A Diagnostics Model for Industrial Communications Networks

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Abstract:

Over the past twenty years industrial communications networks have become common place in most industrial plants. The high availability of these networks is crucial in smooth plant operations. Therefore local and remote diagnostics of these networks is of primary importance in solving any existing or emerging network problems.

Users for most part consider the “plant networks” as black boxes, and often not sure of the actual health of the networks. The major part of the work outlined in this research concentrates on the proposed “Network Diagnostics Model” for local and remote monitoring. The main objective of the research is to aid the establishment of tools and techniques for diagnosis of the industrial networks, with particular emphasis on PROFIBUS and PROFINET. Additionally this research has resulted in development of a number of devices to aid in network diagnostics.

The work outlined in this submission contributes to the developments in the area of online diagnostics systems. The development work was conducted in the following phases:

1. Development of Function Block (FB) for diagnosing PROFIBUS network for implementation on PLC.

2. Development of OPC server for diagnosing PROFIBUS network for implementation on PC.

3. Development of a web based diagnostic software for multiple fieldbuses for implementation on imbedded XP platform.

4. Development of OPC server for diagnosing PROFINET network for implementation on PC

5. Conformance testing of masters (PLC) in PROFIBUS network to increase the health of the network.

6. Use of diagnostics tools for performance analysis of fieldbuses networks for high performance applications.

The research work outlined in this submission has made a significant and coherent contribution to online diagnostics of fieldbus communications networks, and has paved the way for the introduction of the online diagnostics devices to the market place. It has shown that the proposed model provides a uniform framework for research and development of diagnostics tools and techniques for fieldbus networks. Organizations that use fieldbus should consider installing advanced online diagnostic systems to boost maintenance efficiency and reduce operating costs, and maintain the availability of plant resources. Based on the experience gained over a number of years a multilayer model is proposed for future development of diagnostics tools.

Acknowledgements

I would like to thank my academic supervisor Dr David Bagley, and also Prof Peter Smith for all their support and encouragement.

I would also like to thank Dr Jeremy Robinson, my head of department at the University of Limerick for funding my PhD.

Finally I would like to thank my beautiful wife Carmel for her patience and encouragement, and our three boys Farivar, Sam and Bobby for putting up with me during the write up.

Dedication

I would like to dedicate this PhD thesis to my late father Hossain, for his support, encouragement to achieve more and also his wisdom:

"The main goal of education is to live our lives with some level of logic; the fact that we may get a job as a result of education is a bonus"

Contents

Glossary of Terms:

ANN	Artificial Neural Networks
ARP	Address Resolution Protocol
ASIC	Application Specific Integrated Circuit
CAN	Control Area Network
CIP	Common Industrial Protocol
COM	Common Object Model
COTS	Commercial off The Shelf
DA	OPC Data Access
DCOM	Distributed COM
DCP	Discovery and Configuration Protocol
DFP	Dynamic Frame Packing
EMI	Electro Magnetic Interference
FB	Function Block
FCC	Federal Communications Commission
FDL	Fieldbus Data Link
FPGA	Field Programmable Gate Array
GPRS	General Packet Radio Service
HTTP	Hypertext Transfer Protocol
IEC	International Electro technical Commission
IIS	Internet Information Server
IO	Input /Output
IRT	Isochronous Real Time
ISA	Industry Standard Architecture
ISO	International Standard Organisation
IT	Information Technology

LLDP	Link Layer Discovery Protocol
MES	Manufacturing Execution System
MCx	Master Class x=1 or 2
MIB	Management Information Base
MS	Microsoft
NDA	Non-Disclosure Agreement
OPC	Open Process Control
OS	Operating System
OSI	Open System Interconnect
PHY	PHYsical layer
PLC	Programmable Logic Controller
PoP	Proof of Principle
PROFIBUS	PROcess Field Bus
RPC	Remote Procedure Call
SCADA	Supervisory Control & Data Acquisition
SNMP	Simple Network Management Protocol
SSL	Secure Socket Layer
TH	Token Hold
T_{TR}	Token Target Rotation time
T_{RR}	Token Real Rotation time
UA	OPC Unified Architecture
UDT	User-defined Data Type
UL	Underwriters Laboratories
USB	Universal Serial Bus
VABS	Very high performance Automation Bus System
VSD	Variable Speed Drive
WinCC	Windows Control Centre

Chapter 1: Introduction

1.1 Background

Fieldbus networks allow users to significantly reduce wiring costs, and create more flexibility in monitoring and controlling plant functions. With the increased adoption of fieldbus networks, companies are looking for solutions to help the shrinking workforce install, commission, and maintain these more complex communication networks. Advanced online diagnostic systems that provide a rich set of diagnostic data and help predict and pin-point network faults and failures will become a necessary solution as process industries become increasingly more digital.

The research work outlined in this submission contributes to the knowledge within the field of diagnostics of industrial networks, and can be subdivided into software, and hardware as outlined below.

1.2 Motivation

Fieldbuses are widely used in industrial plants. Efficient methods of fieldbus diagnosis are required to keep the plants up and running. Normally in the event of any malfunction on the fieldbus a warning or error message is generated by the application software which indicates that there is a communications problem. However in most cases the end user is not aware of the cause of the problem. Alternative methods of accessing the connected devices and unlocking the diagnostic data are required to identify the possible causes of failures.

Additionally fieldbuses are like black boxes to the end user, the overall health of these communications networks are not known, and they could well be operating at the margins, and any small interference can cause a malfunction. Electrical measurement of the communication signals can give an insight to overall health of the network and establish a safety margin for the network.

Therefore the development of diagnostics models and devices are a necessary part of troubleshooting industrial communications network. The work presented in this thesis proposes a conceptual model for development of diagnostic devices and methods, and outlines a number of approaches in the development cycle.

1.3 Approaches to fieldbus diagnostics

Generally speaking the diagnostics of fieldbus networks irrespective of the underlying technology (CANBUS, PROFIBUS, PROFINET…) can be divided into; diagnostics at the controller level, and the diagnostics at the network level.

1.3.1 Controller level diagnostics

The diagnostics at the controller level is normally a software solution and is based on the relationship between the controller and the devices under its control, as defined in their respective standards or specifications. With the controller level solution to diagnostics, the controller is responsible for obtaining the diagnostic data from the device. This is either voluntarily provided by the device to the controller or it has to be specifically requested by the controller. Once the diagnostic data is retrieved by the controller, a number of approaches can be used to extract the diagnostic data.

One such approach is the use of a PC to communicate with the controller and obtain the diagnostic data stored in the controller. This can be done in an ad hoc manner for example by the use of OPC technology. In this instance the PC can act as OPC server and communicate with the controller (PLC) and represent the diagnostic data in the form of OPC tags. Although this approach uses OPC technology, however it would remain application specific, and not generic.

Another approach could be to use function blocks to obtain the diagnostics data and write the data into a data block within the controller in a prescribed format. The latter is the approach used in paper 1. This method has the advantage that the diagnostic data can be represented in a uniform format irrespective of the make of the controller or the underlying fieldbus network. The uniform data can then be accessed in a standard fashion by the higher level systems.

The work reported in paper 1 developed diagnostic Function Blocks for PROFIBUS networks and implemented on three makes of PLCs. Similar developments can be done for other fieldbuses, and other makes of controllers, maybe by the vendors with a view to include the representation of the diagnostic data as part of future standards.

The research work on using FB for diagnostics is applicable to networks where the controller stores the diagnostics data or when it is requested through the control program it can obtain the relevant diagnostics from the any of the networked devices.

An alternative approach is to add additional controller in the form of a supervisor to the fieldbus network. This could take the form of a PC equipped with a suitable interface card to connect to the underlying fieldbus network. The PC can be setup as an OPC server to obtain the diagnostic data from all the devices connected to the network, and make it available to other computers on the network in the form of standard OPC tags. This is the approach taken in papers 2, 3 and 4.

The research work on addition of supervisor station to the network to obtain diagnostic data is applicable to networks where supervisor functionality is defined within the relevant specification for the network in question. The supervisor functionality is defined for PROFIBUS, PROFINET and Device Net.

1.3.2 Network level diagnostics

The approach taken to obtain the diagnostic data at the controller level requires planning at the engineering design phase and implementation at the start-up phase of a project. The controller based diagnostic can’t be implemented on a running installation, and normally is not an approach that is acceptable to regulated industry such as pharmaceutical due to validation issues. Therefore a different solution to obtain diagnostics data at the network level is required.

The network level diagnostic would require connection of a physical interface unit to the fieldbus network. Although the addition of an interface unit provides extra loading for the network, in most cases the influence of the extra load would be minimal. Depending on the capability of the added interface the diagnostics can be provided at the protocol layer, physical layer or both. The work reported in paper 4, 5, and 6 uses network level diagnostics to access the fieldbus diagnostic information.

The research work on addition of an interface to listen to telegrams on any communications network is applicable to all digital communications networks, provided that a basic transceiver or preferably a communication ASIC is available for the network in question. If off the shelf solutions are not available then additional programming effort will be required such as the development work outlined in this research for PROFINET.

The protocol level diagnostics provides access to continuous flow of raw telegrams on the fieldbus network. Depending on the underlying protocol the diagnostic tool will extract source and destination addresses, Service Access Point, the actual data, and other parameters from the raw telegrams. The protocol level tools represent the telegrams in more understandable way to the end user. The tools provide statistical data on the communication such as the corrupted telegrams, retries by the controller, stations lost and so on.

The research work reported on diagnosis at protocol level for PROFIBUS, PROFINET and Device net, is equally applicable to other networks, however as the framing and protocols are different for various networks the decoding part of the tool has to be modified to reflect the new situation.

The end user can also use oscilloscope to measure the electrical signals at the physical layer of the network. The disadvantage of using a standalone oscilloscope for electrical measurement in a high speed communication network is that it is very difficult to match an electrical waveform to a transmitting station on the network. To overcome this problem modern diagnostic tools have now built-in oscilloscope that can match the electrical waveform to a transmitting station, therefore diagnostics can be made based on electrical measurement. Depending on the frequency of transmission of on the network it is also possible to use DVM to measure the signal levels.

1.3.3 Generality of the proposed approach

As outlined above the proposed diagnostic approaches can be performed at physical and protocol levels on any digital communications networks. Obviously depending on the type of the network under consideration the electrical signal levels as well as protocols used differ for various fieldbuses.

The proposed approach taken in this research work for PROFIBUS, PROFINET and DeviceNet can be duplicated across other fieldbuses. Although the application areas for the fieldbuses vary widely from one industrial sector to another, the developed tools can equally be used across different industries. For example oil and gas industry is mainly dominated by Fieldbus Foundation and PROFIBUS-PA, while car manufacturing plants use mainly PROFINET, and Interbus-S. Process and discrete manufacturing industry use PROFIBUS DP, DeviceNet and others.

1.4 Aims & Objectives

The aims and objectives of the research presented in this thesis on the diagnosis methods for fieldbus networks are:

1. Establish a new method for fieldbus diagnosis at the controller level

   - The objective seeks to find a suitable software solution for fieldbus diagnosis for implementation on the controller. This objective is addressed in paper 1.

   - Contribution to knowledge from this portion of the research work is a new method of diagnosing fieldbuses at the controller level using IEC 61499 conformant Function blocks.

2. Establish suitable methods for fieldbus diagnosis at the network level.

   - The objective seeks new approaches to fieldbus diagnostics at network level to provide vendor independent solutions. This objective is addressed in papers 2, 3, and 4.

   - Contribution to knowledge from this portion of research is a new approach of using emerging OPC technology to obtain diagnostic data from a fieldbus network.

3. Develop and test suitable software solutions for fieldbus diagnosis at the network level.

- The objective is to develop software solutions based on existing and emerging standards for diagnosing fieldbus networks. This objective is addressed in papers 2,3, and 4.

- Contribution to knowledge from this portion of the research is a new approach for diagnosing PROFINET networks in the absence of IO supervisor.

4. Develop hardware interfaces for fieldbus diagnosis at network level with reduced foot print.

- The objective is to develop diagnostics hardware with small foot that can be installed on a DIN rail in electrical cabinets. This objective is addressed in paper 4.

- Contribution to knowledge from this part of research is a new diagnostic tool for multiple fieldbuses with a small form factor.

5. Develop and test diagnostics tool for multiple fieldbuses.

- The objective is to develop a tool suitable for diagnosing multiple fieldbuses simultaneously. This objective is addressed in paper 4.

- Contribution to knowledge from this part of research is a software solution for diagnosing multiple fieldbuses simultaneously with a uniform user interface for all underlying fieldbuses.

6. Analyse behaviour of networked controllers.

- Accurate network timing relies on the timing behaviour of its connected devices. This objective is covered in paper 5.

- Contribution to knowledge from this part of the research proves for the first time through experimentation the differing behaviour of PROFIBUS masters in a multi master network.

7. Establish a practical method for fieldbus performance analysis.

- The objective is to establish a more practical method for analysing fieldbus networks. This objective is covered in paper 6.

- Contribution from this part of research shows a practical comparison of fieldbuses using standard diagnostic tools.

8. Establish a model for further development of diagnostics tools.

- The objective is to develop a multi-layered model for future development of diagnostic tools. Commentary addresses this topic and outlined a multi-layered model for further development of diagnostic tools.

1.5 Methodology

An engineering design approach following a traditional software design life cycle is used (Langer, 2012). Problem analysis was carried out based on reported literature and experience from industrial case studies to establish the “Recognition of need”. A layered conceptual model (Gajski, 2009) was defined to provide the framework for specification of different design approaches. Subsequently a number of designs for network diagnostics based on existing and emerging technologies are presented. Each design is developed further within the proposed model for implementation as Proof of Principle (PoP). Each individual approach was tested experimentally to show that it is a feasible method for network diagnostics.

1.6 Software developments

The contribution made by this portion of the research work, outlines the development of program subroutines(Function Blocks) for a number of Programmable Logic Controllers(PLC), including implementation of these blocks in three makes of PLCs(Mitsubishi, Omron, and Siemens) (Kaghazchi et al, 2007a). These blocks when called by the PLC, obtain the diagnostics data of PROFIBUS network and provide the data in a predefined format irrespective of the maker of the controller. The generated diagnostics data can be used by higher systems such as SCADA (Supervisory Control And Data Acquisition) for visualisation and notification purposes.

The work was extended to obtain the required data directly from the PROFIBUS networks by using a master class 2 and OPC (Open Process Control) server. This work makes the use of standard solutions provided by IT for process control (Kaghazchi et al, 2007b). OPC tags provide diagnostics data from all the masters and slaves on the network.

The OPC work was extended to cover other fieldbus networks such as PROFINET and Device net by developing further OPC servers (Keane et al, 2007). The mechanism developed in this research would make diagnostics data available across Ethernet (PC networks) and accessible within an enterprise from top floor to shop floor. The research work continued to develop a platform independent SCADA system based on C# to enable the visualisation of stations within the PROFIBUS network (Warner et al 2007). The colour coded background of each station identified its operating status (Green=ok, Yellow=dropped out, Purple=configuration problem, Red=Parameter problem). The software development outlined here, contributed to further development of diagnostics of industrial networks, by the use of platform independent SCADA system, and the use of OPC technology in obtaining the diagnostics data. Additionally a prototype device was designed and built to implement the software layer for demonstration and experimentation.

The exact timing of the communications cycles is of paramount importance in real time control applications. For PROFIBUS networks the behaviour of the masters on the network is a contributing factor in repeatable cycle times. Although the behaviour of Master class 1 is defined in PROFIBUS specifications, the implementation was at the discretion of the manufacturer of the device. Up until recently test and certification of the master class 1 was optional. This research work compared the behaviour of three master class 1 PLC's and showed experimentally the different behaviour of these devices (Kaghazchi et al, 2008). Partly as a result of this work, the PI (PROFIBUS and PROFINET International) has now made the certification of PROFIBUS master devices mandatory. The certification process ensures the adherence of the device manufacturers to established international standards.

The last portion of the software work concentrated on the use of the diagnostic tools for performance analysis of fieldbus networks. The tools are used to compare the performance of PROFIBUS and PROFINET class 1 networks. Comparative study was carried out to synchronise a lead and follower motors using both PROFIBUS and PROFINET (class 1) networks (Kaghazchi et al, 2013). The study used identical controller, Variable frequency drives, encoders, and motors. The results showed that the PROFIBUS network outperforms the PROFINET class 1 network in terms of degree of synchronisation, speed of communication and jitter. It is believed that this study brings academic rigour to the type of comparison that may be conducted by industrial practitioners.

1.7 Hardware developments

In tandem to some of the software development, special purpose hardware (gateway) was developed for actual implementations. A PC based system based on imbedded XP with interfaces for two PROFIBUS, one PROFINET, and one Device net networks was designed and built. In addition to the cut down version of the XP, four OPC servers were developed one per physical interface. This gateway can monitor four networks simultaneously, and provide the diagnostics in the form of OPC tags. The latter can be used by operation and maintenance personnel for easy diagnostics of multiple networks within a plant.

A parallel hardware development concentrated on developing an option for remote monitoring of PROFIBUS networks over mobile phone networks using GPRS. The advantage of this unit apart from the lower cost would be to enable connectivity to the outside world from within a plant, where Ethernet connection is not available or allowed.

The hardware development outlined above created unique hardware prototypes. A PC based gateway to provide interface to multiple fieldbuses simultaneously, and a wired/wireless interface for PROFIBUS networks. These devices are both capable of local and remote monitoring of networks.

In parallel to developments on fieldbus diagnostics, a prototype PROFIBUS slave device was designed, build and tested. The device takes inputs from two encoders connected to a lead and a follower motor. It performs the necessary calculations and determines the position difference between the motors and sends this data to the controller, which in turn adjusts the speed of the follower motor.

1.8 Proposed network Diagnostics Model

A layered model is defined for network diagnosis as shown in Fig1.1. This model provides a framework for development of network analysis and diagnostics tools. The approach is similar to OSI model defined by ISO for the development of communications networks. In this model any given network can encompass all or some of the layers in the model. In the proposed model shown below any diagnostics tool can poses some or all of the layers in the model.

