Training in Industrial Ethernet

Giorgos M. Papadourakis
Department of Applied Informatics and Multimedia
Technological Educational Institute of Crete
Heraklion, Crete, GREECE
papadour@cs.teicrete.gr

Wojciech Grega
Department of Automatics
AGH University of Science and Technology
30-059 Kraków, POLAND
wgr@ia.agh.edu.pl

Dominique Daens
Karel de Grote-Hogeschool
Antwerp, Belgium
dominique.daens@KdG.be

Sofie Krol
Karel de Grote-Hogeschool
Antwerp, Belgium
sofie.krol@KdG.be

Abstract—**Technological development has brought the use of networks in control to the mainstream. Ethernet-based systems are becoming an increasingly attractive technology as they combine large capacity and high speed with flexibility. New trends in control technology must be reflected in the respective teaching activity. In the response to the demands the concept of mobile laboratory was proposed and has been implemented by the consortium of university and industrial partners from six European countries and two partners from Turkey. The CoNeT (Cooperative Network Training) project described in this paper aims at training of automation engineers, maintenance engineers, process workers and students both graduate and undergraduate in modern industrial Ethernet technologies.**

Keywords-distributed control; industrial Ethernet; laboratory education; international collaboration

I. INTRODUCTION

The evolution of industrial communication has brought the use of networks in control to the mainstream. Monitoring and control systems wherein data are transferred through a network are already used in most industrial control and monitoring applications. Using a distributed architecture has many advantages over a point-to-point design such as low cost of installation, easy of maintenance and flexibility. Today, leading manufacturers of control and monitoring technology offer network interfaces for their devices. Decreasing costs and increasing demand for a single, standard network type, from boardroom to plant-floor, have led to the development of Industrial Ethernet.

In the response to the demands the concept of mobile laboratory was proposed and has been implemented by the consortium of university and industrial partners from six European countries and two partners from Turkey. Karel de Grote-University College and Limburgs Technologie-Centrum from Belgium, University of Rousse from Bulgaria, Fachhochschule Düsseldorf and Germany-Phoenix Contact from Germany, Technological Educational Institute of Crete from Greece, AGH University of Science and Technology from Poland, Yildiz Technical University and Enosad Industrial Automation from Turkey, and University of Limerick, Ireland – all these partner institution have recognized the demand for efficient development of quality industrial Ethernet systems and need for development of international learning environment.

CoNeT, the EU-funded project [1], stands for Cooperative Network Training. The project aims at training of automation engineers, maintenance engineers, process workers and students both graduate and undergraduate in modern wired and wireless industrial network technology applied to control operations and automated solutions. The current trend in engineering curricula applies the concept of "learning by experiments" or "learning by projects" [2]. Such "learning by doing" concept was also proposed for the collaborative project as a part of the pilot CoNeT implementation phase.

The overall objective of the CoNeT project is to contribute to the qualification of future Ethernet-based network-specialists. The specific objective of the project is to develop training modules in the field of Industrial Ethernet for students, technicians and engineers in industry. It is anticipated that trainees who are already employed will need to fit their learning around existing family or work commitments, therefore the laboratory will be broken up into 'bite-sized' discrete modules and flexible modes of delivery will be used including the use of both distance and face-to-face teaching. These mobile labs can be transported between companies and universities and used to complement the training courses.

II. INDUSTRIAL ETHERNET

Ethernet-based networks are the most dominant form of networks used in the world today. A significant portion of the Internet infrastructure is built on Ethernet-based bridges, hubs, switches and routers. Over the years, Ethernet has improved to support faster data rates and different operating schemes (full and half duplex). Fig. 1 shows the increasing use of Ethernet applications nowadays.

As manufacturers seek to improve processes, increase productivity, reduce operating costs, and integrate manufacturing and business networks, many are turning to Ethernet technology on the factory floor. This migration is rapidly gaining momentum. According to a recent ARC Advisory Group study [3], the worldwide market for Industrial Ethernet devices is expected to grow at a rate of approximately 30 percent compound through 2011. Once considered a solution that was limited to corporate network environments, Ethernet technology has proven to be a robust alternative that can meet the unique needs of the manufacturing environment.

