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Optical interconnection technology in switches, routers and optical cross connects

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Abstract

The performance of data- and telecommunication equipment must keep up with the increasing network speed. Moreover, to allow more input and output ports on such equipment, the internal interconnection complexity often grows exponentially with the number of ports. Therefore, new interconnection technologies to be used internally in the equipment are needed. Optic interconnection technology is a promising alternative and a lot of work has been done. In this report, a number of optical and optoelectronic interconnection architectures are reviewed, especially from a data- and telecommunication equipment point-of-view. Three kinds of systems for adoption of optical interconnection technology are discussed: (i) optical cross connects (OXCs), (ii) switches and routers with some kind of burst switching, and (iii) switches and routers which redirect traffic on the packet or cell level. The reviewed interconnection technologies and architectures are discussed according to their suitability of adoption in the three mentioned systems.

The annex summarises manufacturers of devices required for optical interconnects and backplanes, and needs for optical interconnection technology in future Ericsson systems.

Keyword

Optical backplanes, optical interconnects, VCSELs, fibre-ribbon cables

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1 Introduction

Novel optical technologies result in the possibility of new solutions for the increasing bandwidth demands of data communication and telecommunication equipment. In this report, we explore the possibilities, from an architectural and a device perspective, of using optical interconnections in such equipment. Although there exist many other optical interconnection architectures that might be candidates, only some selected groups or concepts are selected here to give a reasonably broad view of possible solutions.

The interconnection architectures are evaluated according to three types of systems, which mostly varies in terms of switching time requirements. The systems are: (*i*) optical cross connects (OXCs), (*ii*) switches and routers with some kind of burst switching, and (*iii*) switches and routers which redirect traffic on the packet or cell level.

OXCs have relatively slow timing requirements, i.e., in the order of milliseconds or even tens of milliseconds. On the other hand, it is valuable if the signals remain optical all the way through the switch including possible queuing systems, i.e., having optical transparency. In this way it is easier to scale up the bit rate or change protocols.

When using burst switching, packets with the same destination (e.g., the same exterior gateway) can be grouped together to reduce switching time requirements. This has, for instance, been discussed for use in all optical packet switching [Callegati et al. 1999] [Turner 1999]. The switching time requirements are in the order of sub-microseconds.

For pure switching at the packet or cell level, the switching time requirements are in the order of a nanosecond. With longer switching times, the overhead between each packet will be too large. All-optical packet switching has been proposed but is far from a mature technology [Callegati et al. 1999]. However, some experiments have been done [Blumenthal et al. 1999] [Chiaroni et al. 1998]. Another driving application domain for optical system-level interconnections, in addition to data- and telecommunication equipment, is parallel and distributed computing systems.

The rest of the report is organised as follows. Electronic switches and routers are briefly reviewed in Section 2. In Section 3, optical link technologies are described, and in Section 4, fibre-optic interconnection networks are presented. Integrated optical interconnection systems and optical and optoelectronic switch-fabrics are presented in Sections 5 and 6, respectively. The report is then concluded in Section 7. The annexes summarise commercial devices of interest for optical backplanes and interconnects and the needs from Ericsson product units for optical interconnects and backplanes.

2 Electronic switches and routers

Data communication networks can be divided into circuit switching and packet switching networks. These two categories will be treated in Subsections 2.1 and 2.2, respectively. Then, in Subsection 2.3, switch fabrics to be used as the core switching part of networking equipment will be discussed.

2.1 Circuit switching

When using circuit switching, a "physical" channel is allocated before the communication between a pair of nodes can start. The "physical" channel does not need to be a purely physical but can, e.g., be a cyclically available time slot on a time multiplexed channel, i.e., Time Division Multiplexing (TDM). SDH is an example of a communication standard that relies on TDM. The advantage of circuit switching is the guaranteed bandwidth, while disadvantages are long set-up times and low bandwidth utilisation when the channel is idle for a long time, since the bandwidth normally cannot be reused.

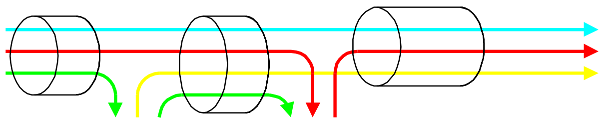


Figure 1: Some wavelengths can be dropped and/or added, while other wavelengths just pass through.

The switching time requirements for circuit switching networks are typically not so demanding because of the duration of channels. However, in, e.g., an SDH Add-Drop Multiplexer (ADM), all traffic (including bypassing traffic) must be electronically processed in some sense. It can, for instance, be needed to be able to separate traffic with different destinations (e.g., be dropped or pass) from different time slots. By multiplexing in the wavelength domain instead of the time domain, a wavelength only carrying traffic which should pass do not have to be processed at all (see Figure 1).

2.2 Packet switching

When using packet switching, the data to be transferred are split into packets that compete for bandwidth with packets from other nodes. Traffic situations with temporary bursts of large volumes of data from one or a few sources can therefore be handled better in a packet-switched network than in the case that much of the bandwidth is allocated by other nodes using circuit switching. Also, sporadic traffic often experiences a shorter latency than in the case that a circuit must be set-up each time. Handling real-time traffic is, however, harder in a packet-switched network. Two main kinds of packet switches are ATM switches and IP routers.

Packet switches can be built in a number of ways for which we here will give two examples of architectures. The first packet switch architecture consist of input interfaces, input queues, switch fabric, output queues, and output interfaces, where some or all of the listed units are coupled to a central control unit (see Figure 2). The main function of the control unit is to configure the switch fabric to pass packets queued in the input queues to the correct output queues, based on some routing decision. Other queuing strategies are possible too, e.g., only at the input side or the output side, a larger shared queuing memory, or internally in the switch fabric.

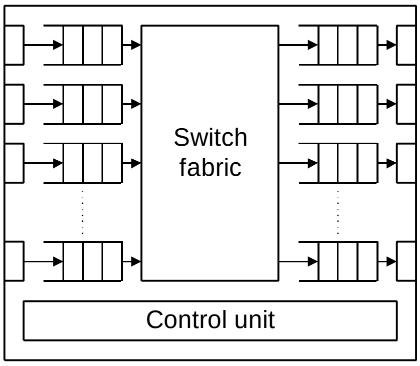


Figure 2: An example of switch architecture.

One of the simplest ways to implement a switch fabric is to have a shared medium to which I/O interfaces or similar are attached. A common way of implementing a shared-medium network is to use the bus topology, but it can also be, e.g., a ring where only one node is allowed to send at a time. The great advantage of a shared-medium network is the easy implementation of broadcast, which is useful in many situations. The disadvantage is that the bandwidth does not scale at all with the number of nodes.

The second example of a packet switch architecture is a bus to which I/O-interfaces and a control unit (routing processor), or units, are connected (see Figure 3). Incoming packets are transferred from an I/O interface to the control unit. The control unit makes routing decisions or similar and redirects each packet to the correct I/O interface for transmission out on the network again. Sometimes, the I/O interfaces have enough intelligence to redirect packets directly to the destination I/O interface, at least for some kind of traffic. More information on switch and router architectures is found in [Kou 1999].

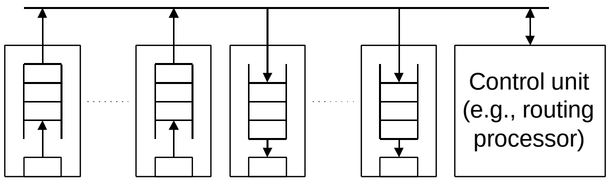


Figure 3: Bus-based switch architecture.

2.3 Switch fabrics

The crossbar is the most flexible switch fabric and can be compared with a fully connected topology, i.e., point-to-point connections between all possible combinations of two nodes. The drawback, however, is the increase by N^2 in cost/complexity of the switch, where N is the number of ports. Systems with a single true crossbar are therefore limited to small systems.

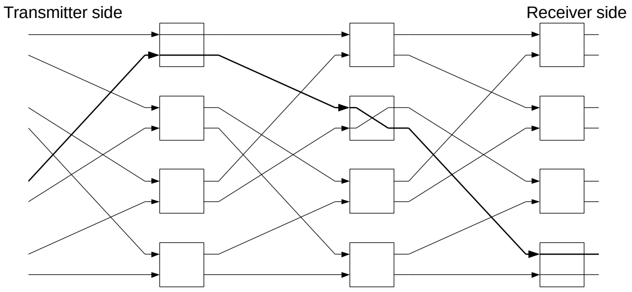


Figure 4: Omega network for an eight-node system. One path through the network is highlighted.

