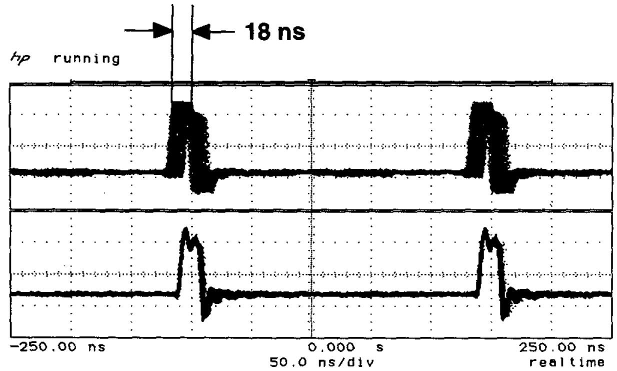

FD1 Fig. 3. Bottom trace: the master ping as received by the slave node. Top trace: the slave ping as received by the slave node after returning back from the star hub. The slave ping fluctuation amounts to approximately 18 ns.

signal after a correction has been made, for the amount of time needed for the shifted slots to come back to the slave node.

In the CORD prototype we used the subcarrier transmitters and receivers reported in Ref. 2 to send and decode the pings. The arrival time comparison as well as bit stuffing or dropping was implemented using commercial fast FPGA's clocked at 80 Mhz. The slave node was connected to the star through a 10K-m-long fiber. The subcarrier power impinging on the receiver photodiode was set at −26 dBm, corresponding to a 10^-9 BER for the headers multiplexed on the subcarriers.[2] The slot synchronization results is shown in Fig. 3. The bottom trace is the received master ping, whereas the top trace is the returning slave ping. The oscilloscope was triggered by the master node internal synch signal. The traces show that the maximum slave ping fluctuation with respect to the master ping was 18 ns.

This technique works with any slot-length and is independent of the packet payload data rate. It could be used in a ring configuration, with minor modifications. In conclusion, we have demonstrated a flexible, distributed digital slot synchronization technique for optical packet networks which is robust and scalable.

The CORD project is funded by ARPA under contract number MDA972-93-1-0028.

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FD2 8:45 am

Signaling protocol implementations on a burst-switched all-optical networking testbed

