Reprint

A Distributed Information Network for Quality Control in a Factory Environment of Production and Distribution of Sensitive Products

T. Antonakopoulos, N. Kanopoulos, D. Antoniou and V. Makios

The Fourth International Conference on Advanced Factory Automation - Factory 2000

YORK, UK, OCTOBER 1994

A DISTRIBUTED INFORMATION NETWORK FOR QUALITY CONTROL IN A FACTORY ENVIRONMENT OF PRODUCTION AND DISTRIBUTION OF SENSITIVE PRODUCTS

T. Antonakopoulos[1], N. Kanopoulos[2], D. Antoniou[3] and V. Makios[1]

[1] *Electrical Engineering Dept., University of Patras, 26110 Patras, Greece*

[2] *Research Triangle Institute, POB 12194, Research Triangle Park, NC 27709, USA*

[3] *SIEMENS AE, POB 61011, 15110 Amarousio/Athens, Greece*

Abstract: This paper presents the design and implementation of a distributed network for intelligent monitoring and control of units storing sensitive products in a factory environment. The network is used by the Quality Control Department (QCD) of a high-technology factory for real time acquisition of the parameters that define the status of various store-rooms for sensitive products and for collecting data during the products distribution process. The network uses the factory power grid as the communication medium and follows the Reference Model for Open System Interconnection (OSI-RM) for communication reliability and expandability. The network topology is dynamically modified based on the products distribution policy and it is automatically detectable by the QCD. The paper describes the functionality of the network both in terms of services supported and of application-dependent characteristics. The hardware of the network node is also described emphasizing the process of collecting and storing the acquired data.

I. INTRODUCTION

The factory environment is characterized by a large number of data collecting and processing applications that have to be supported, Klein et al (1). These applications have different, usually contradictory requirements and the current trend is to have a unified communication system for supporting these requirements, Siemens (2). Although this methology is generally the most appropriate, it is difficult to implement and results to high cost, when data collection of sensors at the factory environment is supported. A large number of sensors is spread in a factory and a large number of sensors is installed in moveable units, like trucks, especially when sensitive products are distributed. In the last case, the use of a typical network is impractical. The distributed network, described in this paper, was mainly developed for such a case, where data from sensors installed in distribution trucks had to be collected at the Quality Control Department automatically whenever a truck is connected to the power grid within the factory. Furthermore, data have to be collected during the distribution process and to be downloaded to the QCD in order to have the complete behavioural profile of each truck. The usage of the power cabling as the communication channel was considered more appropriate than other solutions, like the usage of RF frequencies, due to low cost of installation, no interference with regulatory bodies and due to enchanced reliability since external interference is not possible. Such a distributed network is under installation and prototyping in the largest and more technologically advanced factory (FAGE) for dairy products in Greece.

The FAGE factory produces dairy products and uses a large fleet of vehicles for distribution. Maintaining high product quality from production through storage and distribution, requires that certain environmental parameters (i.e., temperature, humi-dity, etc.) are strictly controlled within specific limits. The approach to achieve this requirement is to install a number of sensors on the distribution vehicles in order to acquire and store the parameters needed by the QCD. The network is implemented using the power grid of the factory and it takes advantage of the connection of the delivery vehicles to the grid after their deliveries, in order to keep their air-conditioning systems functioning while products are still being stored in the vehicles.

Section II presents the network architecture and its protocol organization for reliable data transmission. The network node architecture, both in terms of hardware and software is described in Section III. Section IV emphasizes the data collection process and gives numerical results on systems capabilities.

Factory 2000 - Advanced Factory Automation, 3-5 October 1994, Conference Publication No 398,

II. THE NETWORK ARCHITECTURE

The factory uses hundreds of vehicles for product distribution, which are connected to the power grid after their deliveries. The factory uses a number of parking lots near the main building and each parking position has an outlet for power distribution to each vehicle. The distributed network interconnects vehicle-mounted data collection units with the main computing facilities in QCD for data storage and processing. The network model is shown in Figure 1.

