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A LARGE TOKEN-RING CONTROL NETWORK FOR THE CERN
LEP AND SPS ACCELERATORS AND COLLIDER RINGS

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Keywords. Multi-microprocessor, distributed computer control system, real-time control network, token-ring protocol, time-division multiplex, network management, network reconfiguration.

INTRODUCTION

CERN is constructing a Large Electron-Positron (LEP) collider ring on the Swiss/French border. The new machine has a circumference of 27 kms and is located in an underground tunnel at 60 to 120 m depth below the surface of the ground. Equipment will be installed into the tunnel and be controlled from underground caverns as well as from surface buildings located at eight equidistant areas around the machine. LEP is expected to start operation early 1989.

The LEP control system will implement a fully distributed control architecture having two levels of networking: the token-ring network for the multiprocessor assemblies and the local console communications and the MIL-1553-B multidrop bus for all equipment controls.

The LEP collider will be operated from the same control room as the existing SPS accelerator, in operation since 1976. The philosophy of the LEP/SPS control system follows a functionally and geographically distributed architecture for the real-time control of a very large amount of equipment (Crowley-Milling, 1983). Instead of conventional mini-computers the future LEP and SPS control system will use multimaster-multiprocessor control assemblies communicating via token-ring networks conforming to the IEEE 802.2 and 802.5 standard protocol (Altaber, 1983; Altaber, 1985a).

All accelerator equipment and subsystems are connected to multiprocessor assemblies by a multidrop bus conforming to the MIL-1553-B standard protocol (Rausch, 1981).

To select its VME based multiprocessor control assemblies (Altaber, 1985b), together with a distributed real-time operating system industrially supported, CERN has consulted all major

European computer manufacturers. After analysis of the offers, the choice has been made in favour of the DLX multiprocessor system with its ELECTRE real-time executive available from the French CIMS-SINTRA Company. The ELECTRE real-time executive follows the SCEPTRE norm (Standardisation du Cœur des Exécutifs des Produits Temps Réels Européens) standardized by the French BNI (Bureau de la Normalisation Informatique).

THE CONTROL NETWORK

The LEP electron-positron collider has the shape of a ring of 27 km circumference with eight equidistant access points where service buildings house machine control equipment and several DLX multiprocessors. When choosing the control network architecture for LEP several important parameters had to be satisfied. Some of these parameters are: the medium access method, the distance, the topology, the speed, the real-time response, the number of possible connections, the fault identification and isolation, the reconfiguration capabilities and various other features.

Merits of the Token-Ring

The requirement to minimize the propagation delay on a contention bus restricts the length of the bus, a factor that is not critical in a token-ring protocol. The distances to be covered for LEP and SPS exclude the use of a CSMA/CD access method for the control system; the propagation time over a 27 km coaxial cable being in the order of 140 microseconds.

For real-time control of an accelerator the medium access protocol must be deterministic. Indeed, it is at some critical moments of the particle acceleration cycle that many processes

need to communicate simultaneously on the same medium. A protocol with an automatic back-off mechanism and random retry is bound to load even more the communication network during these critical periods. The token-ring and token-bus protocols provide the required deterministic medium access and offer in addition a better behaviour at high loads than the CSMA/CD. This has been demonstrated by W. Bux (1981) who compared their data throughput characteristics as affected by system parameters such as transmission rate, cable length, packet length, and control overhead. He concluded that the token-ring performs well at high throughputs and transmission speeds while the CSMA/CD performed well as long as the ratio of propagation delay to mean packet transmission time was of the order of 2 to 5.

Another performance study by B.W. Stuck (1983) showed the token-ring to be the least sensitive to workload, offering short delays under light load and controlled delays under heavy load. The token-bus was shown not to be as efficient as the token-ring under heavy load and to have greater delay under light load.

The LEP and SPS ring topology is clearly in favour of a token-ring network; the propagation time being fixed and equal to the round-trip time of the token. A CSMA/CD network requires a bidirectional transmission on the same medium and to cover long distances bidirectional repeaters are needed. These are complex and expensive compared to a unidirectional point-to-point liaison not using any repeater. The MAP broadband token-bus network requires a head-end unit to which all messages are sent at a given carrier frequency. This unit then sends back the messages on the same coaxial cable at another frequency towards the receiver. As a consequence the propagation time may be twice the bus round-trip time for two adjacent stations located at the opposite side of the head-end unit. In addition, bidirectional CATV type repeaters are required to cover long distances.

