IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3, June 1981

'RELWAY': A PROCESS DATA HIGHWAY SYSTEM OPTIMIZED FOR ACCELERATORS*

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Classically, control groups, on accelerator projects, were brought together well after project inception and charged with melding together a multitude of electronic and electromechanical devices of various vintages and orgins. The beginnings of the minicomputer revolution saw control groups patching these computers onto existing accelerator control systems with mixed results. The fears of equipment designers as to control system reliability, availability and redundancy made many systems awkward, complicated and expensive. Old hands in the field are all too familiar with struggling to computer control equipment designed to be manually operated (e.g. PUSH STANDBY BUTTON- hold closed until fans are heard running, release and when ready lamp lights PUSH ON BUTTON - now slowly raise reference voltage until...). Later projects, the SPS most notible among them, elected to integrate control systems into the machine design from the beginning. These design efforts were often well ahead of state-of-the-art computer and command control systems available elsewhere. We like to think that ISABELLE's control system follows in this tradition.

Our immediate topic is the ISABELLE accelerator command/control scheme: specifically the process data highway. Different types of voice, video, timing, and data distribution systems exist. These use coaxial cable, fiber optics, telephone PABX, and twisted pair hardware. Topologically they reduce to the star and the party line (highway) configuration.

These fundamental building blocks may be used individually or combinationally when implementing a control or data communication system. The number of alternative system structures is large. The choice among alternatives depends on many factors: access time, throughput, number of connected stations, geographical distribution of connected stations, and the level of intelligence available at individual stations etc.

Two successful methods of intercommunication between more than one intelligence are illustrated by the telephone exchange and the post office. A telephone exchange assigns a circuit exclusively to a group of users for the length of time needed to exchange information. The telephone exchange provides a path (physical or virtual) which may be used to exchange data (packets). The significant concept is that packets are received in the same order as they are sent. Since a telephone circuit provides a direct, real time, means of detecting faulty transmissions, we are without interest in the routing used. A telephone exchange provides first come - first served access to limited resources. Since resources must be assigned and are finite, it is best suited to pairs of users and relatively long messages. Furthermore, it is difficult both physically and functionally to interrupt a connection with what <u>might</u> be a higher priority communication.

The post office provides a non-exclusive mechanism whereby a message is transported between a group of users. The post office does not guarantee the sequence of delivery of messages. However we do have some control of routing and priority (airmail, express mail, special delivery). The post office approach makes more efficient use of limited resources and allows for priority messages, but has delivery lags and sequence of delivery problems. It is particularly good for many short messages which are to be delivered to multiple users.

A third alternative is to use a traffic cop to determine dynamically when and how any particular user may use a highway. Fast bus uses such a system; this technology is most suitable for systems in which traffic volume could exceed the capacity of the network.

ISABELLE's physical size, the nature of storage ring operation, and the need for an open-ended controls solution have led to the selection of a Multiple-Access Contention Controlled Process Data Highway. We will be using conventional CATV techniques and components.

The selected class of solutions to the problem of information transfer involves the concept of Carrier-Sense Multiple-Access (CSMA) with collision detection. The general idea is that a group of master stations are interconnected via a communications medium. The scheme is, typically, that a station listens to the medium; if that station detects another station's transmission, it will defer its own transmission until the medium is clear. Any station finding the medium clear is free to transmit a message packet. Several stations located along the link could, by reason of their special separation, sense a clear medium and begin data transmission causing interference and reception of garbled information. This problem is known as message <u>collision</u>. Collision detection and/or prevention is <u>the</u> core of these systems. Clearly it is desirable to avoid the full length transmission of collided packets.

Our process data highway design uses the idea of CSMA with data collision prevention. Stations are connected via coaxial cable and directional couplers. Two cables are used, each capable of carrying information in only one direction. All stations listen for data on their receive line. If a station, designated S, wishes to transmit, it first listens on the receive media. If S detects another station's transmission (if S senses a carrier), S will defer its own transmission on the transmit medium until the receive medium is free.