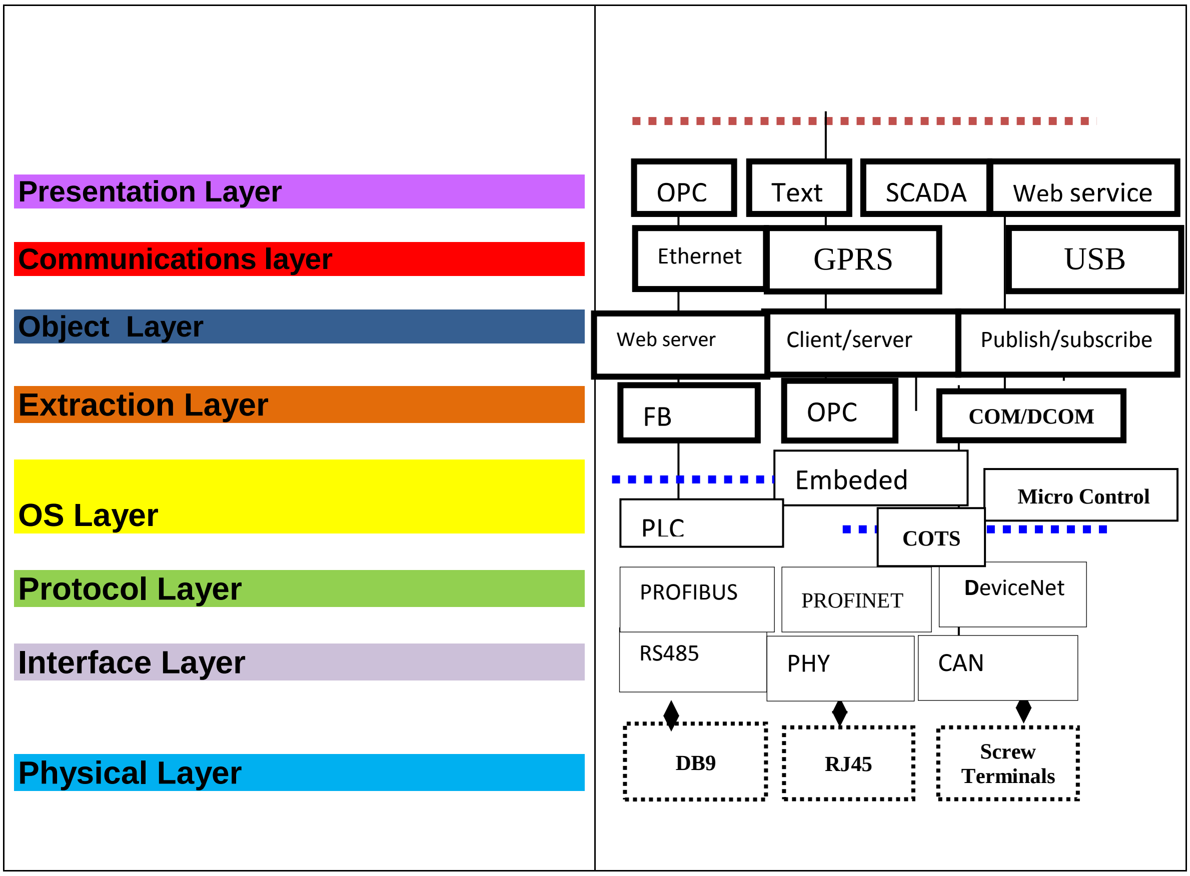

Fig 1.1: Proposed network Diagnostics Model

The first layer of the proposed model is the physical layer. This layer defines the mechanical means of interfacing the diagnostics device to the communications network. In the case of RS485 based networks such as PROFIBUS, this is normally a DB9 connector. For industrial Ethernet based networks it is normally a RJ45, and for CAN based networks such as Devicenet it is normally screw terminals.

As outlined above, layer two and three associate the interface layer with different communication protocols. For example RS485 is associated with PROFIBUS, Ethernet PHY is associated with PROFINET or Ethenet/IP, and CAN is associated with Devicenet and CANOpen.

Operating System (OS) layer can use a number of different options. For example the diagnostics software can run on a PLC, an embedded PC, a standard PC, or a specifically designed micro controller. Use of hardware design based on FPGA can also be implemented in this layer. The advantage of use of FPGA is that the hardware design can stay the same while the diagnostics firmware revisions progressively revised.

Extraction layer encapsulate different technologies that maybe used to convert the network diagnostics data into standard format, and share the information across a computer network. Use of standard communication Function Blocks (FB), Open Process Control (OPC) with UA or DA, and use of MS COM/DCOM are some of the available technologies in this layer.

Object layer classifies the mechanism for accessing the information from the hardware platform. For example if the diagnostics device is also simultaneously a web server, or an OPC server.

Communication layer determines the method that diagnostics device communicates with the local/ remote host system, which is normally a PC. This can be done over USB, Ethernet, or mobile phone networks.

The top layer is the presentation layer for the diagnostics information. A number of different options are available. The simplest format is text. Others such as web pages, SCADA, OPC tags are also possible depending on the options used in the previous layers.

1.9 Implementation

The proposed diagnostics model was implemented over a number of research investigations as follows:

- Development of Function Block (FB) for diagnosing PROFIBUS network for implementation on PLC.
- Development of OPC server for diagnosing PROFIBUS network for implementation on PC.
- Development of a web based diagnostic software for multiple fieldbuses for implementation on imbedded XP platform.
- Development of OPC server for diagnosing PROFINET network for implementation on PC
- Conformance testing of masters (PLC) in PROFIBUS network to improve the health of the network.
- Use of diagnostics tools for performance analysis of fieldbus networks for high performance applications.

Fig 1.2 below shows the implementation of the research work for generic PROFIBUS and PROFINET networks.

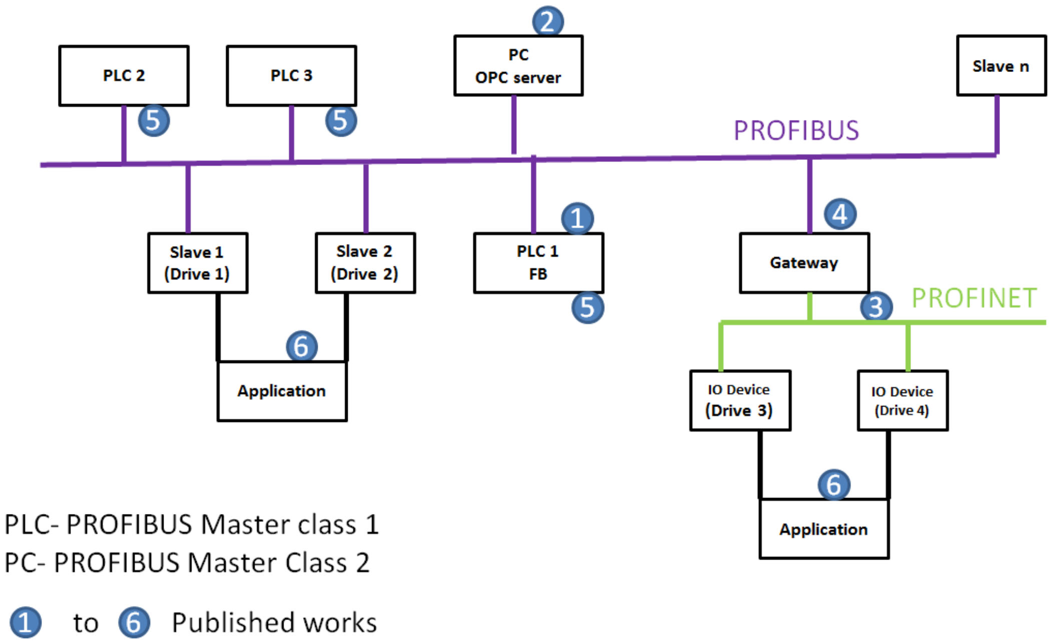

Fig 1.2: Implementation of the proposed diagnostic model for PROFIBUS & PROFINET

The result of research work is reported in 6 published papers and summarised below. For each research paper the title, purpose, methodology, findings, practical implications, and originality is given. Additionally the contribution of the candidate to each research paper is outlined.

1 : A function block diagnostic framework for a multi-vendor PROFIBUS environment

Purpose – This paper sets out to highlight the problem associated with the development of fieldbus diagnostics in a multi-vendor environment and to propose a solution based on diagnostic Function Blocks (FB).

Design/methodology/approach – The work focuses on the "master-slave" communication model in a PROFIBUS fieldbus system, where three different vendor solutions are investigated.

Findings – Although the fieldbus standards specify the type and format of the diagnostics data, the extent, location and sequence of diagnostics data within a controller are entirely vendor-dependent. The outcome from this work defines a framework for representing the diagnostics data in the context of a special data block.

Practical implications- This research provides a diagnostics FB for three popular PLCs(Siemens, Mitsubishi, Omron). The FBs can be used by end users to diagnose PROFIBUS Networks.

Originality/value – This research work defines a novel unified framework for representing the fieldbus diagnostics data using FB for multi-vendor solutions in a PROFIBUS environment.

Contribution of the candidate:

Designed the framework for storing diagnostics information. Developed the mechanism for obtaining the diagnostics data, and developed the function block for Siemens PLC, finally wrote the Journal article on the research work.

2 : Development of an OPC Server for a fieldbus diagnosis tool

Purpose – This research work exploits the development in COM and DCOM technology for the purpose of diagnosing fieldbus networks.

Design/methodology/approach – The work focuses on the relationship between a master class 2 and a slave device in a PROFIBUS network to obtain the necessary diagnostic data.

Findings – Along with developments in OPC (Open Process Control), it is possible to use OPC tags as a method of sharing the diagnostics data from PROFIBUS network across an enterprise.

Practical implications- This research work has developed an OPC server for diagnosing PROFIBUS devices. The server communicates to both slave devices and the master devices alike and makes the diagnostics data available on the Ethernet network as OPC tags.

Originality/value – This research work successfully developed a functioning OPC server, for an embedded PROFIBUS interface, which was tested in a large experimental PROFIBUS network. The OPC tags were made available to office applications such as Excel, and higher level SCADA application (WinCC).

Contribution by the candidate:

Developed the concept of using OPC server for diagnostics. Implementation of PROFIBUS Master class 2. Inclusion of the devices in PROFIBUS network, and testing OPC server. Wrote the article on the research work.

3: Retrieval of diagnostic information from PROFINET networks

Purpose – This research work exploits the development in COM and DCOM technology for the purpose of diagnosing PROFINET networks

Design/methodology/approach – The work focuses on the use an advanced IO device in a PROFINET network to obtain the necessary diagnostic data.

Findings – Along with developments in OPC(Open Process Control), it is possible to use OPC tags as a method of sharing the diagnostics data from PROFINET network across an enterprise.
Practical implications- This research work has developed an OPC server for diagnosing PROFINET devices. The server communicates to an intelligent IO device that stores all diagnostics alarms on PROFINET. The server communicates to the IO device and makes the diagnostics data available on the Ethernet network as OPC tags.

Originality/value – This research work successfully developed a functioning OPC server, which was tested in an experimental PROFINET network. The OPC tags can be made available to office applications such as Excel, and higher level SCADA application (WinCC).

Contribution by the candidate:

Responsible for PROFINET diagnostics collection and interpretation. Implementation of the device on PROFINET networks. Co-wrote the article on the research work.

4 : Development of Web-based software for a multi-fieldbus diagnosis tool

Purpose – This research work aims to develop a platform independent software for monitoring multiple fieldbuses simultaneously.

Design/methodology/approach – The work concentrates on integration of OPC servers developed individually for PROFIBUS, PROFINET, and Device Net. C# is used to develop the front end interface to collect diagnostics data from multiple OPC servers.
Findings – It is possible to develop an online diagnostics device based on OPC servers that can cater for a number of fieldbuses within a plant.

Practical implications- A platform independent diagnostics system was developed for PROFIBUS, PROFINET and Device Net networks, capable of monitoring these networks simultaneously.

Originality/value – A DIN rail mounted device was prototyped, and the application software was tested. The prototype device is now available for licensing and CE marking.

Contribution by the candidate:

Developed the OPC server for DeviceNet. Contributed to implementation of PROFIBUS, PROFINET, and Device net in the gateway. Also was responsible to set up all the networks in experiments. Co-wrote the article on the research work.

5: Influence of token rotation time in multi master PROFIBUS networks

Purpose – This research investigates the timing behaviour of master devices in multi master PROFIBUS network.

Design/methodology/approach – The work uses the master to master communication model for PROFIBUS network, and focuses on the token hold time for each master device.

Findings – It is found that the behaviour of each master is different in terms of token hold time, and varies across different vendors.

Practical implications- Test and certification increases compatibility and reduces network issues. This work demonstrates the differing behaviour of the master devices in PROFIBUS network.

Originality/value – This research work highlighted the nonstandard behaviour of the master devices. Partly as a result of this work that the testing of master devices are now made mandatory by PI(PROFIBUS/PROFINET International)

Contribution by the candidate:

Originated the idea, designed the required series of tests, analysed the results and wrote the paper on the research work.

6: Synchronisation of multi-motor speed control system.

Purpose – The purpose of this research is to compare an industrial ethernet based network (PROFINET Class 1) with a traditional fieldbus network (PROFIBUS).

Design/methodology/approach – Two sets of identical motors were used in the experimental set-up. The speed synchronisation of a lead and follower motors was compared using both PROFINET Class 1 and a PROFIBUS network. The level of synchronisation achievable was used as a measure of performance for each network.

Findings – It was found that PROFIBUS produces a better performance for set point and load changes than PROFINET Class 1 network.

Research limitations/implications – PROFINET Class 2 and higher could not be used in the experiment due to availability of equipment and funding.

Practical implications – This research provides a comparative study of two very popular industrial networks. The results can be referenced by industry for selection of industrial networks.

Originality/value – The paper provides a manufacturer independent practical comparison of two industrial networks. The application area of speed synchronisation is demanding, and should inform the user on the performance and limitation of industrial networks.

Contribution by the candidate:

Originated the idea, responsible for assembly of experimental rig. Designed PROFIBUS, and PROFINET networks. Contributed to analysis of experimental data. Wrote the Journal article on the research work.

1.10 Thesis layout

The commentary includes an introduction to the research topic and the introduction of proposed model for network diagnostics. The research work is carried out over 6 published papers. These will form the main body of chapters 2-7 with added introduction, conformance to proposed model, conclusions, and contribution to knowledge for each paper. Chapter 8 draws conclusions from the work carried out, overall contribution made by the research, and limitations of the approach. It concludes with some possible work for the future.

Chapter 2: A function block diagnostic framework for a multi-vendor PROFIBUS environment

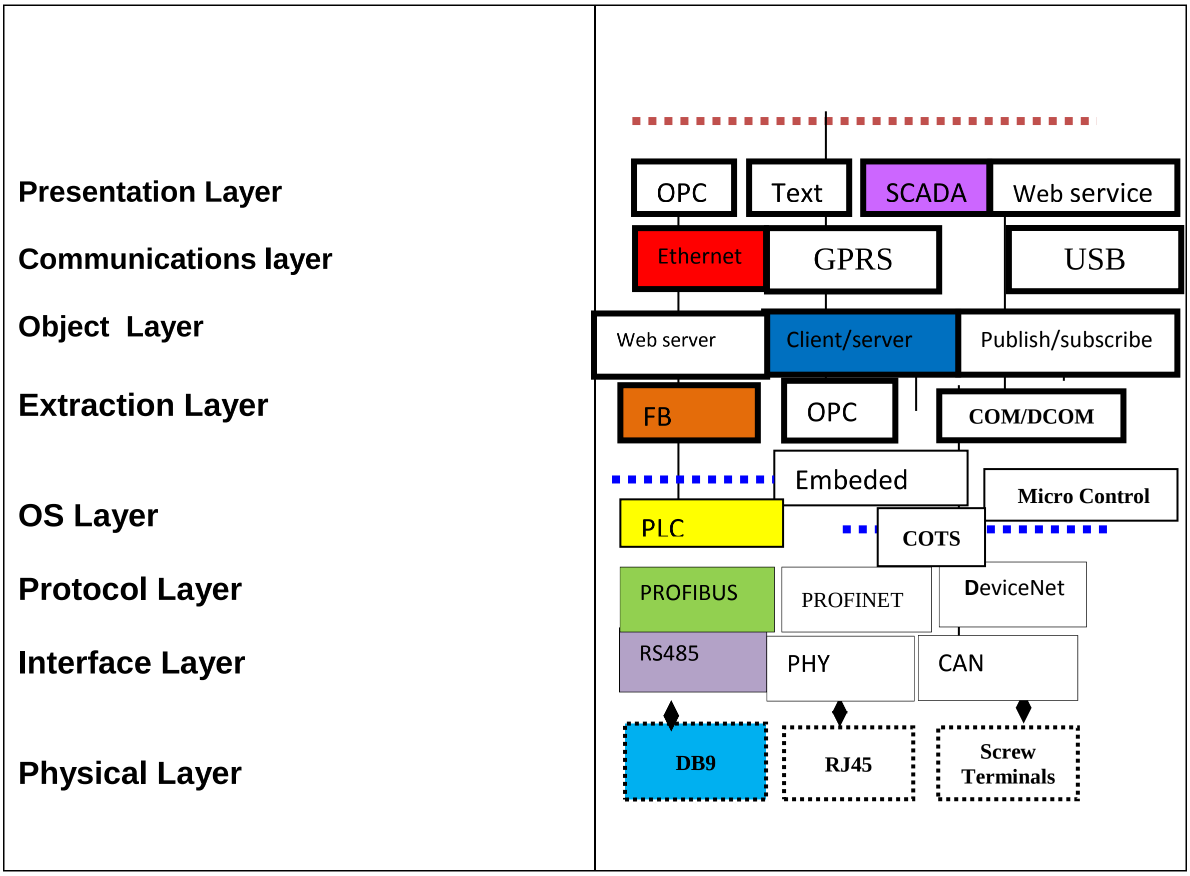

Fig 2.1 Proposed Network Diagnostic Model: Use of Diagnostics FB

2.1 Introduction

Fieldbuses were introduced to the market over 20 years ago. The wide spread use of fieldbuses has accelerated the move from centralised control systems to more distributed arrangements. With a large installed base of fieldbus networks, and the need for continuous operation of plants, fast and reliable methods of network diagnostics are required.