In multistage shuffle-exchange networks, the cost function is reduced to $N \log_2 N$, but where $\log_2 N$ stages must be traversed to reach the desired output port. An example of such a network is the Omega network (Figure 4) which provides exactly one path from every input to every output. The four different switch functions of the 2×2 switch that is used as building block are shown in Figure 5, where the two rightmost configurations are used for broadcast. Switches larger than 2×2 can also be used. Each stage of the switches in an Omega network is preceded by a perfect-shuffle pattern. In contrast to a crossbar network, which is a *nonblocking* network, an Omega network is a *blocking* network. This means that there might not always exist a path through the network as a result of already existing paths that block the way.

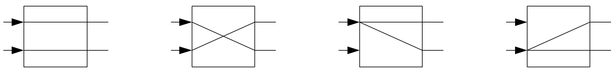


Figure 5: Possible states of a 2×2 switch.

Rearrangeable networks are another category of multistage networks where it is always possible to find a path through the network. However, if not all paths are routed at the same time, it may be necessary to reroute already existing paths. An example of a rearrangeable network is the Benes network shown in Figure 6. Other multistage networks include Banyan networks [Goke and Lipovski 1973].

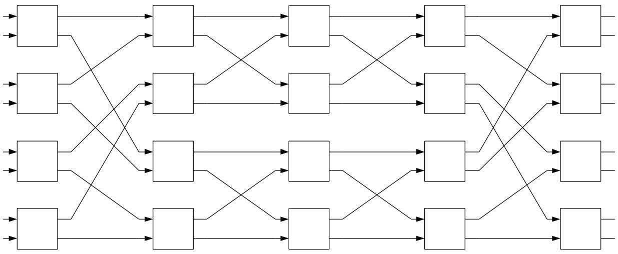


Figure 6: A rearrangeable Benes network.

3 Optical link technologies

Historically, the use of optical fibres for signal interconnection began with the simplest level of point-to-point fibres in telecommunications long-haul networks. However, today, as the complexity and the bit rates increase in switching and routing equipment, optical interconnects are starting to be implemented in the equipment building practice to satisfy the distance and bandwidth requirements.

Connections are usually made from the optoelectronics on printed wiring boards or cards to those on other boards on the same or other shelves. Other types of optical interconnections are between cabinets of multicabinet equipment (such as digital crossconnect switches) or between the central processing units and remote memories of high-performance workstations and computers.

According to ElectroniCast Corp. [Montgomery 2000] the market for optical backplanes is expected to grow from a total of $6.1 million in 1998 to $125 million in 2003 and $1 647 million in 2008. In 1998, two thirds of the total global demand of optical backplanes came from telecom transport terminals and switches.

The potential advantages with optical interconnects are that

- Higher interconnect bit rate per circuit area can be achieved
- Noise is not generated as for wire interconnects
- Scaleable interconnection bandwidths are possible
- The low loss in waveguides and free-space makes longer connections possible

Today, for high data rate (100's of Mbps to over 1 Gbps) electrical connections, twinned-pair LVDS (Low Voltage Differential Signalling) and related technologies are used. With improved impedance matching between the driver and termination circuits and the cable, data rates up to 2-4 Gbps are anticipated to be achieved. For short distances, 0,5 – 1 m, also bit rates up to 10 Gb/s are considered using new board materials.

In the table below is shown a comparison between a commercial parallel optical fibre transmitter [Mitel] with 12 channels, each operating at 2.5 Gbps, and a 400 Mbps serial bus LVDS circuit [National]. The last column shows a few years old goals from a DARPA program on optical interconnection technologies [Towe]. It is evident that today's VCSEL-based fibre ribbon cable technology has properties comparable to those of electrical interconnections, when the full capacity of the fibre-ribbon links are utilised.

	VCSEL array	LVDS circuit	DARPA goals 1997
Price/data rate ($ / Gb/s)	14.7	18.8	10
Data rate/circuit area (Gb/s / cm^2)	4	0.07	10
Data rate/power consumption (Gb/s / W)	15.8	3.8	20

Table 1. Comparison of characteristics for VCSEL array and LVDS circuit

Below, two main categories of optical link technologies are discussed, fibre-ribbon links (Subsection 3.1) and bit-parallel WDM links (Subsection 3.2). Single-channel single-fibre solutions are not treated.

3.1 Fibre-ribbon links

A system component that has reached the market recently [Bursky 1994] [Fibre Systems 1998] is the fibre-ribbon link [Buckman et al. 1998] [Engebretsen et al. 1996] [Hahn 1995] [Hahn 1995B] [Hahn et al. 1996] [Hartman et al. 1990] [Jiang et al. 1998] [Karstensen et al. 1995] [Karstensen et al. 1998] [Kuchta et al. 1998] [Nagarajan et al. 1998] [Nishimura et al. 1997] [Nishimura et al. 1998] [Schwartz et al. 1996] [Siala et al. 1994] [Wickman et al. 1999] [Wong et al. 1995]. Several links can be used to build high bandwidth point-to-point linked networks [Hahn et al. 1995]. With ten parallel fibres, each carrying data at a bit rate of 400 Mbit/s, an aggregated bandwidth of 4 Gbit/s is achieved [Schwartz et al. 1996]. Bi-directional links, with some fibres in the fibre-ribbon cables dedicated for each direction, are also possible [Jiang et al. 1995]. More references to reports on fibre-ribbon links are found in [Tooley 1996].

Modules that support multiple high-speed channels but are not specifically optimised for fibre-ribbons have been reported, e.g., receiver and transmitter modules with five channels, each channel with a bit rate of 2.8 Gbit/s [Nishikido et al. 1995].

In addition to the high bandwidth offered by a fibre-ribbon cable, it also offers a ten-fold increase in packing density as compared to electrical cables, resulting in less rigid cables [Karstensen et al. 1995]. Furthermore, it is not necessary for the designer to be concerned about electromagnetic emissions.

3.1.1 Skew in parallel links

In scaling up the bandwidth of a fibre-ribbon link where a dedicated fibre carries the clock signal, the main problem is channel-to-channel skew. The skew is mainly the result of differences in propagation delay between different fibres and variations of lasing delay time among different laser diodes [Kurokawa et al. 1998]. The 400 Mbit/s OPTOBUS has a specified maximum skew of 200 ps, excluding the fibre-ribbon cable for which 6 ps/m is assumed for standard ribbons [Schwartz et al. 1996]. Even if it is rather short distances in the kind of systems discussed in this report, the scaling to higher speeds calls for the discussion of techniques to reduce the effect of the skew below.

The skew is affected by intrinsic optical properties of the fibres in the ribbon, but also by the effect of the ribbon process on the fibres. Ribbon process parameters affecting the skew are fibre tension, fibre excess length and winding. In short, you should have a small group index difference, e.g. use fibres from the same preform or part of a preform, and have good control of fibre tensions in the ribbon process.

One technique is to actually reduce the skew, either by using low skew ribbons or employing skew compensation. Fibre-ribbons with about 1 ps/m skew [Siala et al. 1994] and below [Kanjamala and Levi 1995] have been developed, which essentially increases the possible bandwidth distance product. All the fibres in the same ribbon were sequentially cut to reduce the variation of refractive index among the fibres. In the fibre-ribbon link described in [Wong et al. 1995], a dedicated fibre carries a clock signal used to clock data on 31 fibres. The transmitter circuitry for each channel has a programmable clock skew adjustment to adjust the clock in 80-ps increments.

The problems with skew in modern ribbon fibres are now attracting large R&D efforts, *c.f.* example [Jason and Arvidsson 2000].

3.1.2 Clock recovery

The clock-recovery circuit in high-speed serial links needs a data stream with a high density of transitions. Commercially available serialiser/deserialiser chip-sets use line-codes such as 8B10B to provide a proper transition density. Both SAW devices and phase-locked loops are used for clock extraction.

The disadvantage of extracting the clock signal from the bit flow on each fibre is increased hardware complexity when adding a clock recovery circuit and a buffer circuit for each channel in the receiver. A hybrid solution is to skip the separate clock channel and encode clock information on the data channels while still sending in bit-parallel mode, as reported in [Yoshikawa et al. 1997] [Yoshikawa et al. 1997B]. In this case, a deskew unit relying on FIFO registers (First In First Out) ensures that parallel data words that are output from the receiver are identical to those which were sent. A possible ± 15-ns deskew was reported. A similar system is reported in [Fujimoto et al. 1998].

