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for a Control System*

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NOVANET:

Communications Network for a Control System*

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Novanet is a control system oriented fiber optic local area network that was designed to meet the unique and often conflicting requirements of the Nova laser control system which will begin operation in 1984. The computers and data acquisition devices that form the distributed control system for a large laser fusion research facility need reliable, high speed communications. Both control/status messages and experimental data must be handled. A subset of NOVANET is currently operating on the two beam Novette laser system.

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This paper first looks briefly at the laser and its control system in order to see how this generates the design constraints for the network. Next, we present a system overview of NOVANET, followed by detailed descriptions of the hardware and software. The experience gained from operating NOVANET on the Novette laser system and some performance data concludes our discussion.

NOVA LASER SYSTEM

For the past several years, scientists at Lawrence Livermore National Laboratory have built and operated a series of neodymium-glass laser systems that are used to study Inertial Confinement Fusion (ICF). The largest of these, the Nova laser system, is scheduled to begin operation in 1984 (Figure 1). Nova's ten 74 centimeter diameter beams will concentrate 100-150 terawatts for 100 picoseconds - 3 nanoseconds on to a target and the resulting fusion reaction will be studied. The fundamental 1.06 micron light from the lasers will be doubled and tripled by inserting potassium dihydrogen phosphate (KDP) crystals between the final laser amplifiers and the target. Each arm of Nova consists of an optical path of approximately 250 meters containing amplifiers, rotators, and spatial filters. This path is aligned by 1000 stepper motors which move mirrors and other beam line components. The laser amplifiers are driven by 4000 flashlamps which are fired by a total of 9 megaamps at 25 kilovolts.

NOVA CONTROL SYSTEM

Operation of the Nova laser is made possible by a distributed

FIGURE 1.

control system. It consists of three Digital Equipment Corporation (DEC) VAX-11/780 control computers, fifty DEC LSI-11 microcomputers, and various data collection instruments including solid state Charge Coupled Device (CCD) cameras and transient digitizers (Figure 2). Operators communicate with the control system through consoles which contain three color graphic video monitors; the center monitor is overlaid with a transparent touch sensitive panel. Buttons are drawn on the color monitor, and the operator touches the area over the button to effect the operations. The two side monitors are used to display status information (Figure 3). The control system also collects and stores for later analysis the 5 megabytes of laser and target performance data that is generated by an experiment.

A high speed array-processor is attached to one of the VAX computers to speed up image processing for alignment. An interactive system such as this needs an operator response time of less than one second and the distributed architecture allows us to meet this goal. In addition to the three control VAX computers, there is a separate VAX for development and testing.

NOVANET REQUIREMENTS

The design of NOVANET is closely intertwined with the design of the Nova control system, but in general, the control system architecture specifies the design requirements for the network. NOVANET must handle a wide variety of message types: Control messages (100 bytes) and data messages (100K bytes) can be sent at arbitrary times. The control messages often occur as a result of

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FIGURE 3.

operator interaction, so they require rapid response.

In contrast, the much larger data messages can tolerate somewhat longer transmission delays. A further difference here is that control and status messages usually involve processor-to-processor communications (typically VAX to LSI-11) while data transfers often occur directly from the data acquisition device. To effect this, the protocol must be suitable for connecting processors and instruments directly to the network.

The pulse power system that energizes the laser flash lamps generates large amounts of Electro Magnetic Interference (EMI), and the control room must be isolated from the 25 kilovolt pulses present in the laser bay for safety.

System reliability must be very high since laser operation is expensive and with 200 nodes separated by as much as 1 kilometer, network diagnostics and repairs could consume a large part of the time allocated to operating the laser.