The need for fast and efficient method of fieldbus diagnostics has prompted the vendors to include some diagnostics capabilities in their programming environments for control systems. Although this vendor specific approach maybe effective to some extent in single vendor environment, however it becomes even less effective in multi-vendor environments.

In addition, third party companies have recognised the need for diagnostics, and have introduced bus analysers, which require deployment of additional hardware, and software. The expertise on the part of end users is required to analyse the diagnostics data. The introduction of additional network components will have an adverse effect on the performance of the network. For marginally stable networks, it is possible to crash the network by addition of extra load.

The concurrent development efforts by IEC and PLCOpen in relation to standard approach and reusability of programme blocks in control systems, has provided the incentive for the development work reported in paper 1.

The development of IEC 61499(2000), has provided the frame work for development of function blocks in measurement, control and distributed applications. Some research work on formal modelling of the functions blocks was reported by Luder et al (2005), while Thramboulidis et al (2004) reports on field device models in distributed applications, and Sunder et al (2005) reports on conceptual modelling of mechatronic components.

PLCOpen efforts have established the use of function blocks for motion control applications (2005). Based on application requirements and project specifications engineers are required to use or select a wide range of motion control hardware. In the past this required unique software to be created for each application even though the functions are the same. PLCopen motion standard provide a way to have standard application libraries that are reusable for multiple hardware platforms. This lowers development, maintenance, and support costs while eliminating confusion. In addition, engineering becomes easier, training costs decrease, and the software is reusable across platforms. Effectively, this standardization is done by defining libraries of reusable components. In this way the programming is less hardware dependent, the reusability of the application software increased, the cost involved in training and support reduced, and the application becomes scalable across different control solutions. Due to the data hiding and encapsulation, it is usable on different architectures, for instance ranging from centralized to distributed or integrated to networked control. It is not specifically designed for one application, but will serve as a basic layer for ongoing definitions in different areas. As such it is open to existing and future technologies.

As outlined in introduction to this paper the use of function blocks for fieldbus diagnostics at the controller level was not reported at that point in time, however the use of function blocks for diagnosing the fieldbus at the network level using OPC was reported by Toro et al (2002). The majority of the reported cases of use of functions blocks seem to concentrate on the formal modelling and verification of distributed control system, and motion control applications at the time.

The approach taken in this research work is the use of standard Functions Blocks (FB) to aid diagnosis of fieldbus networks. The outlined method uses no additional hardware or network component, and it is purely a software solution. The work complies with the IEC standard 61499, and defines a common framework for representing the diagnostics data for fieldbus networks at the controller level. This provides a solution at the controller level, and the diagnostics FBs can be implemented on individual controller.

The development work uses the master-slave relationship in PROFIBUS networks. When a slave has diagnostics to report, it flags this to the master when it is sending the output data to the master. Then the master requests diagnostics from the slave and slave replies with the diagnostic data. So the master will have at any point in time the last diagnostic data from each slave device. The format and location of the data varies from one controller to another.
A function block can query the master and obtain the relevant diagnostic data and put it in a predefined manner in a data block. Therefore by developing function blocks to obtain the diagnostic data from the controller and writing this data in a predefined and uniform layout into a data block, the representation of the diagnostic data can be standardised for all makes of controllers.

The diagnostics FB once tested and verified can be included in the standard FB library for each vendor. This will minimise the programming effort for the end user, and would simply be a drag and drop process to use the FB. The developed FB will mask the complexities involved in obtaining diagnostics data, and to the end user would be a matter of filling the required FB parameters, such as the number of devices on the network, and data block number where diagnostic data are to be stored.

The developed diagnostics FBs can be implemented on any make or model of controller either a PLC or a PC. The diagnostic data is stored into data blocks for each controller, in the same format, and can be accessed by the higher level systems such as SCADA for monitoring and alarm generation.

2.2 Literature update

A number of follow on research work on the topic of “Diagnosing fieldbuses using Function Blocks” are reported since the publication of the candidate’s paper 1. These are outlined below:

A paper by Piggin et al (2008) describes a model for Function Block communication and diagnostic messaging with Ethernet/IP. This work has proposed the use of Function Blocks for the transfer of information between devices on an Ethernet/IP network and a controller.

The work is validated using a CIP-enabled switch, and a Control_Logix PLC. The explicit messaging facility of Ethernet IP is used to obtain the diagnostic data from a device, and also configuration of the device by the controller. The research work defined a framework for representing diagnostic and configuration data in a prescribed format referred to as User defined Data Type (UDT).

The research work acknowledges candidate’s first paper on “Using Function Blocks for diagnosing fieldbuses”. The latter also used a UDT for representing the diagnostic data from devices connected to a PROFIBUS network. The basis for PROFIBUS communication is master-slave principle, and for Ethernet/IP the explicit messaging is used to obtain the required diagnostic data from the device.

In summary the work outlined by Piggin et al (2008) applies use of FBs to Ethernet/IP network, and shows that the diagnostics framework proposed by the candidate can be applied equally to different fieldbuses.

2.3 Conformance to proposed model

The use of Function Blocks for fieldbus diagnostics presented in this paper is the first in the series. The conformance of this research work to the proposed model for fieldbus diagnosis is outlined below, and is highlighted in Fig2.1.

Layer 1: Physical Layer

- As this is a software solution for fieldbus diagnosis, there is no hardware interface. The DB9 interface is normally used to connect the controller to fieldbus network.

Layer 2: Interface Layer

- The research focuses on PROFIBUS, which is based on RS485 transmission technology. The limitation of this transmission in the main is applicable to PROFIBUS.

Layer 3: Protocol Level

- Fieldbus under consideration is PROFIBUS. This is the most common fieldbus used globally with over 50 million devices in operation.

Layer 4: OS layer

- A PLC is used as the PROFIBUS master and is used to execute the code in the diagnostics Function Block (FB).

Layer 5: Extraction layer

- A number of FBs were developed for different PLC vendors. These include Siemens, Mitsubishi, and Omron. These FBs are used to extract the diagnostic data.

Layer 6: Object layer

- In this implementation a client/server arrangement is used to read the diagnostic data from the PLC.

Layer 7: Communication layer

- In this implementation Ethernet is used to communicate from PC to PLCs to transfer the diagnostic information.

Layer 8: Presentation

- Siemens WinCC SCADA system is used to represent the diagnostic data to the end user.

2.4: Paper 1 - A function block diagnostic framework for a multi-vendor PROFIBUS environment

2.5 Conclusions

Continuous and efficient plant operation requires a fast method of diagnostics. IEC 61499 provides the required framework to develop diagnostics FBs for a variety of controllers in order to reduce the programming effort in setting up the fieldbus system and its operation and maintenance. The work presented in this paper has shown the complexities involved in obtaining fieldbus diagnostics from vendor specific hardware platforms. The task of developing diagnostics FBs were made easier for cases where a basic Service Interface FB is provided by the vendor.

Diagnostics FBs were developed according to IEC 61499 for a number of PLCs, these include Siemens, Mitsubishi and Omron, and implemented to obtain diagnostics from PROFIBUS networks. The uniform format of the data blocks enables the fast diagnosis of the network irrespective of the make and the model of the PLC used. These blocks can be made available as standard library by the vendors. The end user can then call these blocks, and fill in the blanks and the diagnostics data is obtained transparently by the PLC.

The interface to the fieldbus is through connected devices, both master and slaves. The master stores the last diagnostics message received from each slave. FB execute every time a slave provides a diagnostics to the master, and obtains the diagnostic data, and places in the correct position within a data block. The format of the data block is the same for all the controllers. The data blocks can be accessed by higher systems such as SCADA through Ethernet communication with the controller.

The look and feel of the diagnostics FB is also similar and this will aid the use of these FBs by the programmers and may provide the opportunity for the standardisation bodies to define the exact format in which the diagnostics data should be presented in fieldbus networks. Additionally, the FB method provides the software modularity required in control systems to enable manufacturing systems to be more flexible.

2.6 Contribution to Knowledge

This research developed a new frame work for diagnosing fieldbus networks at the controller level. It developed and tested an original diagnostic Function Blocks (FB) based on IEC61499 standard for multiple vendors. The FBs were developed for three makes of PLC and tested and verified against known network issues. These FBs can obtain the fieldbus diagnostics data and present the data in a uniform format to the end user. The research work presented in paper 1 addressed the objective no 1 of this thesis.

2.7 Limitation of previous work

As outlined in the introduction to this chapter the introduction of IEC 61499 standard on function blocks paved that way for the research work to be conducted on the development of function blocks for different application areas. The reported work by previous authors such as Luder et al (2005), Thramboulidis et al (2004), and Sunder et al (2005) concentrated mainly in the area of using function blocks for measurement and control purposes as well as modelling of distributed systems. There was also a reported case of fieldbus diagnosis at the network level using OPC by Toro et al.

Therefore no reported case of use of function blocks at the controller level for network diagnostics was presented and this has led to the proposed use of function blocks for fieldbus diagnostics at the controller level which was outlined in paper 1.

2.8 Limitation of current work

As outlined previously, the network diagnostics can be done mainly at the controller level or at the network level. The use of Function blocks for diagnosing fieldbus networks represents diagnostics at the controller level. The developed function blocks need to be implemented at the design stage of the project, in particular in regulated industry. The widespread use of FBs for fieldbus diagnostics would require the co-operation of PLC vendors and standard bodies to agree on the frame work for diagnostic data representation, and development and test of diagnostic FB subsequently.

Chapter 3: Development of an OPC Server for a fieldbus diagnosis tool

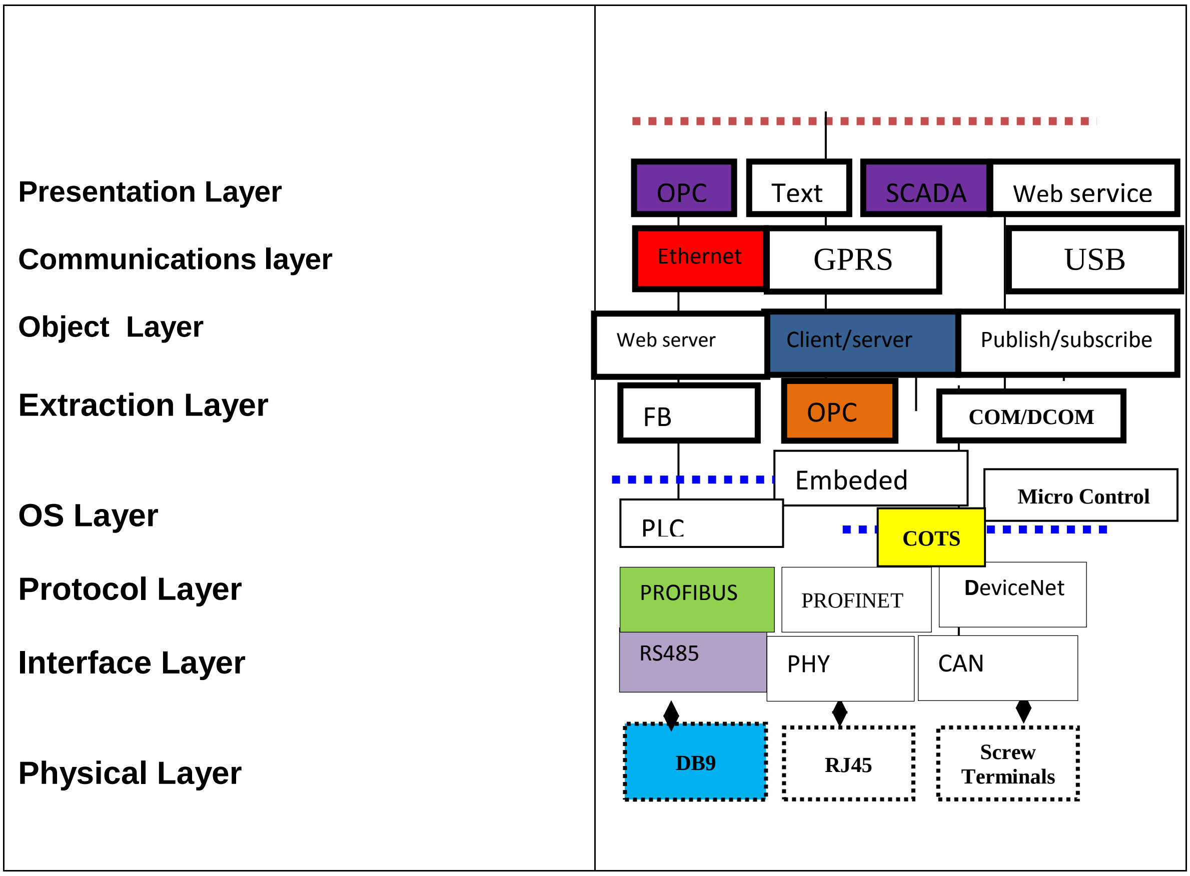

Fig 3.1 Proposed Diagnostic Model: Development of OPC server for PROFIBUS

3.1 Introduction

In modern manufacturing plants the control is distributed to remote I/O using fieldbuses. With the increasing use of fieldbuses and geographical spread of plants, a fast and efficient method of fieldbus diagnostics is required to keep the plants operational and reduce the downtimes.

The emergence of Open Process Control (OPC) standards provide a means of connecting the factory floor data to higher level systems in the plants such as MES. Additionally OPC provides a uniform method of accessing data from across higher level networks such as Ethernet. With OPC, normally a PC communicates with the devices such as masters or slaves on the fieldbus network. The data in the form of OPC tags are made available by the OPC server to OPC clients, which are the users of the data. This enables different category of users, such as maintenance, operation, engineering, management and accounts departments within a plant to access their required data.

The objective of this research is to implement an OPC server with an interface to a PROFIBUS network. The interface is configured as Master Class 2(MC2) on the PROFIBUS network. As the MC2 receives the token from the controlling master (MC1), it communicates to slaves to obtain the diagnostic data. It also communicates to MC1 to obtain the status of the MC1. The data points are then converted to OPC tags, and made available to OPC clients over the Ethernet network. The data can be viewed as raw OPC tags or represented in SCADA system at application layer. Fig 3.1

Current tools for diagnosing fieldbus networks in general provide an interface to a single fieldbus network. In contrast the choice of hardware module used in this research provides the flexibility to develop additional OPC servers for other fieldbus networks. The development of OPC servers for PROFINET and DeviceNet is outlined in the following chapters. This work is part of a larger project to develop diagnostics device for multi fieldbus networks.

The use of pluggable fieldbus modules provides a smaller footprint for the device. Additionally the user interface is similar for all fieldbuses, and makes the interface look and feel similar irrespective of the underlying fieldbus connection.

3.2 Literature update

A number of follow on research work on the topic of “Diagnosing PROFIBUS networks” are reported since the publication of the candidate’s paper 2. These are outlined below:

The researchers at The University of Sao Paulo, Electrical Engineering department has made an attempt in using Artificial Neural Networks(ANN) to identify possible network problems, ranging from long cabling, missing or additional terminations, short between A and B lines, short A or B to shield, broken cable and connector problems. The work was presented in a series of three papers.

First paper Souza, et at (2012) sets out to generate simulated data for the electrical wave form of a PROFIBUS network. The samples were used to train the Neural Networks. An experimental PROFBUS network was set up and a number of scenarios such as long cable, missing or additional terminations were created, and the waveforms recorded for each case. ANN is used to establish the known cause for each case. The conclusions from this work are that ANN can be used to diagnose installation problems that cause distortion of waveform transmitted on PROFIBUS network.

The work reported is a physical layer diagnostic approach, and mainly limited to particular configuration of the network, in terms of the communication speed, number of devices use, and the length of the network. This is a promising work as it may be generalised to cover most configurations.

The second paper Mossin et al (2012), follows on from the previous work reported by the group on the physical layer diagnostics of PROFIBUS networks using ANN. The work reproduces the work and then attempts to use the data link diagnostics layer, as a feedback mechanism for physical layer diagnostics.

A number of simulated problems on an experimental PROFIBUS network were created and waveforms recorded. The recorded waveforms were used to train Neural Networks. ANN was used to classify the possible causes of failures.

Additionally the diagnostic telegrams were used to extract the problems reported by slave devices to the master station. These were used to verify the correct operation of ANN. The conclusions from this paper are the same as the previous paper from the group. Again it shows the limitation ANN to give correct analysis for a given configuration of PROFIBUS networks.

The third paper by Serpa Sestito et al (2014) for most part is the reiteration of what was covered in the previous two papers. One noticeable difference is the training of ANN for EMI problems, although the actual creation of EMI in a laboratory environment remains unclear. As with the previous two papers, although the diagnostics results from ANN remains encouraging for a given network set up, the generalisation of the concept remains elusive.

3.3 Conformance to proposed model

The use of OPC technology for fieldbus diagnostics is presented in this paper. The conformance of this research work to the proposed model for fieldbus diagnosis is outlined below, and is highlighted in Fig 3.1.

Layer 1: Physical Layer

- This is a combination of software and hardware solution for fieldbus diagnosis. A master class 2 with a DB9 interface is used to connect to the PROFIBUS network.

Layer 2: Interface Layer

- The research focuses on PROFIBUS, which is based on RS485 transmission technology. The limitation of this transmission is in the main applicable to PROFIBUS.

Layer 3: Protocol Level

- Fieldbus under consideration is PROFIBUS. This is the most common fieldbus used globally with over 50 million devices in operation.

Layer 4: OS layer

- A PC with MS-XP operating system is used as the PROFIBUS master class 2. The PC can obtain individual diagnostic data from each connected station.

Layer 5: Extraction layer

- The diagnostic data obtained from each station is assigned to an OPC tag. In addition to diagnostics data other data such as configuration of the station and IO can be obtained from any of the stations and assigned to an OPC tag.

Layer 6: Object layer

- The connected PC acts as an OPC server, and any other PCs on the same Ethernet network can connect to the server as a client.