The techniques mentioned above introduce either increased hardware complexity or a more sophisticated fibre-ribbon manufacturing process. If the manufacturing process allows for adding more fibres in each ribbon, this may be a cheaper alternative. For example, 12 channel links with 1 Gbit/s per channel [Karstensen et al. 1995] and 2 Gbit/s per channel [Karstensen 1995] have been reported, and array modules supporting 12 $\times$ 2.4 Gbit/s for, e.g., fibre-ribbon links were described in [Peall 1995]. A fibre-ribbon link with 32 fibres, each with a bit rate of 500 Mbit/s, was described in [Wong et al. 1995], and researchers at NEC have developed a module in which 8 $\times$ 2 lasers are coupled to two fibre-ribbons [Kasahara 1998]. Instead of fibre-ribbons, fibre-imaging guides (FIGs) with thousands of pixels can be used [Li et al. 1995]. In the system described in [Li et al. 1998B], both a 14000-pixel FIG and a 3500-pixel FIG were coupled to an 8 $\times$ 8 VCSEL array in different set-ups.

3.2 Bit-parallel WDM links

Another way is to synchronously transmit on several channels in parallel, i.e., bit-parallel byte-serial transmission [Loeb and Stilwell 1988] [Loeb and Stilwell 1990]. However, compensation for bit-skew caused by group delay dispersion (different wavelength channels travel at different speeds in the fibre) may be needed in these systems [Jeong and Goodman 1996].

A dedicated wavelength in a bit-parallel WDM link can be used for clock information. Wavelengths (or fibres in a fibre-ribbon cable) can also be dedicated to other purposes such as frame synchronisation and flow control. Significantly higher bandwidth distance products can be achieved when using bit-parallel WDM over dispersion shifted fibre instead of fibre-ribbons [Bergman et al. 1998] [Bergman et al. 1998B]. If, however, there is only communication over shorter distances (e.g., a few meters), the bandwidth distance product is not necessarily a limiting factor. Transmission experiments with an array of eight pie-shaped VCSELs arranged in a circular area with a diameter of 60 μm, to match the core of a multimode fibre, have been reported [Coldren et al. 1998]. Other work on the integration of components for short distance (non-telecom) WDM links has been reported, e.g., a 4 $\times$ 2.5 Gbit/s transceiver with integrated splitter, combiner, filters, etc. [Aronson et al. 1998].

3.3 Reliability of optoelectronics

The main degradation modes of laser diodes are: dislocations that affect the interior region, metal diffusion and alloy reaction that affect the electrodes, solder instability that affect the bonding parts, facet damage, etc. The degradation rate increases with increasing temperature and current. By making life time tests at different temperatures and currents it is possible to determine an acceleration factor

$$AF = TTF_1 / TTF_2 = \left(I_{F1} / I_{F2}\right)^n \times \exp\left[E_A / k_B \times \left(1/T_{J2} - 1/T_{J1}\right)\right], \qquad (1$$

where TTF_i is Time To Failure at operation condition i, I_{Fi} is the current through the device, n is an exponential in the range of 1.5 – 2 determined from the test data, E_A is an activation energy also determined from the test data, k_B is the Boltzmann constant, and T_{Ji} is the junction temperature. The activation energy is in the range of 0.7 – 0.8 eV for lasers.

VCSELs from Honeywell have median lifetimes, for normal drive currents and room temperature operation, of around 9 MHours [Honeywell]. That is, on an average a device works without failure for 1 000 years! If the drive current is increased 50 % and the ambient temperature is increased from 25 ºC to 70 ºC, the median lifetime is down to 10 years. Similar performance has also been reported for VCSELs from Infineon and Hewlett Packard [Wipiejewski et al. 1999, Lei et al. 1999].

The reliability of a system, like AXD 301, is normally determined using analyses based on Markov models. Using this technique, it is possible to estimate MTBSF (Mean Time Between System Failures), given the individual components' MTTF (Mean Time To Failure), their redundancy and the MDT (Mean Down Time) of the system at repairs.

Device lifetimes in the range of 10 – 40 years are normally sufficient to keep the MTBSF at an acceptable level. It is concluded that the VCSEL technology now is sufficiently mature to satisfy these requirements.

3.4 Major research activities

3.4.1 POLO

Hewlett-Packard Laboratories is leading an industrial consortium, *the Parallel-Optical Link Organization (POLO)*, which is engaged in the development of economical, high-performance, parallel-optical links. Its purpose includes the development of device, packaging, and interconnection technologies and standards. Other members of POLO working on the VCSEL-based link are AMP (develops connectors and housings), DuPont (provides polymer waveguide technologies), and USC (demonstrates workstation interfacing and networking). The consortium is supported by DARPA.

3.4.2 POINT

The Polymer Optical Interconnect Technology (POINT) program is a collaborative effort among GE, Honeywell, AMP, AlliedSignal, Columbia University, and UC San Diego, sponsored by DARPA/ETO, to develop affordable optoelectronic packaging and interconnect technologies for board and backplane applications. Specifically, progress has been reported on:

- Development of a plastic VCSEL array packaging technology using batch and planar fabrication

- Demonstration of high-density optical interconnects for board and backplane applications using polymer waveguides to a length of 50 cm at an I/O density of 250 channels per inch

- Development of low-loss optical polymer waveguide with loss less than 0.1 dB/cm at 850 nm

- Development of passively alignment processes for efficient coupling between a VCSEL array and polymer waveguides

3.4.3 ChEEtah

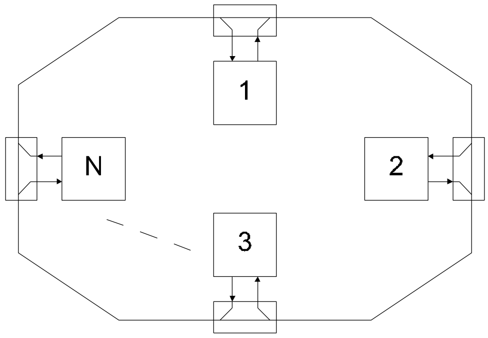
Honeywell is involved in a number of DARPA-sponsored research projects on optical interconnection technologies. Cost Effective Embedding of Parallel Optical Interconnects (ChEEtah) is one of these projects. The objective of the Honeywell-led ChEEtah program is to develop parallel optical links achieving cost parity with copper interconnects, and that address the need for a high bandwidth-density product across a backplane over distances ranging from 0.3 to 1 meter, and between boxes over distances ranging from 1 to 100 meters. The goal is to reduce the optoelectronic transceiver function to the minimum number of parts, and to leverage many of the advances in optical component, IC and optical and electrical packaging technology that have recently occurred. Relevant advances that will be incorporated into this program include: 1) low threshold, high efficiency VCSEL designs, 2) yield, uniformity and reliability demonstrated in VCSEL arrays, 3) the application of low power, high speed CMOS I/O buffer circuits, 4) the development of high strength optical fibre with a small bend radius and techniques for laminating fibre arrays onto a printed circuit board, 5) low cost parallel fibre cabling and connector assembly techniques, and 6) mechanical features for optical self-alignment.

4 Fibre-optic interconnection networks

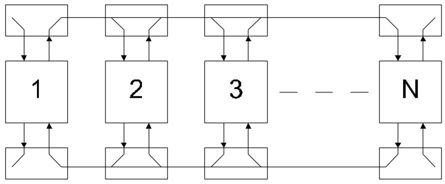
Fibre-optic network architectures, especially passive optical networks are discussed below. First, in Subsection 4.1, different basic passive fibre-optic network architectures are described. Then, in Subsections 4.2 and 4.3, WDM star and WDM ring networks are respectively discussed. Fibre-ribbon ring networks are presented in Subsections 4.4.