Presently the token-ring works at 4 Mbit, ETHERNET and MAP at 10 Mbit. The token-ring speed improvement will follow the semiconductor technology as 16 Mbit CMOS and NMOS chip sets have been announced by several manufacturers. In the long term one can expect token-rings working at 40 Mbit or more. Speed increase is not favourable to CSMA/CD as the transmission distances will decrease proportionally due to the contention mechanism which must occur during the first bytes of the protocol frame while token-ring can benefit from it.

Furthermore, multidrop busses like ETHERNET or MAP token-bus do not allow the use of fiber optic passive derivations while the token-ring point-to-point connection can take direct advantage of fiber optic links. Thus the installation today for LEP of a high quality transmission medium for the token-ring, coaxial cable and optical fibre, will permit CERN to profit later from these technological progresses.

The connection of a large number of multiprocessors in the LEP control network is facilitated by an insertion/extraction mechanism provided for in the token-ring architecture. The star/ring configuration allows local clusters of computers to be easily integrated or isolated in case of local failure. The token-ring wiring medium can be installed within a building using a radial (star) wiring scheme. Star wiring implies that the transmission cable is installed from concentration points within a building to the various user work areas; such as local control

rooms in the eight LEP sites and in six SPS sites.

Another selection criteria is that any network fault or disruption should be quickly detected and isolated to restore normal operation. The wiring concentration points provide centralized access to some of the primary network components to enhance the maintenance and reliability aspects of the overall system. In addition, the flow of data and control signals around a closed ring provides an inherent capability for monitoring normal token operation from a given location in the ring and enables ring faults to be quickly detected.

The previous arguments are considered to be distinctive advantages in favour of the token-ring in comparison with the MAP token-bus and the ETHERNET CSMA/CD network architectures and thus leading to the choice of the token-ring for the LEP/SPS control system. Further to this decision a collaboration has been set up between CERN and the IBM Research Laboratory, Zürich, fall 1983, for a pilot project aimed at the implementation of the token-ring for the LEP/SPS control system.

The LEP and SPS Size Problem

The LEP collider is built underground at a depth varying from 60 m in the plain to 120 m at the foot of the Jura. The tunnel, containing all accelerator equipment, has a diameter of 3.7 m, a circumference of 27 km and is accessed by eight equidistant pits (3.4 km). On the surface near the pits are located the local control rooms containing the multiprocessors linked together by two token-ring networks; one service network and one machine network, as shown in Fig. 1. The distances between two clusters of multiprocessors in adjacent sites is of the order of 4.6 km, taking into account the length of the surface and pit cables. All accelerator equipment in the surface buildings and in the tunnel is controlled from these multiprocessors via multidrop busses following the standard MIL-1553-B protocol (Fig. 2).

The token-ring uses uni-directional transmission on a single high quality shielded and twisted pair cable reaching distances of up to 800 m. In case of by-pass of one token-ring station the distance may be twice as long to reach the next active station. As a consequence, the maximum allowable distance between two stations cannot exceed 400 m. For crossing the 4.6 km between two adjacent LEP control sites it has been necessary to conceive a new transmission method. This has been achieved by using standard telecommunication equipment of the G700 TDM type.

Use of CCITT - TDM equipment. The TDM (Time Division Multiplex) equipment used for inter-connecting the eight LEP sites and the six SPS sites to the control centre is standard equipment conforming to G700 series (ITU-Geneva, 1981) and designed for modern digital telephone. This type of equipment is available from several European manufacturers, conforms to the CCITT standard and is compatible. The principle is to multiplex several digital signals at one LEP/SPS site and to demultiplex them at the next site thus providing several digital channels. 64 kbit channels form a 2.048 Mbit channel of which four channels in turn form one 8.448 Mbit channel. Four of these 8.448 Mbit channels form a channel of 34 Mbit. At the receiver side demultiplexing is achieved and output channels are provided at the same frequency as their corresponding inputs. Higher speeds (140.565 Mbit) are also available industrially. The resulting 34 Mbit channel can

Fig. 1 The LEP computer network

Fig. 2 DLX multiprocessor

be transmitted in-between adjacent sites over high quality coaxial cable or over fiber optic links. LEP will use both media; coaxial cable around the 27 km LEP and the 7 km SPS under-

ground tunnels and fiber optic links on the ground surface for some high speed radial connections to the common control center. Unfortunately, fiber optic links cannot be used in the LEP and SPS tunnels as the radiation would deteriorate them progressively. Thus between adjacent sites the TDM equipment provides many logical links at different input/output frequencies over a unique coaxial cable reducing greatly the number of cables required.

