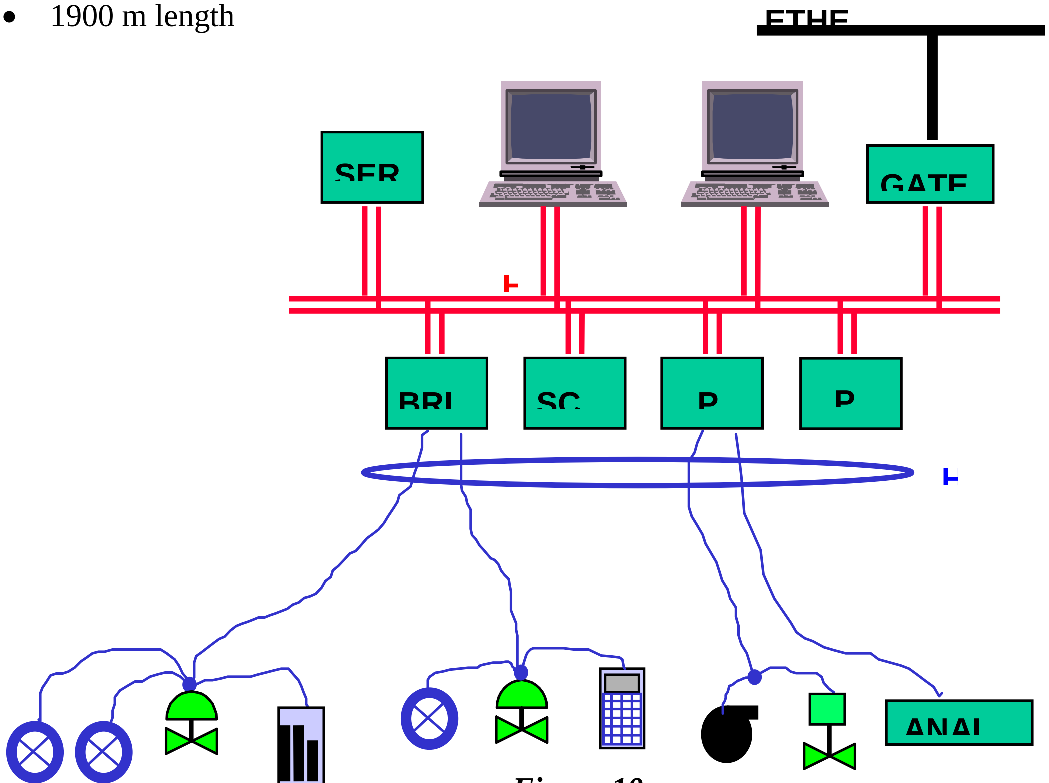
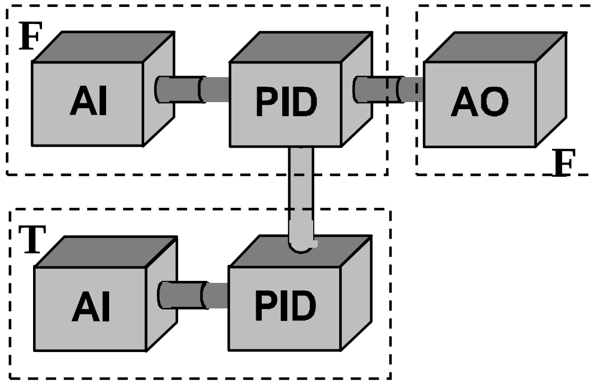


Figure 10
Typical Foundation Fieldbus System



SECONDARY PID IN THE TRANSMITTER

Figure 11
Typical Function Blocks

DeviceNet.

This is also based on the Publisher-subscriber approach and comprises far smaller messages aimed at digital devices rather than analogue quantities as with the Foundation Fieldbus standard.