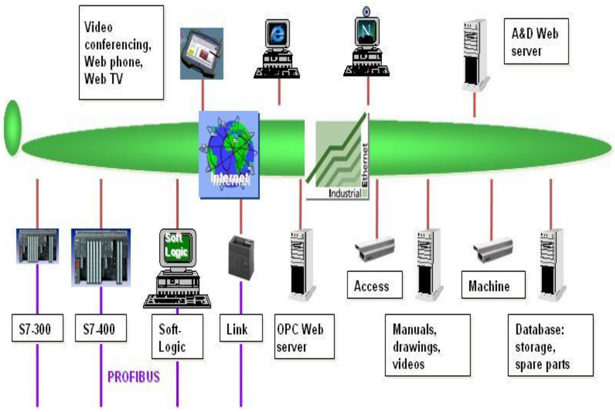

Figure 1. Increasing use of Ethernet.

There are three major trends observed in contemporary industrial control systems:

- distributing and decentralizing structures of automation, as the "intelligence" is shifted towards field components,
- increasing integration of vertical communication through all the levels of the control systems.
- Growing demand for application of IT standards.

Most of the contemporary industrial automation systems adopt multilevel, vertical control architecture.

Logically, the system is structured into three levels (Fig. 2), which are: the direct (device) control level, supervisory level and management level. Basic task of the direct (device) control level is to maintain the process states at the prescribed set values. Device controller level provides interface to the hardware, either as separate modules or as microprocessors incorporated in the equipment to be controlled. A number of embedded control nodes and Programmable Logical Controllers (PLC) are used as the front-ends to take the control tasks. High speed networks and fieldbuses are implemented at the direct control level to exchange in real time the information between front-ends and the device controllers and, vertically, with the supervisory control level. This architecture has the advantage of locating the hard real-time activities as near as possible to the equipment. The supervisory level comprises workstations and industrial PCs providing, the high-level program support, database support, graphic man-machine interface, network management and general computing resources.

Current communication systems for automation include different protocols. This is a substantial disadvantage, leading to necessity of using vendor-specific hardware and software components, which increase installation and maintenance costs. Moreover, presently used fieldbus technologies make vertical communication across all levels of the automation systems difficult. Gateways need to be used to establish connections between different kinds of fieldbus systems used in the lower level, and Ethernet used in the upper levels. Differences in data format also obstruct communication.

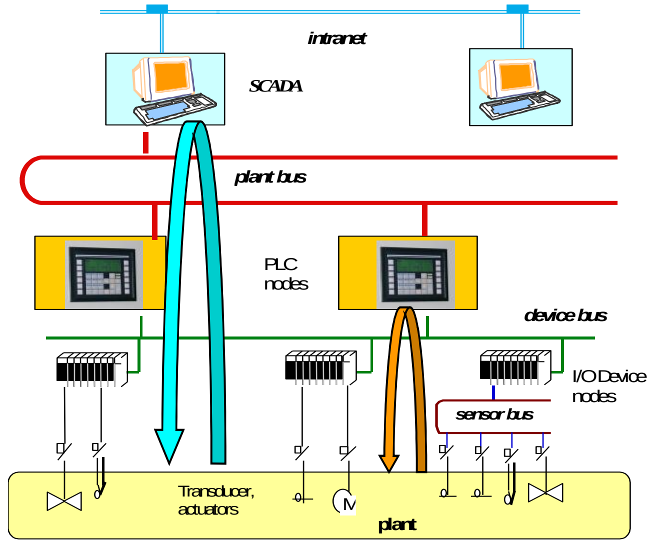

Figure 2. Multilevel structure of the industrial automation system

Ethernet comes as a solution to the problems mentioned above, at last to some extent. It provides unified data formats and reduces the complexity of installation and maintenance, which, together with the substantial increase of the transmission rates and communication reliability over the last years, results in its popularity in the area of industrial communications. It is a result of Ethernet's desirable properties, namely:

- comparatively high transmission rates,
- possibility of connecting large number of nodes in a single network,
- relatively low cost of components and wiring,
- interoperability, ease of integrating multi-vendor products into a single application (Ethernet is an open standard),
- transparency, which allows different protocols to be utilized concurrently in one network,
- scalability and reconfigurability,
- portability of applications,
- compatibility of networks applied on process level with higher level company networks, which facilitates data acquisition, production supervision and management.