Our system's concept embodies the flexible organization of a CSMA network with the deterministic qualities desired in a control system. Adding a receiving directional coupler on the transmit medium at each station, and including a period of unmodulated carrier before actual data transmission starts, allows use of priority - by - position and prevents collision of data, thereby avoiding interference and consequent loss of data. A valid packet will always be sent in the event of contention. Since all stations are connected by a common medium, the PDH will allow an originator's message to be received by multiple recipients: a BROADCAST feature.

The components and media of our process data highway have been used in other applications. The organization of these standardized components has been changed so as to provide priority-by-position during contention, while preserving random access at all other times. The highway is configured such that the

* Work performed under the auspices of the U.S. Dept. of Energy.

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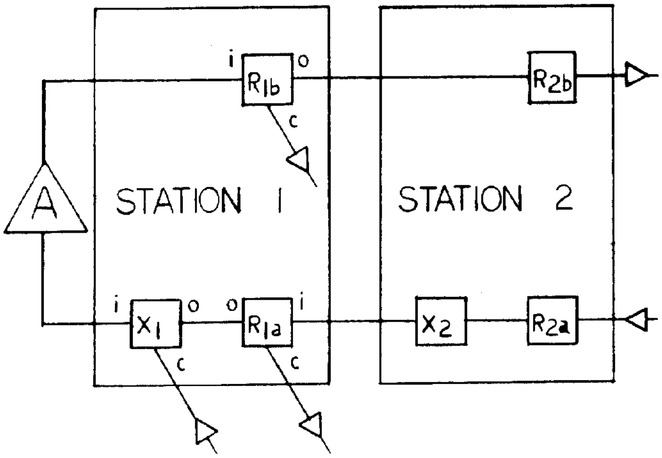

Fig. 1.

controlling computer(s) are physically situated at the highest priority end of the transmitting cable. The line discipline is CSMA: any station wishing to transmit a packet checks the receive line via its receive coupler Rb for the presence of modulated or unmodulated carrier. If carrier is present the originating station defers transmission. If the receive line is free, a station such as S2 begins transmitting carrier (via X2) for at least 2T seconds. T is the electrical length of a line segment. After 2T seconds, S2 via X2 sends the destination code of its packet (destination may be specific or general) followed by the data packet itself, etc. The nature of directional couplers, which encourage selective signal attention, results in a station being able to distinguish between its own transmission on the media and that of a higher priority station. (Fig. 1)

System advantages: (1) The System acts as a master/master democracy until carrier collisions take place. (2) If there is carrier collision, a valid message will always be transmitted (and received) without wait states. (3) The controlling computer(s) situated at the highest priority end will always be able to assert effective system control with no more than a packet time delay. (4) Directional couplers make cable connections passive and thus highly reliable. (5) The system uses standard, low-cost CATV components and can be extended with additional amplfiers for extra stations and longer distances. (6) The wide channel capacity of CATV-type cable, couplers, and amplifiers makes it possible to use frequency multiplexing schemes to separate ISABELLE's subsystems; i.e., Vacuum at 20 mHz, Power supply at 30 mHz, etc. (7) Frequency multiplexing may also be used to raise effective data rates by parallel transmission. (8) Since the CATV industry normally uses 60 hz to power trunk amplifiers, and because of the modulated carrier nature of our signal, ground isolation and resistance to induced power faults appears achievable. (9) Other media such as fiber optics will respond to similar message protocol.