4.0 Ethernet (and TCP/IP) for Fieldbus applications

Interestingly enough both Foundation Fieldbus and Profibus have made provision for the high speed 100 MBps Ethernet standards (as well as TCP/IP).

Until the mid eighties, proprietary industrial networks dominated the factory. Ethernet was avoided as it was perceived as a commercial type network not possessing the robustness required of an industrial network. However one of the main issues driving Ethernet systems into the factory floor is the low cost of the hardware and the existence of a truly open standard such as TCP/IP. The cost comparison between Ethernet and industrial type networks could not be more stark – an Ethernet card costs of the order of $US 45 (even for the 100 Mbit/s high speed standard) whilst an industrial type network card is of the order of $US 800 or more. These issues will make Ethernet the network of choice for industrial applications even for instruments at the field level unless there are very specific requirements (such as Intrinsic safety) which make Ethernet unacceptable.

The main concerns about Ethernet in an instrumentation environment can be summarised below. The brilliant of Foundation Fieldbus is that the H1 standard fills the gap where these concerns have to be addressed. And seamlessly with its associated higher level Ethernet standards (such as HSE); thus providing a complete communications solution – something which has been lacking in the past.

Non-Deterministic and Extremely Precise Timing. This means that there is theoretically the possibility that a (critical) message sent from one station to another one may not get to its destination due to a collision or simply that the traffic level is too high. This can be addressed by structuring the network carefully so that similar stations are grouped as close to each other as possible and operating at a speed of 100 MBps and using switches. If an application requires less than 2ms, it is likely that some other network would have to selected.

Robustness for Electrical interference. The original standard Ethernet (10Base5) has tremendous noise immunity as it comprises four-shielded coaxial cable. The later version of 10Base2 coaxial cable was added but has a reduced noise rejection specification. The later versions of Ethernet use Category 5 unshielded cable which does not provide enough protection from electrical noise. However the use of screening of the Category 5 cable (STP – Shielded Twisted Pair) can provide excellent shielding provided the cable is properly grounded. Theoretically Fieldbus systems have greater noise immunity. However if shielded twisted pair is not acceptable for an Ethernet system due to noise considerations, Fibre optic cable can be used.

Hazardous Environment. In environments requiring intrinsically safe operation, Ethernet would not be suitable. It is probably more effective to use dedicated networks that are certified for use in these areas.

No Loop powering. Often it is the instrument that requires loop powering. Unfortunately Ethernet does not provide any loop powering of instruments. Ethernet only transmits data signals. In addition, the Ethernet chips draw excessive power compared to the Fieldbus chips. There is no ideal solution for instruments which require loop power or if the Ethernet network is drawing too much power.

The Ethernet Frame and TCP/IP packet size are not suitable for communications of small amounts of instrument data. This is a very real concern and the overhead of an Ethernet frame transporting instrument data using the TCP/IP protocol is quite enormous. The only answer to this is the high speed of data transfer of 100 Mbit/s which can tend to "sweep this problem under the carpet".

Triple Redundancy. Double redundancy is available on most Ethernet applications. But Triple redundancy is not provided. Hence proprietary networks would be required from the manufacturer of the safety system.

5.0 Applications to E-Manufacturing (and Supply Chain)

5.1 Introduction

E-Manufacturing and the associated E-Commerce area is emerging rapidly for factory automation and process control products. It is estimated that the number of Internet users will reach one billion by 2005. E-Commerce is not new. EDI (Electronic Data Interchange) has been used by companies such as Ford Motor Company for trading purchase orders and invoices electronically for some time. This is by using private dial-up lines and proprietary applications. The Internet has opened up the world of E-Commerce to every company by replacing private and costly dedicated phone lines with a public network which is considerably cheaper. E-Commerce can be considered to be any transaction that occurs between two computers mainly using a Web Browser to present the appropriate information.

The following issues need to be considered when creating a successful supply chain solution.

Speed. Typically Internet users will not wait longer than 30 seconds for a Web Page to load. If a client has to wait too long, he/she will move onto your competitors site.