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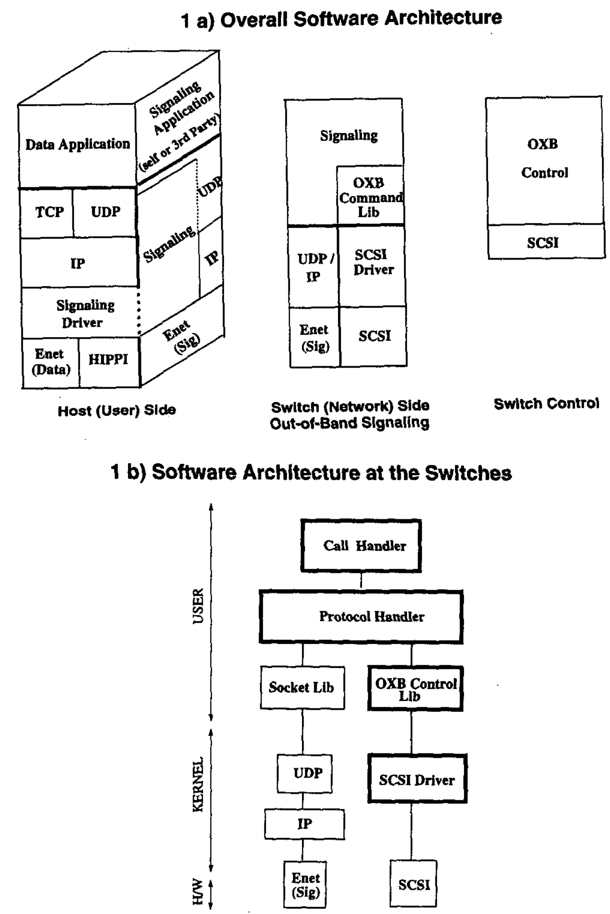
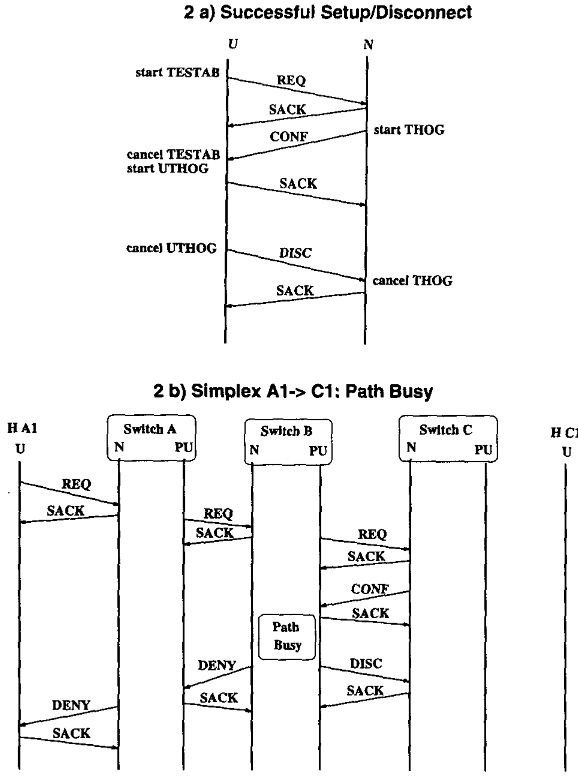
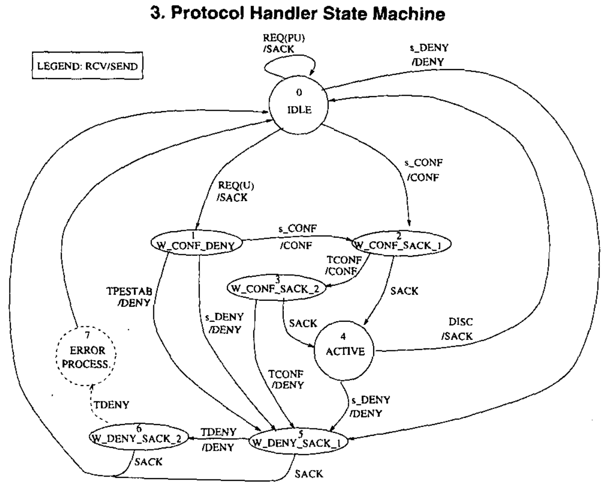
TBONE (Testbed for All-Optical Networking) is a multiswitch all-optical networking testbed under development by MITRE, Optivision, and TASC.[1] TBONE utilizes two optical crossbar switches. A unique feature of TBONE is that no prior provisioning/scheduling of traffic is required. That is, TBONE is a burst-switched network where the optical switches are reconfigured at the burst arrival time. Therefore, a signaling protocol must be implemented on TBONE, which has the ability to rapidly reconfigure the crossbar switches. It was desirable to implement a signaling protocol, which was well-suited to an all-optical gigabit-speed network and which could provide good throughput and delay performance. However, in the design of many signaling protocols implemented today, important characteristics of all-optical very high-speed networks were not considered.[2] Therefore, an analysis of new signaling protocols for all-optical networks was performed to determine which sig-



FD2 Fig. 1. The design and implementation of CC consisted of two major components: the Signaling Protocol Handlers and the Call Handlers. The signaling protocol is implemented by the Protocol Handlers, which reside on each host as well as on each switch. The Switch Call Handler, which resides on each switch, controls the switch fabric and performs network routing. OXB corresponds to optical crossbar. (a) An overview of the software architecture on the hosts and the switches. On the hosts, the Protocol Handler and Call Handler are implemented in the Signaling Application as well as in the Signaling Driver. (b) A more detailed view of the software on the switches. Newly developed software is marked in bold.