Each parking lot with its associated trucks forms an autonomous subsystem with centralized control. Each autonomous subsystem is connected to the factory communication system by using Network Control Units (NCUs). Each NCU consists of two half-gateways, Tanenbaum (3). One part of the NCU, the repeater, is directly connected to the central communication system, while the other part, the subnetwork controller, is attached to the parking lot power distribution center. The two parts of NCU intercommunicate via the power cable to form a point-to-point communication link. In order to increase the available bandwidth at the network, the power grid of each parking lot has been isolated from the main factory by using power line filters (EMI suppressors). These filters do not affect the power distribution process but allow the use of different segments of the power cabling for simultaneous transmissions. For each parking lot two power line filters are used, one near the data repeater and the other near the subnetwork controller, as it is shown in Figure 2. Using this configuration, the power line between the two parts of NCU is devoted to intra-NCU communications, while the traffic conditions of each subnetwork depend only on internal transactions. The NCUs of these subsystems also perform internetworking tasks for the factory infrastructure and are connected to its higher level, which consists of Programmable Logic Controllers (PLCs) and computer facilities interconnected through a SINEC L2 industrial local area network, Siemens (2), in order to collect, store and process the application data. The QCD is attached to this level. The SINEC L2 is an open network for heterogeneous communications. It has been developed based on the ISO-RM, Jain et al (4), and the Manufacturing Message Specification standard (MMS, ISO/IEC 9500). The MMS has various features for automation in a distributed network, like variable services, domain services and program invocation services. For reliably and transparently connecting the NCUs to the QCD, the domain and the variable services are used. The domain services are used during the data downloading process, while the variable services are used for command execution and subnetwork maintenance.

Each truck is a network node, hereafter referred as truck-node, which has not a fixed position at the network but it can be connected to a different subnetwork depending on the distribution process. The QCD is informed about the network topology by receiving 'node connected' tables from each subnetwork controller of each parking lot. Whenever a truck is connected to the power grid, the associated node starts a 'truck connection' process for informing the respective subnetwork controller that a new node participates in this subnetwork. At the end of this process, the subnetwork controller updates its 'node connected' table. When a truck is removed from the network, the truck-node does not have the proper indication for informing its subnetwork controller for the disconnection process. For this reason, the subnetwork controller performs a periodic scan to the nodes indicated in the 'node connected' table for validating their existence in the network. The scanning period is programmable by authorized network users. The QCD receives a new 'node connected' table from each subnetwork either as a result of its own request, or whenever a change (addition or deletion) is performed in the table entries. The 'node connected' tables can also be used for security purposes since they can be

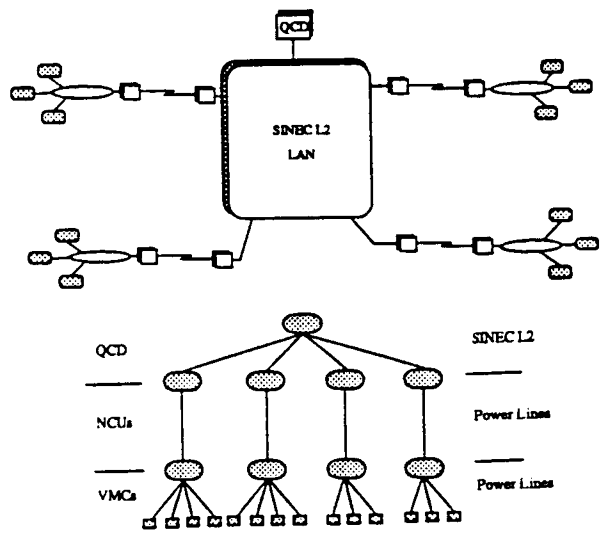

Fig. 1. The Distributed Network Model.

