TELELABS

DESIGN STUDY

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1. INTRODUCTION

The Telelabs concept has been devised by Associate Professor James Trevelyan to enhance students experience and benefit the teaching methods.
Enperit Pty Ltd has been commissioned to conduct Design Study to identify the key technical aspects of the Telelabs concept, research the relevant, commercially available hardware and software and evaluate their suitability in terms of capabilities, limitations and cost.
The Design Study were aimed to provide basis for detailed design of the Telelabs system.

The following requirements have been used as a guidance for the investigations:

- Laboratory experiments will be automated.
- They can be run remotely or locally without staff supervision.
- Safety measures will satisfy Australian Standards requirements.
- Only standard electronics and software will be used.
- The whole system will be scalable.
- The equipment will have preset operational limits and automatic error recovery to minimise the effects of misuse.
- Students can access the labs through the Internet using standard computer hardware.
- University staff will have total control over the accessibility, individual usage records will be provided automatically.

The Telelabs comprise two functional areas: Laboratory Automation and Remote User Interface.
The element bridging the two areas is SCADA (supervisory control and data acquisition) automation software.
Communication is the common underlaying aspect of all three and will be addressed first.

All the relevant commercially available technologies have been developed with a particular industrial (including defence industry) application in mind. No matter how different the teaching environment is, we must consider the Telelabs as an adaptation of an industrial application. It is therefore important to realise how a particular product functions in its primary destination environment to know what to expect from it in the Telelabs system.
The criteria for selection and comparison were often difficult to establish. Many suppliers tend to mix old industrial terms with modern technology. The multiplicity of jargon and acronyms has made it necessary to briefly describe many of the technical components for further reference. Although this was not meant as a tutorial it will hopefully provide a useful introduction for those members of the team who are less familiar with these technologies.

2. COMMUNICATION

When we think of data communication we think of a defined path for transmission of signals commonly called a bus, and usually the rules of governing the transmission - a protocol. The best way to find a common ground for all protocols is to consider the breakdown of data communications proposed by the International Organisation for Standardisation (ISO). ISO developed a seven-layer protocol model known as the Open Systems Interconnect Reference Model (OSI/RM).

Each layer in the model groups protocols with related tasks. Each layer has a specific function in a communications network. In addition each layer in the model provides a service to the layers above it. This also can be considered as support of the protocols from the lower layers for protocols from higher layers, eg IP (Internet) over Ethernet. The organisation of the seven layers in the OSI model shown below and includes examples of where some well-known protocols fit in.

7	**APPLICATION**	MBAP, SMB, FTP, SMTP, FMS, IEC 61158, ANSI/ISA S50.02, IEEE 1451
6	**PRESENTATION**	
5	**SESSION**	
4	**TRANSPORT**	TCP, SPX, UDP
3	**NETWORK**	IP, IPX, NetBeui
2	**DATA LINK**	HDLC, Ethernet, FF821/822, IEC 61158, ANSI/ISA S50.02
1	**PHYSICAL**	EIA-485, Ethernet, IEC 61158, ANSI/ISA S50.02

The function of each layer can be summarised as follows:

Physical: provides the standards for transmitting raw electrical signals over the communications channel. Physical protocols deal with the transmission physics such as modulation and transmission rates.

Data link: contains the rules for interpreting electrical signals as data, error checking, physical addressing, and media access control (which station can talk at any given time on the network).

Network: describes the rules for routing messages through a complex net-work. Defines how to deal with network issues such as faulty lines and congestion.

Transport: establishes a dependable end-to-end connection between two hosts that is transparent in terms of physical, data-link, and network details.

Session: provides management and synchronisation of complex data transactions.

Presentation: establishes protocols for data format conversion, encrypting and security.

Application: contains protocols that accomplish specific applications over a network such as e-mail, file transfer, or reading a set of registers from a PLC.

For the purposes of automation and process control the relevant layers are the bottom four and the top one. Layers 5 (Session) and 6 (Presentation) are important to large commercial networks.
Controller user programs operates above layer 7 and bus topology would be considered below layer 1.

Physically all busses share the same elements. These elements will form an integral part of the telelabs layout. The layout of a bus is important since it always exhibits some trade-off between the flexibility of a bus and the performance. Unfortunately it tends to be an inverse relationship. Following is a simplified overview of bus components.

A node is an addressable physical point on the bus. A protocol firmware is actually embedded in nodes. A node could be an active device connected to the network, such as a computer or a printer. A node can also be a piece of networking equipment such as a hub, switch or a router.

The data (and power) are bussed from node to node via a busline. For balance the data line of most busses also require a terminating resistor.

Repeaters transfer indiscriminately all messages from segment to segment.

The simple addition to a bus is a single drop passive hub, also called a passive Tee. It allows the busline to be branched. Many busses have restrictions on these passive branches. This is because of the distortion that occurs when part of a signal going down the main busline goes down the branch which is cumulative. Perhaps the major drawback of passive branches is that if a short occurs the entire system goes down.
An active Tee offers a solution to this problem by isolating the data lines (and power supply if applicable). An active Tee can be also used to increase the branched distance.

Further extension of bus distance is achieved by repeaters and amplifiers.

Bridges, routers and gateways make it possible to link one bus to another.

The bridge links segments of similar buses. Bridges map the addresses of the nodes residing on each network segment and allow only necessary traffic to pass through the bridge. When a message is received by the bridge, the bridge determines the destination and source segments. If the segments are the same, the packet is dropped ("filtered"); if the segments are different, then the packet is "forwarded" to the correct segment. Additionally, bridges do not forward bad or misaligned messages.

Routers are still more advanced. Their expertise is reading the address and then sending the message on the right route. More often than not the message will go through many routers as it travels from source to destination. Some routers can connect busses that have similar protocols but different timing and electrical characteristics.

A gateway can link completely dissimilar buses, protocol, signal type and carrier, encoding methods, network access. The most popular application of gateways is to feed device level bus into the next higher network level.

Transceivers are used to connect nodes to the various media.