4.1 Passive fibre-optic networks

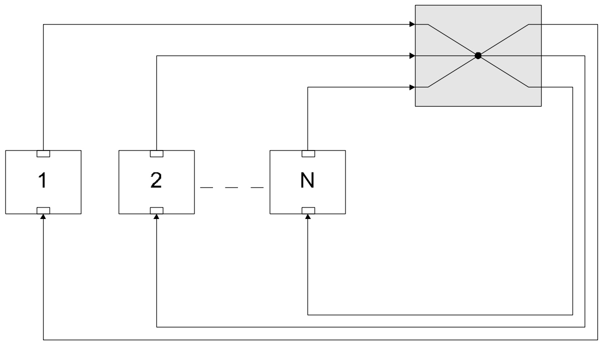
In an all-optical network, the data stream remains in the optical form all the way from the transmitter to the receiver. Three basic architectures for all-optical multi-access networks are the ring, the bus, and the star (see Figure 7). These network architectures will be discussed below. Most work on passive optical networks have been focused on LANs or similar but they can be used as substitutes for switch fabrics in data- and telecommunication equipment too. It should be noted that if one of these networks is used in an OXC (or similar) as a switch-fabric, the signal is converted to electrical and back to optical form at the entrance and the exit of the switch-fabric.



(a)



(b)



(c)

Figure 7: Three passive optical network architectures: (a) ring, (b) (dual) bus, and (c) star.

An all-optical multi-access ring network differs from a traditional ring network in the sense that all other nodes can be reached in a single hop without any intermediate optoelectronic conversion. In contrast to the repeating function of a node in, for example, an FDDI network, messages simply pass a node through passive optics in an all-optical multi-access ring network. This is true for all messages except a node's own messages that should be removed from the ring after one round. Just a fraction of the optical power contained in the bypassing fibre is tapped to the receiver, which gives all nodes the opportunity to read the message, i.e., a multicast (one to many) or a broadcast (one to all). Outgoing messages are inserted into the ring and, in a multi-channel system, mixed together with bypassing messages on other channels.

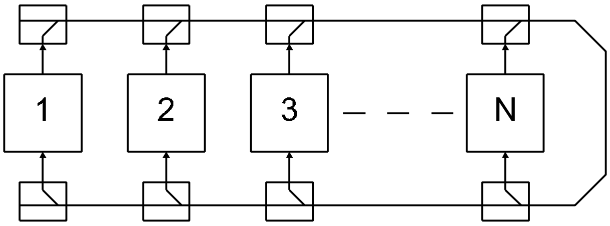


Figure 8: Folded fibre-optic bus.

In an optical bus, the light travels only in one direction, making it necessary to have two buses (upper and lower), one for each direction (higher or lower node index of destination nodes). This kind of bus architecture is called *dual bus*. The disadvantage of the dual bus is that two transceivers are needed in each node. This is avoided in the *folded bus*, where the two buses are connected with a wrap-around connection at one end of the buses (see Figure 8) [Tseng and Chen 1982]. In the folded bus, transmitters are connected to the upper bus while receivers are connected to the lower bus. Several bus architectures and hybrids in which the bus is part of the architectures are discussed in [Nassehi et al. 1985].

In a star network, the incoming light waves from all nodes are combined and uniformly distributed back to the nodes. In other words, the optical power contained in the middle of the star is equally divided between all nodes.

All of the three basic network architectures have different advantages. The ring has the least amount of fibres, a bus network's medium access protocol can utilise the linear ordering of the nodes [Nassehi et al. 1985] and the attenuation for an (ideal) star only grows logarithmically with the number of nodes. However, star networks are the most popular, judging from the number of published papers.

The passive optical networks that only offer one shared channel are no promising alternatives. However, they form the basis for more powerful networks using WDM. These networks can be promising solutions as switch fabrics in some kinds of data- and telecommunication equipment, even though the main target is LANs and similar.

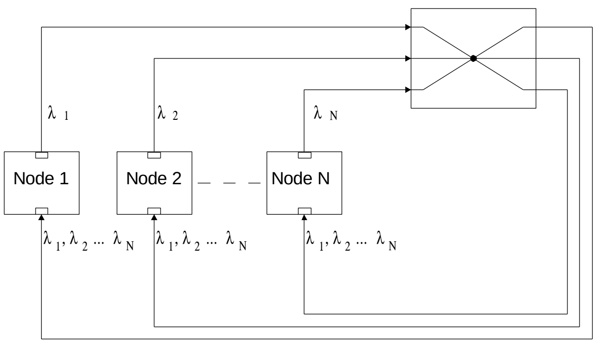


Figure 9: WDM star network.

4.2 WDM star

A passive fibre-optic star distributes all incoming light on the input ports to all output ports. A network with the logical function of a bus is obtained when connecting the transmitting and receiving side of each node to one input and output fibre of the star, respectively. By using WDM, multiple wavelength channels can carry data simultaneously in the network [Brackett 1990]. In other words, each channel has a specific colour of light. A flexible WDM network requires tunable receivers and/or transmitters, i.e.; it should be possible to send/listen on an arbitrary channel [Mukherjee 1992].

Figure 9 shows an example of a WDM star network configuration. Each node transmits on a wavelength unique to the node, while the receiver can listen to an arbitrary wavelength. The configuration is used in the TD-TWDMA network [Jonsson et al. 1996], which has support for guaranteeing real-time services, both in single-star networks [Jonsson et al. 1997] and star-of-stars networks [Jonsson and Svensson 1997]. One can say that this kind of network architecture implements a distributed crossbar. The flexibility is hence high, and multicast and single-destination traffic can co-exist. The number of wavelengths is practically limited to 16-32 [Brackett 1996], but, as stated above, hierarchical networks with wavelength reuse can be built. WDM star networks have, in addition to LANs and similar networks, been especially proposed for internal use in packet switches [Eng 1988] [Brackett 1991] [Sadot and Elhanany 2000].

Tunable components (e.g., filters) with tuning latencies in the order of a nanosecond have been reported, but they often have a limited tuning range [Kobrinski et al. 1988]. At the expense of longer tuning latencies, however, components with a broader tuning range can be used [Cheung 1990]. Such components can be used to achieve a cheaper network in systems where much of the communication patterns remain constant for a longer period, e.g., circuit-switching.

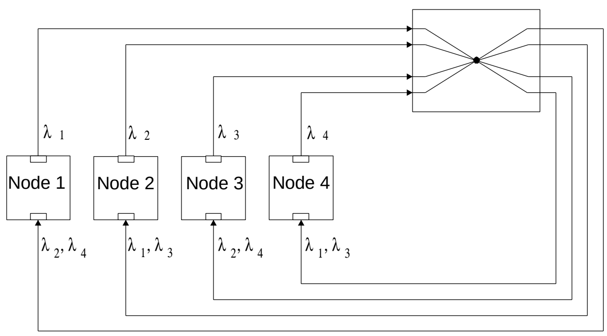


Figure 10: WDM star multi-hop network.

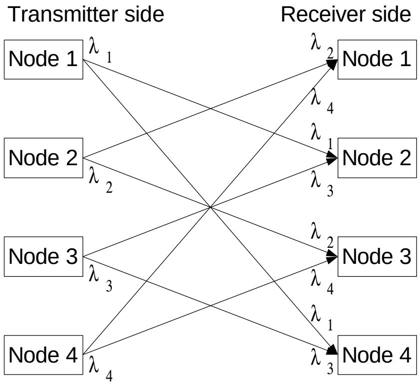


Figure 11: Multi-hop topology.

Complete removal of the ability to tune in a WDM star network gives a multi-hop network [Mukherjee 1992B]. Each node in a multi-hop network transmits and receives on one or a few dedicated wavelengths. If a node does not have the capability of sending on one of the receiver wavelengths of the destination node, the traffic must pass one or several intermediate nodes. The wavelengths can be chosen to get, e.g., a perfect-shuffle network [Acampora and Karol 1989]. One can also choose to have a network in which several topologies are embedded, e.g., a ring and a hypercube. An example of a multi-hop network is shown in Figure 10. This configuration of wavelength assignments corresponds to the topology shown in Figure 11. Dynamic real-time scheduling can be done in a multi-hop network [Yu and Bhattacharya 1997]. The method works like static scheduling, but here a central node runs the scheduling algorithm and high priority messages might pre-empt low priority messages. The highest priority level is used for messages with hard deadlines, while the other levels are used for messages with soft deadlines. Lower priority levels are used for less important messages.

4.3 WDM ring

A WDM ring network utilises ADMs in all nodes to insert, listen, and remove wavelength channels to/from the ring. In the WDMA ring network described in [Irshid and Kavehrad 1992], each node is assigned a node-unique wavelength on which to transmit. The other nodes can then tune in an arbitrary channel on which to listen. This configuration is logically the same as that for the WDM star network with fixed transmitters and tunable receivers. The distributed crossbar again gives good performance for general communication patterns.

