THE ELETTRA FIELD HIGHWAY SYSTEM

D. Bulfone, P. Michelini, M. Mignacco
Sincrotrone Trieste, Padriciano 99, 34012 Trieste, Italy

Abstract

ELETTRA is a third generation Synchrotron Light Source under construction in Trieste (Italy); it consists of a full energy linac injector and a storage ring with beam energies between 1.5 and 2 GeV. The ELETTRA control system has a distributed architecture, hierarchically divided into three layers of computers; two network levels provide communication between the adjacent computer layers. The field highway adopted for the connection of the middle-layer local process computers with the bottom-layer equipment interface units is the MIL-1553B multidrop highway. This paper describes the hardware configuration and the main communication services developed on the MIL-1553B field highway for accelerator control. As an additional feature, typical LAN utilities have been added on top of the basic MIL-1553B communication software allowing remote login and file transfer; these tools are currently used for software development in our laboratory.

I. INTRODUCTION

The ELETTRA Control system is distributed over the about 260 m Storage Ring circumference and 170 m Linac-plus-Transfer Line, with an architecture based on three computer levels (presentation, processing and equipment interface) and two network layers.

High performance UNIX workstations with excellent graphical capabilities are used as operator consoles at the presentation level. The upper layer network, which is based on Ethernet and the TCP/IP communication protocol, connects the control room workstations and the distributed process level computers called Local Process Computers (LPC).

The LPCs, bridging the two network levels, are the "core" of the control system, where all the main application control tasks are executed, acquiring and processing data from the equipment interface level; the ELETTRA LPC consists of assemblies of VMEbus single-board computers (SBC), running the OS-9 operating system. In order to enhance both performances and modularity, a multiprocessor-multimaster architecture has been developed for the LPC, where each board is allowed to take VMEbus mastership and execute its own data transfers.

Separate lower level network branches connect each LPC to the equipment interfaces, called Equipment Interface Units (EIU). Following a definition widely accepted by the control system designers community [1], the term "field highway" is used to indicate the communication system between the local process computers and the interface-level processors.

The VMEbus standard and the OS-9 operating system are adopted also at the EIU level; the typical EIU configuration consists of one microprocessor board associated with several input/output boards of different type.

Exploiting the high performances of the field highway, we have assigned the LPCs with operational criteria, which enhance system design clarity at the same time: 2 LPCs and 48 EIUs are foreseen for magnet power supplies control, 1 LPC and 7 EIUs for vacuum, 1 LPC and 12 EIUs for storage ring beam position monitors, 2 LPCs and 3 EIUs for linac control, etc. A total number of 14 LPCs and 88 EIUs is to be finally installed.

II. THE MIL-1553B MULTIDROP HIGHWAY

In the project of an accelerator control system, the choice of the field highway is strategic: in spite of the growing of standards in the informatics and electronics world, many different solutions are currently used and proposed. The main parameters considered in the choice of the ELETTRA field highway are: communication topology, electrical noise immunity and data integrity, deterministic response, cost and performance. After a careful investigation of the non-proprietary commercially available products, we decided to adopt the MIL-1553B standard [2], slightly modified for accelerator control.

A. Communication topology

The MIL-1553B standard, originally developed for the aircrafts by the U.S. Department of Defense, defines a serial Time Division Multiplexing (TDM) highway on which one Bus Controller (BC) can communicate with up to thirty Remote Terminals (RT) in a multidrop configuration; the BC always provides data flow control and is the sole source of communication. This hierarchical scheme perfectly fits into our control system architecture: placing the BCs and the RTs at the LPC and EIU levels respectively, separate MIL-1553B branches connect each LPC to the EIUs it supervises. A typical configuration is shown in figure 1. Moreover, a multidrop highway topology together with the appropriate communication software permit to add and/or remove EIUs with no system shutdown, catering for future upgrades, requests or simple maintenance.

B. Electromagnetic noise immunity and data integrity

In order to guarantee a very good immunity from the electromagnetic noise of an accelerator environment, a shielded twisted-pair cable is adopted as MIL-1553B highway physical medium on which Manchester II biphase coded differential signals are transmitted.

In addition to that, the following intrinsic "acknowledged message" exchanging mechanism is used to assure data integrity: the BC sends a receive/transmit command word to the addressed RT, eventually followed by up to thirty-two data words; the RT receives the command, receives or transmits data as directed and responds with a status word. Parity checking is applied on each word boundary.