An alternate configuration can also be used. This system works as follows: (see Fig. 2). To each of the unconnected trunklines are attached two directional couplers/station. Information flows left on one line and right on the other. A station listens to both lines prior to sending a packet. If either line is busy the station defers transmission. If the lines are clear, transmission begins left on one line and right on the other. Again, contention is possible for spacially distributed stations. However, no preamble or carrier is required by this alternate line discipline because, by virtue of directional coupler characteristics and the insertion of the couplers to the left and right of Xb and Xa respectively, a station can be considered never to hear its own signal. Thus, any signal received while transmitting means that at least one other unit is transmitting. A station must continue to transmit for at least T seconds after detecting collision, so that we can guarantee that every other transmitting station will halt and thus abort a damaged packet. After detecting collision, a station may restart with a prioritized and/or probabalistic waiting period. Advantages for this system include simple collision detection, random priority for stations, and short delay times for long line runs. Disadvantages include additional components, insertion losses and more complex station logic. This cable and coupler geometry will permit the use of both protocols on individual frequency channels. A single cable system using two frequencies per channel is also possible.

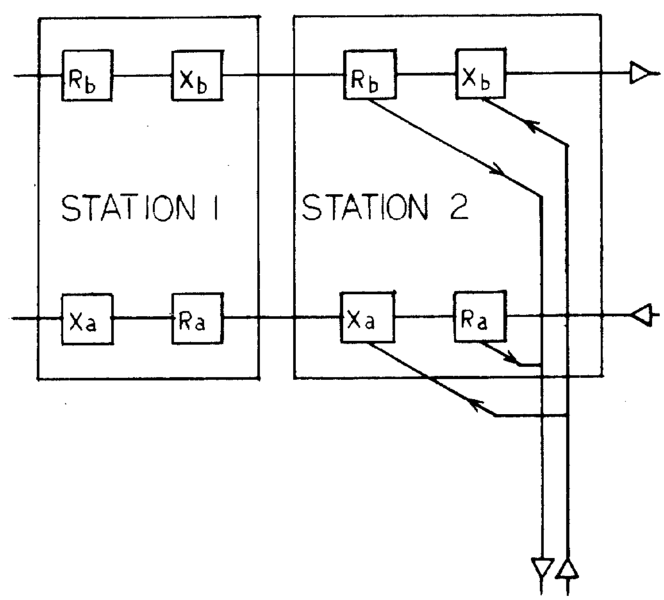

Fig. 2.

Service, support, and maintenance requires the ability to monitor traffic, loop a station, connect/disconnect stations from the line, and extend/shorten or reroute lines. Relway, by virtue of the computer's physical location at lines' end and the broadcast nature of the system, provides and allows the controlling computer(s) to monitor all line traffic. Self-loop appears to be achievable for station testing. The directional couplers allow for station connection/disconnection provided care is taken to preserve line termination. For a given detailed ISABELLE design, there will be a line attenuation and coupler insertion loss characteristic which will determine the details of line extension/shortening. In general, additional line and/or amplifiers will handle any reasonable extension with a small possible loss of reliability due to the insertion of additional amplifiers. Specific factors such as geographical distribution, station bandwidth, maximum allowable access time, and channel capacity could cause us to establish additional main lines with corresponding computer interfaces.

The transmission modes available include broadcast (global), event-driven (interrupt), and polling. Use is intended to be with dedicated transmission lines, but conversion to common carrier is possible with a buffered data gateway.

System speed is expected to be approximately 2M bits/second. This is believed to be more than adequate for ISABELLE applications. If this speed proves inadequate, use of frequency multiplexing will permit 5 additional channels or 12M bits/second.

The system itself does not utilize a single uniform standard. Elements of IEEE488 (GPIB), SDLC, RS422, and IEC "Proway" are imbedded within the design. Every effort will be made to employ the LSI circuit chips developed for the above standards.

Availability and reliability are prime elements in a process data highway system. Since their normal mode of operation is equipment control and data acquisition, both real time events, Process Data Highways typically demand higher data rates and shorter access times than telecommunication links. The nature of control systems also implies frequent succinct messages. The need for high data integrity indicates dedicated cables.

The process data highway design has begun to consider such aspects as auto recovery, single point failure, and redundancy. Auto recovery in our case will mean that a malfunctioning station removes itself from the line. A useful technique is to limit local transmitter power such that a station cannot block the main line. Coupler, cable, and amplifier failures are our single point failure modes. Both the coupler and cable are passive elements and reliable. It is possible to provide redundant amplifier modules. No amplifier is needed between ring support buildings despite their 2200 foot spacing.