Ethernet, as defined in IEEE 802.3, is non-deterministic and thus, is unsuitable for hard real-time applications. The media access control protocol, CSMA/CD with its backoff algorithm, prevents the network from supporting hard real-time communication due to its random delays and potential transmission failures. In real-time systems, delays and irregularities in data transmission can very severely affect the system operation. Therefore, various techniques and communication protocol modifications are employed, in order to eliminate or minimize the undesired effects.

Although Industrial Ethernet is based on the same industry standards as traditional Ethernet technology, the implementation of the two solutions is not always identical. Industrial Ethernet usually requires equipment that can handle more severe environmental conditions, flexible node counts, varieties of media, very predictable real-time data traffic performance, and increased levels of segmentation as compared to traditional Ethernet networks in a corporate data network.

The primary difference between Industrial Ethernet and traditional Ethernet is the type of hardware used. Industrial Ethernet equipment is designed to operate in harsh environments. It includes industrial-grade components, convection cooling, and relay output signaling. And it is designed to operate at extreme temperatures and under extreme vibration and shock (and other conditions). Power requirements for industrial environments differ from data networks, so the equipment runs using 24 volts of DC power. To maximize network availability, Industrial Ethernet equipment also includes fault-tolerant features such as redundant power supplies. The equipment is also modular in order to meet the highly varying requirements of a factory floor.

To employ Ethernet in industrial environment, its deterministic operation must first be assured, which can be accomplished in several ways. Coexistence of real-time and non-real time traffic on the same network infrastructure remains the main problem. This conflict can be resolved in several ways, by [4]:

- embedding fieldbus or application protocol on TCP/IP – the fieldbus protocol is tunneled over Ethernet, and full openness for “office” traffic is maintained,
- using special Data Link layer for real-time devices – special protocol is used on the second OSI Layer, implemented in every device. The real-time cycle is divided into slots, one of which is opened for regular TCP/IP traffic, but the bandwidth available is heavily limited down,
- using application protocol on TCP/IP, direct MAC addressing with prioritization for real-time, and hardware switching for fast real-time,
- maintaining real-time on TCP/IP is achieved by prioritized messaging and time synchronization – the synchronized devices assign higher priority and timestamp real-time messages,
- using Ethernet physical layer with built-in application-specific integrated circuits (ASIC technology) and special protocols – Ethernet is used only as underlying technology.

Recognizing that Ethernet is the leading networking solution, many industry organizations are porting the traditional fieldbus architectures to Industrial Ethernet. Industrial Ethernet applies the Ethernet standards developed for data communication to manufacturing control networks. Fig. 3 illustrates using Industrial Ethernet for Automation Control [5]. Using IEEE standards-based equipment, organizations can migrate all or part of their factory operations to an Ethernet environment at the pace they wish. For example, Common Industrial Protocol (CIP) has implementations based upon Ethernet and the IP protocol suite (EtherNet/IP), DeviceNet, and ControlNet (among others). Most controllers (with appropriate network connections) can transfer data from one network type to the other, leveraging existing installations, yet taking advantage ofEthernet. The fieldbus data structure is applied to Layers 5, 6, and 7 of the OSI reference model over Ethernet, IP, and TCP/UDP in the transport layer (Layer 4).

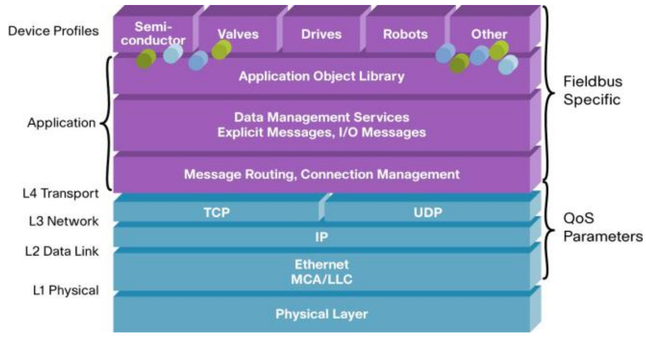

Figure 3. Using Industrial Ethernet for Automation Control.

The advantage of Industrial Ethernet is that organizations and devices can continue using their traditional tools and applications running over a much more efficient networking infrastructure.

Industrial Ethernet not only gives manufacturing devices a much faster way to communicate, but also gives the users better connectivity and transparency, enabling users to connect to the devices they want without requiring separate gateways.