The interface to a controller is technically called a programmable gateway, but commonly accepted term is scanner-module or scanner-card. Network interface cards, commonly referred to as NICs, are used to connect a PC to a network. The NIC provides a physical connection between the networking cable and the computer's internal bus (eg PCI).

From the network users point of view the most important aspects are the bus topology and access. This will play an important role in bus performance, especially in real time control. All modern buses have one of the three topologies: single trunkline, a star or a ring.
Bus access method is a portion of a protocol. The methods of talking on the bus are classified as follows:

- Carrier Sense Multiple Access (CSMA) - the node will not talk if some other node is talking but has equal right to talk if the busline is clear.
- Collision Detection - all nodes listen for data collision while they are talking, if there is a collision the nodes use an algorithm that will create a random time delay before a node will speak again.
- Bitwise Arbitration (BA) - determines which node has the right to continue talking, the node with the lowest address wins.
- Master-to-slave - a slave reports to a master when called without checking the bus.
- Token passing - all messages are transferred in a unidirectional manner along the ring at all times. Data is transmitted in tokens, which are passed along the ring and viewed by each node. When a node sees a message addressed to it, it copies the message and then marks that message as being read. As the message makes its way along the ring, it eventually gets back to the sender which now notes that the message was received by the intended device. The network master can then remove the message and free that token for use by others.

There are two basic modes of message sending - solicited and unsolicited.

The unsolicited (event driven) operation means that only change-of-state messages are on the bus, which makes the bus traffic less than it is for solicited operations. This type of bus is well adapted to prioritization. It's possible for two or more devices to place data on the line at the same time. When this occurs, data may collide and transmitting devices must retransmit, possibly several times before data receipt confirmation is received. This prevents determining a time period for successful data transfers, however most of the busses can predict reporting reasonably well using statistical models. A certain bandwidth margin is then applied to this figure depending how critical the node response is. Nodes can not quickly distinguish between low bus traffic and failures.

The solicited bus traffic control is deterministic. Some fairly accurate methods can be used to determine the scan rate, update and response times. This makes it possible to calculate how long an input must hold its state before that condition is communicated to other nodes (or a master). Nodes are solicited sequentially. Within one scan an attendance check is can be performed and the nodes have the ability to recognise loss of communication.

The disadvantages of solicited messaging are the difficulties to prioritise nodes and repetition of unchanging states for each scan.

2.1. FIELDBUSES

A special class of buses are designed to satisfy the requirements of automation and process control. They are commonly called fieldbuses. All fieldbuses perform digital multiplexed serial data transfer.

Except for very short distances in embedded machine control, point-to-point wiring is being replaced by a fieldbus link. This reduces the amount of wiring resulting in lower installation costs and improved reliability of wiring.

It has to be stressed that fieldbus connectivity comes at a cost - a fact which manufacturers of automation equipment tend not to highlight but it must be considered in smaller installation. The bigger the installation the more economical fieldbus become. Maintenance costs are lower due to increased monitoring and improved diagnostic of field equipment.

Fieldbuses allow for interoperability - products from different manufacturers may be interconnected and operate successfully.

The ultimate goal is interchangeability, where a product from one manufacturer can be replaced with a functionally equivalent product from another manufacturer.

All fileldbus classifications are somewhat artificial and there are no clean cut boundaries.

- Device level fieldbuses connects sensors, pushbuttons and actuators to some type of controller.
- Controller level fieldbuses connect lower level controllers (PLCs and similar) to higher level controllers (SCADA, IT systems)
- Plant level fieldbuses connect the high level controllers within a plant.

Some of the buses have left either the hardware or some level of protocol for the vendors, system integrators or users to finish. They become building block buses: EIA RS-485, Bitbus, LonWorks, ArcNet and most significantly CAN.

There are the general purpose "open" busses and speciality busses.

Speciality busses are designed to work in areas like around welders, explosive areas, RF devices.

The following is a summary of the most practical features of general purpose open fieldbuses.

	ASI	DeviceNet	Interbus-S
Bus Type	M-S, solicited	CSMA/BA solicited	Token pas. solicited
Total No of nodes	32	64	64 remote 192 local
Topology	Straight, unrestr. br.	Straight, restr. drops	Straight
Distance	100m trunk+drops	39m - 500m	400m
Transmiss Media	2 wire unshied IDC	2+2 wire twd, shield	3 pair twd, shield
Input bits/node	4	64	16
Output bits/node	4	64	16
Speed	167kb/s	500kb/s - 125kb/s	500kb/s
Bus power	2A using data wires	8A	Nodes powered ind.

	Profibus	Foundatation Fbs	SDS
Bus Type	Token pas, solicited	Token pas, solicited	CSMA/BA unsolicit
Total No of nodes	126		128
Topology	Straight	Straight	Straight
Distance	500m - 9600m	1900m	75ft - 1500ft
Transmis. Media	2 wire twd, shield.	3 wire +drain, shield	2+2 wire twd, shield
Input bits/node	2048		32
Output bits/node	2048		32
Speed	12Mb/s - 9.6kb/s	3125kb/s	1Mb/s - 125kb/s
Bus power	Separate source	From trunkline	From trunkline

We have to be cautious when comparing speeds of buses. What the manufacturer provides is the gross carrier speed (bits/s). What really matters to the user is the net speed, ie the speed of "on-off" information. In some applications the net information speed was found to be less than 1% of the bus speed. From the other hand a fully loaded token passing ring could theoretically reach 58%.
Big influence on the net speed has the efficiency of the host interface node. Excessive software overheads can introduce large idling periods to bus operation. The next in significance is the utilisation of data message, eg sending 60 bits of a message back and forth to indicate just one "on-off" condition would slow the net speed considerably.

Over the last couple of years there have been three strong trends emerging in the fieldbus area.

