This paper focuses on the implementation of an optoelectronic switching fabric which is distributed, as compared to centralized, as historically deployed. In an attempt to overcome the limitations of centralized switching, a distributed architecture implemented with III-IV based optoelectronic components is presented. The document is organized into three architectural types which we term N2, N3, and N4. N2 represents matrix/vector Boolean multiplier implementations, N3 represents matrix/matrix Boolean multiplier implementations and N4 represents Tensor/matrix Boolean multiplier implementations..

N2 topology:

Typical optical crossbars are of the N2 variety as shown in Figure 1. This type of crossbar suffers from zero fault tolerance, unless redundancy is built into several channels, and has the requirement of external control. The mechanism is not self-routing. Later the more advanced crossbar architectures of the N3 and N4 variety are discussed, which will both provide high degrees of fault tolerance and self routing.

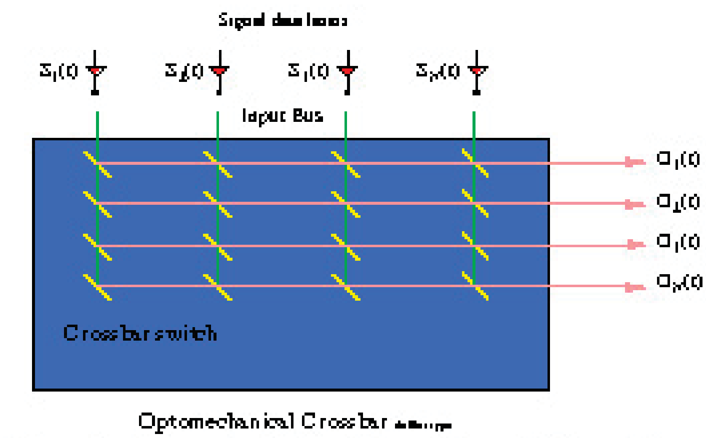

Figure 1: Conventional N^2 variety crossbar architecture with a 2D array of MEMs switches. The N^2 architecture suffers from zero fault tolerance and the need for external control.

For the purpose of illustration, Figure 1 shows an array of MEMs (micro-electromechanical) type devices (mirrors) deflecting input signals to a desired output. For N inputs, N2 mirrors are required, thus the appointment of the phrase -- N2 architecture. The distributed network version of this is shown in Figure 2. Here, the mirrors are first replaced with lasers, and then the vertical columns of lasers are distributed across the network. Signal distribution to the lasers is performed electrically. The distance to each laser is short since it is now local. By distributing the columns of the switching matrix to the location of its respective data source, the original electrical signal may be easily distributed to each optical insertion point.

An issue with the distributed concept is the conventional inability to bidirectionally distribute the data from mirrors. The utilization of epitaxial technology, however, provides methods to guide laser outputs onto the fiber bus.

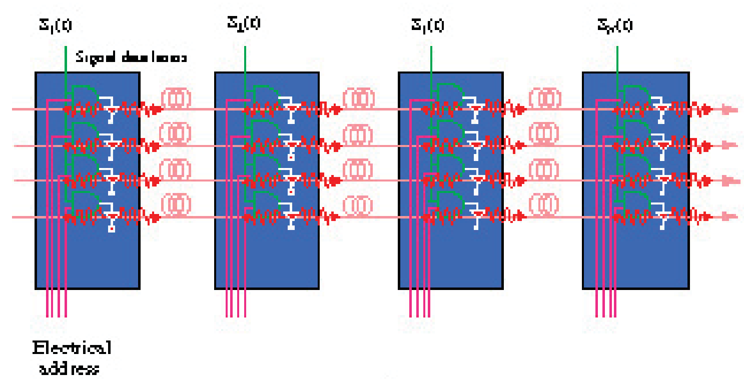

Figure 2: Distributed optoelectronic N^2 architecture, where the MEMs devices have been replaced by lasers for clock rate switching and monolithic high density modules.