NOVANET OVERVIEW

NOVANET is the local area network that we designed to solve the unique data communications problems associated with the control system described above (Figure 4). We now present an overview of the NOVANET network, followed by more detailed hardware and software descriptions. NOVANET utilizes the simple addressing structure of a bus topology. However, limitations on the number of optical taps on a fiber bus before the power reduction inhibits reliable communications forces the physical topology to be a star. Each node is connected point to point with

NOVANET – A VERSATILE NETWORK

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FIGURE 4.

the central "node star" which simply retransmits each message to all nodes. Thus NOVANET's topology is logically a bus, but physically a star. Having been forced into the star topology, we made use of it in several ways. The central node star allows us to split the network in multiple independent subnetworks which improve performance. In addition, the node star provides a central summary of network operations.

NOVANET nodes exist in three flavors: the Master Slave Controller (MSC) is the network interface for processors (VAX and LSI-11), the Q-Bus Device Interface (QBDI), and the Multiple Device Interface (MDI) are used to connect instruments directly to NOVANET. Each of these will be described in detail later. The NOVANET hardware transfers data using Direct Memory Access (DMA) techniques to minimize processor loading and maximize data transfer rates. The DMA transfer facilitates down-line loading of programs to the remote LSI-11s.

The NOVANET protocol was chosen to support both instrument and processor nodes. The link level protocol is 10 megabits per second asynchronous 50 bit packets with the hardware supplying handshaking and error detection (Figure 5). The network level utilizes rotating mastership for collision avoidance and two communications modes (active and passive).

For the active mode, the hardware requests network mastership and initiates the data transfer immediately after becoming master. The passive mode arms the hardware but does not initiate the transfer. In NOVANET, we use the active mode for writes and the passive mode for reads. When the network is idle, the current

NOVALINK PACKET FORMAT

FIGURE 5.

network master is continually polling to see whether some other node wishes to become network master. This is equivalent to a token passing scheme for collision avoidance. In the event of multiple masters on a segment, we use a backoff and wait for a random amount of time to regenerate a single master (token). This multiple master problem is not as rare as one might expect; it happens whenever subnetworks are recombined into a single network.

NOVANET HARDWARE

NOVANET hardware (Figure 6) is built around the Hewlett Packard fiber optic transmitters and receivers which are run at a line speed of 10 megabits per second. The hardware operates in half duplex mode which allows a single forty bit serializer/deserializer to format the packets for transmission and to decode them during reception. An eight bit Cyclic Redundancy Check (CRC) is included as part of each packet; CRC generation and checking is performed by the hardware. In order to operate instruments that are connected directly to the network, the hardware provides a handshake for each fifty bit packet. The polling and the rotation of mastership is also managed by the hardware, making this transparent to the network users. Polling is restarted immediately after the completion of a data transfer by the current master. The logic for these functions and for the Direct Memory Access (DMA) data transfers is performed by three state machines. A protocol state machine that is built from 2910 bit slice electronics with micro code in bipolar fusible link Read Only Memory (ROM) controls the other two. The basic clock frequency

FIGURE 6.

for the 2910 is 5 megahertz. The second state machine is built from a counter and more ROM. This one controls the serializer/deserializer that assembles the fifty bit packets. A third state machines manages the Q-Bus interface, generates interrupts, and detects and returns status through the device registers. The ROMs also contain micro-diagnostics for maintainability. It is possible for multiple masters to exist on a network as mentioned above. The hardware can detect this condition since the message collisions cause CRC errors in almost every packet. When this happens, all masters stop transmitting and begin listening. Each node that is capable of becoming a network master will wait a random time before listening for a poll. If there is no activity on the network, the node will begin polling. This scheme ensures that a single network master will be regenerated whenever multiple masters appear or if the current master should disappear.

We shall now describe the three flavors of network interface hardware. First let us consider the Master Slave Controller (MSC).