1. At the device level - only two wires are being used to carry data and power (data-

2. At all levels - it is the rapid spread of industrial Ethernet.
   It is providing physical and transport mechanism for other buses, resulting in Profibus over Ethernet, ControlNet over Ethernet, Modbus over Ethernet and Foundation Fieldbus H2. The push from the Ethernet, especially Fast Ethernet (100Mb/s) is causing disappearance of controller level fieldbuses.
3. Internet is taking the role of plant level networks.

2.2. ETHERNET

The significance of Ethernet in the global information technologies should not be underestimated.
Ethernet was invented by Robert Metcalfe and David Boggs at Xerox PARC in 1973, which first ran at 2.94 Mbps. In 1983, the IEEE approved the Ethernet 802.3 standard. According to National Instruments, this year the total number of Ethernet connections worldwide will be an estimated 200 million, dwarfing all other industrial networking technologies combined.
The long-standing argument against Ethernet has been nondeterminism, preventing Ethernet in applications requiring real-time data exchanges. Distributed computing technologies and client/server architectures at business levels increased the need for Ethernet to share data among machines on a predetermined basis. The demands for determinism from commercial world resulted in improvements in topology design, communication management devices, speed, and redundancy, making Ethernet viable for consideration in real-time, plant floor applications.
In reality, the determinism problem seemed to be somewhat exaggerated. It has been widely believed that any Ethernet network loaded above 40% would experience an exponential growth in transmission delay times. However, studies conducted in the late 1980s showed that, in practice, Ethernet delays are linear and can be consistently maintained under 2 milliseconds for a lightly loaded network and 30 milliseconds for a heavily loaded network. These delays are inconsequential for most process control applications.
The success of the simple strategy of keeping traffic levels low seem to find evidence in recent products from Modicon, Opto 22 and Sixnet. In their applications the probability of significant delays from collisions is in the same range as delays from noise - an issue all networks face.
New technologies entering the market give Ethernet determinism when needed. These technologies typically fall into one of two categories: one uses Ethernet switches, another implements timing functions into protocols on top of Ethernet. The Ethernet switch solution is being driven by the convergence of video and voice-over networks, two technologies with very sensitive timing requirements. An Ethernet switch lies at the center of the network and connects directly to each device. It provides each device with its own private network, which reduces signal collisions to almost zero. This can be improved further if full-duplex Ethernet is used between the device and the switch. Full-duplex Ethernet technology uses separate channels for transmissions to and from the switch, so there are never any collisions. The switch can also arbitrate who gets to talk to whom and when, thus allowing prioritization of Ethernet packets. Applications and

messages are assigned priority and time-sensitivity parameters, and the switch manages these according to specified rules.
Upper-level timing proponents use a protocol on top of Ethernet that coordinates interdevice timing and time stamps all packets. The devices then correct for any network or processor-induced delay. By using this technique, Hewlett-Packard were able to demonstrate timing accuracy in the 200 nanosecond range.

Taking into account the 10Base-T installations in all engineering buildings Ethernet must be considered as the prime candidate for the Telelabs network.
Ethernet transmits variable length frames from 72 to 1518 bytes in length, each containing a header with the addresses of the source and destination stations and a trailer that contains error correction data. Higher-level protocols, such as IP and IPX, fragment long messages into the frame size required by the Ethernet network being employed.
Ethernet uses the CSMA/CD technology to broadcast each frame onto the physical medium (wire, fiber, etc.) at one of the three standard speeds: 10 Mbps (Ethernet), 100Mbps (Fast Ethernet) or 1000 Mbps (Gigabit Ethernet).
An important part of designing and installing an Ethernet is selecting the appropriate Ethernet medium. There are four major types of media in use today: Thickwire for 10Base5 networks, thin coax for 10Base2 networks, unshielded twisted pair (UTP) for 10Base-T networks and fiber optic for 10Base-FL or Fiber-Optic Inter-Repeater Link (FOIRL) networks. This wide variety of media reflects the evolution of Ethernet and also points to the technology's flexibility. Thickwire was one of the first cabling systems used in Ethernet but was expensive and difficult to use. This evolved to thin coax,
which is easier to work with and less expensive.
The most popular wiring schemes are 10Base-T and 100Base-TX, which use unshielded twisted pair (UTP) cable. This is similar to telephone cable and comes in a variety of grades, with each higher grade offering better performance. Level 5 cable is the highest, most expensive grade, offering support for transmission rates of up to 100 Mbps. Level 4 and level 3 cable are less expensive, but cannot support the same data throughput speeds; level 4 cable can support speeds of up to 20 Mbps; level 3 up to 16 Mbps. The 100Base-T4 standard allows for support of 100 Mbps Ethernet over level 3 cable, but at the expense of adding another pair of wires (4 pair instead of the 2 pair used for 10Base-T); for most users, this is an awkward scheme and therefore 100Base-T4 has seen little popularity. Level 2 and level 1 cables are not used in the design of 10Base-T networks.
For specialised applications, fiber-optic, or 10Base-FL, Ethernet segments are popular. Fiber-optic cable is more expensive, but it is invaluable for situations where electronic emissions and environmental hazards are a concern. Fiber-optic cable is often used in interbuilding applications to insulate networking equipment from electrical damage caused by lightning. Because it does not conduct electricity, fiber-optic cable can also be useful in areas where large amounts of electromagnetic interference are present, such as large electric drives and welding.
10Base-T Ethernet and Fast Ethernet use a star topology, in which access is controlled by a central computer. Generally a computer is located at one end of the segment, and the other end is terminated in central location with a hub. The primary advantage of this

type of network is reliability, for if one of these 'point-to-point' segments has a break, it will only affect the two nodes on that link. Other users on the network continue to operate as if that segment were nonexistent.

ETHERNET LIMITATIONS

Type	Maximum Segment length (no repeaters)	Maximum Devices
TWISTED PAIR (star topology)		
10BaseT	100 m	1
100BaseT	100 m	1
COAX (trunk line topology)		
10Base5 "thick"	500 m	100
10Base2 "thin"	185 m	30
FIBER (star topology)		
FOIRL	1 km	1
10BaseF	2 km	1
100BaseFX multimode	2 km	1
100BaseFX single-mode	10 km	1

Most computers and network interface cards contain a built-in 10Base-T or 10Base2 transceiver, allowing them to be connected directly to Ethernet without requiring an external transceiver. Many Ethernet devices provide an AUI connector to allow the user to connect to any media type via an external transceiver. The AUI connector consists of a 15-pin D-shell type connector, female on the computer side, male on the transceiver side.