III. Industrial Ethernet Protocols

Industrial Ethernet on the plant floor has gained mass acceptance across multiple industries. Designed to create the real-time seamless flow of information between the plant floor and the back office. Industrial Ethernet networks are also becoming an integral part of real-time control systems for process control and discrete manufacturing applications.

The desire to incorporate a real-time element into this popular single-network solution has led to the development of different real-time Industrial Ethernet solutions, called Real-time Ethernet, as PROFINET, EtherCAT, Ethernet/IP [6], [7] and many more as shown in Fig. 4 along with their respective organizations.

The report "The World Market for Industrial Ethernet - 2009 Edition" [8], contains data about the total quantity of installed Ethernet nodes and shown in Fig. 5. The analyses are divided into regions, product groups and industries. According to the study, EtherNet/IP has the largest market share with

30%, followed closely by Profinet with 28%. Modbus TCP/IP is used in 22% of the applications, Powerlink in 11% and EtherCAT 4%. All other systems together make up for the remaining 5%. The popular Ethernet protocols are listed below:

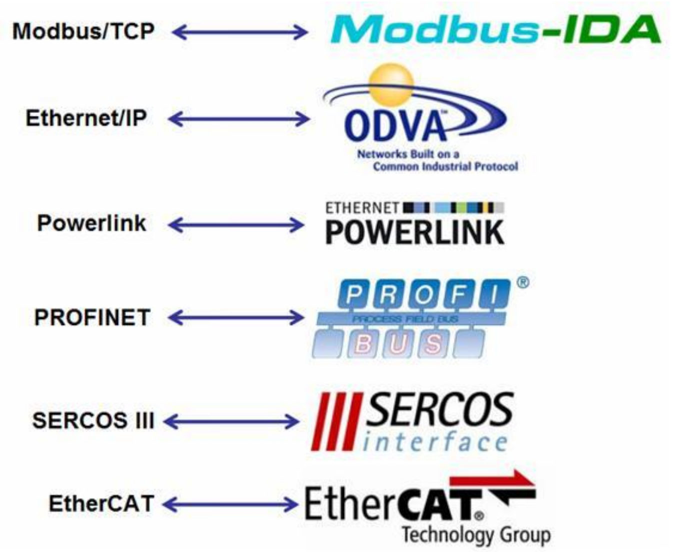

Figure 4. Protocols and their respective organizations.

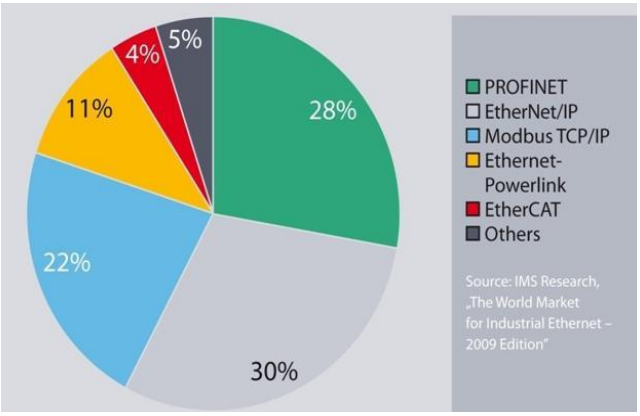

Figure 5. Industrial Ethernet Protocols market share.

A. *EtherNet/IP*

Managed by the Open Device Vendors Association (ODVA), Ethernet/IP for manufacturing automation not only provides the network tools to deploy standard Ethernet technology, but also enables Internet and enterprise connectivity for access to data 24/7 from anywhere. Ethernet/IP (and all CIP networks) implement the Common Industrial Protocol (CIP) at the Open System Interconnect (OSI) Session layer and above and adapt CIP to specific Ethernet/IP technology at the OSI Transport layer and below. CIP provides a media-independent communications platform for manufacturing automation applications such as control, motion, synchronization, and safety. ODVA's CIP Safety, CIP Sync, and CIP Motion provide the network extensions for safety, synchronization, and motion into the wider enterprise network topology.