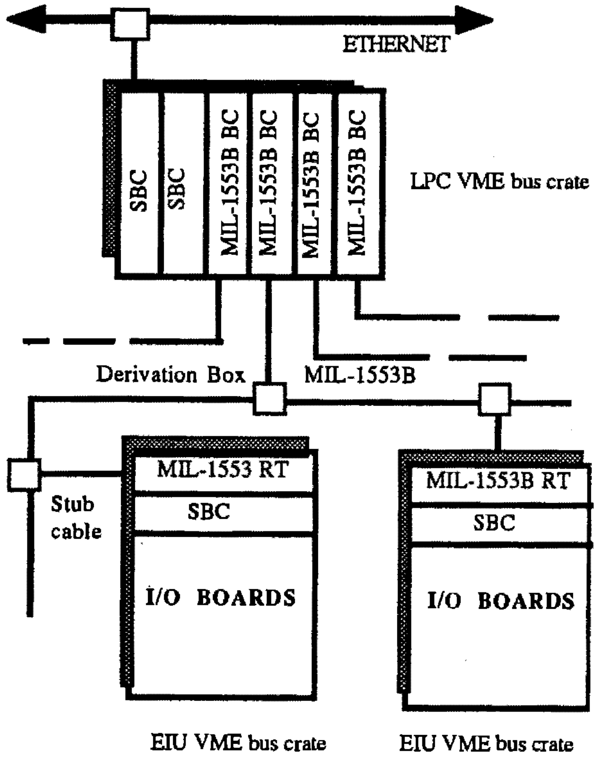

Figure 1. The ELETTRA field highway system.

C. Deterministic response

Dealing with the accelerator equipment at the interface level, the undefined network access times associated with the CSMA/CD (Carrier Sense Multiple Access with Collision Detection [3]) methods of Ethernet cannot be accepted; a deterministic behavior of the field highway is strongly requested. In the MIL-1553B standard configuration the BC "polls" (the so called "roll-call polling" type [3] is used) the status of its RTs at regular time intervals under software control and checks if new data is ready to be received. On this basis, real time operation with pre-configured timings is achievable.

D. Cost and performance

The price of the single highway interface board must be carefully considered, as a high number of nodes (about 100) are connected, especially at the RT level. Using commercial type electronics, the cost of an RT node is lower then that of a standard input/output interface board. The adopted physical medium is also inexpensive and no special installation tool is needed.

In order to provide the necessary flexibility of the control configurations implemented for ELETTRA, the field highway must be able to operate over distances up to some hundreds meters: with the chosen implementation, a raw bit transfer rate of 1 Mbit/s over about 300 m can be achieved; lower transmission speeds for longer distances are possible.

The MIL-1553B standard permits to send broadcast messages, which are often useful for accelerator control: issuing a special type command word, the BC can transmit to all the connected RTs at the same time.

III. THE ELETTRA FIELD HIGHWAY HARDWARE IMPLEMENTATION

The highway physical medium consists of a 100 % shielded twisted-pair cable which has a characteristic impedance Z_0 = 78 Ohm; each branch is matched by two termination resistors of value $Z_0 \pm 1\%$. The nominal attenuation, measured on a 1 MHz sinusoidal signal, is about 15 dB/Km; the wire-to-wire distributed nominal capacitance is 64.6 pF/m.

Each MIL-1553B device (BC or RT) connects with the highway through a so called derivation box and a short (less than 2 m) stub cable: the derivation box contains a couple of resistors which are serially inserted on the two stub cable wires in order to prevent BCs or RTs from damaging in case of short circuits on the highway.

Both the BCs and the RTs [4] are equipped with on-board transformers for ground isolation between nodes. They use a commercial type VLSI protocol chip automatically dealing with the "acknowledged message" exchanging mechanism described above.

The BCs have been integrated in the multiprocessor-multimaster environment of the ELETTRA LPC. Starting from a CERN/SL BC design [5], we developed a standard VMEbus Requester and implemented some hardware modifications [6] in order to achieve full compatibility with the other LPC commercial VMEbus SBCs; this allows future increases in the LPC performances as more powerful boards are available on the market. The OS-9 operating system is installed on each BC board.

IV. BASIC COMMUNICATION SOFTWARE

The communication software allows both MIL-1553B equipment and VMEbus LPC SBCs to exchange user messages.

The communication software for the field highway system mainly consists of three layers (figure 2): physical, translation and routing.