Layer 7: Communication layer

- In this implementation Ethernet is used to communicate from the server PC to client PCs to transfer the diagnostic information.

Layer 8: Presentation

- Siemens WinCC SCADA system and OPC tags are used to represent the diagnostic data to the end user.

3.4 Paper 2-Development of an OPC Server for a fieldbus diagnosis tool

3.5 Conclusions

The work outlined in this paper is the first phase of development of a multi fieldbus diagnostics device. In this phase the interface was developed for PROFIBUS networks, and in the follow on phases interfaces were developed for PROFINET and DeviceNet.

The choice of a modular pluggable interface provides the flexibility for inclusion of other interfaces, and at the same time reduces the foot print of the final device.

The use of OPC technology enables the standardisation of data access methods, and sharing of data across higher networks such as Ethernet. The diagnostic data in the form of OPC tags can be accessed both locally and remotely.

Configuration, IO data, and diagnostics information for each slave device is represented as OPC tags, as well as diagnostics of the master stations. The developed OPC server for PROFIBUS interface is one of the servers for a multi fieldbus interface device. The tags from the server can also be used in a SCADA system for visualisation of diagnostics and other data.

The use of interface as MC2 provides the advantage of requesting the latest diagnostics information from devices as and when it is required. This is an advantage over other sniffing tools, where a device continuously is listening for diagnostics data. On the down side use of MC2 will marginally increase the communication cycle time. The experimental investigation shows that the effect of increase in cycle time is negligible.

The use of OPC server for diagnosing fieldbus networks provides a uniform approach to data capture, representation, and access. The development work carried out for PROFIBUS network provides a frame work for inclusion of other fieldbuses such as PROFINET and Device Net. It is worth to mention that the final multi fieldbus diagnostics device will have two PROFIBUS interfaces, one PROFINET interface, and one DeviceNet interface. Therefore the number and type of interfaces can be varied in the device depending on the requirements.

3.6 Contribution to Knowledge

The research work established a software solution for fieldbus diagnostic at the network level. This research work successfully developed a functioning OPC server for a new hardware interface with a small foot print. The interface was developed and tested in a large experimental PROFIBUS network. The OPC tags were made available to office applications such as Excel, and higher level SCADA application such as WinCC. The research work reported in paper 2, addresses the objectives no 2 and 3 of this thesis.

3.7 Limitation of previous work

The previous reported work such as Turau et al (2004) on vertical integration of fieldbus systems, Errath et al (1999) on remote drive condition monitoring, Zurawski(2005) on co-existence of multiple fieldbuses within a plant provided some of the background to the research work reported in this paper. The non-standard approach taken by previous research work also informed the research work reported in paper 2 to the necessity for a standard approach using OPC.

Additionally the developments by the vendors have provided the interface hardware in the form of ISA PC cards and commercial OPC servers developed for the hardware. The hardware used would require a large foot print. The development of the standard form factor (PC104) with smaller footprint provided the incentive for this research to develop a stackable hardware, which would be small and compact. This would provide an opportunity to expand the device to include diagnostics mechanism for additional fieldbuses, while maintaining a small foot print. The use of Master class 2 functionality was not widely explored in previous reported work, and this also inspired the research work reported in this paper.

3.8 Limitation of current work

The work reported describes the development of an OPC server for a PC 104 PROFIBUS interface card; this was the first reported case of an OPC server for this hardware platform. The development was the start phase for a larger project on developing a multi-fieldbus diagnostics device. The limitation of using a PROFIBUS master class 2 for diagnosing at the network level applies to this work, in that the cycle time of the network will slightly increase, which in most cases is negligible.

Chapter 4: Retrieval of Diagnostic information from PROFINET Networks

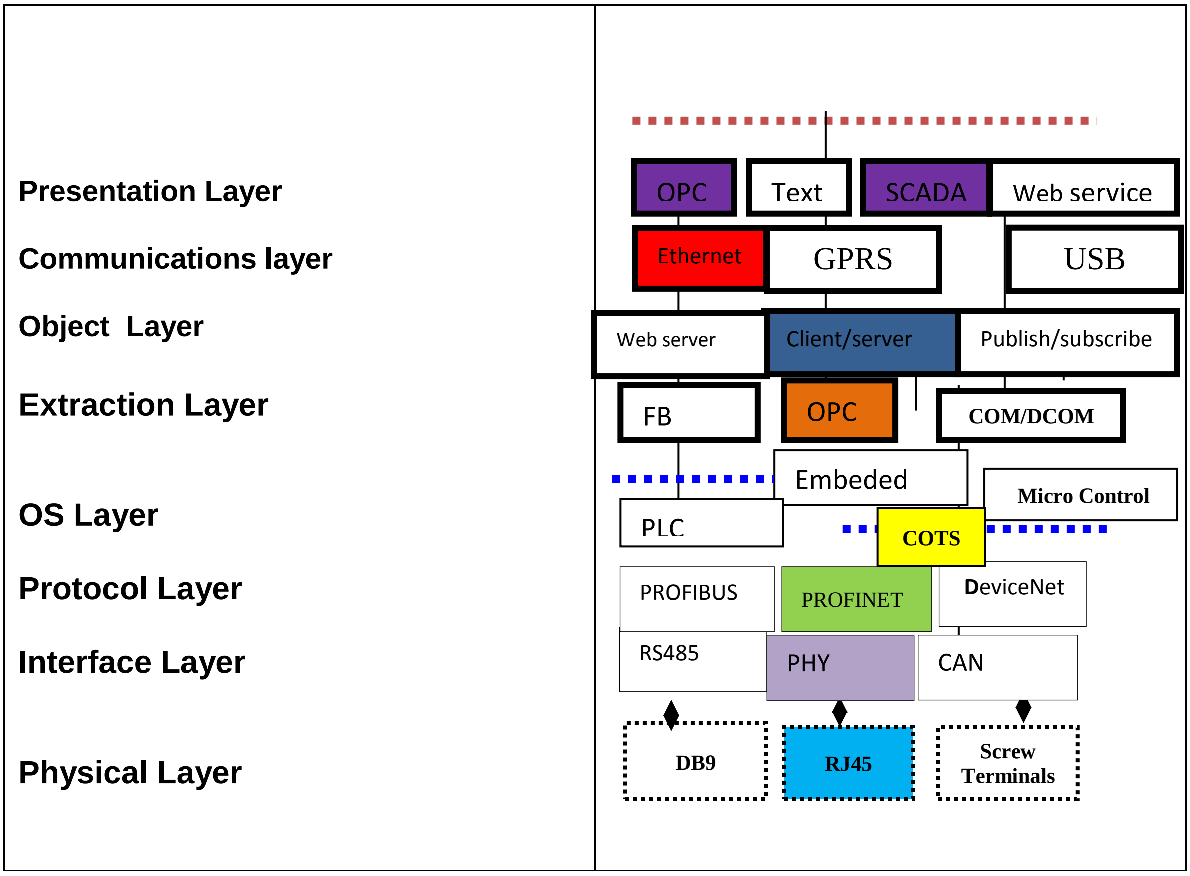

Fig 4.1 Proposed Diagnostic Model: Development of OPC server for PROFINET

4.1 Introduction

The increased number of networked field devices in manufacturing and process industries brings about issues for diagnosing the interconnected devices, and networks to achieve continuous plant operations.

In this research work a diagnostics tool is proposed, with an interface to PROFINET networks. The research work is part of development of a multi fieldbus diagnostics tool. The emergence of OPC technology has enabled a uniform data access across an enterprise from factory floor to board room.

The development of the interface for PROFIBUS networks and the use of OPC technology were covered in the previous paper. The extension of the work to cover PROFINET interface is reported in this paper. A lot of similarities exist between the development work for PROFIBUS and PROFINET in terms of development environment and OPC server; however the implementation of IO supervisor functionality (similar to MC2 in PROFIBUS) could not be implemented. Although the IO supervisor is defined in PROFINET standard, no physical implementation could be found at the time. A work around solution was devised to use an additional IO device to capture the diagnostics messages on the PROFINET network.

Similar to PROFIBUS an OPC server is developed to present the diagnostic data as OPC tags on Ethernet. In general the PROFINET diagnostics is similar to PROFIBUS with the addition of alarms.

4.2 Literature update

A number of follow on research work on the topic of “Diagnosing PROFINET networks” are reported since the publication of the candidate’s paper 3. These are outlined below:

A paper by Cupek et al (2009) reports on the development of a passive OPC DA server for PROFINET networks. It outlines the work involved in using Windows Packet Capture (WinPCap) to capture and classify PROFINET frames. The experimental setup uses port mirroring to duplicate the traffic from PROFINET IO controller port to a PC. All PROFINET telegrams with Ether type 0x8892 are classified under different classes such as RPC, ARP, Alarm, and DCP.

An OPC DA server was developed using an OPC development kit from Softing to covert the data into OPC tags. The resulting tags can be made available to the client. The latter was implemented on the same PC. Although the research work reports OPC server update time of 10 ms, in reality the update time of OPC client will be slower due to communication delays, as the server and client will likely to be on different PCs on the network.

This work is an extension of OPC server developed in candidate's paper 3 to include data tags, identification tags, Connect/control tags, and alarms. However unlike the work reported in paper 3 the Alarm tags are not further analysed to produce specific diagnostic information such as device, module and channel related diagnostics.

A paper by Jager, et al (2011) proposed an automatic topology discovery algorithm as a method of diagnosing PROFINET networks. A three step procedure is proposed in the scheme. The first step is to collect IP addresses of connected devices by the use of DCP. Step 2 is to identify local neighbourhood by analysing LLDP-MIB of each device via SNMP. The last step is to merge the nodes to create a topology graph.

This work is an attempt to create a high-level mechanism for device identification within a PROFINET network, by establishing a correct topology of the network. This is useful for fast identification of a device on the network, in particular in large PROFINET networks used for example in car manufacturing plants.

Although this work references the candidate's paper 3, however the reported work provides only a layout of the network, and the detailed diagnostics such as alarms, and module or channel related diagnostics are not made available to the user. The proposed work is complementary to candidate's work and if combined, can produce both a high-level and low-level diagnostic of PROFINET networks.

A paper by Sahin et al (2013) uses Wireshark for discovery of PROFINET network topology. Similar to the paper above this work concentrates on high level neighbourhood discovery of device.

The research work uses DCP protocol to discover the devices on the PROFINET network, then LLDP protocol is used to identify the neighbours of each device, and finally SNMP is used to extract the neighbourhood information stored in each device. It is worth noting that all the devices used in this experimental PROFINET network support LLDP and can store the neighbourhood information in MIBs.

This research work references candidate's paper 3. The commonality between the reported works is that both use Wireshark to analyse the communication frames for different purposes. The work reported by Sahin et at, focuses on the high level topology discovery while the work by the candidate focuses on diagnosing individual device, modules within a device and channels within a module.

4.3 Conformance to proposed model

The use of OPC technology for fieldbus diagnostics presented in this paper. The conformance of this research work to the proposed model for fieldbus diagnosis is outlined below, and is highlighted in Fig 4.1.

Layer 1: Physical Layer

- This is a combination of software and hardware solution for fieldbus diagnosis. A special IO device with a RJ45 interface is used to connect to the PROFINET network.

Layer 2: Interface Layer

- The research focuses on PROFINET, which is based on Ethernet PHY for transmission. The limitation of Ethernet in terms of determinism is overcome by introduction of switches.

Layer 3: Protocol Level

- Fieldbus under consideration is PROFINET. This is an emerging technology used globally with over 8 million devices in operation.

Layer 4: OS layer

- A PC with MS-XP operating system is used to obtain the network diagnostic data from the special IO device. The PC can obtain diagnostic data for most connected stations.

Layer 5: Extraction layer

- An OPC server is used on the PC and the network diagnostic data obtained from special IO station is assigned to OPC tags.

Layer 6: Object layer

- The connected PC acts as OPC server, and any other PC on the same Ethernet network can connect to the server as a client.

Layer 7: Communication layer

- In this implementation Ethernet is used to communicate from the server PC to client PCs to transfer the diagnostic information.

Layer 8: Presentation

- Siemens WinCC SCADA system and OPC tags are used to represent the diagnostic data to the end user.

4.4: Paper 3 - Retrieval of Diagnostic information from PROFINET Networks

4.5 Conclusions

The paper outlines the process of inclusion of PROFINET interface in a multi fieldbus environment. The main difficulty encountered in this work is the lack of implementation of IO supervisor functionality for devices on the market. A work around solution was used, where a special IO device was used on the network to capture the diagnostics telegrams. The application program is used to obtain the diagnostics data from the special IO device and pass it on to the OPC server. In turn the OPC server converts the data into OPC tags and makes it available to OPC clients.

Until such a time that PROFINET IO supervisor becomes available, the use of an additional IO device (Anybus module in this case) or similar will provide a work around solution. However this is not an ideal situation, as the devices cannot be interrogated to obtain the diagnostics data, rather the diagnostics data has to pass on the network, before it can be captured.

The work outlined in this paper provides a solution to diagnosing PROFINET networks as part of the development of a multi fieldbus capable device. An important side issue is use of an advanced IO device to emulate the IO supervisor functionality on the PROFINET network. The downside of this implementation is that once the alarm condition is resolved the diagnostics data is no longer available from the Anybus Module. Therefore reading of the data from Anybus module by the application must be performed while alarm exists.

The development work outlined in this paper made a substantial contribution to development of OPC server for PROFINET interface and implementation of IO supervisory function as defined in PROFINET specifications. The work builds on the OPC server development for PROFIBUS network outlined in the previous paper, and will form the basis for the development of a PC based multi fieldbus diagnostics device outlined in the next paper.

4.6 Contribution to Knowledge

This research work has developed a software solution for diagnosing fieldbuses at the network level. This work introduced the new approach for vendor independent PROFINET diagnosis by using an Intelligent PROFINET IO device as a work around solution in the absence of a standard PROFINET IO supervisor. It developed an OPC server based on OPC standard for diagnosing PROFINET devices. The server communicates to an intelligent IO device that stores all diagnostics alarms in a PROFINET network. The OPC server communicates to the IO device and makes the diagnostics data available on the Ethernet network as OPC tags. The work reported in this paper addresses the objective 2, and 3 of the thesis.

4.7 Limitation of previous work

The co-existence of fieldbuses in plants and the ever increasing need to provide timely diagnostics data to keep the plants running provided the background for this research.

PROFINET was at the time of publication of research reported in paper 3 a new networking technology which was just introduced to the market. The reported literatures such as Jasperneite (2005) were mainly on the operation of PROFINET and not many reported cases of work on diagnosing PROFINET networks. This provided the incentive to start the development work on diagnosing this new network technology. As outlined previously the emergence of OPC technology as de facto standard inspired this work. The experience gained from similar work on development of OPC server for diagnosing PROFIBUS network reported in paper 2 also informed this work

4.8 Limitation of current work

Similar to previous work reported in paper 2, the concept of “supervisor” functionality was investigated. A work around solution using an intelligent IO device provided a reasonable solution. The limitation of this work in principle would be similar to that reported for PROFIBUS. In the main addition of devices to capture diagnostic telegrams on the network will increase the communication cycle time marginally. More importantly the addition of an intelligent IO device will require a reconfiguration of the hardware in the PLC, and this may not be possible in all cases.

Chapter 5: Development of Web based software for a multi-fieldbus diagnosis tool

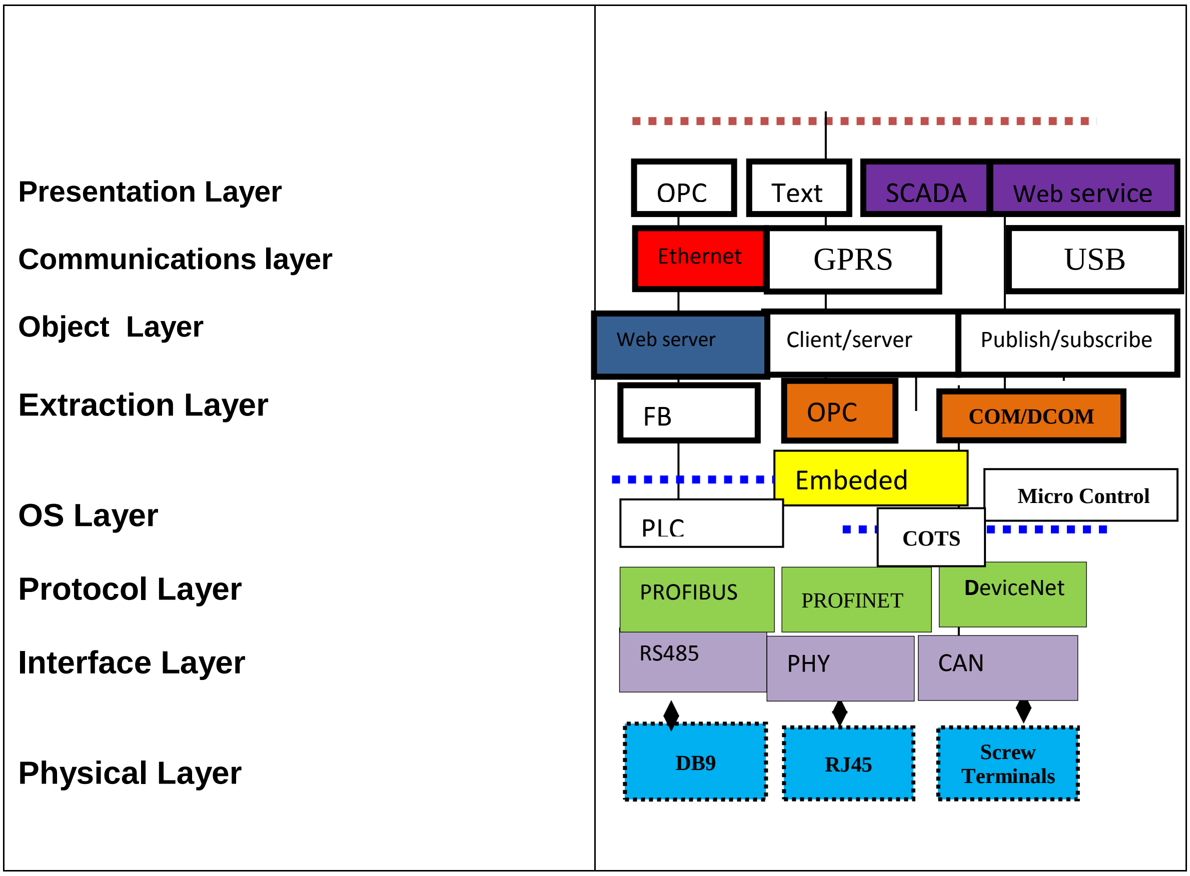

Fig 5.1 Proposed Diagnostic Model: Multi-fieldbus diagnosis tool

5.1 Introduction

Current manufacturing plants use variety of fieldbuses for automated manufacturing. Normally the type of fieldbus used is determined by the country of the origin of the equipment manufacturer. For example German machine builders use PROFIBUS and PROFINET, while their American counterparts may use DeviceNet and ControlNet. As a result it is possible to have multiple fieldbuses within a plant.