B. *PROFINET*

PROFINET was developed by Siemens AG and is comparable to PROFIBUS. PROFINET adopts Industrial Ethernet standards for the automation environment that includes fieldbus-across- the-factory, office-to-factory, and equipment-to-equipment communications. PROFINET is designed to simultaneously handle standard TCP/IP and real-time transmissions. PROFINET uses PROFIBUS technology wherever possible to maintain system compatibility with legacy systems and can also interface any existing fieldbus to preserve existing investments in factory and networking equipment. PROFINET (and PROFIBUS) technology enhancements and promotions are directed by PROFIBUS International (PI). The PROFINET Trade Organization (PTO) addresses PROFINET for the North American region.

C. *Modbus/TCP*

Modbus is an open, royalty-free serial communications protocol for programmable logic controller (PLC) applications. Modbus/TCP is a Modbus/RTU message transmitted with a TCP/IP wrapper and sent over a network instead of serial lines. As with the serial Modbus architecture, Modbus/TCP is managed by Modbus/IDA, a group of independent users and suppliers of automation devices seeking to drive the adoption of this protocol.

D. *Ethernet Powerlink*

Ethernet Powerlink is a deterministic, real-time Ethernet-based protocol. Powerlink can be described as a software solution for CANopen over Ethernet with real-time capabilities that rely on standard hardware and fully standard-compliant Ethernet frames. The Ethernet Powerlink Standards Group (EPSG) drives the specification and marketing of Powerlink.

E. *EtherCAT*

Ethernet for Control Automation Technology (EtherCAT) is the open, real-time high-performance Ethernet fieldbus protocol. EtherCAT supports any line, ring, or star topology; versatile and synchronized master/slave, slave/slave, and master/master communications with low jitter; minimum-effort implementation on devices equipped with CANopen; mapping of SERCOS servo drive profile to EtherCAT; and functional Safety-over-Ethernet. EtherCAT is supported and promoted by the EtherCAT Technology Group (ETG), a global organization of OEMs, end users, and technology partners.

IV. Mobile Laboratory

The overall objective of this project is to contribute to the qualification of future Ethernet-based-network-specialists. The project produced independent training modules in Industrial Network Systems, each of them based on Industrial Ethernet communication solution. For the practical implementation of the training modules, mobile laboratories were developed and assembled. The laboratories are mobile, because laboratories can be exchanged between the partners, as the labs are small, can be brought to the companies where the engineers and technicians can be trained on the floor, or can be brought to one place for training, for example an Intensive Program of two weeks. A typical mobile laboratory is showed in Fig. 6. These portable laboratories are equipped with industrial network devices.

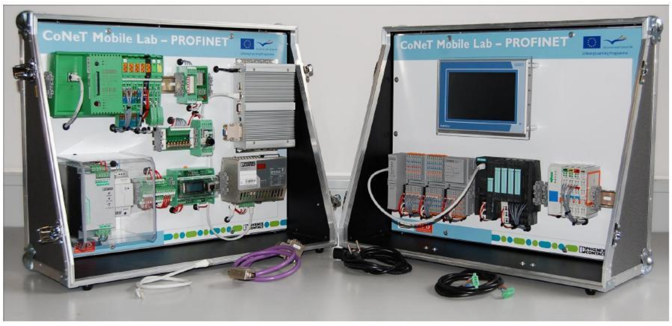

Figure 6. A typical mobile laboratory.

The didactical approach in the modules implementation goes for blended learning by applying classroom lectures, expert presentations, self- and team study sessions as well as team work. The training load for each module will be 12 hours for 2-day course, consisting of 4 hours theory and 8 hours of practice.

The following training modules were implemented:

1. Ethernet based I/O systems.

The basic aims of the Ethernet based I/O systems module (Fig. 7) are: a) to understand the basic knowledge of Ethernet, b) to understand the logic of the routers, switches, hubs and manageable switches, c) to give knowledge about the properties of basic network components, d) to understand the difference between real time and not real time communication, and e) to give the ability to realize the differences between manageable and unmanageable switches and also the differences between an office LAN and industrial LAN.