FD2 Fig. 2. (a) This timing diagram illustrates a successful connection setup and disconnect using the CC protocol. U corresponds to the User side, N to the Network side. TESTAB is a timer set by the originating host Protocol Handler and its expiration indicates that the connection cannot be established; UTHOG is a timer also set by the originating host Protocol Handler and its expiration indicates the connection should be terminated on the user side; THOG is a timer set in each switch Call Handler indicating the total time any connection can be established. (b) This timing diagram illustrates an unsuccessful connection setup between host A1 and C1 involving three switches. U and N are as in (a). Timers are not shown here for simplicity.



FD2 Fig. 3. This is a state machine diagram for the Protocol Handler on one of the switch interfaces. THOG is as described in Fig. 2. TREQ, TCONF, TDENY, and TDISC denote timers expiring for each of these messages. s_DENY and s_CONF indicate DENY and CONF messages sent from the Call Handler to the Protocol Handler.

naling protocol to be implemented on TBONE. As a result of this analysis, two new signaling protocols were chosen for implementation on TBONE: Connect/Confirmation (CC) and Tell-and-Go.[2]

The CC signaling protocol has been designed, implemented, and demonstrated on TBONE simultaneously supporting both analog video, as well as HIPPI and other digital imagery applications. The signaling protocol is implemented out-of-band, transported on channels separate from the information traffic. Tell-and-Go design and implementation are currently underway. We believe this is the first demonstration of a burst- (or packet-) switched all-optical multiswitch network.

The design of the CC protocol assumed a general size network consisting of any number of optical switches. Although TBONE is a network of only two switches, the CC protocol design is not limited as such. The overall software architecture for TBONE appears in Fig. 1. The peer-to-peer message set for CC consists of five messages: REQuest, DISConnect, CONFirmation, DENY and SACK (Signaling ACKnowledgement). The behavior of CC is illustrated with the use of timing diagrams in Fig. 2. Figure 3 shows the state machine diagram for the Protocol Handler on one of the switch interfaces. State machine diagrams for the Call Handlers on the switches and hosts, as well as the Protocol Handlers on the hosts are not shown here due to space limitations. The CC protocol exhibits robust behavior in the presence of lost signaling packets, misdelivered signaling packets and protocol violations.

One of the most important performance measures of the CC protocol is the connection setup time. This is the time from when the Signaling Driver on a host sends a REQuest, until the CONFirmation from the switch is received. The TBONE configuration currently has a SCSI interface interconnecting the switch control workstation (Sparc IPC) and the optical crossbar controller (physical switch control).

With a 10 Mbit/s Ethernet signaling channel, for a route containing one switch, the following preliminary performance measurements were obtained:

avg. connection setup time† from a host (Sparc LX)	14.5 ms
avg. processing time of switch control workstation plus SCSI communication	14.1 ms
avg. delay due to SCSI communication	14 ms

†This time includes the processing time of the host, the processing time of the switch control workstation, as well as the SCSI communication needed to set the switch crosspoints.

Note that most of the connection setup time is due to the SCSI communication. In the coming year, the SCSI interface will be eliminated and the connection setup times should improve immensely. More accurate performance measurements excluding the effect of the SCSI interface will be presented at the conference.

The behavior of the CC protocol may appear to be similar to other signaling protocols implemented in telephone (or in ATM) networks[3,4]; however, in order to improve the performance in an optical high-speed network such as TBONE, several major differences exist. One major difference is that in CC, the route/path is established (i.e., the switch crosspoints are set) proceeding from the destination switch back to the source switch. This characteristic improves overall network utilization in high-speed networks where the propagation delay is comparable to, or may exceed, the burst transmission time. This differs from telephone (or ATM) networks where the path is established as the request proceeds towards the destination. Another difference is that in CC, simplex connections are established because all-optical networks are inherently simplex. This differs from signaling in the telephone network, where historically, duplex connections have been established. (More recently with ATM, simplex connections will be required.) Another difference is that CC contains a "third-party" feature to support the analog applications. In third-party signaling, a host requests a connection setup for a host/application other than itself. Such a feature does not exist in signaling protocols implemented today.