The objective of this research work is to bring together the previous work outlined in the last two papers and integrate the hardware and software developed into a single multi-fieldbus diagnosis device. The interfaces developed previously for PROFIBUS, PROFINET, and DeviceNet and their associated OPC servers are used to provide network interface for the final device. The OPC servers provide the diagnostics information from each underlying network in the form of OPC tags to the application. The latter runs on a PC platform with cut down version of MS Windows XP (Embedded XP). The application is developed within MS .Net environment, and in C-sharp.

Microsoft's IIS (Internet Information Server) is used for the development of web pages; these pages show the status of each networked device. The web pages have similar look and are independent of the underlying fieldbus connection. There are four interfaces provided on the device, two PROFIBUS ports, one PROFINET port, and one DeviceNet port. The device is small and DIN rail mountable.

For communication security SSL (Secure Sockets Layer) is used for encryption of data. Microsoft's IIS server is capable of transferring web pages via an SSL encrypted HTTP connection. This ensures that unauthorised systems or users cannot listen in on the communication between server and client. This option has been selected due to standard web browser support for SSL based communications.

The prototype device was tested in a multi fieldbus network environment. The network consisted of PROFIBUS, PROFINET and DeviceNet networks, each with number of controllers, and devices. The operation of the diagnosis device was verified against network specific diagnostic tools, and vendor specific software.

5.2 Literature update

A number of follow on research work on the topic of “Diagnosing fieldbus networks” are reported since the publication of the candidate’s paper 4. These are outlined below:

Research work reported by Faldella, et al (2009) focuses on the implementation of a custom support tool to help diagnose the control systems based on Ethernet Powerlink, and Mechatrolink fieldbuses. The tool supports the end user with three levels of plant diagnostic views, namely fieldbus level, device level and IO level. In particular the fieldbus view performs an automated discovery of the nodes connected to the fieldbus. It shows if the right device is in right position with the correct settings, according to the configuration phase. The logical IO view allows the user to organise the physical IO into structures reflecting their arrangement on the plant side.

The tool has been used for the preliminary set-up of a tea-bag packaging machine, capable of production rate of 350 bags per minute, with a digital IO count of around 700. The use of the tool has enabled a faster diagnostics of the machine at commissioning stage. The tool has reduced the time taken for manual commissioning from 8 days to 4 days.

The work reported in this research work is useful for equipment manufacturers where the commissioning of the equipment is a time consuming effort. The tool is likely to be used for a specific machine or process; otherwise the effort taken to develop the tool for a one off machine would be longer than the time it takes to commission the same machine.

The fieldbus view of the devices reported in this work is similar to candidate's paper 4, however the application is limited to a specific machine, and additionally it requires an extra layer of software to implement the tool.

Prototyping of a diagnostic instrument for testing CAN bus is reported by Pekar, et al (2012). The designed diagnostic instrument can be interfaced to a CAN bus, and can operate in two modes; listen and discover. In listen mode the device monitors the flow of data telegrams on the bus, and in discover mode it sends a request to devices to query their current state.

The diagnostic device is a portable device and operates on a 9V battery. It is capable of diagnosing failure of the bus, overvoltage on the bus, cable break, and failure of a node.

The diagnostic instrument works as a slave on the CAN bus, and is initially designed to be used in railway application. The prototype device was tested in laboratory environment to diagnose simulated failures on the CAN bus.

Although the researchers claim that the device performs the diagnostics functions satisfactorily, the details of the reported diagnostic by the device are unclear. The current state of the research is to bring the diagnostic device from prototype stage to product stage.

The main differences between the work reported by this research and candidate's paper 4 are:

The diagnostic device is portable and battery powered in this case and not a network component.

The diagnostic device is based on microcontroller design and not standard PC. The device is used with CAN bus, and not multi fieldbus (PROFIBUS, PROFINET, and DeviceNet).

5.3 Conformance to proposed model

The use of OPC technology for multiple fieldbus diagnostics is presented in this paper. The conformance of this research work to the proposed model for fieldbus diagnosis is outlined below, and is highlighted in Fig 5.1.

Layer 1: Physical Layer

- This is a combination of software and hardware solution for fieldbus diagnosis. Two master class 2 with DB9 interfaces are used to connect to the PROFIBUS network. An IO supervisor with RJ45 interface is used to connect to PROFINET. Scanner with screw terminals is used to connect to Devicenet. In Each case a PC 104 interface card is used.

Layer 2: Interface Layer

- The research focuses on PROFIBUS, PROFINET and Devicenet. The limitation of different transmission technologies used is in the main applicable to each case.

Layer 3: Protocol Level

- Fieldbuses under consideration are PROFIBUS, PROFINET, and Devicenet. These are some of the most common fieldbuses used globally in manufacturing and process plants.

Layer 4: OS layer- A miniaturised PC with MS- embedded XP operating system is used in this layer. The PC as an OPC server can obtain individual diagnostic data from each connected PC104 interface.

Layer 5: Extraction layer

- Diagnostic data obtained from each OPC server is assigned to an OPC tag. In addition to diagnostics data other data such as station configuration and IO can be obtained from any of the stations and assigned to an OPC tag.

Layer 6: Object layer

- The connected PC acts as an OPC server, and any other PC on the same Ethernet network can connect to the server as a client.

Layer 7: Communication layer

- In this implementation Ethernet is used to communicate from the server PC to client PCs to transfer the diagnostic information.

Layer 8: Presentation

- HTML pages and OPC tags are used to represent the diagnostic data to the end user.

5.4: Paper 4- Development of Web based software for a multi-fieldbus diagnosis tool

5.5 Conclusions

The main aim of this research was to produce a prototype multi fieldbus diagnostics tool. Both hardware and software aspects were covered in this work. The layered approach taken in developing the application software makes the device very flexible, in that the underlying fieldbus interface can be replaced without a major re work of the application level software. The hardware specific details were dealt with by the OPC servers and hidden from the web application layer and in turn the remote client.

The developed web application provides the diagnostics data and live list for any of the connected fieldbuses with the same look and feel. The live list provide a quick snap shot of the devices in data exchange, devices with parameter or configuration errors, devices not in communication and devices with diagnostics data. More detailed information on each device can be obtained by clicking on the device number. Based on the type of error more details are displayed for the given device.

The security for the web application is provided by Secure Socket Layer (SSL) encryption of web page data and user login data that creates a user session. Once correctly logged in the user has full access to the data that is accessible by the diagnostic tool.

The developed multi fieldbus diagnostic tool is at prototype stage, further funding will be required for CE marking and UL and similar tests to bring the device from prototype stage to product level. Some discussions has taken place with companies such as Molex to licence the product, however to date no significant breakthrough has been made.

5.6 Contribution to Knowledge

Vendor independent software and hardware solutions for diagnosing single and multiple fieldbuses were designed and developed. A platform independent diagnostics system was developed for PROFIBUS, PROFINET and Device Net networks capable of monitoring these networks simultaneously. A DIN rail mounted device based on PC104 interfaces and imbedded XP and with a small foot print was prototyped. The device was the first of its kind capable of diagnosing multiple fieldbuses, and built on established standards. The developed application software was tested for different error scenarios in all underlying networks. The prototype device is now available for licensing, UL, and CE marking. The reported research work in this paper addresses the objectives, 2, 3, 4, and 5 of the thesis.

5.7 Limitation of previous work

Generally an industrial site may have a number of fieldbuses installed. For example in a soft drinks manufacturing plant, it is possible to see PROFIBUS DP and PA networks, DeviceNet and others. Therefore the need for a single device to be able to diagnose multiple fieldbuses is desirable, and this need inspired the research work to develop a single device for diagnosing multiple fieldbuses. The reported literature such as Toro (2002) was mainly concerned with use of OPC technology for automatic configuration of the network in the case of addition or removal of a networked device. The lack of reported work in the area of fieldbus diagnostics in general, and lack of physical devices for both single and multi-fieldbus diagnostics in particular has formed the background to work reported in paper 4.

The work reported on developing OPC server for PROFIBUS diagnosis in paper 2 and similar work on developing OPC server for PROFINET reported in paper 3 has formed the basis for this work.

5.8 Limitation of current work

The developed prototype device can be used for diagnosing PROFIBUS, PROFINET, and DeviceNet fieldbuses. The device uses stackable PC104 interface cards for each fieldbus and can simultaneously diagnose the underlying networks. The reported diagnostic covers the diagnostics defined in each standard, and decoding of extended diagnostic data is not possible in the current issue of the prototype. The connection to factory network would require a risk assessment, and permission from the IT department of the company to connect to internet for remote monitoring purposes.

Chapter 6: Influence of token rotation time in multi master PROFIBUS networks

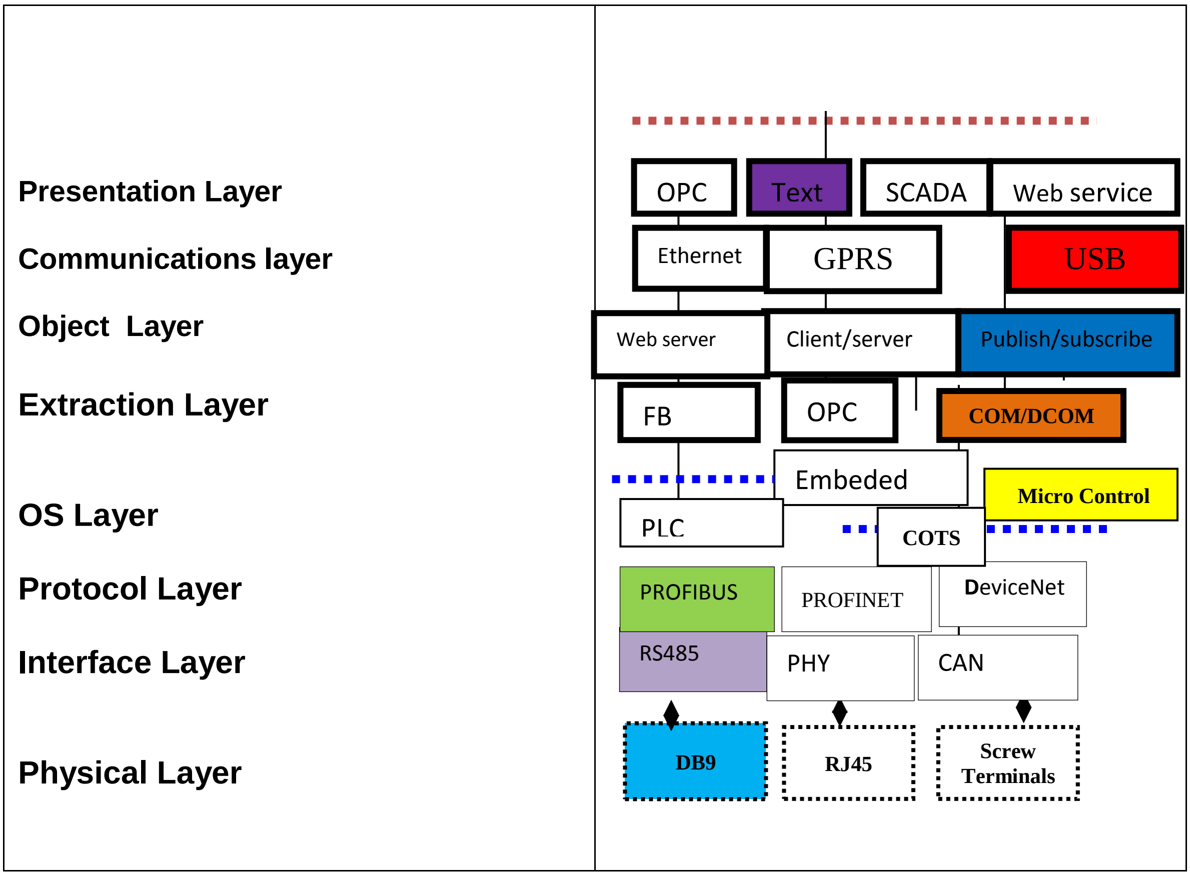

Fig 6.1 Proposed Diagnostic Model: Token Rotation Time

6.1 Introduction

Wide spread use of industrial networks necessitate high reliability, and up time. Most of the network issues are related to installation shortcomings and the environment where these networks operate, however the integrity and adherence to standard of the devices used on the network is crucial. The research reported in this study concentrates on the token rotation time for the master devices on PROFIBUS networks, and explores their behaviour in a multi master environment.

An experimental PROFIBUS network comprising approximately 30 devices was set up to investigate the influence of token rotation time in multi master PROFIBUS networks. Three Master PLCs were used in this study from three different vendors. Two configurations were investigated with masters from same vendor and multi-vendor arrangement.

A network diagnostics tool was used to capture all the telegrams on the network. Time stamping with micro second precision was used to stamp each message. The messages are normally data exchange telegrams, FDL, global control, and diagnostics for a running network.

The theoretical Target Token Rotation time (T_{TR}) for each master was compared to Real Token Rotation time (T_{RR}) for different network configurations.

6.2 Literature update

A number of follow on research work on the topic of “Performance analysis of PROFIBUS networks” are reported since the publication of the candidate’s paper 5. These are outlined below:

Zhang et al (2009) investigate the influence of PROFIBUS frame transmission time on transmission delay property. The group use OPNET modeller to simulate the time delays. In the simulation two master stations are used, first master has 3 configured slaves and the second master has two slave stations. The bus transmission rate is 1.5 Mbps. The max T_{SDR} for the slave stations is $200T_{bit}$, and the bus idle time is $100T_{bit}$. Data transmission adopts SRD (Send and Request Data with acknowledgement, and SDN (Send Data with No acknowledgement) service. The data length of SRD frame is 128 bytes, and data length of SDN is 246 bytes.

The conclusion from this work is that SRD frames will take longer time to process, while SDN would be shorter. The contribution of this paper is debatable, and the fact that the maximum data unit can be transferred in a PROFIBUS frame is 244 bytes and not 246 as assumed in this simulation work.

A paper by Bao et al (2009) describes an improved method of analysing PROFIBUS real time features in single master system. It promotes the use of PROFIBUS message model and provides sample calculations for the response time of PROFIBUS network for a worst case scenario. It concludes that a number of factures effect the poll time of the network such as the baud rate and the number of retries. The authors suggest the use of a retry limit in the range of 3-5. Additionally they acknowledge that at high baud rates the problem of EMI becomes more pronounced.

The conclusions from this work is not particularly new, as the number of retries is normally set at 3, and as with any communications network as the speed increases so does the amount of interference.

Real time property analysis of single master DP/PA hybrid network was reported by Chen et al (2010). The hybrid network is a combination of PROFIBUS DP and PROFIBUS PA networks. The work suggest some improvement to the timing mechanism currently used in DP to PA couplers. It suggests a cut through mechanism for message transmission in DP/PA coupler instead of store and forward mechanism currently used. The cut through mechanism is used in high speed networks such as PROFINET devices.

6.3 Conformance to proposed model

The use of commercially available tools for fieldbus diagnostics presented in this paper. The conformance of this research work to the proposed model for fieldbus diagnosis is outlined below, and is highlighted in Fig 6.1.

Layer 1: Physical Layer

- This is a combination of software and hardware solution for fieldbus diagnosis. A RS485 interface with a DB9 is used to connect to the PROFIBUS network.

Layer 2: Interface Layer

- The research focuses on PROFIBUS, which is based on RS485 transmission technology. The limitation of this transmission is in the main applicable to PROFIBUS.

Layer 3: Protocol Level

- Fieldbus under consideration is PROFIBUS. This is the most common fieldbus used globally with over 50 million devices in operation.

Layer 4: OS layer

- A purpose build hardware (Proficore) based on FPGA design is used in conjunction with a micro controller. .

Layer 5: Extraction layer

- The hardware is used to capture the telegrams and decode all standard messages. Also the cycle times and transmission sequence is obtained.

Layer 6: Object layer

- The connected PC acts as publisher, and any other PC on the same Ethernet network can connect to the publisher as a subscriber.

Layer 7: Communication layer

- In this implementation USB is used to communicate from Proficore interface to PC.

Layer 8: Presentation

- A combination of graphical and text based system is used to represent the network data to the end user.

6.4: Paper 5- Influence of token rotation time in multi master PROFIBUS networks

6.5 Conclusions

Fieldbuses have become a common place in vertical integration of IT and automation in manufacturing operations. In the case of PROFIBUS networks, Master Class 2(MC2) devices provide a means of integration of automation with IT world. This means a multi master environment comprising of master class 1 and master class 2 and possibly additional masters in the same network. In practice it is possible that masters from different vendors are used, and setting of different parameters for each master and its influence on master behaviour is not well established.

In this research the different traffic in a multi master network is analysed for a better understanding of system performance. As a starting point the influence of T_{TR} for two cases of $T_{TR} << T_{RR}$ and $T_{TR} >> T_{RR}$ were investigated.

For masters that don't comply with PROFIBUS standard, an estimate of T_{TR} has to be obtained either theoretically or experimentally with some safety margin. In this research a trial and error method is used to obtain a reasonable T_{TR} by using Profitrace tool.

The results from this research show differing behaviour of masters from different vendors. This could result in master missing data exchange intervals and the performance of the network can be compromised.