Security. It is important that all information transferred between you and your client is transferred securely without any security breaches.

Reliability. The servers and communications links must be available 100% of the time. No failures or even temporary suspension of service is acceptable.

Scalability. If you are handling 1000 transactions today, you should be able to ramp up seamlessly to 10,000 tomorrow as your site grows.

Ease of Management. The network traffic should flow smoothly at all times.

5.2 Creation of E-Manufacturing Solution

Typical Steps to Follow in creating a solution are:

Create an externally accessible Web Site via the Internet. This will allow external clients to access your web site with emphasis on secure access.

Establish secure policies for your trusted partners and employees. Add an extranet switch to guarantee secure access beyond the Web server so that external parties can access defined internal applications.

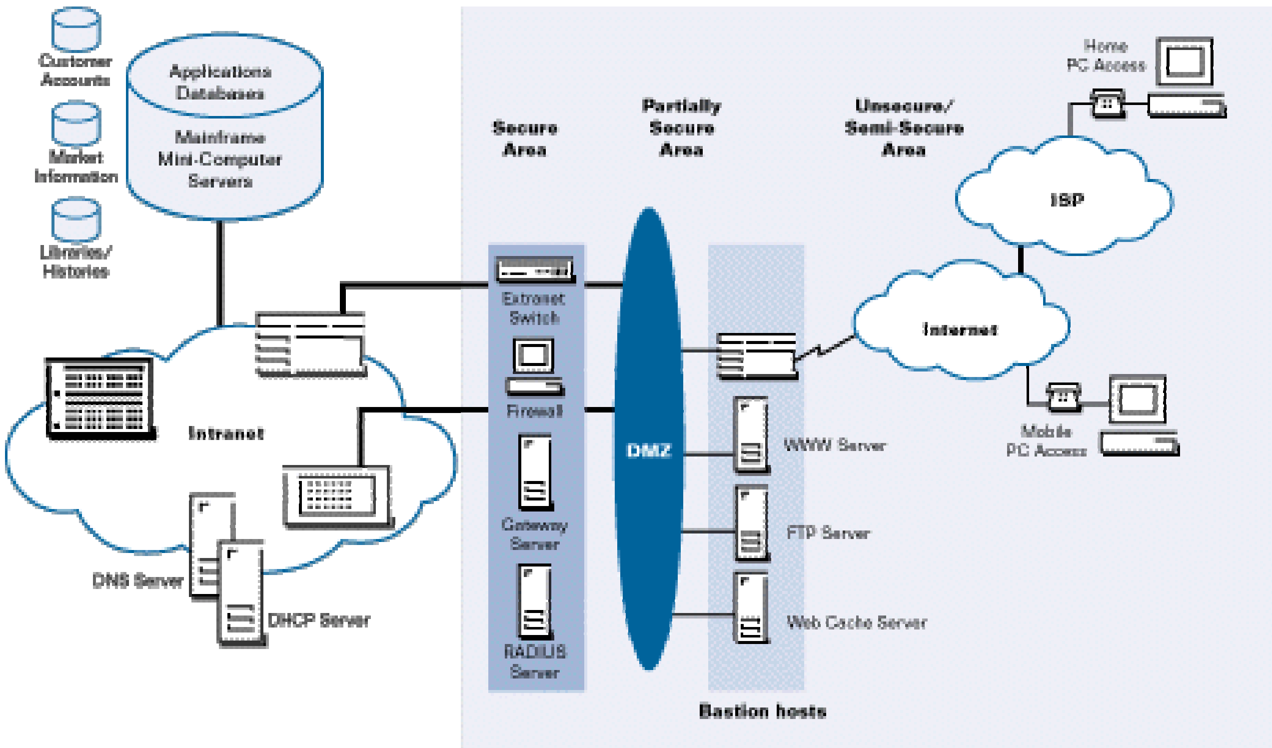


Figure 12
First Two steps in creating the solution
(Courtesy of Nortel Networks)

These steps are indicated in Figure 12 above.

