HEAL TIME CONTROL NETWORKS FOR THE LEP AND SPS ACCELERATORS

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Abstract

The multiprocessor control system for the LEP and SPS accelerators uses three complementary networks to achieve real-time operation. To cover the geographical size of both machines the IEEE 802.5 token-ring standard has been retained to interconnect the DLX multiprocessors and the operator consoles. Locally in each site all equipment is controlled via multidrop buses following the MIL-1553-B standard protocol. The real-time actions are triggered by a general timing network to which dedicated process controllers are connected. The purpose of this paper is to present the criteria for these choices and to provide, for each level, the achievable throughput and real-time response.

Introduction

The LEP/SPS 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. In addition an accelerator synchronisation network permits real-time equipment triggering for control and data acquisition.

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 [1]. 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 [2][3].

All accelerator equipment and subsystems are connected to multiprocessor assemblies by a multidrop bus conforming to the MIL-1553-B standard protocol [4].

To select its VME based multiprocessor control assemblies [5][6], 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 CNRS-SIMETA Company. The ELECTRE real-time executive follows the SCEPTRE norm (Standardisation du Cœur des Exécutifs des Produits Temps Réels Européens) standardized by the French INI (Bureau de la Normalisation Informatique).

The Inter-processor network

The LEP electron-positron collider has the shape of a ring of 27 km circumference with eight equi- distant 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 the communication network even more 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 [7] 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 [8] 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 chip sets have been announced by some manufacturers. In the long term one can expect token-rings working at 40 Mbit or more. Speed increase is not favorable to CSMA/CD as the transmission distances will decrease proportionately 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 buses 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 fiber 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 buses 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 [9] and designed for modern digital telephone. This type of equipment is available from several European manufacturers, conforms to the CCITT standard and is electrically 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 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 underground 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 cause them to deteriorate 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 Münchischikon 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.

The equipment network

All accelerator equipment is connected to the DLX multiprocessors by a multidrop bus conforming to the MIL-1553-B standard [10]. This standard has been developed initially for avionic applications but is now used for industrial control. Standard temperature range protocol chips are available from several semi-conductor manufacturers.

The MIL-1553-B protocol allows both command/response access and message communication with the equipment. A single command may be accompanied by 1 to 32 words of 16 bit data in read or write mode. Long messages are constructed from series of data packets [11].

The data bus uses a single screened twisted pair of wires. The connection of up to 31 equipments is made by transformer coupling and passive derivation.

The distance covered by the multidrop bus depends on the transmission speed and the quality of the cable. At the nominal frequency of 1 Mbit 400 m can be reached. At lower frequencies and with the same quality of cable longer distances are possible, typically: 500 kbit 800 m, 250 kbit 1.5 km, and at 125 kbit 2 km. These long distances are needed to reach equipment located in the LEP underground alcoves.

Interfacing of accelerator equipment to the MIL-1553-B data bus is straightforward, standard G44 or VME cards, containing the bus receiver/transmitter, two read/write memory buffers and a communication register, have been developed [12].
For long messages, between a DLX multiprocessor and an intelligent equipment, a throughput of up to 20 kbytes/second of data are achieved at the nominal 1 Mbit/s data rate.

The synchronization network

For control systems, a time response of the order of one tenth of a second is sufficient. The majority of the transmission networks and particularly the token-ring allows this response time, thus no particular precaution is required for this type of action.

However, for large control systems using many processors and equipment distributed over a wide area, there is a problem to keep synchronism amongst remote and cooperative processes. This problem has been solved for SPS and LEP by a specialized network independent of the computer network distributing a synchronisation clock each millisecond and information in the form of coded events. This synchronisation information is brought to all equipment via a second twisted pair located in the MIL-1553-B multidrop cable [13].

Thus, for example, all function generators of a certain type of power supply are controlled by several DLX multiprocessors spread over the whole LEP site, which generate a perfectly synchronised current ramp in the machine magnets. These generators will have been loaded initially with data tables and instructions like: "at the nth clock pulse, after event k, load first data of the table, then the successive data of that table every m clock pulses". By this principle it is possible to guarantee the synchronisation of hundreds of pieces of equipment with a resolution of a fraction of a microsecond and independently of the number of computers and microprocessors involved in this action.

Such a synchronisation signal can be transmitted via a 2 Mbit/s TDMA channel, giving a resolution of 0.5 μs which is adequate for the majority of applications.

Synchronisation of radio frequency or beam observation systems must be done with nanosecond time resolution. For this equipment special direct links have been foreseen. In some cases the time information is taken from the particles themselves circulating in the accelerator vacuum chamber.

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 interstation distances, based on the use of standard TDMA equipment has been developed and successfully tested.

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 and the MIL-1553-B standard protocol for the control of industrial equipment.

References