Thickwire (10Base5) cables also use transceivers to allow connections. For Fast Ethernet networks, a new interface called the MII (Media Independent Interface) was developed to offer a flexible way to support 100Mbps connections. The MII is a popular way to connect 100Base-FX links to copper-based Fast Ethernet devices.

As mentioned before, in star topologies such as 10Base-T Ethernet hubs are necessary . A multi-port twisted pair hub allows several point-to-point segments to be joined into one network. One end of the point-to-point link is attached to the hub and the other is attached to the computer. If the hub is attached to a backbone, then all computers at the end of the twisted pair segments can communicate with all the hosts on the backbone. The number and type of hubs in any one-collision domain is limited by the Ethernet rules.

A network of hubs/repeaters is termed a "shared Ethernet," meaning that all members of the network are contending for transmission of data onto a single network (collision domain). This means that individual members of a shared network will only get a percentage of the available network bandwidth. The number and type of hubs in any one collision domain for 10Mbps Ethernet is limited by the following rules:

Network Type	Max Nodes Per Segment	Max Distance Per Segment
10Base-T	2	100m

10Base2	30	185m
10Base5	100	500m
10Base-FL	2	2000m

A network using repeaters functions with the timing constraints of Ethernet. The Ethernet standard assumes it will take roughly 50 microseconds for a signal to reach its destination.

Ethernet is subject to the "5-4-3" rule of repeater placement: the network can only have five segments connected; it can only use four repeaters; and of the five segments, only three can have users attached to them; the other two must be inter-repeater links. If the design of the network violates these repeater and placement rules, then timing guidelines will not be met and the sending station will resend that packet. Fast Ethernet has modified repeater rules, since the minimum packet size takes less time to transmit than regular Ethernet. The length of the network links allows for a fewer number of repeaters. In Fast Ethernet networks, there are two classes of repeaters. Class I repeaters have a latency of 0.7 microseconds or less and are limited to one repeater per network. Class I repeaters have a latency of 0.46 microseconds or less and are limited to two repeaters per network. The following are the distance (diameter) characteristics for these types of Fast Ethernet repeater combinations:

Fast Ethernet	**Copper**	**Fiber**
No Repeaters	100m	412m*
One Class I Repeater	200m	272m
One Class II Repeater	200m	272m
Two Class II Repeaters	205m	228m

* Full Duplex Mode 2 km

On a moderately loaded 10Mbps Ethernet network being shared by 30-50 users, that network will only sustain throughput in the neighbourhood of 2.5Mbps after accounting for packet overhead, interpacket gaps and collisions.

When conditions require greater distances or an increase in the number of nodes/repeaters, then a bridge, router or switch can be used to connect multiple networks together. These devices join two or more separate networks, allowing network design criteria to be restored. Switches allow network designers to build large networks that function well. Each network connected via one of these devices is referred to as a separate collision domain in the overall network.

Filtering packets, and regenerating forwarded packets enables bridging technology to split a network into separate collision domains. This allows for greater distances and more repeaters to be used in the total network design.

Most bridges are self-learning task bridges; they determine the user Ethernet addresses on the segment by building a table as packets are passed through the network. This self-learning capability, however, dramatically raises the potential of network loops in networks that have many bridges. A loop presents conflicting information on which segment specific address is located and forces the device to forward all traffic. The

Spanning Tree Algorithm is a software standard for describing how switches and bridges can communicate to avoid network loops.

Routers filter out network traffic by specific protocol rather than by packet address. Routers also divide networks logically instead of physically. An IP router can divide a network into various subnets so that only traffic destined for particular IP addresses can pass between segments. Network speed often decreases due to this type of intelligent forwarding. Such filtering takes more time than that exercised in a switch or bridge, which only looks at the Ethernet address. However, in more complex networks, overall efficiency is improved by using routers.

Ethernet switches are an expansion of the concept in bridging. LAN switches can link four, six, ten or more networks together, and have two basic architectures: cut-through and store-and-forward. The speed of store-and-forward switches has caught up with cut-through switches so the difference between the two is minimal. Also, there are a large number of hybrid switches available that mix both cut-through and store-and-forward architectures. Both cut-through and store-and-forward switches separate a network into collision domains, allowing network design rules to be extended. Each of the segments attached to an Ethernet switch has a full 10 Mbps of bandwidth shared by fewer users, which results in better performance (as opposed to hubs that only allow bandwidth sharing from a single Ethernet). Newer switches today offer high-speed links, either FDDI, Fast Ethernet or ATM. These are used to link switches together or give added bandwidth to high-traffic servers. A network composed of a number of switches linked together via uplinks is termed a "collapsed backbone" network.
One of Ethernet’s greatest strength is the ease of installation and connection, however care must be taken to prevent the network design strategies from being defeated by a small oversight, like one incorrectly configured workstation generating high levels of broadcast packets.

Although the Ethernet standard used on plant floors is the same as used in office environments, its implementation is different.
Industrial Ethernet components are designed to be powered by low-voltage sources 18 to 24 V dc., operate in 0-60degC temperature range, have improved noise immunity and built-in redundancy.
The telephone-like fragile RJ-45 connectors are replaced by screw down DB9.
In the industrial environment there is a growing need for the network serving measurement and control devices to see an object rather then just a collection of registers. Object technology specifies a common object model for devices, how they communicate (either client/server or publish/subscribe), and how they are managed.
In1998, the Fieldbus Foundation agreed to use fast Ethernet as the base-level protocol for its H2 network. The foundation is now mapping all the Layer 2 technologies from its H1 standard into Ethernet, including key features such as the scheduling, the publisher/subscriber services, and the object model. Most of the other systems simply plan to encapsulate their protocols inside of an Ethernet frame, a technique commonly known as tunneling, which is simpler but will require devices to use the specific

protocol chips for the tunnelled fieldbus protocol, rather than a general purpose microprocessor with support for the TCP/IP. Ethernet can be now realistically considered in the fieldbus category.