The conclusions from this research show the necessity for certification of master devices. As the result of this research and similar work, the testing of master devices have become mandatory in the past few years.

6.6 Contribution to Knowledge

Timing behaviour of network devices is crucial in reducing network issues. This work demonstrated the differing behaviour of the master devices in multi-master PROFIBUS networks. This research work experimentally demonstrated the nonstandard behaviour of the master devices in PROFIBUS networks. Additionally it established the use cases of network diagnosis devices for detailed network analysis. This work covers the objective 6 of the thesis.

It is also worthwhile to mention that partly as a result of this work that the testing of PROFIBUS master devices has been made mandatory by PI to ensure compliance with standards.

6.7 Limitation of previous work

The majority of previous work reported concentrated on the timing issues in PROFIBUS single master systems. The work included mathematical modelling and consideration of worst case scenarios. The work relating to setting Target Token Rotation Time in single master systems was reported by Tovar et al (1998), Vitturi (2004), Tover et al(1999), Cavalieri et al(2002) and Lee et al(2004). Additional work on ring stability of PROFIBUS over error prone links was reported by Willig(2001) and assessment of PROFIBUS networks using a fault injection framework was reported by Carvalho et al(2005).

The analysis of master behaviour in multi master system was not carried out or reported. This inspired the research reported in this paper on analysis of master behaviour in multi master PROFIBUS networks. The efficient use of fieldbus back bone would result in a multi master arrangement. Therefore correct behaviour of master devices is necessary to achieve the real time requirement from the network which is essential for most distributed control systems.

6.8 Limitation of current work

The research work on the behaviour of Master devices highlighted the discrepancies involved when it is left to the vendors to interpret the standard. The difference between master behaviours outlined in this research work, has resulted in mandatory testing of master devises for the past few years. It is a major improvement, and the test procedure conducted by independent test labs for master devices guarantees uniform adherence to the standards.

Chapter 7: Synchronisation of a multi motor speed control system

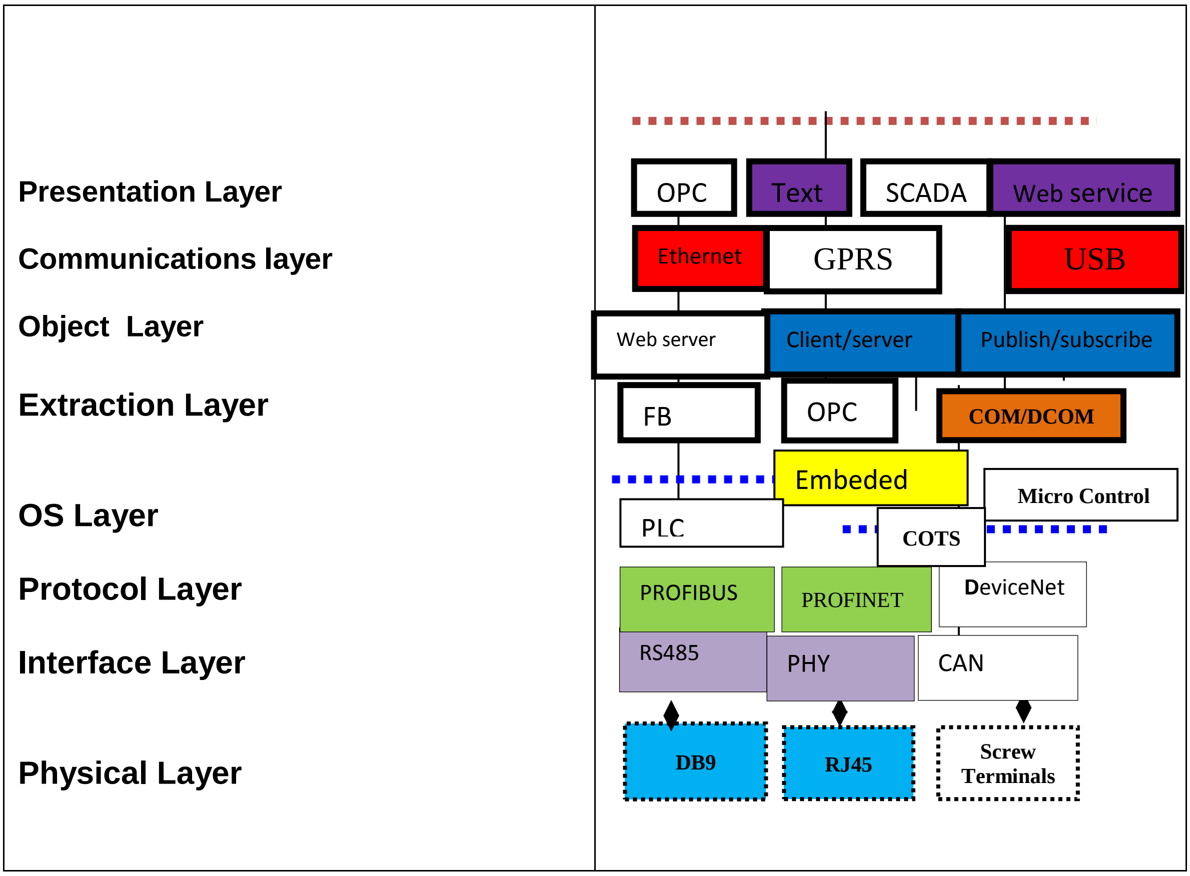

Fig 7.1 Proposed Diagnostic Model: Motor synchronisation

7.1 Introduction

The emergence of Ethernet based industrial communications network has brought new opportunities for demanding applications such as printing presses and other real time applications.

In order to establish a comparison matrix, the performance of industrial Ethernet networks such as PROFINET and traditional fieldbuses such as PROFIBUS has to be established.

This research uses diagnostics tools for PROFIBUS and PROFINET as a means of providing accurate data to analyse and compare these two networks. The performance analysis of these networks enables a means of performance comparison of different technologies, and also gives an insight into operation of a given network. Users can use this type of research to make the correct choice in selecting the industrial network suitable for their application.

Two identical PROFIBUS and PROFINET networks were used for this study. One PLC controller with both PROFIBUS and PROFINET communications ports was also used. The hardware is identical in all aspects, except that they use different communication technologies. Profitrace is used as diagnostics package for PROFIBUS analysis, and Netilities is used as the equivalent diagnostics package for PROFINET. Both these packages are developed and marketed by PROCENCTEC.

Synchronisation of both lead and follower motors are carried out on both PROFIBUS and PROFINET-class1 networks.

7.2 Literature update

A number of follow on research work on the topic of “Performance analysis of PROFIBUS and PROFINET networks” are reported since the publication of the candidate’s paper 6. These are outlined below:

A paper by Ferrari et al (2007) looks at the timing characteristic of PROFINET IO RT_Class 3 network. The aim of this work is the experimental evaluation of PROFINET IO RTC_3 nodes built with development Kits. The hardware used is based on ERTEC400, and ERTEC200. The work mainly looks at the timing issues, and is not application specific. The work looks at mainly two network configurations, one with RTC3 frames only, and one with combined RTC3, RTC1 frames, and TCP generated frames. It concludes that due to the priority given to the RTC3 frames the cycle times for RTC3 frames in each configuration remains at 30.4 microseconds.

The work reported in this work is not a comparison of two different fieldbuses, as reported by candidates 6th paper (comparison of PROFINET RTC1 with PROFIBUS); however it shows that the performance of PROFINET RTC3 is independent of the networks traffic and that the RTC3 provides a better performance than RTC1. The latter is in agreement with the conclusions from candidate’s paper.

A theoretical analysis of three real time Ethernet networks was reported by Schlesinger et al (2014). The work studies the performance of Ethercat, VABS, and PROFINET IRT with DFP and line topology.

Few different cases are considered; in the first case it is assumed all devices would have 50 bytes of inbound and outbound payloads. In this case VABS achieves the best performance followed by PROFINET IRT.

Second case considers more realistic scenario where 50% of devices have a payload of 4 bytes only and the other 50% remain at 50 bytes of payload. In this comparison VABS again performs best followed by Ethercat.

Third case considers a situation where 50% of the devices have inbound payload of 50 bytes and no outbound, and vice versa for the other 50%. For this extreme case PROFINET IRT outperforms both VABS and Ethercat.

Conclusion from this work is that PROFINET IRT has advantages over Ethercat and VABS in case of a symmetric distribution of outbound and inbound payloads. However, for very small payloads PROFINET IRT has disadvantages. This could be improved by reducing the forwarding delays of PROFINET devices and implementing a topology based addressing.

7.3 Conformance to proposed model

The use of commercially available tools for fieldbus diagnostics presented in this paper. The conformance of this research work to the proposed model for fieldbus diagnosis is outlined below, and is highlighted in Fig 7.1.

Layer 1: Physical Layer

- This is a combination of software and hardware solution for fieldbus diagnosis. Proficore with a DB9 interface is used to connect to the PROFIBUS network. A Profitap with a RJ45 is used to tap into PROFINET network.

Layer 2: Interface Layer

- The research focuses on PROFIBUS, which is based on RS485 transmission technology, and PROFINET which is based on Ethernet. The limitation of transmission technologies used is applicable to each case.

Layer 3: Protocol Level

- Fieldbus under consideration is PROFIBUS, and PROFINET. These are the most common fieldbuses used globally with over 58 million combined devices in operation.

Layer 4: OS layer

- For PROFIBUS a purpose build hardware (Proficore) based on FPGA design is used in conjunction with a micro controller. For PROFINET, Profitap is used to tap into the network

Layer 5: Extraction layer

- The hardware is used to capture the telegrams and decode standard messages from both networks. Also the cycle times and transmission sequence is obtained.

Layer 6: Object layer- The connected PC acts as publisher, and any other PC on the same Ethernet network can connect to the publisher as a subscriber.

Layer 7: Communication layer

- In this implementation USB is used to communicate from Proficore interface to PC for PROFIBUS and from Profitap to PC for PROFINET.

Layer 8: Presentation

- A combination of graphical and text based system is used to represent the network data to the end user.

7.4: Paper 6 - Synchronisation of a multi motor speed control system

7.5 Conclusions

The synchronisation achievable varies considerably depending on the, speed change, acceleration and deceleration and load change. The synchronisation achievable from both PROFIBUS and PROFINET Class 1 would be suitable for applications where exact position synchronisation is not essential. No considerable advantage has been identified in using PROFINET Class 1 over PROFIBUS for this application with PROFIBUS outperforming PROFINET Class 1 in all tests carried out. Other factors impact on the synchronisation achievable for example the control program, PID tuning, and equipment being used. To obtain the best performance from the PROFINET system, PROFINET Class 3 (IRT) should be used.

Although the research shows a comparative study of the two different communications technologies, it underpins the inherent use of diagnostics tools to enable this comparison. The research shows the use of diagnostics tools for analysis of each individual network on one hand, and comparative study of networks on the other.

The results from this research can enable the end users to select the correct technology for a given application.

7.6 Contribution to Knowledge

The research work provided a manufacturer independent practical comparison of two industrial networks using standard diagnostic tools. Two identical test platforms were established for comparison of PROFIBUS and PROFINET networks. The application area of speed synchronisation is demanding, and should inform the user on the performance and limitation of industrial networks. Additionally this research work showed the use of standard fieldbus diagnostics tools to establish the performance parameters for fieldbus networks. The work reported in paper 6, addresses the objective 7 of the thesis

7.7 Limitation of previous work

The work reported in the area of practical comparison of fieldbuses is not very common. This is partly due to the fact that providing an exact comparison environment is not easy, and would require an exact set of hardware and software to enable a fair comparison. Only reported experimental comparison of PROFIBUS and PROFINET is by Ferrari et al (2006). The lack of reported cases of practical comparison of fieldbuses inspired the work reported in paper 6.

The establishment of timing behaviour of a high speed communications network is always challenging, and individual researchers or research groups take different approaches to this. Some involve sophisticated hardware for triggering and recording. The use of diagnostics tools for comparison is not widely used perhaps due to lower level of accuracy of timing in millisecond range. This level of accuracy is adequate for basic comparison for majority of control applications and this has formed the basis for the comparison of PROFIBUS and PROFINET Class 1 network reported in paper 6.

7.8 Limitation of current work

The work shows the use for fieldbus diagnostics tools apart from the ability of these tools to diagnose common network issues. The ability to use diagnostics tools to establish the performance of a fieldbus network and to be able to compare this performance with that of other fieldbuses, provides the end user with capability to make informed decision in selection of suitable networks for a given application.

The main limitation of use of the diagnostic tools for comparison purposes is the accuracy of the tool in time stamping the events. Although this can be done to an accuracy of 1ms, this may not be sufficient for example in high speed applications such as motion control. The later currently only makes up 20% of total fieldbus use cases.

Chapter 8: Use of diagnostic tool – A Case study: Intermittent PROFIBUS Network Fault

8.1 Introduction

The developed diagnostics tools were used in a number of industrial cases. This chapter will outline the use of the diagnostic tool in one of the industrial settings. All the reported cases are investigated by the candidate and network issues in each case were diagnosed and a number of recommendations were made in each case to the company involved. As there is NDA in place with each company, the name of the company is not mentioned; however the industrial sector that the company is active in is highlighted.

Company:	xx Pharma, Carrigtwohill, Cork, Ireland
Section:	Line 4, bottling
Representative met:	Maintenance Manager, other Engineering staff
Networks analyses:	PROFIBUS DP Line 4
Equipment used:	Lap top (XP-Professional) with diagnostic tool
Date of visit	3^{rd} June 2011

Description of the Network: The network consists of one master (Siemens CPU315-2DP) and 22 slave stations. The slave stations are made up of Temperature Controllers, VSD, remote IO, Operator Panel, and encoders. The network runs at 1.5MBPS (Mega Bits per Second) with a cycle time of 6 ms approx.

Nature of the Problem: Maintenance staffs have observed the random failure of one Variable Speed Drive (VSD). This is the station 15 on PROFIBUS DP network.

8.2 Observations: PROFIBUS Network line 4-Before

The network is controlled through PROFIBUS port of CPU-315-2DP master. Analysis of the signal levels indicated a lower than average DC levels on the network (Fig 8.1), however continuous communication was possible to all the stations with exception of station 15. This station failed regularly due to destruction of the response telegram from slave to master station (approx. 5% failure of telegrams).(Fig8.2). The waveform received at the master station from station 15 was also not healthy(Fig8.3).

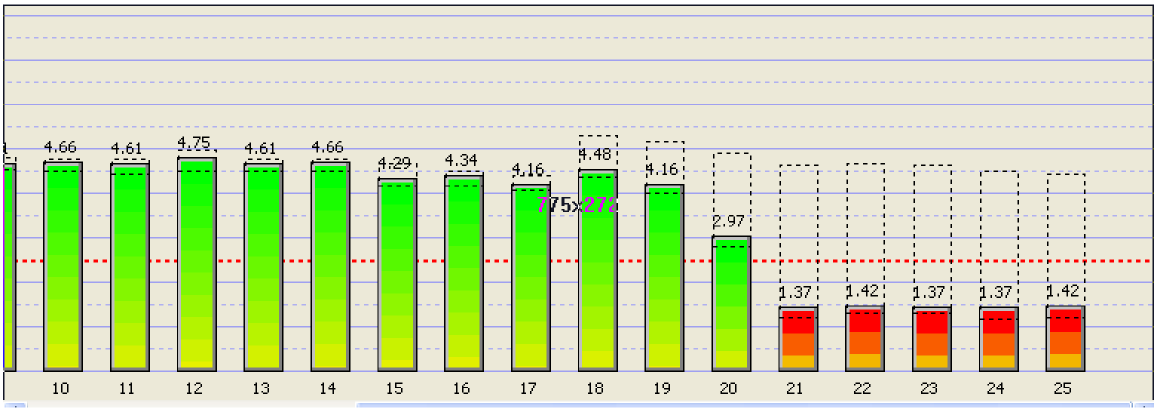

Fig 8.1: DC signal levels (Before)

As can be seen from Fig 8.1 the signal levels (B-A differential) should be around 4-5 VDC. The diagnostic tool marks the signals which fall below 2.5 VDC to indicate that these require further investigation. Stations 21-25 are below the threshold level of 2.5 VDC.

FrameNr	Timestamp	Attention	Frame	Addr	Service	Msg type	Req/Res	SAPS	DataL
0	3-Jun-20...		SD2	2<-11	DL	Data Exchange	Res		4
1	3-Jun-20...		SD2	2->12	SRD_HIGH	Data Exchange	Req		4
2	3-Jun-20...		SD2	2<-12	DL	Data Exchange	Res		4
3	3-Jun-20...		SD2	2->13	SRD_HIGH	Data Exchange	Req		4
4	3-Jun-20...		SD2	2<-13	DL	Data Exchange	Res		4
5	3-Jun-20...		SD2	2->14	SRD_HIGH	Data Exchange	Req		4
6	3-Jun-20...		SD2	2<-14	DL	Data Exchange	Res		4
7	3-Jun-20...		SD2	2->15	SRD_HIGH	Data Exchange	Req		4
8	3-Jun-20...	Parity error	Illegal						13
9	3-Jun-20...		SD2	2->16	SRD_HIGH	Data Exchange	Req		4
10	3-Jun-20...		SD2	2<-16	DL	Data Exchange	Res		4
11	3-Jun-20...		SD2	2->17	SRD_HIGH	Data Exchange	Req		4
12	3-Jun-20...		SD2	2<-17	DL	Data Exchange	Res		4
13	3-Jun-20...		SD2	2->18	SRD_HIGH	Data Exchange	Req		2
14	3-Jun-20...		SD2	2<-18	DL	Data Exchange	Res		34
15	3-Jun-20...		SD2	2->19	SRD_HIGH	Data Exchange	Req		2
16	3-Jun-20...		SD2	2<-19	DL	Data Exchange	Res		34
17	3-Jun-20...		SD2	2->20	SRD_HIGH	Data Exchange	Req		2
18	3-Jun-20...		SD2	2<-20	DL	Data Exchange	Res		2
19	3-Jun-20...		SD2	2->21	SRD_HIGH	Data Exchange	Req		2
20	3-Jun-20...		SD2	2<-21	DL	Data Exchange	Res		2
21	3-Jun-20...		SD2	2->22	SRD_HIGH	Data Exchange	Req		2
22	3-Jun-20...		SD2	2<-22	DL	Data Exchange	Res		2

Fig 8.2: Garbled telegram from station 15(Before)

It can be seen from Fig 8.2 that the master sends a request telegram to station 15(Frame number 7) above. The response telegram from station 15 is garbled as indicated by the diagnostic tool in frame number 8. This means that the response telegram is destroyed and no longer recognisable by the master PLC. A consecutive occurrence of this will result in loss of communication to station 15.