Integration with Enterprise Resource Planning/Production and Call-centre applications .

This is where customer service, technical support and call centres are integrated with Web Applications. This can reduce the cost of customer service from typically say $5 to less than 50 c per call.

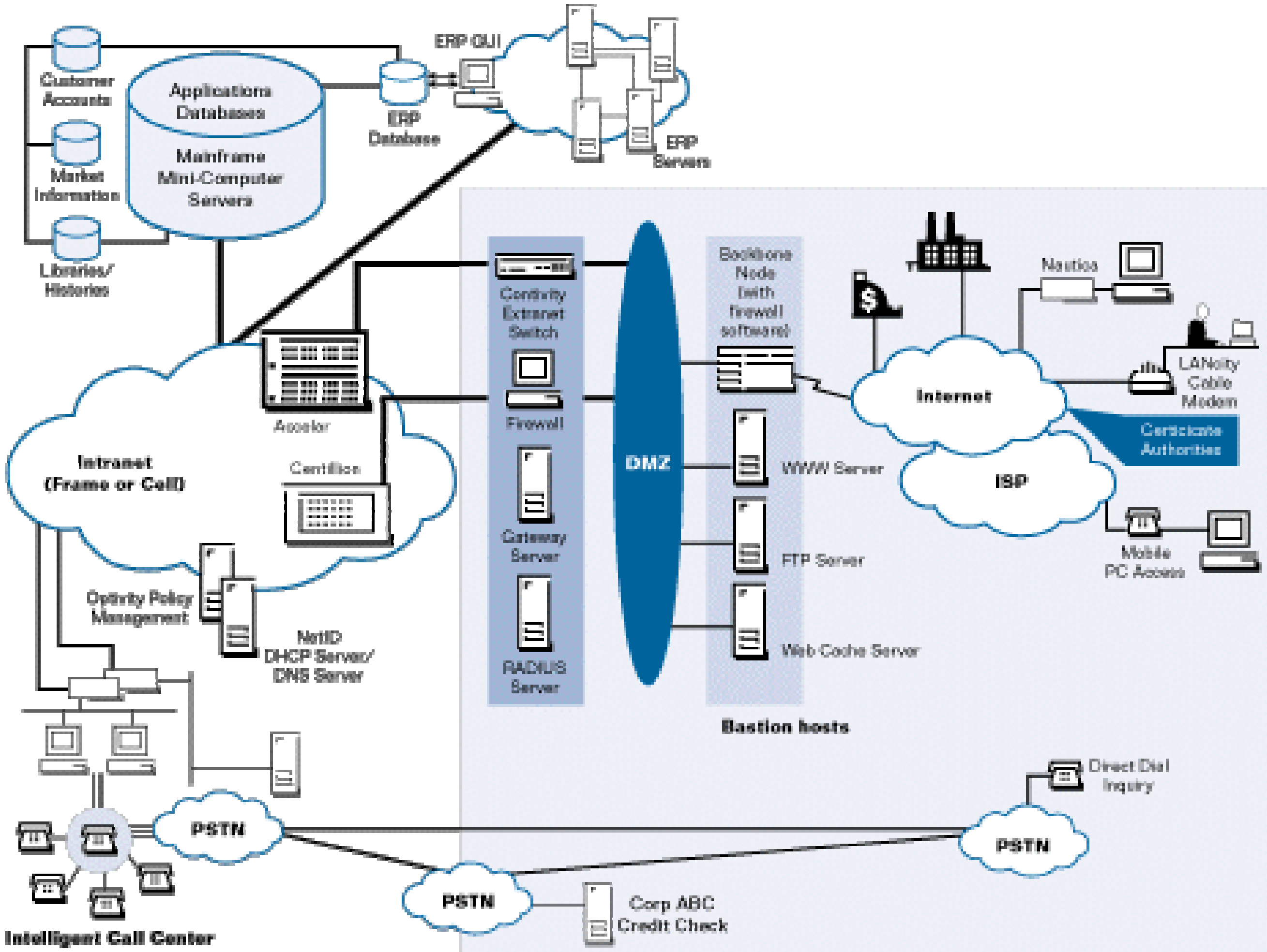


Figure 13

Final Step in Creating an E-Manufacturing Solution (Courtesy of Nortel Networks)