This is used to connect processors such as VAXs and LSI-11s to NOVANET. It is the only type of card that can become a network master and thus initiate an active transfer. The NOVANET interface can listen to the network, receive a message and continue polling even when its host processor is halted, since the lower levels of protocol are all implemented in the network hardware whose operation is largely independent of its host. The MSC is built on two quad-sized DEC Q-Bus boards and has eight control and status registers. All Q-Bus DMA and interrupt control

logic is resident on the MSC. The master slave controller is compatible with the eighteen bit extended addressing mode, and the multi-level interrupt structure of the LSI-11/23. It may be connected to the VAX Unibus by using a commercial Unibus to Q-Bus converter.

The Multiple Device Interface (MDI) is used primarily to connect Charge Coupled Device (CCD) cameras directly to NOVANET. It consists of three cards that fit into an Augat card cage together with the CCD camera's memory and controller. The MDI electrically regenerates a Q-Bus and acts as the Q-Bus master. It allows a processor node (usually a VAX) to directly access the control and status registers of a remote CCD camera via NOVANET.

The MDI cannot become a network master; hence, a camera cannot initiate a data or control transfer. It also includes a sixteen bit parallel data port that is functionally equivalent to a DEC DRV-11 interface.

The Q-Bus Device Interface (QBDI) is electrically identical to the MDI, but it is built on one quad-size DEC Q-Bus board. Thus, the QBDI acts as a bus master in the quad-wide backplane where it regenerates the Q-Bus signals from NOVANET commands. If a Q-Bus device is plugged into the backplane, remote processors have access to it, almost as if it were in their address space. This versatility allows many standard Q-Bus devices to be connected directly to NOVANET for use by a remote processor. A very useful function of the QBDI is to use commercially available Q-Bus interface boards as gateways to other networks. We have been very successful in using a Tektronix IEEE-488 Q-Bus interface

card to connect Tektronix 7912AD transient digitizers to NOVANET. This allows the digitizers to be located near the experiment while the operator can control them and display images on the consoles.

The node star is the central point of the NOVANET network (Figure 7). It is not a network node; it is simply a repeater that broadcasts each message to all nodes on the network. All nodes are physically connected point-to-point to the node star by the fiber optics. Since the node star is central to the network, it provides NOVANET with some additional capabilities.

The most important of these is the ability to split NOVANET into multiple independent subnetworks. This allows the control and status messages to maintain their short response times while the large volume data transfers that monopolize the network for several seconds take place. Furthermore, distinct subsystems can have separate subnetworks which improves performance and enhances minimal subsystem interdependancies. The node star is constructed of 4 x 16 crossbar switches which facilitate this segmentation into subnets.

The point-to-point connections to the node star make it easy to monitor network activity and optical power for each node and thus facilitate the location of faulty nodes. In addition, the node star has the ability to electrically isolate a malfunctioning node to permit operation of the remainder of the network. These node star control and status functions are available both on a front panel for manual operation and as registers in the address space of a dedicated micro-computer for computer control. In any star network, the central node is a location for single point

NODE STAR CONTROL AND STATUS

SEA. NI

FIGURE 7.

failure, but our node star is designed to be as simple as possible for high reliability. In addition, it is constructed of many identical printed circuit boards for board replacement maintainance.

The final component of NOVANET is a network analyzer. Some type of device that can monitor network traffic at the bit level is very valuable during the hardware debugging, verification, and initial installation phases of operation. Since we are not using an industry standard protocol, we built our own link analyzer for NOVANET. It consists of a custom designed network interface, coupled with a commercially available Biomation data analyzer and a Tektronix display monitor. This approach is more cost effective and faster than designing and building the entire instrument ourselves. We found the NOVANET analyzer most useful during the initial stages of network installation.