Spatial wavelength reuse can be achieved by removing the transmitted light at the destination node (last destination node for multicast). At high degrees of nearest downstream neighbour communication, throughputs significantly higher than 1 can be achieved for a single wavelength. In this way, a smaller number of wavelength channels are needed.

4.4 Fibre-ribbon pipeline ring network

Bit-parallel transfer can be utilised when fibre-ribbon cables/links are used to connect the nodes in a point-to-point linked ring network. In such a network, one of the fibres in each ribbon is dedicated to carry the clock signal. Therefore, no clock-recovery circuits are needed in the receivers. Other fibres can be utilised for, e.g., frame synchronisation. Figure 12 shows how a ring network is used as a switch-fabric.

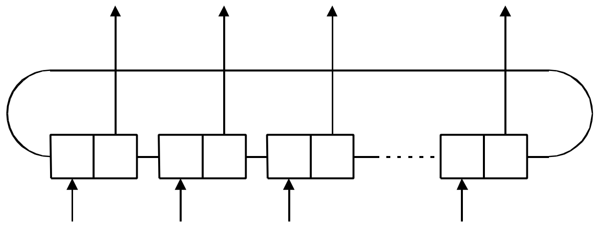


Figure 12: Ring network as switch-fabric.

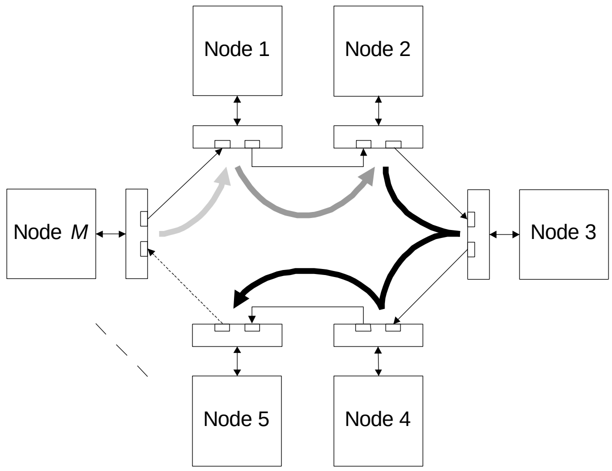


Figure 13: Example of spatial bandwidth reuse. Node M sends to Node 1 at the same time as Node 1 sends to Node 2 and Node 2 sends a multicast packet to Nodes 3, 4, and 5.

As seen in Figure 13, aggregated throughputs higher than 1 can be obtained in ring networks with support for spatial bandwidth reuse (sometimes called pipeline rings) [Wong and Yum 1994]. This feature can be effectively used when most of the communication is to the nearest down stream neighbour. Two fibre-ribbon pipeline ring networks have recently been reported [Jonsson 1998B]. The first network has support for circuit switching on 8+1 fibres (data and clock) and packet switching on an additional fibre [Jonsson et al. 1997B]. The second network is more flexible but is a little more complex, and has support for packet switching on 8+1 fibres and uses a tenth fibre for control packets (see Figure 14) [Jonsson 1998]. The control packets carry MAC information for the collision-less MAC protocol with support for slot reserving. Slot reserving can be used to get RTVCs (Real-Time Virtual Channels) [Arvind et al. 1991] for which guaranteed bandwidth and a worst-case latency are specified (compare with circuit switching). The fibre-ribbon ring network can offer rather high throughputs due to the aggregated bandwidth of a fibre-ribbon cable but the spatial reuse will probably be limited due to the general traffic.

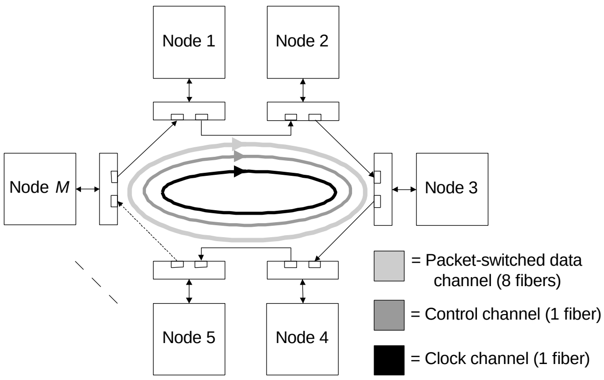


Figure 14: Control channel based network built up with fibre-ribbon point-to-point links.

Another fibre-ribbon ring network is the PONI network (formerly USC POLO), which is proposed to be used in clusters of workstations and similar systems [Raghavan et al. 1999] [Sano and Levi 1998]. Integrated circuits have been developed for the network, and tests have been performed [Sano et al. 1996] [USC 1997].

5 Integrated optical interconnection systems

Below, three kinds of systems were optical interconnections are integrated into a more or less pure interconnection system, are presented. Such an interconnection system can be used, e.g. to interconnect electronic switch chips or I/O interfaces. In Subsection 5.1, integrated fibre and waveguide solutions are presented, while planar free space optics and free space optical backplanes are discussed in Subsections 5.2 and 5.3, respectively.

5.1 Integrated fibre and waveguide solutions

Fibres or other kinds of waveguides (hereafter commonly denoted as channels) can be integrated to form a more or less compact system of channels. Fibres can be laminated to form a foil of channels, for use as intra-PCB (Printed Circuit Board) or back-plane interconnection systems [Eriksen et al. 1995] [Robertsson et al. 1995] [Shahid and Holland 1996]. Fibre-ribbon connectors are applied to fibre end-points of the foil. An example is shown in Figure 15, where four computational nodes are connected in a ring topology. In addition, there is a clock node that distributes clock signals to the four computational nodes via equal-length fibres to keep the clock signals in phase. In other words, a fibre-optic clock distribution network [Kiefer and Swanson 1995] and a data network are integrated into one system. If one foil is placed on each PCB in a rack, they can be passively connected to each other via fibre-ribbon cables. Using polymer waveguides instead of fibres brings advantages such as the possibility of integrating splitters and combiners into the foil, and the potential for more cost-effective mass production [Eriksen et al. 1995].

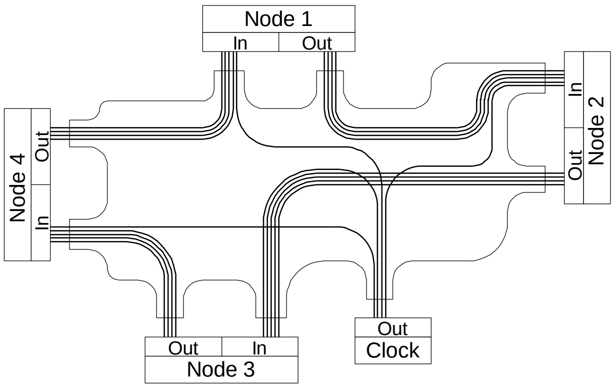


Figure 15: A foil of fibres connects four computational nodes. In addition, a clock node distributes clock signals to the computational nodes.

Integrated systems of channels can be set-up and used in a number of configurations, some of which are discussed below. One way is to embed a ring with bit-parallel transmission and the possibility for spatial bandwidth reuse, as described in Subsection 4.4; the medium is simply changed into a more compact form. Besides pure communication purposes, channels for, e.g., clock distribution (as seen in the example) and flow control can be integrated into the same system.

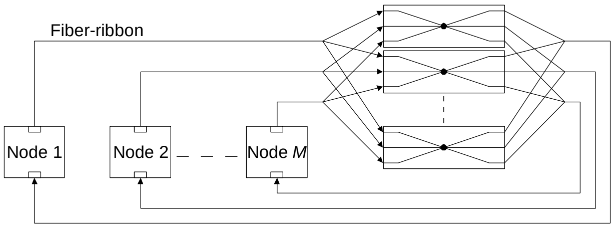


Figure 16: Array of passive optical stars connects a number of nodes via fibre-ribbon cables.

Another way is to follow the proposed use of an array of passive optical stars to connect processor boards in a multiprocessor system via fibre-ribbon links, for which experiments with 6 x 700 Mbit/s fibre-ribbon links were done (see Figure 16) [Parker 1991] [Parker et al. 1992]. Of course, the processor boards can be exchanged with, e.g., transceiver cards and/or switch cards. As indicated above, such a configuration can be integrated by the use of polymer waveguides. The power budget can, however, be a limiting factor to the number of nodes and/or the distance. Advantages are simple hardware owing to bit-parallel transmission (like other fibre-ribbon solutions) and the broadcast nature, but the star array can become a bottleneck as in all bus-like systems. In a similar system, the star array is exchanged by a chip (with optoelectronics) that has one incoming ribbon from each node and one output ribbon [Lukowicz et al. 1998]. The output ribbon is coupled to an array of $1 \times N$ couplers so that each node has a ribbon connected to its receiver. The chip couples the incoming traffic together in a way that simulates a bus. At contention, the chip can temporarily store packets.