Major manufacturers of Ethernet related products are:
ABB
AMR Research
Cisco Systems
Fisher-Rosemount Systems
Foxboro
Schneiders Automation
Hirschmann
Opto 22
Rockwell Automation
Synergetic Micro Systems
Total Control
Zone Automation

3. SCADA

SCADA software can interface to real time controller platforms (PLC, PC, SBC) or perform real time control itself, communicating with field devices (sensors, actuators, switches) through a fieldbus. SCADA can provide a customised GUI to represent a particular lab experiment, log experiment data, usage details, manage safety (alarms) and generate graphics (charts, etc). SCADA also allows for a remote user terminal.

All the main SCADA suppliers were reviewed, including:
Citect
GE Fanuc - Cimplicity
Intellution -FIX
National Instruments - BridgeVIEW
Opto22
Wanderware - FactorySuite 2000
Wizcon

Cimplicity, FIX, Opto22 and FactorySuite 2000 are limited in Internet connectivity.

Citect and National Instruments offer the highest functionality in a single integrated package. Both operate in Windows95 or NT and provide drivers for variety of commercially available fieldbuses and instruments.
Citect is strongly represented in Perth by Ci Technologies in Applecross. They offer training and field support if required. The main strength of Citect is a true client-server architecture. Citect operation is divided into tasks, each task works as a distinct client and/or server module, preprocessing its relevant data no matter how distributed the data

sources are. Citect has five fundamental tasks which handle communication with I/O devices, alarm conditions monitoring, reports, trending and user display.
Citect provides drivers for over 130 control devices.
Internet link is facilitated through the Internet Display Client module which can also handle video and audio data in any suitable form. The very rough estimate of the video bandwidth indicates a rate of 1frame/s. This is quite acceptable for general observation but far to slow for real time feedback. Special techniques need to be devised to alleviate this problem.
Citect also provides a convenient way of managing access to the labs. An administrator-designed HTML page including a booking scheme can be exported to Citect for all users.
Citect licences are basically a function of points (any I/O device). Unlimited point Citect is $17000, however there is also a very attractive, 40k points, $500 per user, educational version, which automatically closes after eight hours of running but can be immediately reopened.

National Instruments have a reputation for high quality and reliability. Their SCADA product - the BridgeVIEW includes all the management functions and is a complete superset of the popular LabVIEW control development environment. LabVIEW is fully functional in BridgeVIEW environment, in fact LabVIEW can bypass the BridgeVIEW SCADA engine for a direct control if required.
National Instruments also offers a new Internet programming technology - the DataSocket that simplifies data exchange between computers and applicants. It provides access to several I/O mechanisms allowing effective pass of raw data over the Internet and response to multiple users without the complexity of low level TCP programming.
Remote users can use a 'free' executable BridgeVIEW operator interface, specially developed for each lab station, which would communicate with one central server.
The BridgeVIEW development licence is for one machine without I/O limits. The cost of BridgeVIEW is about twice the cost of a corresponding package of LabVIEW:
base ~$4000, full ~$6500, professional ~$8500 (includes all tools)

National Instruments also offer wide range of development tools for motion control, image acquisition and large variety of signal processing.
Drivers for various buses are available but expensive. DeviceNet PC interface card costs ~$2500, Profibus ~$4000.

It should be noted that National instrument also offer an object-based SCADA called Lookout. It is oriented to large plant applications and does not include LabView programming facilities.

National Instruments are competently represented in Perth by ICON Technologies in Victoria Park.

The performance bandwidth for both SCADA systems is limited by the speed of the slowest communication link. Internet seems to be the bottleneck in the Telelabs system.

All modern industrial fieldbuses offer carrier speed significantly faster than the 56k modem.
Finally to use the SCADAs behind a firewall: Citect IDC uses ports 2072 and 2078 and DataSocket uses registered port number 3015.

4. LABORATORY AUTOMATION

A lab experiment should employ a similar type of testing technology which would be used by an engineer in professional environment. A data acquisition system equipped with some kind of GUI would be the most common tool used.
This moves the user interface beyond the old fashioned front panel with buttons, switches, dials and meters towards virtual instrumentation, where the user is free from the uncertainty of manual adjustments, misreading gauges and manual results recording. The user can concentrate on the actual merit of the experiment rather than the running of it.
A modern user interface lends itself naturally to remote access requirements.
Many data acquisition systems provide also a number of digital and sometimes even analogue outputs so a very simple control scheme could be built however these capabilities are seldom found adequate.

4.1. LOCAL CONTROLLER

The most common solution, used in about 75% of industrial applications is PLC. Despite its shortcomings in performance and programming, historically PLC proved to be robust and reliable, many believe more reliable than an industrial PC.
The selection of PLCs was mostly limited to the mini size and modular type. This category commonly includes PLC with up to 150 I/Os although the classification varies from manufacturer to manufacturer. This number of I/Os would certainly be sufficient to control the most sophisticated lab experiment. To help the development, many of these PLC provide PID loop templates, floating math, analog inputs with 12bit A-to-D converters, analog outputs or PWM outputs and a fieldbus connection.
The speed of PLC operation is the most difficult parameter to ascertain for design purposes. PLCs operate in a continuous scan cycle: read inputs, perform programmed operations, update outputs.
Any A-to-D conversion or PID loop is performed once per scan (interrupts allow to jump the queue in the scan). PLCs speed is usually specified as the time for execution of 1k binary statements. The scan time is also strongly affected by the number of inputs. As a result the designer has difficulties to evaluate the PLC's performance until the programming is fully developed!
For the mini class of PLCs the 1k statement execution is on average close to 2ms.