The design and implementation of the CC signaling protocol also included the specification of the routing and addressing schemes. TBONE utilizes a hierarchical addressing scheme, which allows routing decisions to be made at each switch based on the source and destination addresses. On TBONE, the routing choice at each switch is made independently of the other switches in the route, except for ensuring that a loop does not occur. Each switch contains a routing table, which contains several next-hop switch IDs from the given switch to every other switch in the network. Although the routing tables are not populated dynamically, this routing scheme is more flexible than current dynamic schemes which use source routing, with which if a link is busy, the partial route must be disconnected and the search for a path must be restarted (e.g., in telephone networks). The routing scheme used in TBONE is more suited to high-speed networks where link states are changing very rapidly. Currently implemented in software, this routing scheme is quite simple and will be suitable and be moved into hardware to improve performance.

In summary, a burst-switched all-optical network, TBONE, has been demonstrated using a new signaling protocol, CC. A routing scheme is used that pro-actively prevents looping by dynamically selecting a path that avoids a loop. Future work includes the implementation of Tell-and-Go on TBONE, and examination of its performance in comparison to CC.

Acknowledgement: This work was supported by ARPA under Air Force contract F19628-94-D-0001.

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FD3 9:00 am

Management protocol of a reconfigurable WDM ring network using SDH overhead bytes

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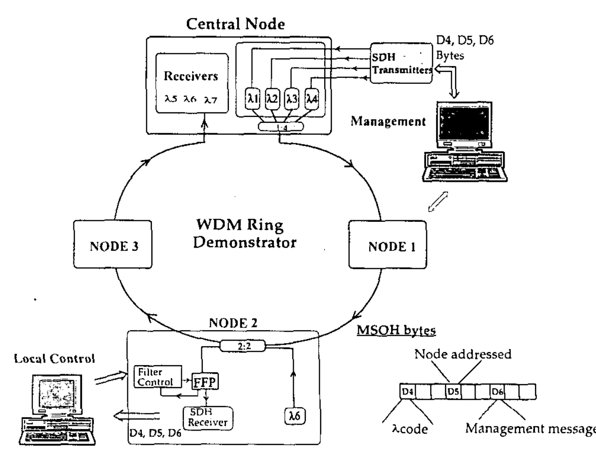
Wavelength-division multiplexing (WDM) networks will very often interconnect SDH equipment, the management system of which is difficult to upgrade to take into account WDM specificities. Two main issues have to be addressed: (1) How to monitor the WDM equipment and what data communication network use; and (2) How to interface the WDM specific management system with the SDH management system. Many possibilities can be used to carry supervisory information in WDM networks such as an SDH overhead,[1] a pilot tone,[2] an assigned wavelength,[3] or an external network. In SDH standard, a significant number of bytes of the STM frame, called the overhead, are used for locating errors and for transporting network information. The management bytes called data communication channel (DCC) are located in both regenerator and multiplex section overhead (RSOH and MSOH).

In this paper, we describe an experimental management system of a reconfigurable WDM ring using MSOH bytes.

Figure 1 shows the WDM rings and its management system. A reconfigurable optical add drop multiplexer (OADM) is used in each secondary node.[4] It is composed of one 2:2 coupler and a tunable FFP filter. Two management functions are implemented in the frame of an SDH/WDM ring (Fig. 2), namely: (a) Channel authentication: The D4 byte inserted in the central



FD3 Fig. 1. WDM ring demonstrator and its management system.