NOVANET SOFTWARE

NOVANET software consists of device drivers and auxiliary control routines and programs (Figure 8). As is the case with most network software, NOVANET software protects the users and the hardware from each other. It synchronizes user requests with the operating system and with the network interface and programs the hardware for the DMA transfers. Diagnostics and the gathering of operational statistics are further software tasks. Software also allows the users to communicate with the network at a sufficiently high level that the irrelevant details of network operation are not troublesome. In the case of NOVANET, the network hardware is

NOVANET COMMUNICATIONS SUMMARY

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FIGURE 8.

half duplex, but network software allows the user to view it as being full duplex. This is implemented in the drivers by using separate queues for active and passive functions and giving the active queue higher priority. An active transfer request will displace a passive transfer request that is pending, replacing it when the active transfer is completed. The software is designed and implemented in a variety of languages, but it is all modular by functionality for maintainability. It also allows users access to different levels of the network software. NOVANET hardware provides error detection with CRCs and timeouts; the software uses these hardware features to provide error correction by retransmission.

There are device drivers for the VAX-11/780 running VMS and for LSI-11/23 running in stand-alone mode. There is also an LSI-11 driver that runs under RSX, but it is not used now and so will not be discussed. Above the drivers, there are high level language interface routines, a variety of specialized interface modules, and a gateway handler to the IEEE-488 bus.

The VAX/VMS driver is written according to the template for device drivers included in the VMS documentation. It interfaces with the users through the VMS SYSSQIO system service which provides parameter checking, a status return mechanism, and other input/output (I/O) functions that are common to all device drivers. The VMS driver contains software hooks to allow it to operate with an optional Ancillary Control Process (ACP) that provides additional network functionality.

The LSI-11 stand-alone driver is functionally equivalent to

the VAX/VMS driver and is structurally similar to it for maintainability. It makes use of the extended eighteen bit address space and the multilevel interrupt structure in the LSI-11/23.

In both the VAX/VMS and the LSI-11 there are software modules that sit above the device drivers and provide additional features and utilities for users. In the LSI-11, these are primarily interfaces to Fortran, Praxis (a Pascal/Ada like language developed at LLNL), and LSI-11 Macro. The VAX/VMS high level software consists of the language interfaces as in LSI-11 version, some driver arbitration software, a gateway handler to the IEEE-488 bus and a utility to down-line load programs into an LSI-11. The driver arbitration software uses semaphores to allow several processes to time share a network node while guaranteeing exclusive access when necessary. The IEEE-488 gateway handler controls a Tektronix IEEE-488 Q-Bus interface board to allow a user program to access IEEE-488 instruments from the VAX. The handler performs the raising and lowering of the IEEE-488 control lines and, in general, implements the lower levels of IEEE-488 protocol. The handler allows the user to send ASCII string messages to specific devices without regard to the details of the IEEE-488 protocol. The LSI-11 downline loader program allows LSI-11 programs to be developed on the VAX and the executable image can then be loaded into LSI-11 for operation. If an LSI-11 crashes during an experiment, it can be rebooted from an operator console.

NOVANET EXPERIENCE ON THE NOVETTE LASER SYSTEM

Although the Nova laser is scheduled to begin operation in 1984, the Novette laser facility consisting of two Nova beams has been operating since June of 1982. The Novette control system is a subset of the Nova control system and consists of one VAX-11/780, twenty LSI-11/23s, four transient digitizers, five CCD streak cameras and two consoles.

The NOVANET that links Novette together mirrors this configuration and consists of four VAX-11/780 nodes, twenty LSI-11/23 nodes, five MDI nodes for the CCD cameras, and two QBDI nodes for the transient digitizers. A two board node star completes the network hardware. The maximum length of optical fibers in Novette is 100 meters.

We have experienced a few NOVANET problems while operating Novette. The most serious of these is diagnosing network faults. The network users are interested only in a success/failure status for network transactions; hence, they discard the rest of the information that is returned. This makes the diagnostic task much more difficult and almost always requires a team effort to locate even the simplest of errors. Many times, the solution is as simple as applying power to a machine that has been unplugged. We have had a few node interfaces fail, but once the defective node is located, repairing it (off-line) is facilitated by the micro-diagnostics included in it. Another, more subtle problem is that of network performance. When used properly, the network performs very well. However, a user can easily write programs that slow network transfers to the point of unacceptability.