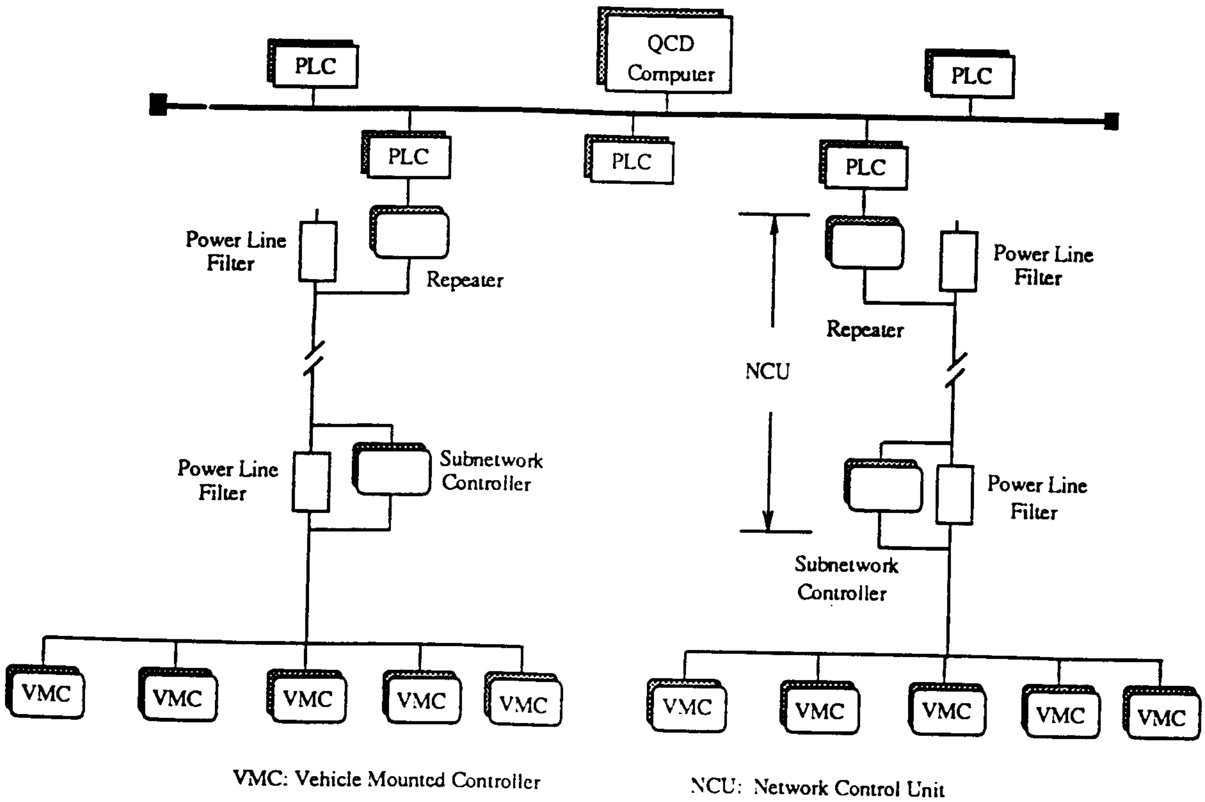

Fig. 2. The Distributed Network Configuration

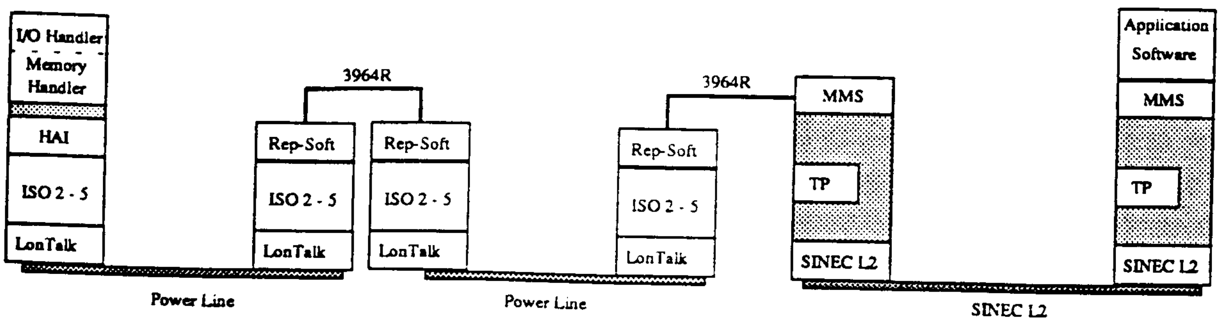

Fig. 3. The Network Protocol Stack.

related with other vehicle status data (like distribution schedule, current time etc.) for generating alarm indications whenever an improper truck condition is met.

As it is shown in Figure 3, the network has been based on the ISO-RM 7 layer communication protocol stack. At the physical layer, power line transceivers are used while the LonTalk protocol, LonTalk (5), is used for media access and data encoding. Although the SINEC L2 has an inactive network layer, the subnetworks use a network protocol hierarchical addressing structure for single, group and broadcasting message delivery. The transport protocols ensure reliable message delivery with different message types and characteristics. At the higher layers, the subnetwork protocol ensure management and diagnostic functions, message authentication and the use of network variables for data exchange.

The system supports three types of messages exchanged between the various network nodes:

- Application messages,
- Network maintenance messages and
- Configuration messages.

The application messages relate to sensory data and supporting functions (communication protocols) for reliable data transmissions. The network maintenance messages are used for determining the network configuration and for detecting topology errors. The configuration messages are used from the QCD to program the nodes functionality. This function is mainly performed to truck-nodes either for reorganizing their I/O interface or for reconfiguring the data collection process. The configuration messages are authenticated by implementing an 48-bit key algorithm. The authenticated keys are hardwired during the production process and are independent from the network addressing scheme.