A. Physical layer

The physical layer is mainly in charge of shielding the low level communication details. Since many MIL-1553B boards can be both BC and RT, we decided to split this level into two parts; the first one is strictly related to the adopted hardware, while the second part handles the most common functions (circular buffers, fragmented packets, etc.). After defining a physical number for each board, user applications can easily exchange data packets through the network, independently of the hardware used. The physical number is fixed by on-board switches and it is not usually changed after the first setting.

The only drawback of this addressing mode is that identical boards with different numbers cannot be exchanged without modifying and recompiling all the user programs.

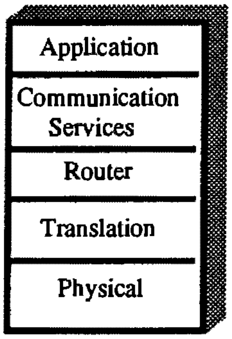

Figure 2. The ELETTRA field highway software layers.

B. Translation layer

The translation layer, built on top of the physical one, avoids the aforementioned problem. It consists of an OS-9 driver maintaining an internal table of correspondences between physical numbers and the new logical station numbers which are used by the routing layer. A logical station number is associated with each LPC board and with the SBC managing the EIU RT.

C. Routing layer

The routing layer, or router, performs a reliable user message transmission starting with a configuration file which describes the logical system topology. All the stations attached to the same physical medium (VMEbus or MIL-1553B) form a so called "subsystem" and the configuration file contains as many lines as the subsystem number.

Many advantages are associated with the layered architecture. The software is easily ported on different MIL-1553B boards; user messages between two stations attached to different subsystems can be exchanged independently of the interconnecting physical medium; the identical routing interface is maintained. In order to add new subsystems and stations, the following steps have to be taken:

- develop a new dedicated low level hardware driver and eventually a new address translation driver;
- assign new logical station numbers to each subsystem SBC;
- add the new subsystem station numbers to a new line of the routing configuration file.

V. THE ROUTING LAYER INTERFACE LIBRARY

A clear interface library to the routing layer functions is provided to allow a straightforward implementation of the higher level services. This interface consists of a collection of C language routines which have a common first argument: the communication channel number. This is an integer ranging from 0 to 7, which is associated with a routing path, a service code and a circular buffer for the incoming user messages. At present only one channel per process is used, but up to eight are available to increase flexibility.

The description of the principal library calls follows:

error = OpenRouterService (channel, bufnum, service)

int error;	router error code or zero
int channel;	channel number
int bufnum;	number of circular buffers
short service;	communication service code

OpenRouterService opens a communication channel with a specific service code;

error = CloseRouter (channel)

int error;	router error or zero
int channel;	channel number

CloseRouter closes the specific channel previously opened by OpenRouterService;

error = WriteMsg (channel, buffer, len, dest, service)

int error;	router error or zero
int channel;	channel number
char *buffer;	message buffer
int len;	message length
short dest;	destination logical station number
short service;	communication service code

WriteMsg transmits a message to the specific destination station in a reliable way;

error = WaitMsg (channel, timeout)

int error;	router error or zero
int channel;	channel number
in timeout;	timeout in system ticks, 0 for infinitum

WaitMsg waits for a user message to arrive. The type of service is fixed by the OpenRouterService function.

VI. COMMUNICATION SERVICES

The described communication interface is the base on which all the communication services are built. Even if it represents a flexible and hardware independent interface, it cannot be given to the application programmers for software development. A typical user is not, in fact, aware of the logical station numbers, circular buffers and communication service codes; he refers to the accelerator equipment only by logical names and uses the communication services without taking care of the control system topology details. In order to provide a completely symbolic equipment access [7] [8], we have developed a higher software level, which shields part of the router library function parameters.

The Symbolic Address Resolution, Command/Response, Inform, Alarm and Broadcast services have been written. Their implementation is based on the general concepts of client and server processes, with clients located on a LPC (Command/Response and Broadcast) or an EIU (Inform and Alarm) according to the different service types and data flow involved.

A. Symbolic Address Resolution service

This special service hides the incoming user message logical routing from the application programmer. It consists of a server process running on the LPC and an associated table called Equipment Directory Unit (EDU).

When a client request arrives, the server process looks up the logical equipment name in the EDU and translates it into a logical station number. Moreover, the server checks the equipment access permissions and provides for on-line EDU reconfiguration.

B. Command/Response service

The Command/Response service allows the user applications to access the equipment. There are two operating modes: synchronous and asynchronous. In the first case the client sends a command and suspends its execution until a result comes back from the server. In the asynchronous mode the client process sends a command without stopping and, after some time, reads the results prepared in the meantime by the server process.