Electronic crossbars can be distributed on the PCBs and/or placed on a special switch PCB in a back-plane system, and be connected by integrated parallel channels.

Other similar systems include the integration of fibres into a PCB for the purpose of clock distribution [Li et al. 1998]. Distribution to up to 128 nodes was demonstrated. The fibres are laminated on one side of the PCB, while integrated circuits are placed on the reversed side. The end section of each fibre is bent 90 degrees to lead the light through a so called via hole to the reversed side of the PCB.

5.2 Planar free space optics

By placing electronic chips (including optoelectronic devices) and optical elements on a substrate where light beams can travel, we get a planar free space system (Figure 17) [Jahns 1994] [Jahns 1998] [Sinzinger 1998]. Electronic chips are placed in a two-dimensional plane, while light beams travel in a three-dimensional space. In this way, optical systems can be integrated monolithically, which brings compact, stable and potentially inexpensive systems [Jahns 1998]. By using, e.g., Spatial Light Modulators to dynamically direct the optical beams, a flexible interconnection network can be obtained. Using only fixed interconnection patterns and electronic switching can, however, give shorter switch times. A planar free space optical crossbar switch has been reported [Reinhorn et al. 1999].

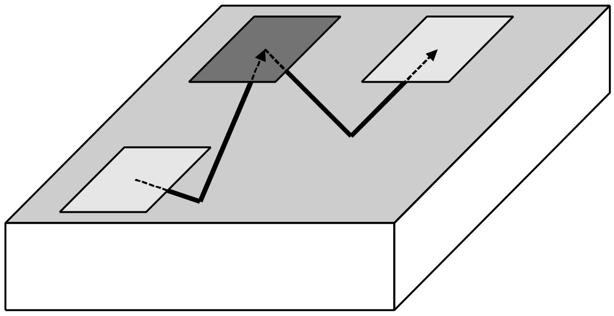


Figure 17: Example of a planar free space system. The direction of the beam is steered by the optical element on the way between two chips.

5.3 Free space optical backplanes

Several different optical backplanes have been proposed, three of which are discussed below. As shown in Figure 18a, using planar free space optics is one means of transporting optical signals between PCBs. Holographic gratings can be used to insert and extract the optical signals to/from the waveguide, which may be a glass substrate [Zhao et al. 1995]. Several beams or bus lines can be used, i.e., each arrow in the figure represents several parallel beams [Zhao et al.1996].

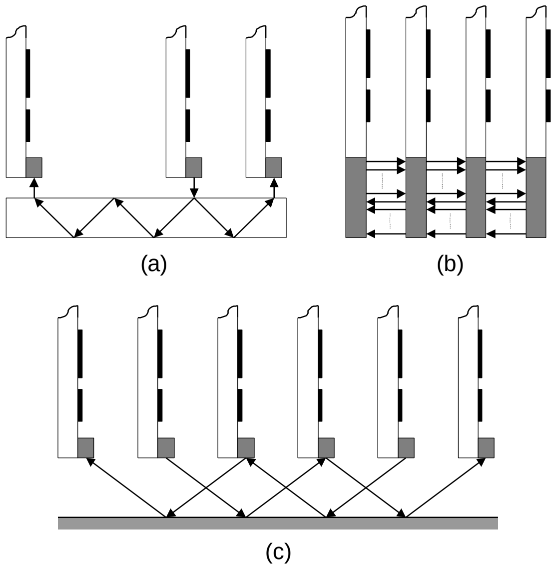


Figure 18: Optical backplane configurations: (a) with planar free space optics, (b) with smart pixel arrays, and (c) with a mirror.

In the system shown in Figure 18b, two-dimensional arrays of optical beams (typically 10 000) link neighbouring PCBs together in a point-to-point fashion [Szymanski 1995] [Hinton and Szymanski 1995]. Smart pixel arrays then act as intelligent routers that can, e.g., bypass data or perform data extraction operations where some data pass to the local PCB and some data are retransmitted to the next PCB [Supmonchai and Szymanski 1998]. Each smart pixel array can typically contain 1 000 smart pixels arranged in a two-dimensional array, where each pixel has a receiver, a transmitter, and a simple processing unit. One way of configuring the system is to connect the smart pixel arrays in a ring, where the ring can be reconfigured to embed other topologies [Szymanski and Hinton 1995] [Szymanski and Supmonchai 1996].

The configuration shown in Figure 18c is similar to the optical backplane based on planar free space interconnects. The difference is the replacement of the waveguide by a mirror [Hirabayashi et al. 1998]. An optical beam leaving a transmitter is simply bounced once on the mirror before it arrives at the receiver. A regeneration of the optical signal (multi-hop) might be needed on the way from the source to the final destination.

Of the three types of optical backplanes discussed, the one with smart pixel arrays seems to be the most powerful. On the other hand, a simple passive optical backplane may have other advantages. Other optical backplanes have been proposed, e.g., a bus where optical signals can pass through transparent photo detectors or be modulated by spatial light modulators [Hamanaka 1991].

6 Optical and optoelectronic switch-fabrics

In this section, optical and optoelectronic switch-fabrics are introduced. First, in Subsection 6.1, the combination of optical interconnections and electronic crossbars is treated, while WDM/SDM switches are discussed in Subsection 6.2.

6.1 Optical interconnections and electronic crossbars

Communication systems such as Myrinet [Boden et al. 1995], by which arbitrary switched topologies can be built using electrical switches, have been proposed for parallel computing systems and can be adopted for data- and telecommunication equipment too. Fibre-ribbons can be used to increase bandwidth, compared to electrical systems, while still sending in bit-parallel mode. It is possible to have bit rates in the order of 1 Gbit/s over each fibre in the ribbon over tens of meters using standard fibre-ribbons. As noted in Subsection 5.1, foils of fibres or waveguides (e.g., arranged as ribbons) can be used to interconnect nodes and crossbars on the PCB and/or back-plane level.

The switch itself can also be modified to increase performance or packing density. A single-chip switch core where fibre-ribbons are coupled directly to optoelectronic devices on the chip is possible [Szymanski et al. 1998]. Attaching 32 incoming and 32 outgoing fibre-ribbons with 800 Mbit/s per fibre translates to an aggregated bandwidth of 204 Gbit/s through the switch when eight fibres on each link are used for data.

A 16×16 crossbar switch chip, with integrated optoelectronic I/O was implemented for switching packets transferred using bit-parallel WDM [Krisnamoorthy et al. 1996]. Each node has two single-mode fibres coupled to the switch, one for input and one for output.

6.2 WDM/SDM switches

The architecture with optical interconnections and electronic crossbars is flexible and powerful. Optics and optoelectronics can however also be used internally in a switch fabric, i.e., more than just in the I/O interface. A broad spectrum of solutions has been proposed, and some examples are given below.

SDM (Space Division Multiplexing) switches [Goh et al. 1998] [Guilfoyle et al. 1998] [Kato et al. 1998] [Lai et al. 1998] [Moosburger and Petermann 1998] [Sawchuk et al. 1987] and WDM switches (consisting of, e.g., wavelength converters and wavelength selective components) [Pedersen et al. 1998] [Flipse 1998] can be used both as stand-alone switches and as building components in larger switch fabrics [Reif and Yoshida 1994]. As an example, a Banyan multistage network built of 2 x 2 switch elements has been described [Chamberlain et al. 1998]. Another multistage network uses both WDM and SDM switches but in different stages [Kawai et al. 1995]. A multistage network can also be implemented using chips with processing elements placed on a two-dimensional plane [Christensen and Haney 1997]. The processors then communicate with each other by a mirror that bounces back the beam to the plane but to another processor. Switching is made on the chips while each pass between two switch stages corresponds to a bounce on the mirror.