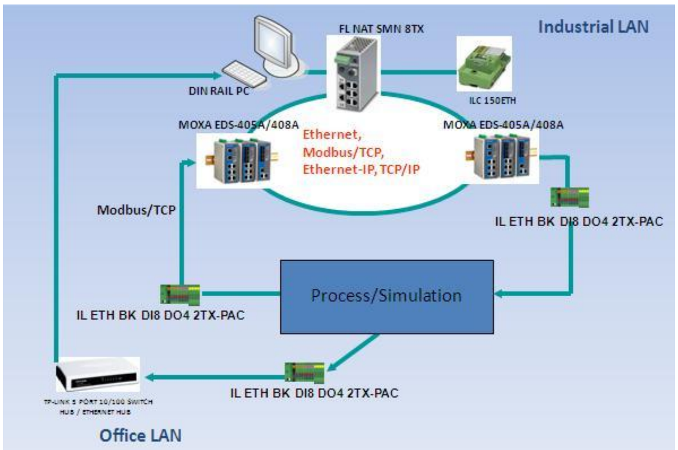

Figure 7. Structure for Ethernet based I/O systems module.

There will be mainly three basic parts of theoretical lectures; basics of Ethernet technology, introduction to industrial communication and routers-switch technology. After the theoretical part, there will be some demonstrations and examples in the mobile laboratory such as: a) Control of a process via Ethernet based communication, b) Control of distributed I/Os via Modbus, c) Feedback via unmanageable switch/hub, d) Feedback via manageable switch/hub and differences of manageable and unmanageable switches, and e) Monitoring the traffic via Wireshark.

2. PROFINET on SIEMENS Platform

The objectives of this module are (Fig. 8): practical implementation of a Profinet IO systems (Phoenix Contact, Wago, Beckhoff) on a Siemens PLC, such as Simatic S7 (Simatic S7 Manager), Profinet CBA, and study of different Gateways: Profinet/Profibus, Profinet/Interbus.

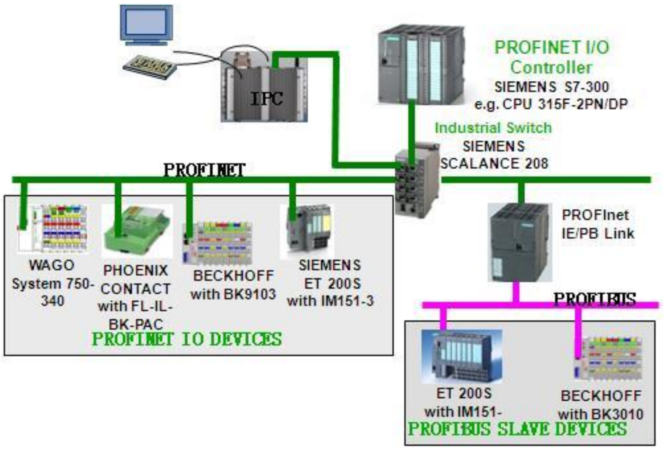

Figure 8. Architecture of PROFINET on SIEMENS Platform.

The training material of this module consists of: a) PROFIBUS Overview, b) PROFINET Basis, c) SIMATIC Manager, d) Configuration of a PROFINET I/O System, and e) Diagnostic of PROFINET IO Systems.

3. Profinet on Phoenix Contact Platform

The objectives of this module (Fig. 9) are the development of a mobile laboratory to learn Profinet I/O systems (multi-vendor) on a Phoenix Contact platform and study of different gateways.

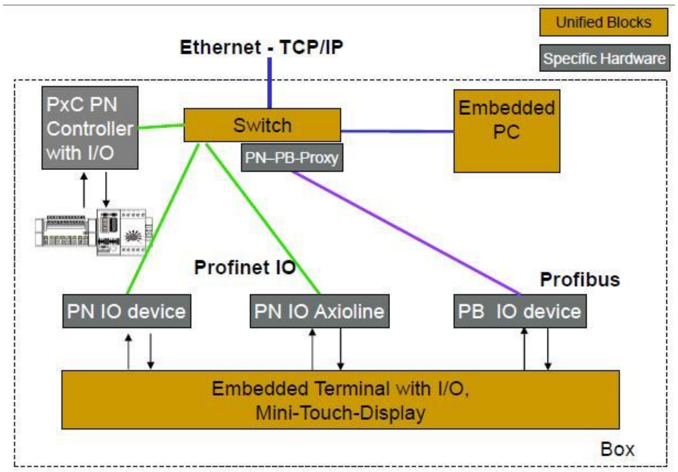

Figure 9. Architecture of Profinet on Phoenix Contact Platform.