We are naturally concerned with how long a high priority message must wait before it can be transmitted. This time, called access time, will be determined by the length of the longest packet. At 1.6M bits/second, a 200 byte packet takes 1 millisecond. PDH availability as a function of intersystem usage and repair requirements has been studied. It is possible to continue to operate the highway for a single functional system, provided that the cables and amplifiers remain intact. Pulling computers and/or other functional systems off the line does not impact other users.

The proposed PDH makes use of direct data exchange between distributed intelligences. The number of hierarchical levels is kept to a minimum; it is topoligically flexible. The junction boxes will store and forward information to microprocessing units connected to the junction boxes via a parallel branch highway. In other words, local memory in the junction boxes will buffer the transfer of data between the coaxial cable system (main line) and a local data bus (branch line) which is implemented with a group of parallel wires and line drivers/receivers. (IEEE488).

Some factors affecting system integrity are electromagnetic interference, differences in ground potential, and state transitions. Use of coaxial cables and frequency modulation will aid system resistance EMI/RFI, but we will have to exercise care because of the low power levels anticipated at some junction stations. The nature of our frequency modulated signal allows earth potential isolation. However, the best way to establish a grounding system is yet to be determined. State transtion refers to power on/off, local/remote, busy/ready, and on-line/off-line changes. Directional coupler characteristics and the democratic line discipline act to ease these problems.

I will summarize by reiterating the elements of the ISABELLE PDH design (Fig. 3):

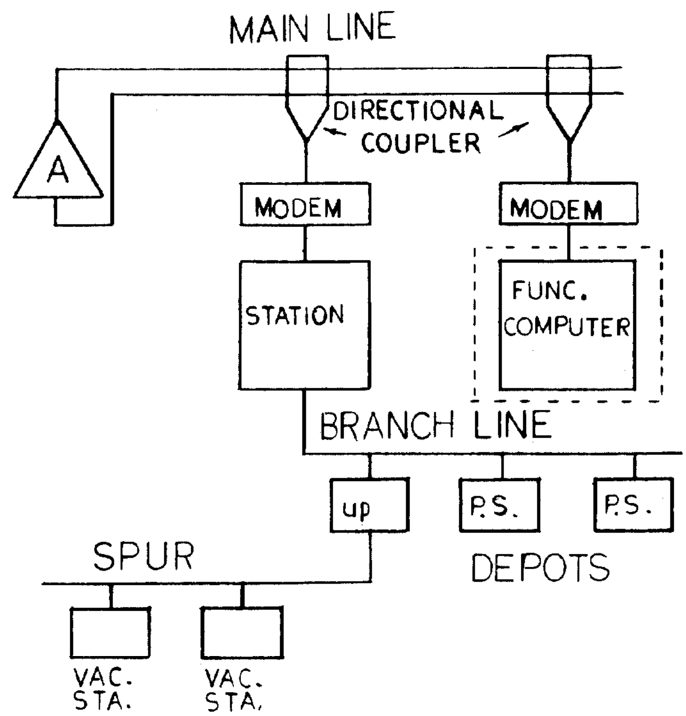

Fig. 3.

Main line – CATV cable system
Station – a microprocessor with DMA entry from main line and IEEE488 bus controller to branch line.

Branch line – IEEE 4888 bus with repeaters
Depot – microprocessor controller
Spur – a private (subsystem specific) connection from a depot to its accelerator component(s) such as a vacuum pump station sytem.

The system is not only realizable in a hardware sense, but it is also one which will integrate smoothly with operating software and computer networking. At the present time working prototypes of a 1M bit system exist. The immediate future will establish system validity for multiple stations on separate channels at 1M bits/sec rate. By June of this year a final selection of highway topogoly will be made and the end of the calendar year will bring completion to the detailed PDH hardware design phase.

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