The simplest N2 crossbar incorporates an array of lasers of the same wavelength at each node of the distributed system, as shown in Figure 3. Each node also requires its own data detector to receive information. As is typical in N2 systems, each node receives its data from a dedicated fiber. As with any N2 architecture redundancy is the only way to approach the fault tolerance problem. In addition, network control is required and data self-routing is not possible. However, for small systems this may be attractive. The controller must arbitrate all processors and data paths between them, which this is expected with N2 systems. Architectures implementing an N3 interconnect density and higher solve these problems.

N3 topology

The N3 architecture essentially introduces a third dimension of interconnection not realizable in N2 systems implemented with MEMs and others. In N2, each of N inputs are spread to N possible outputs producing N2 interconnects. In N3, each of N inputs are spread to N2 possible outputs. This is what produces the fault tolerance and full system redundancy. This is accomplished when each module on the network has N detectors, one for each fiber. Consequently each laser has a fan-out of N, and each detector has a fan-in of N. With N fibers, this produces an N3 interconnect space.

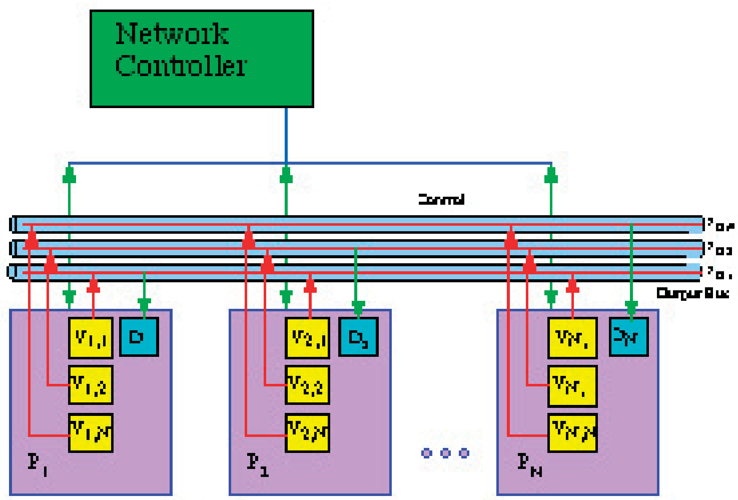

Figure 3: An N^2 fiber crossbar utilizes an N-element laser array and one detector per distributed node. The system also requires external control.

This is shown schematically in Figure 4. Each access port on the network has an N-element laser array as well as an N-element detector array. These detectors are referred to as sense detectors. Each laser and detector are connected to their respective fiber. Essentially the system may be operated, for example, like an N-channel ethernet. Each port or node on the network is “listening” to all fibers simultaneously.

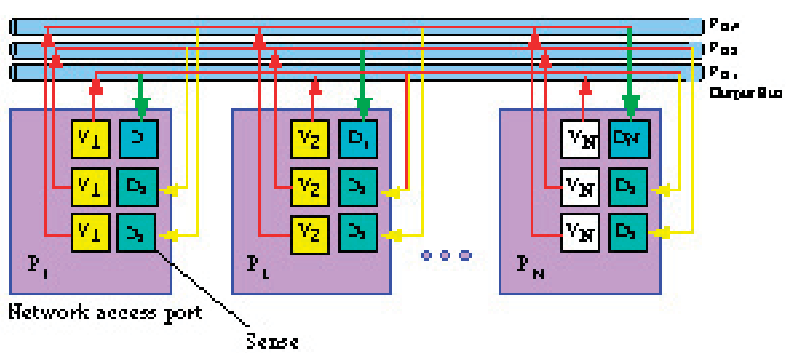

Figure 4: Parallel fiber, single wavelength configuration for an N^3 crossbar module. A sense detector array is added to provide N-element fan-in.

When one is quiet, it “fires” its data onto that fiber. Since the data has an IP address header, each node on the network is listening for its respective IP bits by through the use of a comparator register under each detector in the processing electronics. If it detects and correlates its header, it starts caching the data from that fiber. Should one or many fibers break, or lasers or detectors fail, then the system will operate on the remaining viable channels. This is due to the “sense” nature of the architecture which is only possible in the N3 environment. Consequently the system is highly fault tolerant. If all the fibers are severed except one, the system will still work, albeit slower. If all of the laser sources except one fail at a given node, that node will still function if the remaining fiber channel is still viable. This type of fault tolerance is also locally controlled. The network controller is eliminated and thus, each module in the system is autonomous. Data flow may be set up as a full anarchy. The architecture may also support multiple data formats as well as asynchronous data flow..