A typical Command/Response request, including EDU access, takes about 30 ms.

C. Inform service

The Inform service has been developed in order to cater for the necessity of sending data from an EIU to the LPC without waiting for an LPC data request.

The Inform is therefore very similar to the Command/Response service: the main difference is that it allows only unidirectional data flow.

D. Alarm service

The surveillance programs have a fundamental role among the processes running on an EIU; they continuously check the equipment status and detect anomalies or fault conditions. When a serious error occurs, these programs must act as client processes sending an alarm message to the associated LPC server. In this special case we are interested in delivering an alarm message as fast as possible. In order to increase the transmission speed, the alarm message does not access the EDU table for symbolic destination address resolution.

E. Broadcast service

The Broadcast service permits to send the same user message to all the EIUs attached to the same MIL-1553B multidrop highway branch. Exploiting the MIL-1553B standard broadcast capability described above, we are studying the possibility of using this service to generate a software synchronization among the EIUs: the transmitted broadcast messages can in fact produce hardware interrupts on the EIUs, waking up the processes to synchronize.

VII. IMPLEMENTED LAN UTILITIES

Taking advantage of our layered software structure, we have developed a special level which interfaces the Translation Layer with the commercial OS-9/NET [9] communication software package (figure 3). OS-9/NET is based on the Network File Manager (NFM) and provides for typical Local Area Networks (LAN) utilities like remote login and homogeneous file access. These tools are the basis for the distributed software development environment we created in our laboratory: using a single LPC equipped with a disk, we can download software and start task execution in the diskless EIUs; moreover, the laboratory LPC works as a common remote disk server and virtual terminals can be opened on the EIUs for software testing.

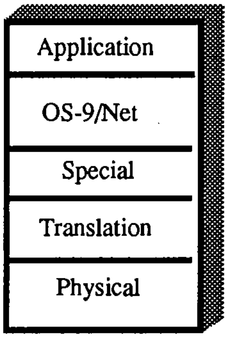

Figure 3. OS-9/Net layer implementation.

In the final system implementation, where diskless LPCs and EIUs are installed, NFM and TCP/IP tools can be effectively combined. In this way a remote login from the control room can be executed on both LPCs and EIUs; a UNIX disk server can also be shared by all the field highway system stations.

VIII. CONCLUSIONS

Starting from the military MIL-1553B communication standard, a multidrop field highway has been developed for the control of the ELETTRA equipment.

Despite the low cost of the used communication boards (BC and RT) and physical medium, the typical functionalities needed for accelerator control are catered for. Compared with existing similar products, the implemented MIL-1553B highway offers one of the best cost/performance ratio available.

The chosen VMEbus MIL-1553B BC board has been integrated in the multimaster environment of the ELETTRA LPC, increasing system performance at least by a factor of two.

The layered communication software allows to send data packets between the LPC SBCs and the dropped EIUs in a completely transparent way. A data transmission rate of 70 kbytes/s has been achieved with 100 byte packets.

The implemented LAN utilities are currently used for the development of system and application software.

IX. ACKNOWLEDGEMENTS

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X. REFERENCES

[1] D.P. Gurd and M. Crowley-Milling, "Preface" in *Proceedings of the ICALEPCS*, Vancouver, BC, Canada, October 30-November 3, 1989.
[2] *MIL/STD-1553B, Aircraft Internal Time Division Command-Response Multiplex Data Bus*, Department of Defense, Washington, DC 20360, USA, 1978.
[3] A. S. Tanenbaum, *Computer Networks*, Prentice-Hall International Editions, 1988.
[4] D. Francart et al., "MIL-1553B Multidrop Bus for Controlling LEP and SPS Equipment", LEP Controls Note 56 Rev., August 1987.
[5] C. Guillaume and C. Pignard, private communication.
[6] L. Barbina and D. Bulfone, "The MIL-1553B Bus Controller Board for the ELETTRA VMEbus Multimaster Local Process Computer", Sincrotrone Trieste Internal Report ST/M-TN-91/3.
[7] "The LEP/SPS access to equipment", LEP Controls note 54 Rev., Geneva, March 1988.
[8] M.C. Crowley-Milling, "Naming Conventions for the ELETTRA Components", Sincrotrone Trieste Internal Report ST/M 88/13.
[9] *OS-9/NET Version 3.0*, Microware Systems Corporation.