The theoretical aspects the module will cover the areas of: a) basics of Ethernet (industrial and real time), b) Proxy concept of Profinet, c) Profibus and d) Automation WorX. The practical demonstrations and exercises will include: a) System configuration and parametrizing, b) to parametrize proxy, c) Profinet implementation, d) to parameterize and to configurate PxC + Wago components, e) to parametrize and to configurate PxC + Siemens components, and to f) to modify and to test SPS program for PxC + Wago.

4. *EtherCAT*

The aims of the module (Fig. 10) is to bring the knowledge about EtherCAT technology, by means of study of Beckhoff IPC connected with an EtherCAT network with different I/O devices and gateways. It allows students to get familiar with characteristics of data transmission using an EtherCAT network. Students get familiar with different, industrial equipment on a real time Ethernet network.

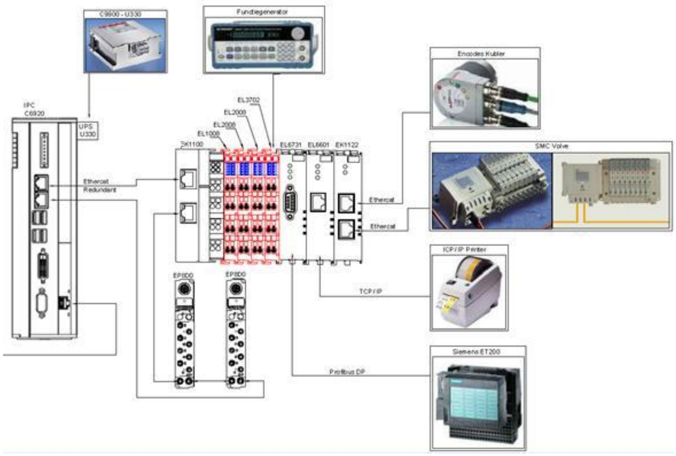

Figure 10. EtherCAT configuration.

There will be mainly three basic parts of theoretical lectures; EtherCAT Overview, EtherCAT features, and EtherCAT Diagnostics. The associated exercises include: a) configuration of EtherCAT with one I/O slave, b) configuration of EtherCAT with many I/O slaves, c) configuration of EtherCAT network with multiple devices from different manufacturers, d) configuration of EtherCAT network with multiple modules, e) configuration of PROFIBUS network within an EtherCAT network using the PROFIBUS master interface, f) configuration of an Ethernet TCP/IP printer in the EtherCAT network, g) configuration of a redundant EtherCAT network, and h) configuration of an EtherCAT network with multiple I/O terminals and use of diagnostic tools to detect errors.

5. *Ethernet IP*

The Ethernet IP mobile laboratory, shown in Fig. 11, consists of six nodes: 1) CompactLogix L35E PLC, 2) POINT_IO: 1734-AENT, 3) PowerFlex 40 inverter, 4) WAGO 750-341 Coupler, 5) Internet Camera (WebCam), and 6) PanelView 600 Plus – Touch Panel. A PC is used as a development and Ethernet monitoring platform and the WebCam generates noises in the network packet traffic. The issues for consideration by the students are: a) analyzing the Ethernet/IP packets and Ethernet network parameters (throughput, round trip time etc.) by utilizing the Wireshark application, b) diagnose and analyze the jitter for a several scan times and the RPI parameter (Request Packet Interval) and c) effect of load Ethernet network to stabilize the position of the Aerolift.