Relevant PLC models were found among products from:

- Allen-Bradley: Micrologix11000, 1500

- GE Fanuc: VersaMax
- Koyo: DL205
- Mitsubishi: Melsec FX
- Modicon: TSX Micro
- Siemens: SIMATIC S7

Allen-Bradley provides very good local support and high quality development and educational tools. GE Fanuc (Motherwell) has to be also considered, especially in view of their recent affiliation with UWA.
When direct costs are considered Koyo offers clearly the best choice. Their top of the range processor unit (DL250) costs $495 - less than half the price of equivalent Siemens yet Koyo's pedigree is highly respectable; For years Texas Instruments, Siemens and General Electric were selling Koyo PLC rebadged under their own brand. The Koyo DL205 is the only PLC in this class offering Ethernet Interface. The H2-ECOM supporting 10Base-T is $590.

In order to present to the remote user the same GUI as for the local user, SCADA needs to operate the interface on the PC attached to each lab station.

Perhaps the easiest task in automating a lab experiment is the selection of sensors and actuators. A number of manufacturers offer vast variety of sensors, often comparable in performance many of them equipped with fieldbus interfaces. Uniform connectivity would offer significant installation and maintenance advantage, therefore a single manufacturer should be selected. Turck/Banner was found to offer the most comprehensive range of sensors, specially of optical type.
It is not possible to recommend a single source of actuator supply. The manufacturers tend to specialised in one of the three categories: pneumatic, electrical, hydraulic.
The sensors and actuators do not need to be addressed until the detailed design stage for each station.

4.2. DISTRIBUTED INPUTS/OUTPUTS

In many industrial applications it was found more effective to have just the I/Os placed close to the field devices and use a remote central controller.
In the distributed I/O area there are three major products: the FieldPoint modules from National Instruments, EtherTRAK from SIXNET (endorsed by Ci Technologies) and SNAP Ethernet I/O from Opto22.
All types can communicate through Ethernet TCP/IP and are remotely configurable.
The modules perform all type of functions available from PLCs. Their cost is also similar to corresponding PLC modules ($300-$700). Their bandwidth is practically determined by the communication link.
Because of the compatibility with BridgeVIEW the FieldPoint I/O are of more importance to Telelabs.
The FP-1600, at a cost of $1500, is the latest network interface module for the FieldPoint system that connects a bank of I/O modules directly to standard TCP/IP

networks. The FP-1600 automatically senses and self-configures for 10 Mb/s and 100 Mb/s connections. An embedded data server executes in the FP-1600 module, implementing exception-based communications - the FP-1600 can be configured to only transmit data when the data changes values, maximising system efficiency and bandwidth. The FP-1600, which can manage a bank of up to nine I/O modules, is compatible with all analog and digital modules, and implements the HotPnP (Plug and Play) autoconfiguration and diagnostics features of standard FieldPoint systems.
An Ethernet FieldPoint system includes all the software components necessary to simplify the configuration and usage. Configuration of network parameters, I/O hardware attributes, and server parameters are handled by a friendly configuration utility, the FieldPoint Explorer.
A FieldPoint node is powered with 11 - 30V dc supply, connected to screw terminals on the FP-1600. The FP-1600 filters and regulates the power input, distributing power to all of the I/O modules in the node via the backplane bus in the terminal bases.

5. SAFETY

Remotely operated equipment poses a particular danger to the staff or students who in a process of conducting their own experiment or maintenance may inadvertently step into the zone operation of another lab station.
Safeguarding must be used for all moving equipment. This should both, prevent personnel access during operation and limit the operating range of the equipment to prevent damage.
Fieldbuses have not been approved for emergency shutdown applications. All emergency action must be performed locally and as directly as possible on a moving part. The safety devices have auxiliary connections which can be utilised to manage the alarm over the network.
All Australian Standards pertinent to safety are mandatory, those relevant to the Telelabs are listed below.

AS4024.1	Safeguarding of machinery General Principles
AS4024.2	Safeguarding of machinery Installation and commissioning requirements for electro-sensitive systems Optoelectronic devices
AS4024.4	Safeguarding of machinery Installation and commissioning requirements for electro-sensitive systems Pressure sensitive devices
AS1543	Electrical equipment of industrial machines
AS2243.5	Safety of laboratories Mechanical aspect
AS2243.7	Safety of laboratories Electrical aspect

AS1319 Safety signs for the occupational environment

Some of the best sources of safety equipment and application guidance are Pilz and Banner.

6. RECOMMENDATIONS

The growing industrial support for Ethernet builds up a convincing argument to bring Ethernet close to field devices. The industry demand for 10 years backward compatibility adds to the confidence that a network designed today will benefit from the continuous development.

Already, advantage should be taken of the compatibility of 10BaseT and 100BaseT, to switch to Fast Ethernet wherever suitable.

The requirement for project scalability, perhaps contrary to the common understanding, should be approached from the large model end. Because there are several technically viable solutions to the general arrangement of the laboratories, a large scale model will provide the best answers to:

- communication bandwidth limitations
- most favourable physical layout of lab stations grouped in one larger location
- potential influence of hardware and software elements on the reliability of the whole project
- impact of different SCADA licensing schemes on the economy of the project, possibly contributing to the selection of the manufacturer
- basis for negotiation with potential suppliers of hardware, software and technical support

After that detailed design and construction can indeed start with the smallest practical implementation.

CITECT 5.2 and National Instruments BridgeView are the best choices for SCADA.

It has become clear that a thorough evaluation of accessibility and behaviour of the two systems on different computing platforms is necessary. The results of that have to be combined with hardware implications of using either system. In order to enable that two arrangements are proposed, each utilising the best features of each SCADA system.

Large part of the communication is Ethernet based and can be identical for both arrangements. It taps into the existing LAN in engineering buildings. The representation of all nodes in the figures has been deliberately simplified for easier comparison between the two setups. Subject of detailed design, switches, hubs, routers and repeaters need to be used according to the characteristics of each node segment, following the Ethernet rules and limitations described earlier. In both drawings a laboratory experiment setup is represented as Lab Station. Station No 1 is an example of single experiment distanced from others, Station Nos 2 and 3 are close together (in the same room).