Making use of TDM trunks for transporting the token-ring protocol implies the solution of two technical problems. Firstly, the standard signal coding of the TDM equipment is HDB3 while the token-ring uses Manchester II bi-phase coding. The Manchester II bi-phase signal at 4.224 Mbit is in fact identical to an 8.448 Mbit NRZ code. As a consequence a transcoder unit is required at each end of a TDM trunk joining two LEP sites. Code converter chips from NRZ to HDB3 and vice versa working at 8.448 Mbit exist. Secondly, to match the 4 Mbit token-ring speed to an 8.448 Mbit TDM channel one must change the token-ring frequency. Thus by using an 8.448 Mbit HDB3 TDM channel one can transmit the 4.224 Mbit Manchester II bi-phase signal over long distances as does allow standard CCITT telephone equipment.

This method has been implemented and successfully tested at CERN over five TDM multiplexers/demultiplexers and five TDM trunks of 4 km each thus achieving a 20 km long token-ring. Jitter measurements have been made in collaboration with the IBM Rüschlikon Research Laboratory to ensure that the elastic buffer provided in the token-ring interface chip set is sufficient and that no unforeseen adverse effect shows up.

Network Architecture

Figure 3 shows an overall view of the global LEP/SPS control network. The SPS control network designed in 1972 and operational since 1976 uses a multistar network to interconnect today more than 70 minicomputers of the N100 model from Norsk Data. The SPS multistar network is of the store and forward packet switching type with full duplex point-to-point links working at 750 kbit/s between the message transfer computers (MHC, MHX, MHE,...) and the various process minicomputers.

The LEP control network consists of two token-rings, one for all vital services (electricity radiation, lifts, personnel access, vacuum etc.) and another for major machine components (radio-frequency, power converters, beam instrumentation etc.). Around the SPS a new token-ring control network will also be installed to take over progressively the communication activity.

The LEP service token-ring will link up to ten DLX multiprocessors, with the highest possible security; in fact, it will carry, in addition to the above mentioned services, all alarm messages for personnel safety, equipment protection and software interlocks. All components of the service network are powered from 48 volt batteries giving an autonomy of at least four hours in case of a major power cut. This service network will be fully reconfigurable in case of breakdown of one element in the ring. The reconfiguration facilities are described later in this paper.

The LEP machine ring will link up to 30 or more DLX multiprocessors and all its components will be powered from an "assured mains" meaning that only short-cuts for switch-over to diesel gene-

rators or to the Swiss grid, are permitted. To mask-off these minor perturbations local batteries associated with DC/DC converters will be provided.

In addition to the multistar network the SPS control system is being upgraded by the addition of a token-ring onto which will be connected 16 DLX multiprocessors required for new major accelerator components (RF cavities, LEP beam transfer lines, etc.). This is a first step towards a homogenous LEP/SPS control architecture using the same modern network protocols and the same DLX multiprocessors built in standard VMEbus (Aitaber, 1986).

The four previously described networks are connected to a Main Control Room (MCR) token-ring via bridges or gateways. The interconnection of the four token-rings is done via bridges built from conventional IBM PC/AT by using two token-ring cards with the medium access layer software thus giving a high bridge throughput. The connection of the present SPS multistar network will be done by a particular form of gateway called "relay" as the two network protocols are completely different. This relay is implemented using a N100 with the normal star network connection and a VME crate containing an intelligent token-ring interface. The MCR token-ring will link various machine operator workstations, file servers, database servers, printer server, modelling server, a gateway to the central computer center and other facilities.

The physics groups need to communicate with the operators of the main control room, to get information on the particle beam parameters to tag their data acquisition or to control some accelerator element upstream or downstream their experiment set-up. To this purpose a gateway

Fig. 3 LEP/SPS control network

between their ETHERNET network and the LEP machine token-ring is foreseen. Again this gateway will be a PC/AT with an ETHERNET card and a token-ring card, the software interface being at the network layer.

Thus the LEP/SPS network architecture offers a good separation of data traffic between the various domains of activities. Typically part of the data traffic on the MCR token-ring is separated from the SPS and from the two LEP token-rings avoiding unnecessary congestion of these control networks. Similary SPS data traffic does not sum up with LEP control information while a full homogenous communication is offered when data exchange is required between the different entities forming the LEP/SPS control network.