According to The Real Cost of Network and Systems Management (a study by Infonetics Research) LAN and data communications support staff spend their time on five main activities:

- Administration (34%)
- Physical Management (24%)
- Troubleshooting (21%)
- Asset Management (13%)
- Device Management (8%)

This can come to a significant cost when looking at a system

One should also remember that the definition of reliability changes when you consider the implications of E-Commerce. Downtime corresponds directly to lost revenue.

The eventual system will look like something in the diagram below.

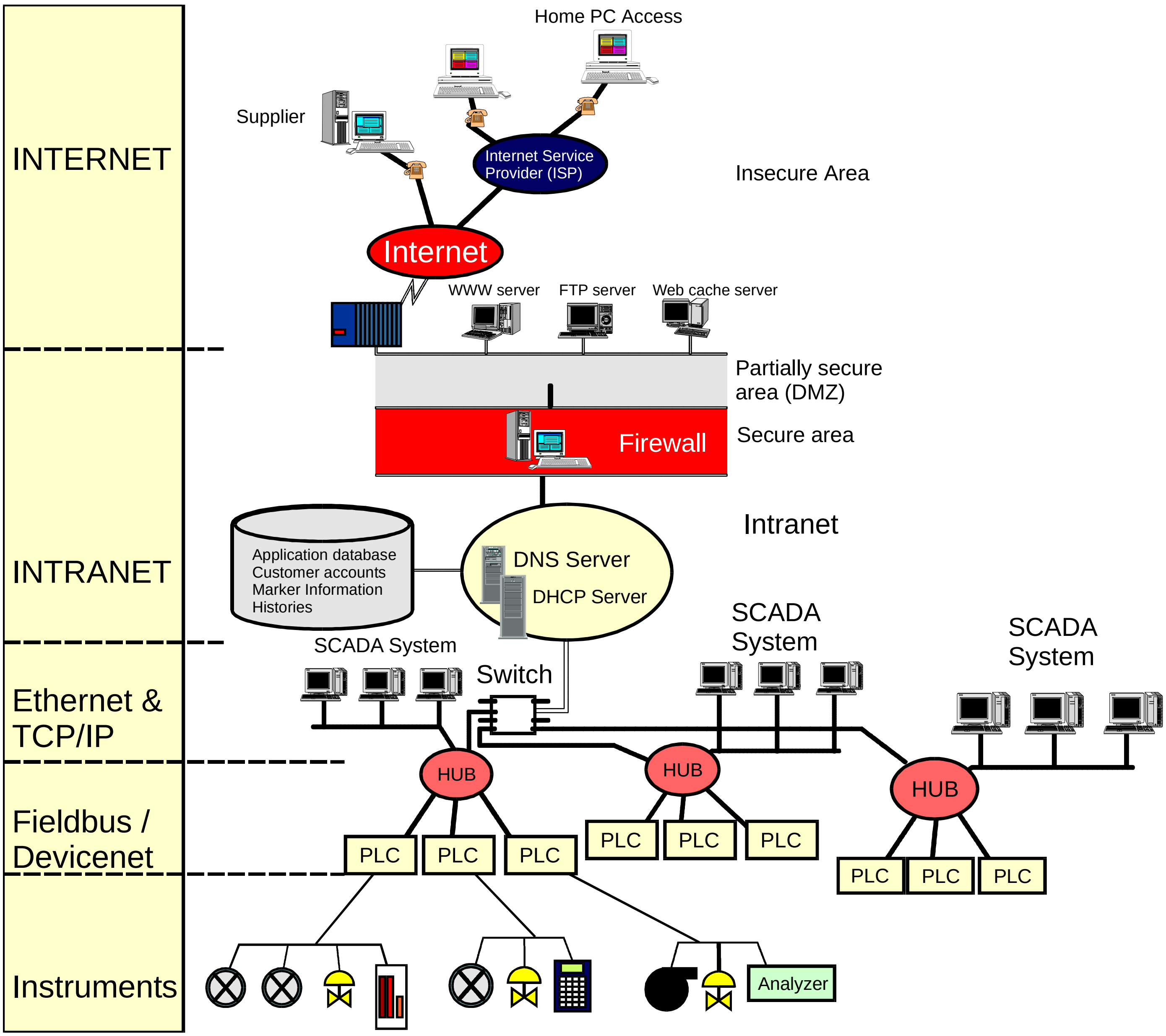


Figure 14
Typical E-Manufacturing Solution with a Process Control/Automated Facility

There is a tremendous interest in e-manufacturing throughout the business world but significant challenges for businesses in integrating their voice, data and video systems. When used correctly this will create stronger relations with the customer base, and reduce the costs of marketing, service and sales and production. Businesses today cannot ignore the implementation of e-manufacturing – failure to do so will likely mean that they will lose significant market share to their competitors and thus the bottom line will eventually suffer.

5.0 Conclusion

Industrial communications networks are a standard part of the Process Control system connecting PLC's and PC's together to the instruments on the factory floor. The impact of the Internet is allowing for connection to the outside (insecure) world for a tighter connection to the customer and the supplier. This will enable the customer to have his requirements translated almost immediately into production requirements. The production facility will be able to liaise tightly with the suppliers through an e-manufacturing solution. This will bring costs down and enable the manufacturer to be more competitive.

A few suggestions on implementing a e-manufacturing strategy from Rockwell Automation's white paper, *Making sense of e-manufacturing: A Roadmap for Manufacturers* is:

- Use the Internet as much as possible in the implementation
- Make Engineers central to the decisionmaking
- Build up an internal team to draw up the strategy for e-manufacturing
- Try and get the CEO or equivalent as the champion of the strategy
- Implement one step at a time and demonstrate that this works
- Measure success and failure carefully and dispassionately
- Assess carefully traditional channels
- Build on solid foundations and incremental successes
- Outsource non core competencies in the implementation

Finally, from a career point of view being able to assist companies in implementing their industrial networks and fit this into an overall e-manufacturing and supply chain solution appears to have a brilliant future.

References

Building an E-Commerce Network by Nortel Networks
http://www.nortelnetworks.com/prd/consultant/newsletter/alliances.html

Practical TCP/IP Networking for Industry – an IDC Technologies workshop manual.
Practical Industrial Networking for Engineers and Technicians – an IDC Technologies workshop manual.

Practical Fieldbus and DeviceNetworks for Engineers and Technicians – an IDC Technologies workshop manual.

Practical E-Commerce for Industry – an IDC Technologies workshop manual.

Internet World – Guide to One-to-One Web Marketing Cliff Allen, Deborah Kania and Beth Yaeckel. Mecklermedia. John Wiley & Sons, Inc. 1998.

Prepared by

Steve Mackay CP Eng B.Sc(Elec.Eng) B.Sc(Hons) MBA
Technical Director – IDC Technologies

Steve has specialised in industrial data communications for over 20 years and has been engaged in engineering projects in Australia, Europe, Africa and North America. He is with IDC Technologies who have provided consulting work and engineering training workshops in this area to over 80,000 engineers and technicians worldwide over the past ten years. The company's training and consulting activities range from Automation / Industrial data communications / Instrumentation to industrial IT.