WDM implementation of N3

Introduction and utilization of wavelength division multiplexing (WDM) will consolidate the single wavelength, multi-fiber system onto a single fiber using multiple wavelengths as shown in Figure 5. By fabricating each laser on the array to operate at a separate spaced wavelength, the N3 architecture is enabled on a single fiber. Each row of the matrix is operated at the same wavelength. The output of each laser is fed bidirectionally through a single fiber.

Figure 6 shows an alternative diagram of the N3 WDM crossbar. For a 4 x 4 crossbar, a single fiber and four network processing cards (NPCs) are required and represent an array of distributed processing nodes, labeled P1 to P4. WDM lasers, shown in Figure 6 as Vl1 through Vl4, transmit through a single fiber. Sense photodetectors at each processing node again preclude the need for a network controller. Only three sense photodetectors are added to the array. Each photodetector is assigned to a specific WDM wavelength (channel) and “listens” to the data going to a specific processor. When the sense photodetector does not detect any signal, it informs its host processor, the local node. Then, its host processor can transmit information to the processor where the inactive WDM wavelength (channel) was sensed. This makes the architecture autonomous by distributing the crossbar.

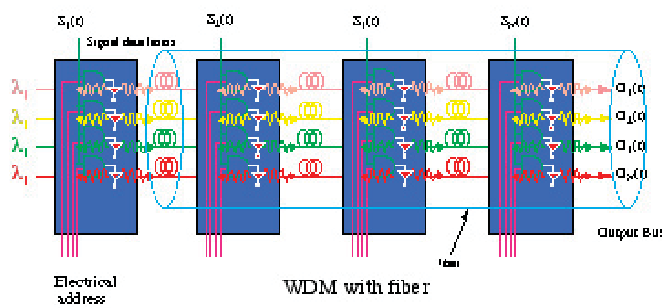

Figure 5: Multi-wavelength lasers permit implementation of the crossbar on a single fiber.

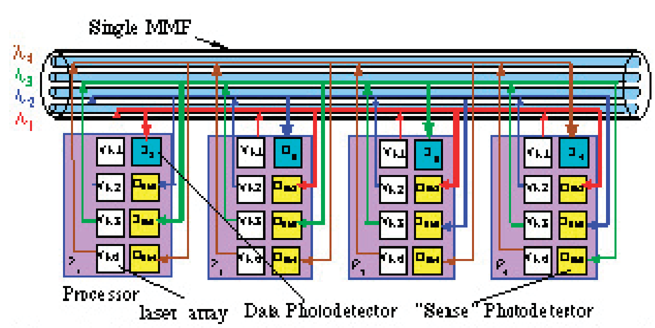

Figure 6: WDM arrays monolithically integrated with WDM resonant cavity photodetector arrays permit the fault tolerant N^3 crossbar to function across a single fiber.

N4 topology

The N4 architecture represents a parallel version of the N3 architecture, which may tie several networks together. The primary benefit of N4, is the scalability for the crossbar to be implemented to relatively large numbers for example, >1024 x 1024, N3 modules may be reasonably expected to approach 32 x 32 in scale. To realize a 32 x 32 crossbar, 32 lasers and 32 detectors will be required per node. By repeating several N3 modules in parallel, much higher crossbar densities are envisioned using identical channel spacings. By having separate optical fibers, the same wavelengths may be used as compared to the use additional wavelengths in a single fiber system. This feature will provide a lower cost mechanism to obtain high cross connect modules. The transparent nature of the distributed crossbar enables protocol independent switching where multiple protocols could be used simultaneously over the same network. Protocols can also be changed over the same channel (fiber and wavelength) at packet switching speeds. The highly redundant nature of the crossbar also simplifies fault prediction, isolation, and management.