Network Management

A large network of the LEP type dealing with real-time controls, alarms, personnel safety and equipment protection must be as reliable and secure as possible. Failure of one component or of one entire site must not stop operation of the rest of the system. In addition, a project of this size is constructed progressively over several years and accelerator subsystems are brought into operation progressively one after the other. Later when the accelerator is completed, parts of the machine may be modified, upgraded or dismantled. For these reasons a flexible reconfiguration scheme must be devised from the beginning of the project. In the following paragraph we will described the two major reconfiguration facilities considered.

Token-ring reconfiguration. The token-ring protocol as defined in IEEE 802.5 provides MAC frame management facilities such as beacon which can be exploited for recognising transmission errors, localising the faulty equipment and disconnecting it from the ring. Furthermore, the token-ring interfaces perform automatic self test before insertion into the ring, or drop out automatically if errors are detected by the interface. The ring monitor function takes care of the token circulation and regeneration in case of drop/insert or drop/out to retrieve normal operation. The monitor station can be any token-ring interface so that no single point is a sensitive point of failure.

On top of these facilities, inherent to the protocol itself and exploited by the MAC frame microcode software, additional provisions must be made for network reconfiguration and loop-back transmission. As mentioned earlier TDM trunks are used between LEP buildings and as the token-ring transmission is uni-directional a second TDM channel is used in opposite direction to loop back in case of failure further down the ring; e.g. the power-cut of a building in the next LEP site. In this case the site can be either bypassed by interconnection of the TDM output channel to the input channel of the next TDM trunk or alternatively both sides of the failure point loop back in the same manner reconstituting a closed ring which may be twice as large but nevertheless still operational.

Local isolation is also required for fault diagnostics or autonomous operation; sites might be in construction and brought independently into operation. All these situations have to be considered and taken care off. A central token-ring management station is foreseen to keep track of the current ring status and in each site a local reconfiguration hardware will be provided.

TDM reconfiguration. The TDM system is a logical replacement of many cables around the LEP tunnel saving space and money. Despite its high quality and built-in reliability this equipment is prone to failures like any electronic material. In addition, one needs for an operational system to provide rerouting facilities which can be operated either manually or automatically. To fulfill these various requirements full duplication of the TDM trunks is envisaged for the forward transmission of the token-ring as well as the backward transmission in case of loop-back. An electronic reconfigurator system must be used with separate power unit and cables to guarantee a maximum availability of TDM trunks and to be able to reconfigure both service and machine token-rings in case of problems. The remote control of the TDM and token-ring reconfiguration facilities can be done by two methods.

Firstly, by an interconnection of the two service and machine networks in each of the eight LEP sites. Thus if one of the token-rings fails the other can contribute to the switch-over mechanism.

Secondly, the provision of a separate slow control line going around the whole machine which may be connected to both the token-ring and to the TDM terminal equipment to switch-over the various logical lines.

A detailed study of the optimum token-ring and TDM reconfiguration strategy is currently being done, models are being devised and simulation will be done in the future before the final methodology is decided.

Network Software

At the early stage of the project it was foreseen to make use of communication protocols following the emerging ISO standards. However, considering the statement of direction to make the maximum use of available commercial products, the full ISO approach had to be partially postponed. There is no availability problem for the two lower layers of ISO: commercial products are nowadays offering the physical layer, the Medium Access Control (MAC) and Logical Link Control (LLC) sublayers. The LEP/SPS control system will make use of the connection-less LCC class 1 as specified by IEEE 802.2.

For upper layers a drastic move has been made recently to adopt the U.S. Defence Advanced Research Project Agency (DARPA) suite of protocols: TCP/IP. DARPA has defined the protocols for communication over an inter-connected system of networks. This is exactly the framework of the LEP/SPS control system which is made from a number of token-ring inter-connected by bridges and connected to various ETHERNET links in the LEP experiments and to the CERN Computer Center via gateways.

The DARPA suite of protocols is complete up to the Application layer and File Transfer Protocol. Remote terminal access and electronic mail are commercially available as portable packages written in the C language. Within this framework we are currently defining, above the DARPA Internet Protocol, playing the role of the ISO network layer, a Transport Protocol which suits our real-time constraints.

CONCLUSION

This paper has presented the global LEP/SPS control network as it is currently being constructed and the technical arguments in favour of the token-ring network architecture.

A new method for extending the token-ring inter-station distances, based on the use of standard TDM equipment has been developed and successfully tested. Finally the network reconfiguration capabilities provided for in the control system are discussed. The CERN LEP/SPS control project, when completed, will be one of the largest real-time networks using the standard IEEE 802.5 token-ring protocol promoted by IBM as an international standard.

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