The sensor-data acquisition process has been based on a Request/Response message service (RRS), supported by the protocol stack. In this case, the message transmitted to the remote node by the QCD device is handled by the intermediate nodes in transparent mode and a direct logical link is established between the truck-node and the QCD. The incoming message is processed by the communication processor for verifying its integrity and then is passed to the application processor for further processing. No acknowledgement is generated at the lower layer protocols, since the response message generated at the remote node's application processor is used for command acknowledging and for application data delivery. Although the protocol stack detects duplicate messages and delivers them only once to the application processor, whenever the RRS service is used, application messages are delivered more than once at the truck-nodes, but this does not affect the

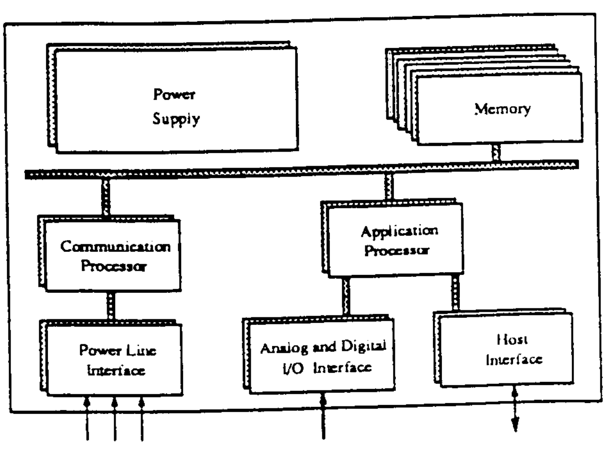

Fig. 4. The PLNode Hardware Architecture

system reliability since the duplicate messages are rejected at the QCD processing unit. This is used in order to decrease the number of packets associated with each transaction.

For critical application parameters (e.g. temperature out of range) a packet priority mechanism is used for improving the system response time. Each truck-node is assigned a priority time slot in the channel where it belongs. The same time-slot is assigned to a number of truck-nodes in each subnetwork. This is due to the low probability of having alarm conditions in more than one truck-node simultaneously since the nodes operate completely asynchronously. This minimizes the time added to each message transmission for supporting priority data.

III. THE NODE ARCHITECTURE

For all types of nodes, a reconfigurable hardware platform, the PLNode, was developed. The same hardware, populated with different submodules is used for the truck-nodes, the repeater and the subnetwork controller. Since the subnetwork controller has access to two isolated power lines, two PLNodes are used. The two PLNodes exchange packets using their optically isolated host interfaces which are based on the 3964R protocol format. The PLNode is called Vehicle Mounted Controller (VMC) when it is used as a truck-node.

Each PLNode consists of various modules, as it is indicated in Figure 4. It has two processors, one for the communication tasks, the communication processor, and the other, the application processor, for application dependent functions. The application processor is a powerful MC68HC11 family MCU while the communication processor is a Neuron chip, Echelon (6). The Power Line Interface implements the node physical layer and has been based on commercially available power line transceivers with the appropriate coupling circuit. The power line transceivers use direct sequence spread spectrum (DS-SS) technique, Feher (7), for interfacing this error-prone communication channel due to impedance change, intermittent noise sources and signal attenuation. For increasing system throughput, a forward error correction technique is used for reconstructing corrupted data and the receiver

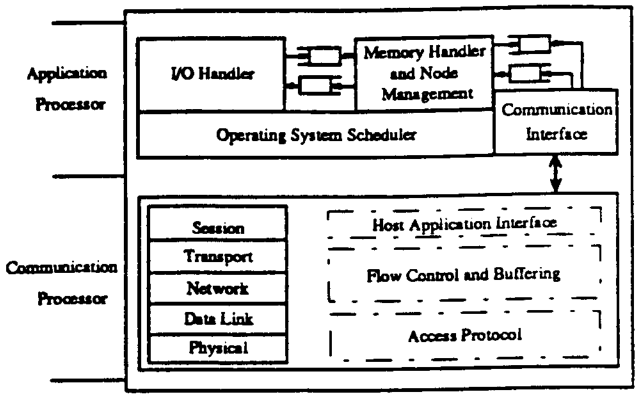

Fig. 5. The PLNode Software/Protocol Architecture

sensitivity dynamically changes based on noise characteristics. The generated spectrum is between 100kHz and 450kHz and a 10Kbps transmission rate is achieved. The interface supports both common and differential modes of transmission, depending on the available wiring.