Placing each subsystem on its own independent subnet helps locate the culprits and allows the rest of the network to maintain high performance. More instruction to the network users will help to eliminate this problem.

NOVANET PERFORMANCE

NOVANET performance is sufficient for the Nova and Novette control systems as viewed from the operator consoles. While this type of measurement is always the bottom line in any type of system performance, a more detailed study of the interaction of various parts of the system is in order. The line speed of NOVANET is ten megabits per second. The overhead of the fifty bit packets, the handshake for each packet, and the line turn around time yields a data rate of 640 kilobits per second. We measured the VAX/VMS overhead for a transfer and found it to be about 0.5 milliseconds and the time for a one word DMA transfer to be 1.2 milliseconds. We also measured the end-to-end transfer rate for a 64 kilobyte transfer from a CCD camera to a VAX and found it to be about 1.0 seconds and from a CCD camera to an LSI-11 about 0.7 seconds. These figures are consistent with the 640 kilobits per second data rate stated above. The difference between the VAX and LSI-11 is that the VAX's Unibus is being shared with a lot of devices such as disks, other network cards, and terminals which slow down the DMA transfers. In monitoring control system performance on Novette, we find that the network transfer time is a small part of the total control system time. Typical control and status messages are 100 bytes long and thus their end-to-end

time is under ten milliseconds. The QBDI network interfaces contain error counters that may be read by a processor node. For a network of ten nodes, the measured error rate is approximately 10^{-2} errors per second. Combining this with our transfer rate, we see an error rate of $2.5 \times 10^{-9} - 10^{-8}$ errors per bit. This is somewhat misleading, however, as our traffic tends to be bursty and much of the time the network is polling where errors are much less problematic than those that occur during a data transfer.

Our Novette experience has led us to consider some minor changes in NOVANET for the Nova control system. We will write a more complete network diagnostics package. Error reporting will be incorporated into the network software instead of leaving this to the users since our experience indicates that they will not report sufficient information for easy diagnosis and correction. This becomes more important for the larger Nova system (approximately 200 nodes compared to Novette's 31). Network status displays will be integrated with the diagnostics package and will provide on line performance and error statistics as well as the current network configuration. The Nova control system has three VAX-11/780 computers which allows us to split the Unibus load into three parts. This increase in Unibus bandwidth and processor power will improve NOVANET's performance which in turn will enhance the performance of the entire control system. There is also the possibility of reconfiguring the node star from the VAXs to allow dynamic segmentation of the network. We are currently reevaluating the need for a network Ancillary Control Process (ACP) to provide multiplexing, blocking and more services

to the users. Multiplexing on Novette is accomplished by multiple network nodes, but the larger Nova control system makes this solution less desirable.

SUMMARY

In summary, the NOVANET fiber optic local area network was designed to meet the diverse need of the control system for the Nova laser fusion experiment. Our experience on the smaller Novette laser system indicates that NOVANET will meet the communications requirements for Nova.

GLOSSARY

Bus	A network topology in which all nodes share a common data pathway.
CRC	Cyclic Redundancy Check. A method for detecting communications errors that is performed by the NOVANET hardware.
Device	An instrument or memory which has no local intelligence (no processor) which can be controlled by a processor via NOVANET.
LSI-11	A micro computer manufactured by Digital Equipment Corporation used to control stepper motors in the Nova laser system.
Node	An addressable location on NOVANET through which an instrument or a computer may communicate with others.
Nodestar	The central hub for the NOVANET network.
Segment/subnetwork	The Nodestar can be split NOVANET into multiple independent subnetworks. These subnetworks are called segments.

Shot time	The time when the laser is fired and the Inertial Confinement Fusion experiment takes place.
Star	A network topology in which all nodes are connected to a central hub.
VAX-11/780	A minicomputer manufactured by Digital Equipment Corporation used as the main control computers for the Nova laser system.

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