In both arrangements the local GUI is PC-based. At this level it is virtually irrelevant whether Citect runs locally on each station (PC) or from a central Server, in the drawings links are shown for a central server.

The Citect-based scheme

This arrangement is based on a local controller, PLC-based, close to each lab station. This provides (relatively) the best conditions for real time control, there is no LAN communication traffic related to the actual Station control scheme, which improves the effective LAN bandwidth.

It has to be noted, that certain high performance controllers for motion control, signal processing or image acquisition can be installed in the Station's PC, typically through PCI bus.

For a single station control a mini-sized PLC is used as a master, the PC functions in a slave mode.

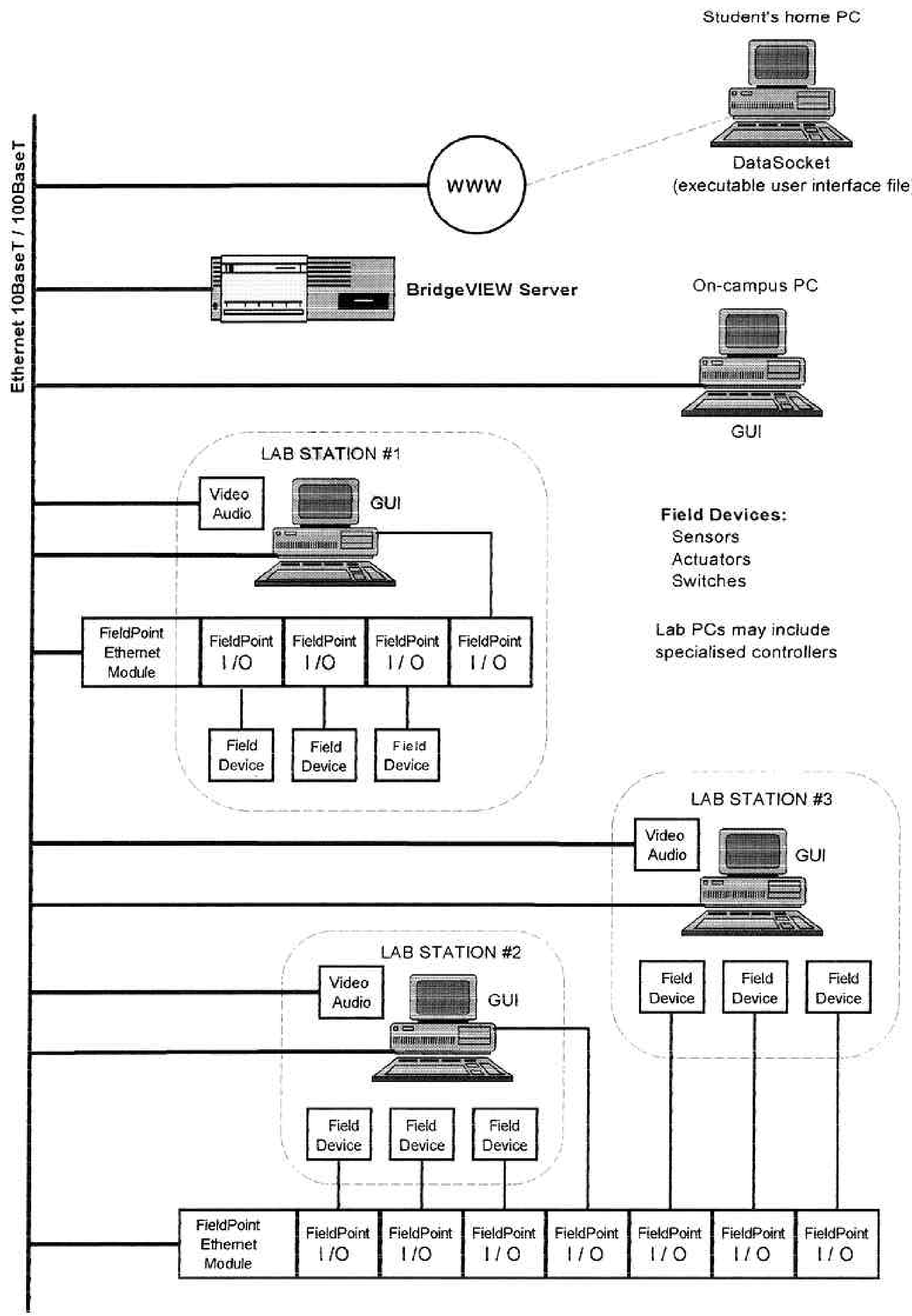
All field devices are connected directly to the PLC, a simple serial link (RS232, RS485) between the PLC and the PC will be sufficient.

The first choice for the PLC is Koyo DL250 equipped with H2-ECOM (Ethernet 10BaseT) module and required type and number of I/O modules.