The Analog and Digital I/O Interface is used for connecting various types of sensors, like PT-100 type sensors, battery voltage, motion detector, air-conditioning system status sensors etc. It can support up to four (4) analog inputs and up to eight (8) digital inputs. The Host Interface is used only on the NCU parts and can either support RS-232C or TTY interfaces and follows the 3964R protocol format. The PLNode memory is used for data storage whenever the truck-node is disconnected from the factory communication system and it can also store in non-volatile positions the PLNode parameters. The truck-nodes operate from the truck battery and its power supply has been designed especially for automotive conditions and is controllable by the application processor for energy saving in low-battery conditions.

The PLNode software has been splitted into the two processors, as it is shown in Figure 5. The communication processor implements layer 1 through 5 for reliable communications and uses its host application interface for packet exchange with the application processor. The two processors form a master/slave configuration, the communication processor being always the slave processor. The application processor software has been developed upon a multitasking operating system and has a modular structure. Depending on the PLNode functionality, the application software can be reconfigured for supporting new functions. This reconfiguration can be performed either via the host interface or by a remote command via the power line interface. The Memory Handler of the application software is responsible for the memory management during the data collection process, as it is described in the following section.

IV. THE DATA ACQUISITION PROCESS.

The truck-nodes memory is organised in a number of constant length buffer blocks. Each buffer block contains data for up to four analog inputs and up to eight digital inputs (Figure 6). The Sensor Scanning Timing and Accuracy Schedule block (SSTAS) determines which I/O signals participate in the scanning process, which is the sampling rate for each signal and, for the analog ones, which accuracy must be used for storing their value. The SSTAS is stored in EEPROM positions and can be reprogrammed by authorised QCD personnel. During truck-node power-up or whenever new values are stored in SSTAS, the node timing system is reconfigured accordingly. The timing system is based on a free-running counter and two internal compare registers (CR) in a master/slave configuration. The two registers generate interrupts whenever a match is found between a specific time-register and the free-running counter. The master CR is used for synchronizing the buffer blocks timing while the slave CR is used for intra-block timing. The memory is organized as a cyclic buffer where new data overwrite the oldest data if no more space is available. Following this organization, each truck-node contains a number of buffer blocks which store the truck history in timing order.

Considering that:

- k_a: the activated analog inputs,
- k_d: the activated digital inputs,
- t_a: the analog sampling period (in min),
- t_d: the digital sampling period (in sec),
- n_a: the analog signal accuracy (in bits),
- l_b: the buffer block length (in bytes), and
- L: the memory length (in bytes),

then the length of each buffer block is equal to:

$$l_b = \frac{1}{8}\left(k_a.n_a + m.k_d\right) \quad \text{where} \quad m = t_a/t_d,$$

considering that $t_a >> t_d$. The memory is organized in $8L\Big/\left(k_a.n_a + \frac{t_a.k_d}{t_d}\right)$ blocks and can keep the truck

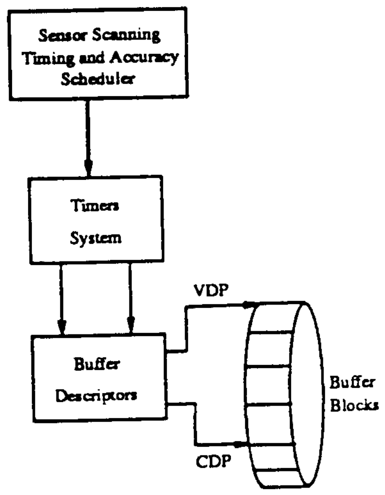

Fig. 6. The Memory Organization

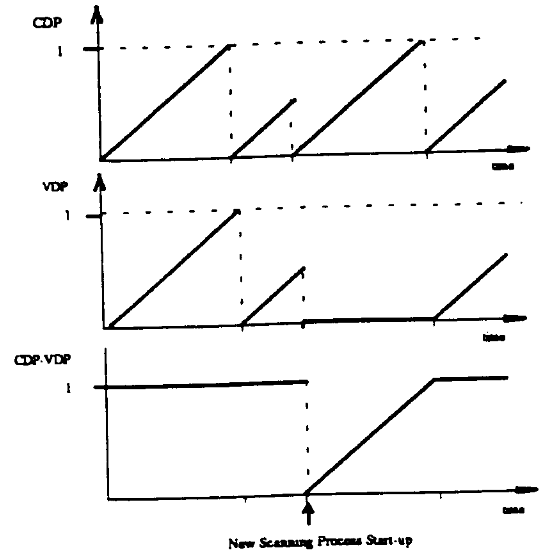

Fig. 7. The Memory Pointers versus time during a new scanning process start-up.

sensor history for a time duration up to $8.L.t_a \Big/ \left(k_a.n_a + \frac{t_a.k_d}{t_d} \right)$ minutes.