A multistage switch incorporating both electrical and optical switching, but in different stages, has also been reported [Duan and Wilmsen 1998]. Some work has focused on the communication between stages, e.g., perfect shuffle with lenses and prisms [Lohmann et al. 1986]. Switch times for SDM switches in the order of 1 ns have been reported [Kato et al. 1998], while some SDM switches have switch times in the order of 1 ms [Tajima et al. 1998]. A switch can be placed on a dedicated board in a cabinet and be connected to processor boards (or, e.g., line cards) via fibres or via an optical backplane [Maeno et al. 1997].

A system that implements a distributed crossbar, or a fully connected system, connecting N nodes with only passive optics between the transmitters and receivers has been demonstrated [Li et al. 1998B]. All optical channels turned on from a transmitter's two-dimensional $\sqrt{N} \times \sqrt{N}$ VCSEL array are inserted into a fibre image guide. The fibre image guides from all transmitters end at a central free space system with lenses. The lenses are arranged in such a way that the light from each VCSEL pixel in a VCSEL array is focused on a single spot together with the corresponding pixels in all other arrays. This gives N spots where each is focused into a single fibre leading to a receiver. Hence, selecting a pixel in a VCSEL array to be turned on corresponds to addressing a destination node.

Wavelength converters are important components in many WDM switches. A way of building fast wavelength converters is to first have conversion to the electrical domain and then back to the optical domain but on another wavelength. However, this is not a valid solution if an all-optical switch is desired.

Lately, a lot of focus has been paid on using MEMS (microelectromechanical systems) technology to build all-optical SDM switches. As reported in [Lin 1999], an array of electrically controlled mirrors can be used to build an 8×8 OXC. Lucent Technologies has already announced 256×256 OXCs to be released on the market [Kenward 2000]. Due to the relatively low loss possible in MEMS switches, multistage MEMS switches are also possible. In this way, rather large optically transparent switches can be built. In addition to pure SDM switches, the MEMS technology can be used in equipment for wavelength routing networks (wavelength routers), e.g., consisting of wavelength splitters, a MEMS SDM switch, and wavelength combiners. More information on all-optical switching is found in [Pattavina et al. 2000].

7 Commercial system implementations

In this section three products are described where optical interconnect technology is used. The exact backplane technology is not stated in the companies' material. The fourth section deals with InfiniBand, which is an industry association to promote a common interconnect standard for computer-related hardware.

7.1 Sycamore

The Sycamore SN 16000 is an optical switching platform that provides a transition of the optical network from a ring-based architecture to a mesh-based network topology. According to Sycamore, the SN 16000 delivers automated provisioning, routing, and restoration of lightpaths.

VCSEL (Vertical Cavity Surface Emitting Laser) technology is used to interconnect the switch fabric shelf with the port card shelf as well as to interconnect card to card within a shelf. According to Sycamore, this optical interconnect technology system enables scalability to large switch matrix sizes, while maintaining a high port density.

7.2 Pluris

The Pluris terabit network router architecture uses a distributed switching fabric and an *n*-dimensional fibre optic interconnect structure to provide scalability in terms of switching capacity, line capacity, port density and line rate forwarding. The system supports thousands of IP enabled OC-12, OC-48 and OC-192 interfaces by combining up to 1920 line cards within a single system.

7.3 Sirocco Systems

The Sirocco Zephyr Optical Access Device is a network element, designed to aggregate services onto the optical network. There are two Zephyr models: the Zephyr Z-48 which provides aggregation up to OC-48/STM-16 and includes an integral optical backplane for support of multiple wavelengths, and the Zephyr Z-12 offering aggregation up to OC-12/STM-4 for entry-level applications. Zephyrs are designed for deployment in the Metro or Access layer of the network and will typically be located in central offices and multi-tenant buildings.

7.4 InfiniBand Trade Association

Seven computing companies, Compaq, Dell, Hewlett-Packard, IBM, Intel, Microsoft and Sun Microsystems have joined together to develop a new common I/O specification to deliver a channel based switched fabric technology. This issue is addressed through an independent industry body called the InfiniBand Trade Association. The specification will support both copper and fibre implementations and the performance range will be scalable from 500MB/s to 6GB/s per link.

8 Conclusions

Reviewed interconnection architectures are summarised in Table 2 with remarks on their suitability in data- and telecommunication equipment from different aspects. Switch time is marked as slow (ms), medium (sub-microsecond), or fast (ns) in the table depending on the suitability of adoption in OXCs, packet switches with burst switching, or true packet switches, respectively.

Optical transparency is valuable to get protocol-independent OXCs. The MEMS technology is promising for such systems, at least as long as the requirements on switch times are moderate. Multistage networks using MEMS technology can be especially good alternatives because of their scalability. All-optical packet switches, however, will probably not be mature technology in the near future. Also, one must think of the flexibility and power of electronic switches, and of processors to control the switches.

Scalability is desired to be able to build equipment with many in-/output ports. We state the scalability as poor if only tens of ports is realistic, medium for hundred to a few hundred ports, and good for thousand ports or more. Different multistage networks and free space optical backplanes with a high density of optical channels seems to be good candidates from a scalability point of view. When building smaller systems instead, e.g., the WDM star distributed crossbar with its passive optical star can be a good and simple alternative.

	Switch time	Optical trans-parency	Scala-bility	Blocking	Notes
WDM star distributed crossbar	fast	internally	poor to medium	non-blocking	Slow switching relaxes component's tuning time requirements.
WDM ring	fast	internally	poor	non-blocking	Slow switching relaxes component's tuning time requirements.
Fibre-ribbon pipeline ring	fast	no	poor	blocking	Can be compared with a bus but with spatial bandwidth reuse
Free space optical backplanes	varies a lot	internally for some systems	varies a lot	varies a lot	Scalable if many I/O channels on one card. Switching and line cards can be mixed.
Nonblocking MEMS system	slow	yes	medium (or better)	non	
Multistage MEMS system	slow	yes	good	topology dependent	Scalable optically transparent for systems with relaxed switching time requirements
WDM/SDM switches	slow (or better)	(yes)	varies a lot	topology dependent	For optical transparency, only all-optical wavelength conversion is allowed.
Optical interconnections and electronic crossbar	fast	no	poor to medium	non-blocking	Many optoelectronic I/O channels can be integrated on a switching chip/module
Planar free space optics	fast if no SLMs	no	good	topology dependent	Chips are only placed in two dimensions. Promising in terms of assembly.

Table 2: Summarising evaluation of reviewed interconnection architectures.

If an interconnection network implements a true crossbar it is non-blocking (e.g., WDM star distributed crossbar), while it is topology dependent for many of the reviewed architectures whether they are blocking or non-blocking. It should, however, be noticed that the fibre-ribbon pipeline ring network is blocking. On the other hand, the increasingly good price/performance ratio for fibre-ribbon links indicates a great success potential for interconnection systems using fibre-ribbon links.

Having optics inside a switch gives the same flexibility as electronic crossbars, but it might be possible to build larger switch fabrics with high transmission capacities using optics. The suitability of the different free space systems depends a great deal on the more detailed configurations of the systems. For example, planar free space systems can be arranged in arbitrary topologies.

Integrated fibre and waveguide solutions make the building of compact systems possible, especially for networks such as those using fibre-ribbons. The same reasoning about compactness can be argued for free space systems. Optical backplanes may earn their success from the similarities with current rack-based systems, while future planar free-space systems might give the possibility to integrate optics and electronics in a compact way, easy to assemble.

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10 Annex

10.1 Commercial solutions

10.1.1 Backplanes

10.1.1.1 Optical

Notice that the companies presented below primarily focus on the backplane connectors. The actual backplane technology that will be used is more uncertain, whether it will be fibres stuck on plastic foil, fibres mounted on the PCB or optical waveguides within the PCB.

10.1.1.1.1 Amphenol

Amphenol has developed a modular optical backpanel interconnect system capable of providing optical and electrical interconnections between components housed within an integrated rack, as well as input/output connections and rack-to-rack interconnections. The interconnect system is particularly suited for military avionics applications.

10.1.1.1.2 Diamond

Diamond's E-2000 Optical Backplane is targeted towards data communication and telecommunication applications. Its architecture is optimised to provide optical design flexibility through 2 and 6 channel configurations for deployment of 8 to 40+ channel systems.

As part of the E-2000 product line, the Backplane System utilises Diamond's "Active Core Alignment" technology. This ensures, according to Diamond, that mating fibres align with zero core offset resulting in low back-reflection and low and repeatable insertion loss.

The E-2000 Backplane is available in multimode, single mode, convex polished (PC), and 8 degree angle polished (APC) versions as well as a field mountable version called the E-2000 FUSION.