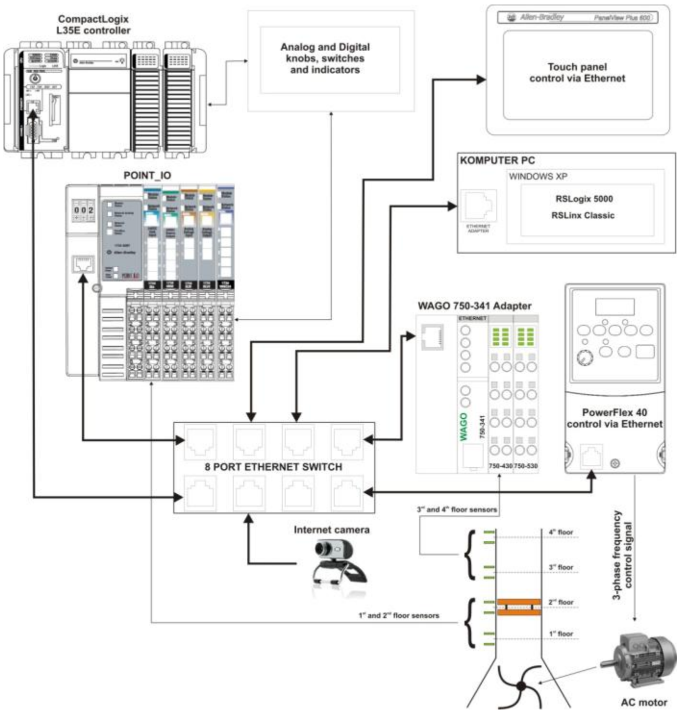

Figure 11. Ethernet IP laboratory setup.

6. *Real-time processes*

The objective is presentation and practical exercises on laboratory real-time processes in which several Ethernet IO and fieldbusses can be integrated. Processes will be connected to the PLC modules by using several fieldbusses and Ethernet-based IO by simple replacement of the fieldbus module. Examples of controlled processes are: level control, temperature control, magnetic levitation, some mechatronics laboratory models, pneumatic manipulators etc.

7. *Wireless communication*

Implementation of wireless communication concepts in an industrial environment that is: Wireless Ethernet, Access Point, Access Client, Bluetooth based wireless, GPRS.

The theoretical aspects the module will cover the areas of: a) differentiating between wireless technologies, b) IEEE 802.11 standards and architecture, c) IEEE 802.11 layers description, d) power management, and e) WLAN security. The practical aspects of wireless communication will include: a) Wireless communication between PC (notebook) with WLAN interface and the FL WLAN AP 802.11, b) wireless communication between PC with WLAN interface and the FL WLAN EPA, c) WLAN between PC, Access Point and the FL

WLAN EPA, d) configuration Profinet Network Siemens S7 315 3DP/PN with Profinet devices IL PN BK 2TX_PAC, e) research of the maximum update rate of the ProfiNet IO devices , and f) to study the influence of other TCP/IP traffic.

Each module is supported by a number of documents available on-line. Between them are: technical documents: description of the CoNeT Mobile Lab, handbooks, technical manuals, wiring diagrams, and didactic materials: training tasks, laboratory instructions, exercises, test questions, laboratory report template, WBT systems, additional useful information. It is proposed that the Moodle [9] course management system will be used to manage the educational contents of the modules. It is envisioned that all didactic documents for all CoNeT Mobile Labs are stored in and managed by Moodle while all technical documents and functional programs for each CoNeT Mobile Lab are stored in an embedded PC as shown in Fig 12.

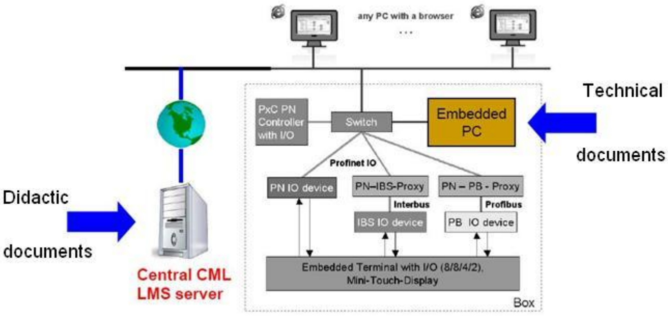

Figure 12. The didactic approach for CoNeT Mobile Labs.

In the framework of another Long Life Long Learning program under Erasmus called Intensive Programs, the project entitled “Modern Data Transfer Standards for Industrial Automation” was run successfully in Krakow, Poland 14-25 February 2011, where 24 students from Belgium, Bulgaria, Greece, Germany and Poland where trained with the CoNeT Mobile Labs and received 5 ECTS as academic credit.

Several more training activities are scheduled within 2011 and 2012. The project aims at training of automation engineers, maintenance engineers, process workers and students both graduate and undergraduate in modern wired and wireless industrial network technology applied to control operations and automated solutions.

V. Conclusions

Technological development has brought the use of networks in control to the mainstream. Ethernet-based systems are becoming an increasingly attractive technology as they combine large capacity and high speed with flexibility. New trends in control technology must be reflected in the respective teaching activity. In the response to the demands the concept of mobile laboratory was proposed and has been implemented.

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