Table 1 shows some indicative values for these parameters. In the implemented scenario, where two analog inputs (temperature, battery voltage) and one digital (the truck-motion profile) are currently used, the truck-node contains the truck history for eight (8) days, as it is shown in Table 2.

Table 2: The truck-node implemented scenario

k_a: 2	t_a: 35 min	n_a: 6 bits
k_d: 1	t_d: 3 sec	
Storage Duration:	*8 days*	

Although the truck-nodes do not contain real-time clock, their memory organization can be used for extracting this information. The buffer descriptors contain two pointers, the Valid Data Pointer-VDP, and the Current Data Pointer, CDP (Figure 7). The CDP pointer indicates the working buffer (and its internal storage position) while the (VDP+CDP)-mod(2) value is used for determining the valid buffer area. Whenever the first overwrite is performed, the (VDP+CPP)-mod(2) value takes its maximum and remains contstant up to the next start-up of the scanning process. Whenever the QCD downloads a buffer block, it uses the buffer block offset position from the CDP pointer and the SSAS values for determining its time offset from current time and, by extracting this value from its real-time clock, it determines the exact acquisition time of this specific block. Whenever a truck is connected to the factory power grid, the latest sensory information is downloaded to the QCD database and a detailed status timing profile for each truck becomes available. The processing of this information is used for measuring the mean truck performance, the performance of individual trucks and for determining the crew performance. This information is also used for truck maintenance purposes since it allows the early detection of abnormal behaviour. For example, the battery voltage/timing profile can increase the truck reliability since it allows the early detection of a faulty or weaken battery.

Table 1: Truck-node buffer parameter (L=32Kbytes)

k_a	k_d	t_a *[min]*	t_d *[sec]*	n_a	m	l_h *[bytes]*	*Storage Duration [days]*
4	8	1	2	8	30	34	0.66
4	1	1	2	8	30	8	2.84
1	8	1	2	8	30	31	0.73
4	1	5	10	8	30	8	14.22
4	1	1	10	8	6	5	4.55
1	8	5	5	8	60	61	1.86
1	1	1	5	6	12	3	7.58

A very useful feature of PLNode application software is that it can be programmed to associate measurements from different sensors for decision making, to validate input signals for being within specific boundaries, or to apply different rules on the processing of input signals. For example, the temperature measurement is related with the status of the air-conditioning system relays for determining the cause of temperature increase. Upper and lower limits are set to the temperature measurement and asynchronous alarm messages are generated. The truck motion profile is generated by observing the behaviour of a pulse stream whose frequency changes linearly with the truck motion.

V. CONCLUSION

This paper presented the architecture of a factory-based distributed information network, used for collecting quality control data during sensitive products storage and distribution. The network has been organized as a set of various subnetworks which use the power grid as the communication medium, splitted in various independent areas by using power EMI filters. A SINEC-L2 network is used for interconnecting these subnetworks with a processing unit at the QCD center. The main advantages of the developed network are its low-cost installation and maintenance by using the existing power cabling, its expandability to a large number of nodes due to bandwidth reuse and protocol functionality and its reconfigurability to different application requirements both in terms of hardware and software.

REFERENCES

1. M. H. Klein, J.P.Lehoczky and R. Rajkumar: "Rate Monotonic Analysis for Real-time Industrial Computing", *Computer*, Vol. 27, No. 1, January 1994, pp. 24-33.
2. SIEMENS AG: "SINEC: Industrial Communications Networks". IK10, Germany, 1992.
3. A. Tanenbaum: "Computer Networks", Prentice Hall, New Jersey 1989.
4. B. N. Jain and A.K. Agrawala: "Open Systems Interconnection: Its Architecture and Protocols", Elsevier Science Publishers, The Netherlands, 1990.
5. LonWorks Engineering Bulletin: "LONTALK Protocol", April 1993.
6. Echelon Corp.: "Neuron 3120 Chip and Neuron 3150 Chip", April 1993.
7. K. Feher: "Digital Modulation and Spread Spectrum", Course-107 Notes, March 1994.