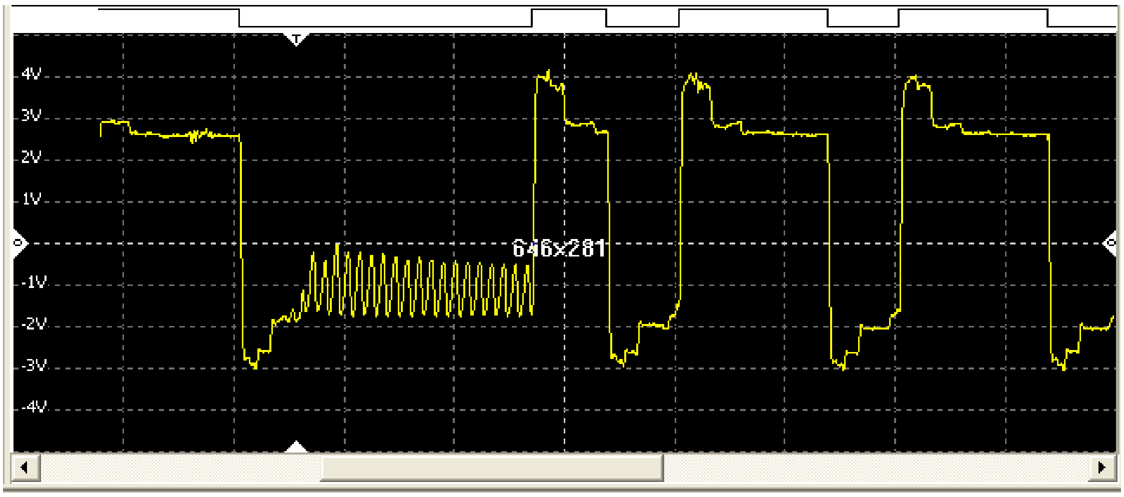

Fig 8.3: Signal Waveform station 15(Before)

As can be seen in Fig 8.3 the electrical waveform from station 15 shows a degree of reflection within a single bit. When this reflection crosses the zero-voltage line, the frame is corrupted, and no longer recognisable by the PLC.

The following observations are also made in relation to PROFIBUS DP network of Line 4:

1) The terminating resistors on Danfoss 5000 series drives were all in the engaged (ON) positions. This also contributed to low DC-level on the network.

2) In relation to cabling the minimum cable length of 1 meter between two consecutive devices should be maintained, this is not the case in this installation (Fig 8.4).

3) Also the minimum bend radius of 75 mm on the PROFIBUS cable is not adhered to (Fig 8.5)

4) PROFIBUS cable is routed alongside the three phase cable to the drives. The minimum air gap of 10cm between PROFIBUS cable and power cable not observed.

Fig 8.4: Danfoss drives

As can be seen from Fig 8.4 the minimum cable length of 1 meter between two consecutives devices are not observed. The short lengths will increase the level of signal reflections.

Fig 8.5: The PROFIBUS cable inside the cabinet

A minimum of 10cm air gap is recommended between PROFIBUS cable and power cables. This is not the case in this installation.

8.3 Actions taken to improve the signal quality on the network:

1) DIP switches on all Danfoss 5000 series are set to OFF (disengaged terminator resistors in middle of the segment) this increased the DC levels on most stations to over 5VDC.
2) Bends on the PROFIUS cable removed.
3) Some PROFIBUS cable separated from three phase power cables.
4) Length of defective cable from station 15 to 16 was replaced.
5) As drives cable is daisy chained without connectors, so the network is terminated at the next available station with PROFIBUS connector (station 18 ET200L). This improved the signal levels, and no failure of station 15 occurred.

6) Termination at station 18 switched OFF, and termination at station 19 switched ON. The failure of station 15 resumed.
7) It was noticed that the station 4(Operator Panel) is physically located between station 18, and station 19, although the documentation made available does not match this.
8) Station 4 was disconnected from the network, and no failure of stations occurred. Note the low voltage level at station 4(Fig 8.6)

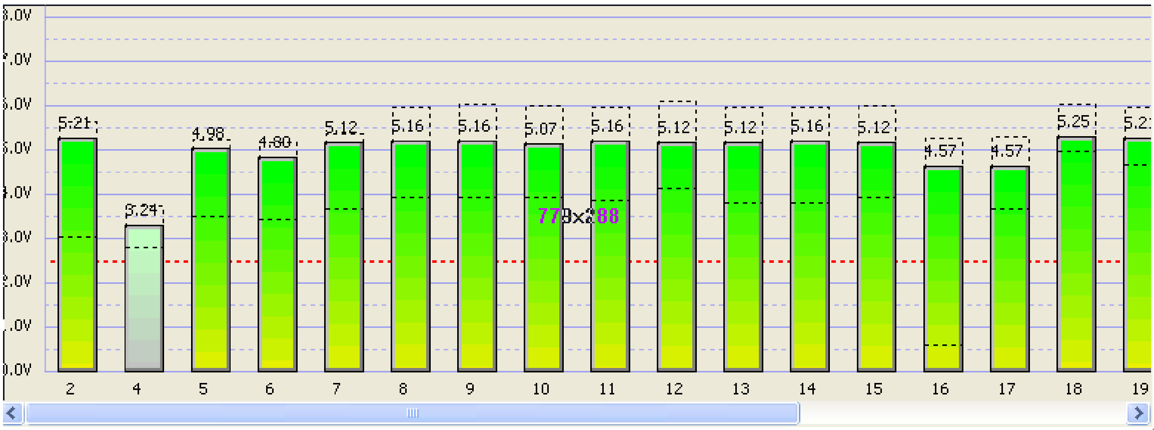

Fig 8.6: Signal level from station 4-Before

9) Operator Panel was replaced, and replacement OP connected to the network.

10) A final health check was carried out on the network

8.4 Observations: PROFIBUS Network line 4(After)

It can be seen from Fig 8.7 that once the terminating resistors on Danfoss 5000 VSDs were switched to OFF position, the DC level of the signals increased from previous levels (shown as black dotted lines).

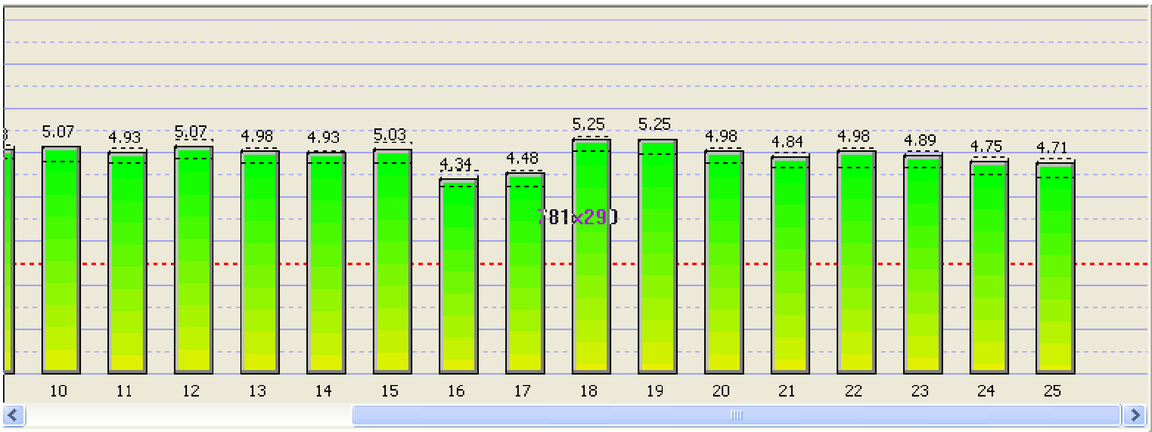

Fig 7: DC signal levels-After

The Operator Panel (OP) with defective PROFIBUS interface was replaced with another unit. Fig 8.8 shows the improvement in the DC signal level in station 4 (Operator Panel) from 3.24 VDC to 5.76 VDC.

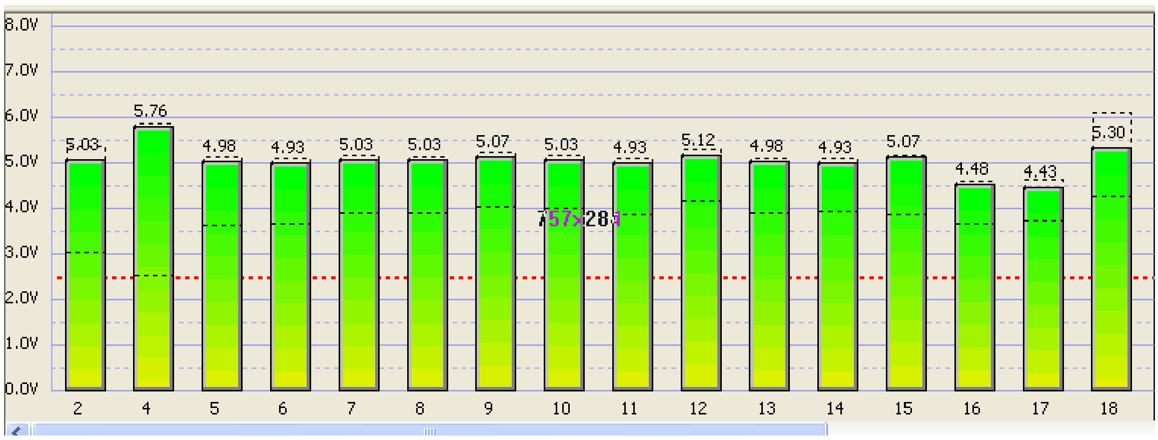

Fig 8: Signal level from station 4-After

Upon replacement of OP the signal received from station 15 was recorded again, as shown in Fig 8.9. The comparison of Fig8.3 and Fig8.9 shows the improvement.

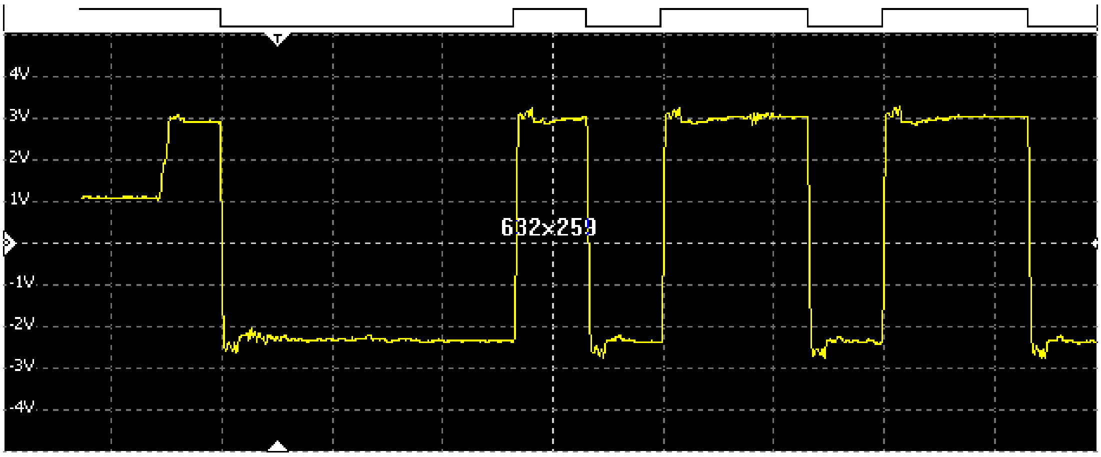

Fig 8.9: Signal Waveform station 15(After)

As the verification of the impact of modifications made, a recording of one million telegrams were made, with no garbled telegrams as seen in Fig 8.10

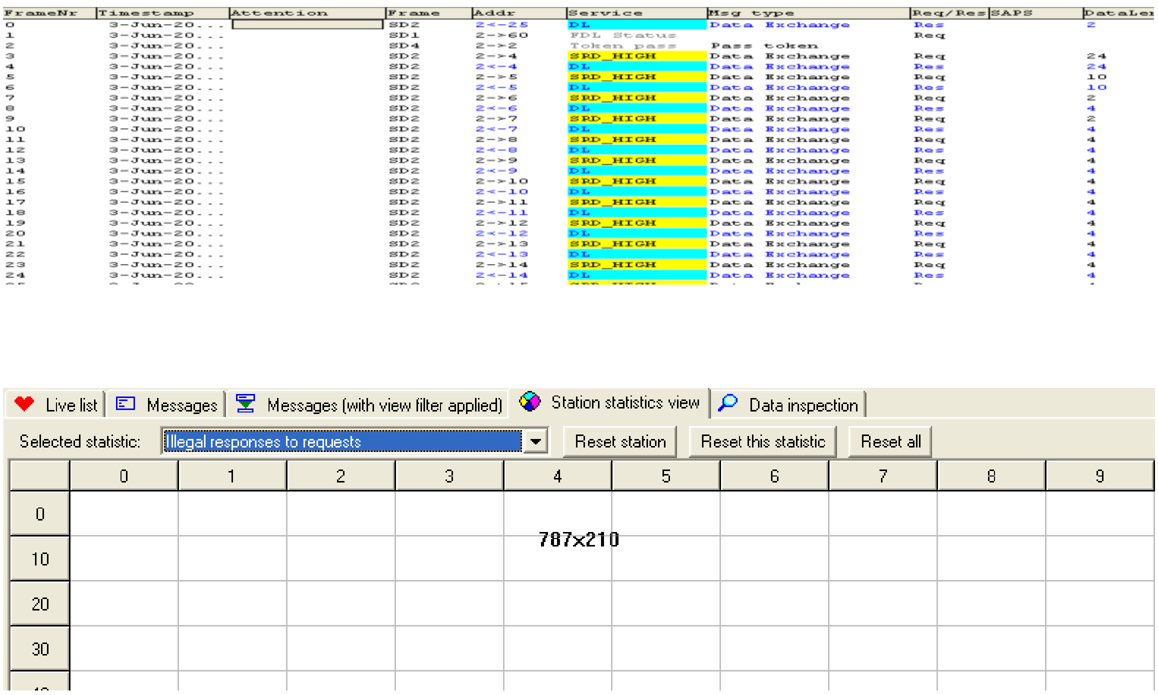

Fig 8.10: No Garbled telegrams from station 15 (After)

8.5 Possible Cause of failure Network line 4:

The PROFIBUS network should only be terminated on the first and last device of a segment. Normally the first station on the network is the PROFIBUS master, and the last station should be powered at all times to provide the 5VDC to terminating resistors.

Having additional terminations in the network, will cause the average DC levels to drop. This explains some of the random failures of the communications.

Additionally the PROFIBUS interface on the original OP was defective, and was distorting the signals on the network, and was replaced by another unit. This improved the signals throughout.

Although the network is currently operating without any errors, it can be improved further by implementing the recommendations made in this report in relation to cabling, shielding and grounding.

8.6 General Recommendations:

The general recommendation is to design the PROFIBUS network for maximum speed and operate at the lowest acceptable speed to reduce the problems associated with high speed communications. The following recommendations should be observed where possible:

8.6.1 Cable layout:

1) A minimum air gap of 10 cm between PROFIBUS cable and supply cables to drives where voltages are below 400 VAC. The gap should be a minimum of 20 cm where voltage of >400 VAC is involved.

2) A minimum of one meter of cable should be between two consecutive devices on the network. This is important for speeds 1.5 MBPS and over.

3) The PROFIBUS cable should be fed to interface unit of drives from the top, and not from the bottom where possible. This seems to be a design issue with drives in general.

8.6.2 Shielding & Grounding

Although the use of fiber optics will eliminate the EMI (Electro Magnetic Interference), however the following points should be considered in relation to PROFIBUS copper cable:

1) As it stands the shield of the cable is grounded through the grounding plates to ground rail. It is important to ensure that all the grounding points are at the same potential. It may be necessary to run an equipotential cable in parallel to PROFIBUS cable to achieve this. Additionally a clamping mechanism should be used to ensure proper contact between cable shield and ground plate.

2) It is also advisable to separate the ground points of the communication system from that of power lines to ensure a clean earth.

3) The PROFIBUS cable should be grounded at entry point to electrical cabinets, using grounding plates and appropriate clamps.

8.7 Other Recommendations

The following recommendations are based on best practice:

1) The speed of the network could be decreased such that the average PROFIBUS bus cycle is just below the average controller cycle time. This will ensure a timely exchange of process data, without the problems associated with high speed communications. Currently the CPU program cycle is over 40 ms, while the PROFIBUS cycle time is 6 ms.

2) All the physical stations on the PROFIBUS network should be labelled with their station numbers on the PROFIBUS interfaces.

3) Documents showing the layout of the PROFIBUS network should be made available at each control panel and centrally. These drawing should show at the minimum: Distance between each station, location of each station, network components such as repeaters & active terminations, shielding and grounding arrangements. This will provide the information at the local level for troubleshooting and maintenance.

4) The number of retries on the master is set to one; the normal number of retries is 3. This means if the master does not get a response from a device, it will try three times before it drops the device from communication cycle. It is advisable to increase the number of retries to at least 3.

5) It is advisable to carry PROFIBUS repeater as spare. The repeater can be used to boost signals from weak interfaces. This will enable the machine operation to continue, until a longer term solution is found.

6) Finally engineering staff should be trained on PROFIBUS technology.

8.8 Advantages of using developed diagnostic tools

In comparison to other tools the proposed approach identifies not only the problems associated with protocol layer, but also the underlying electrical signals at the physical layer. It also ties in the protocol layer problems to physical layer issues.