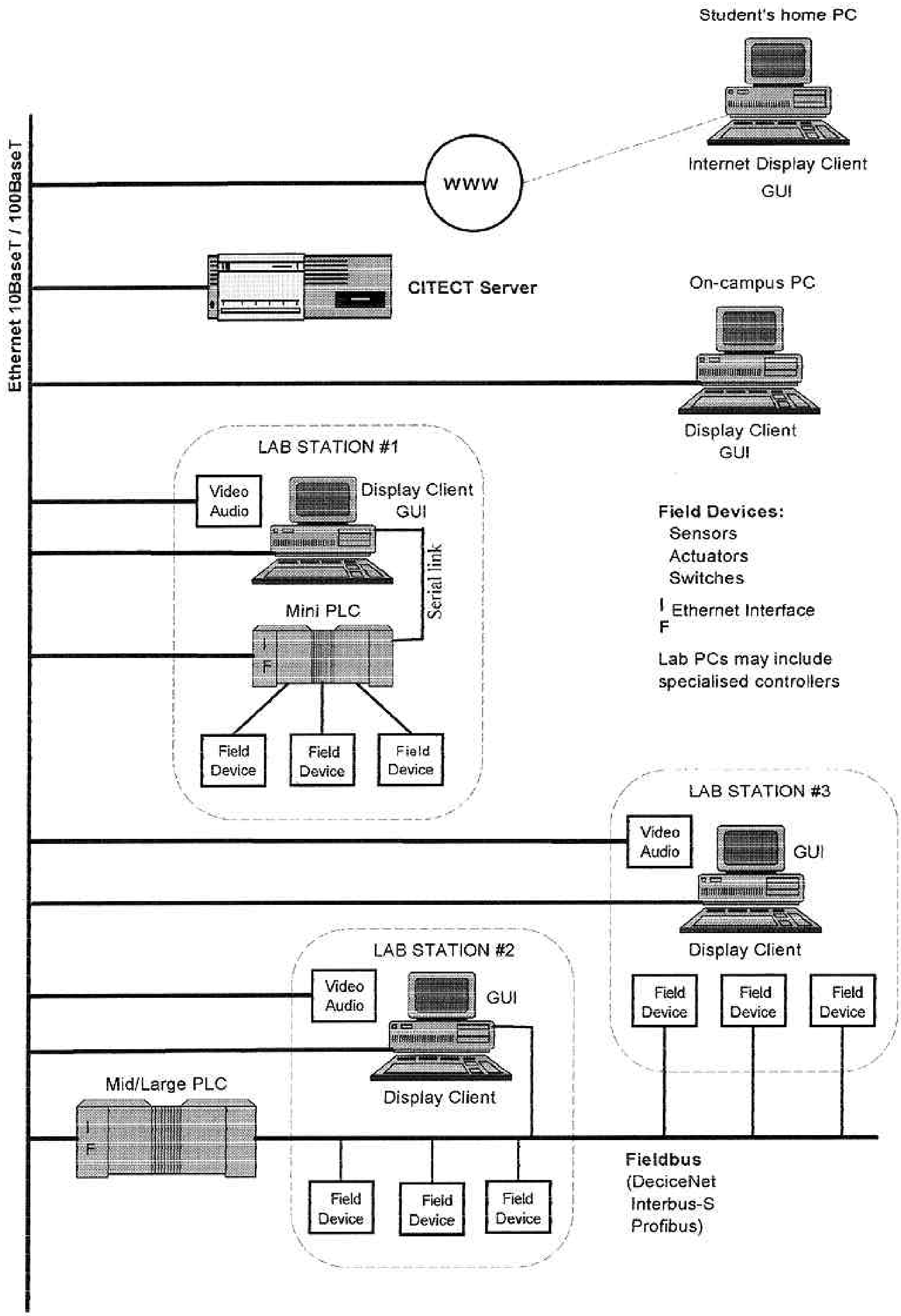
Where a number of Lab Stations are located in a close vicinity, one local controller can be used for all of them. A medium-to-large size PLC should be used for this purpose. This type of PLC makes up for the increased number of point with much higher scan speed than the smaller PLCs. Because larger distances are involved for signal integrity a fieldbus should be used.

It is beneficial to limit the PLCs to one brand and this can certainly be maintained for all small PLCs.

In the midium size however the best choice lays elsewhere. The GE Fanuc Series 90-30 appear to be the most versatile PLC in this class (unfortunately GE Fanuc does not have an Ethernet compatible PLC in the mini size). Apart of the Ethernet interface and the



Student's home PC
DataSocket
(executable user interface file)
WWW
Ethernet 10BaseT / 100BaseT
BridgeVIEW Server
On-campus PC
GUI
LAB STATION #1
Video
Audio
GUI
Field Devices:
Sensors
Actuators
Switches
FieldPoint
Ethernet
Module
FieldPoint
I/O
Lab PCs may include
specialised controllers
Field
Device
LAB STATION #3
LAB STATION #2



Student's home PC
Internet Display Client
GUI
WWW
Ethernet 10BaseT / 100BaseT
CITECT Server
On-campus PC
Display Client
GUI
LAB STATION #1
Video
Audio
Display Client
GUI
Serial link
Mini PLC
I
F
Field
Device
Field
Device
Field
Device
Field Devices:
Sensors
Actuators
Switches
I
F
Ethernet Interface
Lab PCs may include
specialised controllers
LAB STATION #3
Video
Audio
GUI
Display Client
Field
Device
Field
Device
Field
Device
LAB STATION #2
Video
Audio
GUI
Display Client
Mid/Large PLC
I
F
Field
Device
Field
Device
Field
Device
Fieldbus
(DeciceNet
Interbus-S
Profibus)

vast variety of I/O modules it supports all major fieldbuses. This is particularly useful at
this stage, where the connection requirements could not be specified. These specifications, which will influence the choice of a fieldbus should use the following guidelines:

- Number of nodes required (split into remote and local nodes)
- Overall distance
- Distances between remote nodes
- Distances between local nodes
- No of input and output bits per node
- Minimum acceptable speed of information

BridgeView-based scheme

Compared to other high level SCADA systems the biggest strength of BridgeView seems to lay in the industry proven graphic programming for data acquisition and automation through LabView. This seem to be reflected in the fact that LabView contributes 50% to the price of a similar level BridgeView. LabView would be particularly suitable to develop and run control schemes for every Lab Station. This leads to the use of a central controller with distributed I/Os.

It has to be noted that BridgeView can be used with local controllers (and Citect can operate in a central controller setup) however its best feature would not be utilised.

I/Os are grouped into field point nodes. One node can include up to 9 16-point modules. In practice some of the modules will be less than 16 points resulting in a total number op points close to 120.

This can be used to control up to 4 stations, which should be arranged in a square or a triangle. 4-20mA links to the FieldPoint I/Os can be used if required to improve the noise immunity.

The centralised controller arrangement offers the most uniform approach to all control requirements and appear to be the easiest to develop, however it places the highest demand on communication bandwidth.

In special cases time-critical controls can be performed on dedicated PC-based cards.

At this stage both, the local and the centralised controller arrangement warrant further consideration.