10.1.1.1.3 AMP

The AMP Fibre-Optic Backplane Connector is used for optical interconnection of daughter cards to motherboard. An SC connector interface is used from motherboard, with 2 to 8 positions and a centreline spacing of 12.5mm. Singlemode or multimode versions are available. The daughter card floats and alignment pins on mother card assure mating.

10.1.1.1.4 MOLEX

MOLEX Backplane Connector System (BCS) was designed to provide a smooth transition from board mounted and pigtailed active devices (LEDs, lasers and receivers) to backplane fibre optic components using a standard SC interface. Pigtailed active devices, located anywhere on the daughter card, are terminated to the card edge mounted BSC connectors. These BSC connectors provide a blind mating interface through backplane BSC adapters and NTT-SC standard input/output ports. A floating ferrule design allows the connectors to self-align inside the adapter and provides physical contact. The BSC backplane connector system provides a great deal of flexibility for designing and servicing the daughter card. Its blind mating interface provides the daughter card with a plug-in feature that allows the card to be inserted, removed or exchanged without disrupting the input/ output ports and the associated cabling. For multiple fibre applications, alignment pins in the BSC housing allow the connectors to be stacked. BSC to standard SC connector mating is accomplished through the BSC adapters, which are available with either zirconia ceramic or phosphor bronze, sleeves. In addition to the traditional SC style adapter, a shuttered SC version is also available. A spring-loaded cover on the shuttered version shields against exposure to laser radiation and dust contamination.

10.1.1.1.5 FCI

The ***MACII*** is a multi-fibre (18 fibre positions) backplane optical connector developed by AT&T. MACII was used in the first optical backplane deployed in a large-scale telecommunications platform. It was deployed in 1994 by AT&T in the DACS VI-2000 digital access and cross-connect system designed for the SDH synchronous transmission standard. Berg Electronics has further developed it into the ***miniMAC*** connector. Berg was subsequently acquired by FCI.

10.1.1.2 Electrical

10.1.1.2.1 National Semiconductor

Low Voltage Differential Signalling (LVDS) is a technology addressing the needs of today's high performance data transmission applications. LVDS technology features a low voltage differential signal of 330mV (250mV MIN and 450mV MAX) and fast transition times. This allows the products to address high data rates ranging from 100's Mbps to greater than 1 Gbps. Additionally, the low voltage swing minimises power dissipation while providing the benefits of differential transmission.

The Channel Link chipsets multiplex and demultiplex slow TTL signal lines to provide a narrow, high speed, low power LVDS Interface. These chipsets provide systems savings in cable and connector costs, as well as a reduction in the amount of physical space required for the connector footprint.

Bus LVDS (BLVDS) is a new family of bus interface circuits based on LVDS technology specifically addressing multi-point cable or backplane applications. It differs from standard LVDS in providing increased drive current to handle double terminations that are required in multi-point applications.

10.1.1.2.2 Texas Instruments

Texas Instruments have both LVDS and pseudo-ECL (PECL) circuits for high-speed data transmission.

10.1.1.2.3 Teradyne

Teradyne has an 8-row VHDM HSD (Very High Density Metric High-Speed Differential) interconnect designed to meet the needs of the newly emerging 2.5Gb/sec device families. Stripline shielding allows 100% of the signal pins to be used for signal transmission, yielding 38 real signal pairs per linear inch.

10.1.1.2.4 Litton

According to Litton, they are producing, in volume, boards at speeds of 2.5 GHz and 1.2 Gbit/s on standard and emerging PCB dielectric materials. They are actively designing and testing for 2.4 Gbit/s and have design activities for up to 6 GHz and 5 Gbit/s.

10.1.2 Link optoelectronics

10.1.2.1 Mitel Semiconductor

The MFT62340 and MFR62340 is a transmitter and receiver pair for parallel fibre applications. This pair, together with a multimode parallel fibre ribbon cable, constitutes a complete 12-channel parallel fibre link. The link provides 2.5 Gbps interconnects for use within and between large capacity switches, routers and data transport equipment. The transmitter and receiver have a differential common mode logic interface and support MPX, MPO/MTP and MT fibre connectors.

10.1.2.2 Gore

W. L. Gore & Associates, Inc. is completing the development of a family of multichannel optical transmitters and receivers targeted at intra-system and short reach inter-system high data rate communication links. The transmitter module utilises Gore’s Vertical Cavity Surface Emitting Laser (VCSEL) technology, which makes multi-Gigabit/sec data rates possible while minimising space and cost. The nLIGHTEN™ modules offer an 8X improvement in density over standard 1x9 serial transceiver products and reductions in costs at the same time. It utilises 62.5-mm multimode fibre and its operational wavelength is 850 nm.

10.1.2.3 Emcore

EMCORE has designed a new 2.5 Gbps 850nm oxide Vertical Cavity Surface Emitting Laser (VCSEL) specifically for the next generation data communications networks. The VCSEL could be used for applications such as Storage Area Networks (SANs) and Local Area Networks (LANs).

10.1.2.4 Honeywell

The HFT428X is a single package transmitter and receiver designed to interface with the MT-RJ style optical connectors. The transmitter is an 850nm VCSEL packaged for up to 2.5 Gbps data communications. The PIN + pre-amplifier converts optical power into a differential output electrical signal.

No VCSEL array devices were found on the Honeywell home page.

10.1.2.5 Infineon

Infineon has a parallel optical link product, denoted PAROLI, with 12 channels each operating at up to 2.5 Gbps. The footprint for the PAROLI device is slightly larger than that of Mitel's parallel link device.

10.1.2.6 Agilent

Agilent has several different single VCSEL devices for Fibre Channel and Gigabit Ethernet applications. No VCSEL array devices were found on Agilent's home page.

10.1.2.7 Lucent

Lucent has made laboratory demonstrations of transmission of 10 Gbps over a single channel, using a VCSEL and their new LazrSPEED multimode fibre, for a distance of 1.6 km. The LazrSPEED fibre is for sale now, but Lucent is not offering any VCSELs.

10.1.2.8 Cielo

Cielo recently demonstrated an 850nm Vertical Cavity Surface Emitting Laser (VCSEL) operating at 12.5 Gbit/sec on link lengths of greater than 300 meters of Lucent LazrSPEED multi-mode fibre. The laser supports direct modulation and was packaged in an optical subassembly (OSA) designed to couple light efficiently into the new fibre.

10.1.2.9 New Focus

New Focus has presented a VCSEL transceiver operating at 10 Gbps. These VCSEL transceivers have a power consumption of approximately 1.25 W, and require no active cooling.

These 10-Gb/s transmitters and receivers are intended for, multimode, fibre-optic links between network equipment within a central office. The transmitter includes a directly modulated 850-nm VCSEL with laser-driver circuitry and automatic power control; the receiver includes a transimpedance amplifier with automatic gain control (AGC) and DC restoration. The units use a differential CML electrical interface.

10.2 Demands from future Ericsson products

To clarify the needs for optical interconnection technology in future Ericsson products, interviews were made with people involved in the product development of certain Ericsson products.

10.2.1 AXD 301

The AXD 301 is a carrier class scalable multi-service ATM switching system, enabling highly reliable edge and backbone network solutions. The modularity and load sharing architecture, of the internal ATM switching fabric, allows the switching capacity of the present system to be scaled from 10 Gbps up to 160 Gbps. The full 160 Gbps system consists of nine cabinets, with the switch core cabinet surrounded by four access subrack cabinets on each side.

The channel data rate today is 500 Mb/s over a 1-metre backplane or 10 metres of cable. When considering optical interconnects for AXD 301, and certainly for other products as well, the most important factors are power, cost and bit error rates. Optical interconnects would be advantageous for distributed switching architectures.

10.2.2 ERION OXC

Optical interconnects are evaluated for opto-electrical cross connects (OEXCs) with hundreds of input and output ports. The technology chosen must be “clean”, in the sense that dust and dirt in the air and from the connectors themselves should not degrade the connector properties.

10.2.3 Cello

Cello is a general platform for radio base stations and media gateways. The Cello backplane consists of two different buses: the common Cello ATM bus and the application bus. The Cello ATM bus is the same for all different products, whereas the design of the application bus depends on the particular product requirements.

For the Cello platform, power consumption is more important than space, as the costs for power supply and cooling is larger than the cost for floor space. There should be a power-efficient electrical interface between the ASICs and the optical interconnect drive modules.