The use of diagnostic tools developed in this research work has enabled a faster and more efficient means of diagnosis of fieldbus networks. As shown in this case study the identification of problems at protocol level was indicated with repeat messages, sync, etc. This was then crossed checked at the physical layer by observing the electrical waveform from the effected station. Additionally as shown the statistics (retries, lost, sync, framing errors, etc) provided by the tool helps in speedy identification of network issues, and provides the answer to the research question of finding more efficient methods of network diagnosis.

8.9 Conclusions

This case study was selected from at least a dozen use cases of the diagnostics tool in industrial trouble shooting performed by the candidate. It is absolutely vital to use these tools to diagnose the network problems in a speedy and efficient manner. The cases covered by the candidate are mostly in pharmaceutical sector with batch values ranging from 0.5 Million Euro up to 15 Million Euro.

Fieldbus networks are like black boxes and the use of diagnostics tools gives an insight to the operation and health of the network. The ability of the tool to provide the diagnostics at protocol, and physical layers gives the user the required information to diagnose the issue in a running installation.

The expertise is still required on the part of the user to correctly interpret the telegrams and electrical measurements and systematically check for possible causes of random failures.

Chapter 9: Conclusions & Future work

9.1 Use of FB

1. To date more than 30 fieldbus protocols have been presented at various times and the present standardisation efforts (IEC IS 61158, IS 62026 and ADIS 62026) include 13 different solutions. Thus, it is going to be difficult to realise a unified communications solution with such a diverse types. A number of requirements are driving the need for a unified solution in this space. Such requirements include: enhanced diagnostics; demand for better control on processes; higher network availability and integration of enterprise networks. Currently, an integrated diagnostic capability for local and remote diagnostics is one of the primary requirements.

2. The research work described in the first paper is limited to one fieldbus type, i.e. PROFIBUS, and attempts to show diagnostic solution that works across different vendor products, rather than across multiple types of fieldbus standards. This work is also confined to the "master-slave" communications model. However, there are far wider implications for standardised diagnostic solutions for fieldbus and other industrial automation control system that use multiple buses. Present-day open control systems are concerned with data flow across devices of different types and from different vendors. To date standardisation efforts towards common architectures and application objects, that would allow systems to communicate, have been disappointing.

3. Accepting that the variety of diverse fieldbus types exists, solutions for seamless integration for diagnostics, in industrial automation systems, tend to rely on software components. However, such software components act at a high level in the device and communication hierarchy, and cannot provide a true integration solution.

4. Connected equipment adhering to OPC is another approach for integration at higher levels. Although this approach does provide a level of integration, true integration can only be achieved if the industrial players can agree integrated protocols at the lower levels. OPC itself also suffers from the diversity problem, in that OPC is a Microsoft standard and other companies in the software community will compete with different solutions.

9.2 Use of OPC

5. The second paper outlined the development and test of an OPC server for a diagnostic tool suitable for PROFIBUS networks. The choice of PC104 as a generic interface provides a suitable platform for diagnosing fieldbus networks. It additionally provides a more general model for the development of relevant OPC servers for each underlying fieldbus network.
6. The developed diagnostic tool will function as an active network component in the form of a Master Class 2 device capable of retrieving device diagnostics data without requiring network reconfiguration. The functions developed to obtain the diagnostics give the tool an advantage over other sniffing devices that can only listen to telegrams on the network. It is shown that the tool has a minimal effect on the overall PROFIBUS cycle time, and performs well particularly at high baud rates.

7. Diagnostics, configuration, and I/O data of PROFIBUS slave devices as well as diagnostics of master stations, is represented in OPC DA format, and can be accessed by local or remote clients. Although the OPC server is intended to be used as part of the development of a multi fieldbus diagnostic tool, it can also be integrated into existing SCADA systems, asset management applications and other packages using the OPC DA interface.

8. The hardware and software used in this research work is intended to provide a framework for the integration of other fieldbus networks without necessitating major redesign. This has been accomplished by using the PC104 PCI interface in conjunction with OPC technology.

9. In order to integrate other fieldbus networks, the respective interfaces must be installed on the main board. The OPC server toolkit can then be used to generate OPC servers for each interface similar to the work carried out in this research.

10. Developing OPC servers for other fieldbus networks would require configuring the hardware as an equivalent PROFIBUS master class 2 device. Subsequently diagnostic functions need to be developed to retrieve data from network devices and the latter to be integrated into OPC server project.

11. Paper three outlined the issues surrounding the inclusion of a PROFINET interface in the development of a multi fieldbus diagnostic device. In the implementation of a PCI PROFINET interface for the diagnostics tool it is necessary to have PROFINET IO-Supervisor functionality. Given that this functionality, which is defined in the PROFINET specification, has yet to be implemented, it wasn’t impossible to include PROFINET IO-supervisor functionality in the device.

12. It is possible to include a Siemens specific or, in theory, any vendor specific PROFINET interface which would communicate directly with the IO-Controller using the native protocol of that controller. This would require vendor specific software which increases the footprint of the device which is impractical.

13. Another possible solution is the use of Function Blocks (SFB52 and/or SFB54) to write diagnostic information to an I/O module on the PCI interface configured as an IO-Device. Once the diagnostic information has been written to the device, an OPC server application may be free to transmit the data to local and remote OPC client applications.

14. Until such time as an IO-Supervisor becomes available, the AnyBus-S module may be a suitable replacement. Given that this is an IO-Device it cannot gain access to data within other devices and therefore cannot request diagnostics. However, when the module is configured in advanced mode, it can monitor diagnostic alarms that appear on the network. This means that diagnostic information is available for devices that have generated a diagnostic alarm. When the event that has caused the diagnostic alarm has been resolved, the diagnostic data associated with the alarm is no longer available from the module. The main drawback of this model is that the device cannot gain access to diagnostic data from a device on request and only information about devices currently in a state of alarm is available.

15. Given that PROFINET is a relatively new technology, it is only a matter of time before the IO-Supervisor functionality is implemented to meet greater demand. For further development of diagnostics device it should be relatively simple to replicate the device model for PROFINET. This will involve using the IO-Supervisor in place of the IO-device and reading the diagnostic data directly from connected devices.

16. The 4th paper outlined the development of web application software for monitoring data collected from a multi-fieldbus diagnostics tool. The diagnostic tool utilizes a Woodhead DC100 multi-interface card to connect to various fieldbus types. The Windows XPe operating system provides the basis for controlling the hardware. It was chosen due to its compatibility with the DC100 board and its customisability and reasonably low memory footprint.

17. A major aim of the development process was to develop a software solution that was generic for any fieldbus that may be integrated into it. The use of OPC servers provided an implementation layer in the software that ensured this was possible. Hardware specific details were dealt with by the OPC

servers and hidden from the web application layer and in turn the remote client. The web application is able to provide a selection of data based on the connections provided by the diagnostics tool. This data includes available OPC servers (one for each connected fieldbus), live list view and tag data. The live list view visually displays the status of devices on a fieldbus. This provides the user with a quick method of viewing possible network issues and overall status. Security for the application is provided by SSL encryption of web page data and user login data that creates a user session. Once correctly logged in the user has full access to the data accessible by the diagnostic tool.

18. Future development of the device and software will include the addition of further fieldbus types and the modifications required to implement them. Also the merits of implementing parts of the OPC Unified Architecture will be considered as it has many features that could be of use to the diagnostic tool.

9.3 Use of diagnostics tools

19. It has become a trend in factory automation that field-bus networks are vertically integrated with IT departments for the purpose of management and maintenance. In PROFIBUS case, MC2 masters are indispensable in satisfying these requirements; therefore it is inevitable to use multi-master arrangement in a PROFIBUS network. It is also common in actual practice that masters from different vendors are employed for different application areas. However, the master behaviour under different parameter settings is still not clear.

20. In 5th paper, various traffic on a multi-master PROFIBUS network is analysed for a better understanding of system behaviour and system performance. As a first step, the influence of T_{TR} on master behaviour is studied for different T_{TR} settings. For masters that don’t strictly comply with PROFIBUS

specifications a safety margin for T_{TR} setting has to be identified either through theoretical or experimental methods. From the experiments conducted in this research, a trial and error way of setting T_{TR} parameters with PROFIBUS monitoring tool such as Profitrace is suggested. Otherwise, system performances will get worse as the master may miss out on data exchange for a number of bus cycles even it has enough positive TH (Token Hold) time.

21. The result of other studies using a small PROFIBUS multi-master network, and follow on study using a much larger PROFIBUS multi-master reported in this paper confirm that the PROFIBUS master implementation varies between different vendors. Therefore, more stringent testing and certification of master devices is required. This work has contributed to making the PROFIBUS master certification mandatory by PI.

22. Use of independent axis of motion using VFDs, or servo controlled systems is common place in motion control applications. The research work reported in the last paper has focused on the application of VFDs and shown that the synchronisation of a multi speed control system is achievable using PROFIBUS and PROFINET Class 1. However, the level of synchronisation achievable varies considerably depending on the, speed change, acceleration, deceleration, and load change. The synchronisation achievable from both PROFIBUS and PROFINET Class 1 would be suitable for applications where exact position synchronisation is not essential.

23. No considerable advantage has been identified in using PROFINET Class 1 over PROFIBUS for this application with PROFIBUS outperforming PROFINET Class 1 in all tests carried out. Other factors impact on the synchronisation achievable for example the control program, PID tuning, and equipment being used. To obtain the best performance from the PROFINET system, PROFINET Class 3 (IRT) should be used. The advantage of using

PROFINET Class 3 (IRT) is a fast and constant bus cycle time. The availability of equipment to set up a multivendor experimental rig also plays a major part in conducting further comparison tests.

9.4 Model Conformance

24. It has been shown that the proposed model provides a framework for development and use of diagnostic tools, and outlines few different development approaches taken as test cases.

25. The proposed model outlines the mechanism for interfacing the different diagnostics tools to the underlying fieldbus networks, and the methods that diagnostics information can be relayed to the end user.

26. It has been demonstrated that the developed diagnostics tools can be used for troubleshooting fieldbuses as well as fieldbus comparisons, and determination of device behaviour of networked devices.

27. The proposed model for developing and using diagnostic tools for fieldbuses is similar to ISO, OSI model for development of communications networks. This would aid the uptake and use of the proposed model in future developments.

9.5 Achievement of objectives

The following objectives were set out for the research work on the diagnosis methods for fieldbus networks reported in this thesis:

- Establish a new method for fieldbus diagnosis at the controller level

  The objective here was to find a suitable software solution for fieldbus diagnosis for implementation at the controller level. This objective was addressed in paper 1. This research developed a new frame work for diagnosing fieldbus networks at the controller level. It developed diagnostic Function Blocks (FB) based on IEC61499 standard for multiple vendors. Function Blocks were developed for three different makes of PLCs and were tested for different network faults. Data blocks were used to store the diagnostics information in a unified fashion. The diagnostic data were verified against commercial tools for validity. These FBs can obtain the fieldbus diagnostics data and present the data in a uniform format to the end user. The research work presented in paper 1 formed the basis for other researchers such as Piggin et al (2008) to extend the frame work to other fiedlbus systems.

- Establish suitable methods for fieldbus diagnosis at the network level.

  The objective here was to develop new approaches to fieldbus diagnostics at the network level to provide vendor independent solutions. The research work established a software solution for fieldbus diagnostic at the network level exploiting the relationship between the controller and the devices under its control. In the case of PROFIBUS network the Master-slave relationship is used to request diagnostic information from the slave devices, while in PROFINET networks the relationship between the IO Controller and IO device is used to gather diagnostic data. Similarly in the case of DeviceNet the relationship between Scanner and the device is used to obtain the required diagnostic data. The research work presented in papers 2, 3, and 4 achieved this objective.

- Develop and test suitable software blocks for fieldbus diagnosis at the controller level.

  The objective was to develop software solutions based on existing and emerging standards for diagnosing fieldbus networks. This research work has developed a software solution for diagnosing fieldbuses at network level. It developed a number of OPC servers based on OPC standard to obtain diagnostic data from fieldbus networks. This research work successfully developed three functioning OPC servers, for PROFIBUS, PROFINET, and DeviceNet fieldbuses. For each fieldbus the OPC servers were tested in a large experimental network. The diagnostic data from each underlying fieldbus network in the form of OPC tags were verified against other tools. The tags were made available to the developed diagnostic tool for visualisation. The research work reported in papers 2, 3, and 4 addresses this objective.

- Develop hardware interfaces for fieldbus diagnosis at network level with reduced foot print.

  The objective was to develop diagnostics hardware with small foot that can be installed on a DIN rail in an electrical cabinet. Fieldbus interfaces in the form of PC104 boards were used that can be stacked up to reduce the physical size of the device. A small headless PC with embedded XP is used to connect with two PROFIBUS interfaces, one PROFINET interface, and one DeviceNet interface. Aluminium housing was designed and built to house all the hardware for the diagnostic tool. This objective was addressed in paper 4.

- Develop and test diagnostics tool for multiple fieldbuses.

  The objective was to develop a tool suitable for diagnosing multiple fieldbuses simultaneously. Vendor independent diagnostics hardware was developed for PROFIBUS, PROFINET and DeviceNet networks capable of monitoring these networks simultaneously. A DIN rail mounted device based on PC104 interfaces and imbedded XP was prototyped. The application software was developed in C# within Microsoft .Net environment. All the necessary security measures were added to the device in order to provide web server functionality securely. The device is capable of obtaining diagnostic information in the form of OPC tags from each fieldbus, and visualising this in a unified manner. The application software was tested in large experimental networks for different error scenarios in all underlying networks. The prototype device is now available for licensing, UL, and CE marking. The reported research work in papers 2, 3, and 4 addressed this objective.

- Analyse behaviour of networked controllers.

  Timing behaviour of network devices is crucial in reducing network issues. This work demonstrated the differing behaviour of the master devices in multi-master PROFIBUS networks. This research work highlighted the nonstandard behaviour of the master devices in PROFIBUS networks. Partly as a result of this work testing of master devices has been made mandatory. Test and certification increases compatibility and reduces network problems. Additionally it highlighted and promoted the use of network diagnosis devices for detailed network timing analysis. The work reported in paper 5 covers this objective.

- Establish a practical method for fieldbus performance analysis.

  The objective was to establish a more practical method for analysing fieldbus networks .The work provided a manufacturer independent practical comparison of two industrial networks using diagnostic tools. The application area of speed synchronisation is demanding, and should inform the user on the performance and limitation of industrial networks. This research work promotes the use of fieldbus diagnostics tools to establish the performance parameters for fieldbus networks. The work reported in paper 6 covers this objective.

- Establish a model for further development of diagnostics tools.

  From the analysis of different approaches taken to fieldbus diagnostic work reported in papers 1 to 6. A multilayer model is defined in Fig1.1 for future development of diagnostic tools for fieldbus networks.

9.6 Original Contribution to Knowledge

The research work outlined in this thesis has made original contribution to knowledge in the area of fieldbus diagnosis tools and techniques. This is achieved by introducing original software methods, original and improved diagnostics hardware, and new use cases of diagnostics tools for fieldbus analysis. The original contributions made are summarised below:

- A new method of diagnosing fieldbuses at the controller level using IEC 61499 conformant Function blocks.
- A new approach of using emerging OPC technology to obtain diagnostic data from a fieldbus network.
- A new approach for diagnosing PROFINET networks in the absence of IO supervisor.
- A new diagnostic tool for multiple fieldbuses with a small form factor.
- A new software solution for diagnosing multiple fieldbuses simultaneously with a uniform user interface for all underlying fieldbuses.
- Demonstrated for the first time through experimentation the differing behaviour of PROFIBUS masters in a multi master network.
- A new conceptual multi-layered model for future development of diagnostic tools.

The overall original contribution made has resulted in tested and verified software modules for fieldbus diagnostics at controller level, and introduction of new and improved software & hardware for fieldbus diagnosis at the network level for both single and multiple fieldbuses.

9.7 Limitations

The various tools and techniques developed in this research work provide a satisfactory solution to fieldbus analysis; however each and every solution has its inherent limitations.

- The issue of interfacing any tool to the network under investigation is a problem in some installations. For example absence of a piggy back connector in the case of a PROFIBUS networks, and availability of a spare port in the case of a PROFINET networks.

- The influence of the tool on the network under investigation is another issue. For networks that are operating at the margins of stability, it is always a concern that connection of additional load on the network may cause further malfunctions.

- For some of the diagnostics tools that act as a node on the network, such as Master class 2 in the case of PROFIBUS, or IO supervisor in the case of PROFINET, the cycle time of the communication will increase marginally. For example in motion control applications, this may not be acceptable.

- For the diagnostic tools that provide a remote monitoring capability, it is not always possible to have a connection to plant IT networks at the point of interface. Additionally some IT departments limit the access to their network, both for internal and external access.

- With the tools that provide remote monitoring capability, the continuous streaming of network traffic may not be possible, for example if GPRS network is used for data transfer. For these cases a sample of network traffic is provided to remote locations for analysis.

- For regulated industry such a pharmaceuticals, a permanent connection of a network analysis tool to plant fieldbus networks is not normally allowed due to validation issues.

- Most standalone diagnostic tools are open loop, and would require a technical person to operate, and make decisions on the nature of the problem.

- Normally a risk assessment, safety induction for third party companies, and other procedures are required before a diagnostic tool can be connected to plant networks.

9.8 Future work

For the past few years the concept of continuous monitoring of fieldbus networks has been gaining momentum. Continuous monitoring provides an early warning of possible network issues. In order to satisfy this trend the future network diagnostics tools will be required to be installed permanently as network components. Therefore the development cycle for the tools would require in addition to CE marking, certification by UL, FCC and others.

Diagnostics tools in the form of network components, in addition to providing the capabilities of standalone tools, may encompass extra functionality. These could be in the form of signal conditioner, digital I/O, and the like.

Most of the current diagnostic tools are open loop, and require a human operator to close the loop. Future diagnostic tools will be required to provide some closed loop operation, and send notification to both the main control system as well as operating personnel in the form of, discrete inputs, SMS, and Emails.

Additionally for connection of tools to outside world, the cyber security concerns needs to be addressed adequately to convince the end user to avail of technology.

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