
Photonics phenomenon

Bart Stuck

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Photonics is moving quickly to pick up as much of the multiplexing and switching functions of electronic telecommunications as possible. This is leading to a renaissance of analog photonic transmission technology, comparable with that of analog microwave telecom transmission technology from the 1940s through the 1960s.

The 1980s first saw long-distance carriers and then local exchange carriers start to deploy massive amounts of optical fiber for backbone network transmission. The late 1980s and early 1990s saw the emergence of global optical transmission standards: Sonet for North and South America and SDH for the rest of the globe.

The capability to bridge to the legacy wireline copper and coaxial cable networks and microwave radio networks to handle multiplexing, interfacing and network management proved to be a driving force in creating international standards for optical fiber transmission.

Over time, some of this functionality will move from electronic components and systems to photonic components and systems, so carriers can achieve some Sonet and SDH functions with photonics.

Reliable as electronics In the early 1990s, photonic components started to appear that operated at acceptable levels of network reliability and could be cost-effectively manufactured in volume, to do the same things that electrical components did for telecommunications.

These include: Single mode optical fiber. This optical fiber can achieve 0.1 dB of loss per kilometer at a wavelength of 1550 nm and twice that at a wavelength of 1310 nm. Because chromatic dispersion is different at these wavelengths, dispersion-compensating optical fiber has begun to be widely deployed-especially in new carrier networks such as Level 3 and Qwest Communications.

Passive components. These are lenses, mirrors, prisms, splitters, attenuators, isolators, circulators, couplers. Sources include lasers that operated for millions of hours between failures available from multiple manufacturers in both 1550 and 1310 nm bands, at discrete, manufacturable wavelengths or frequencies.

Modulators. These lasers could be directly modulated (direct feedback or DBF lasers) and were available at relatively low cost but generated intermodulation harmonic products and had limited dynamic range. External modulators that mechanically squeezed a waveguide through which light was transmitted (and hence modulated) were available at a relatively higher cost with significantly less intermodulation harmonic distortion and far greater dynamic range.

Optical amplifiers. These EDFAs could photonically regenerate analog signals (without conversion to electrical signals and then back again) across a 4 THz frequency band centered at 1550 nm. Optical signals can be transmitted over hundreds of kilometers without optoelectronic amplifiers (which can only transit up to 80 kilometers before requiring signal regeneration), all of which would reduce the complexity of both devices as well as interconnection and packaging, increase reliability and lower costs.

Filters. Optical bandpass filters are based on imprinting a grating on an optical fiber using Bragg's Law to filter out all but a single band of optical frequencies. These filters could be reliably manufactured by several different groups around the globe.

Wavelength division multiplexing. Several different optical signals from different optical fibers could be multiplexed together at slightly different frequencies or wavelengths and transmitted over a single optical fiber pair.

Given all these functions, the only significant task that cannot be achieved in a cost-effective, reliable manner today is photonic switching-and related areas of photonic storage and photonic bit-by-bit processing-the ability to switch any wavelength on any optical fiber pair to any wavelength on any optical fiber pair. This active area of research and product development should yield a variety of optical switches at different price points and functionality within the next three to five years that will be widely deployed throughout photonic networks (Table 1).

This has led to photonic network carrier infrastructure equipment that is rapidly evolving but is still in its infancy compared with electrical network carrier infrastructure equipment (Table 2).

Over time, part of the link level Sonet/SDH digital transmission functionality will migrate to the photonic analog transmission level, as network equipment vendors and operators understand what functions they can do most cost-effectively at each point, and as new physical phenomena appear in photonic devices.

The current photonic active and passive component manufacturing processes and packaging and interconnection technologies are comparable with the 1970s semiconductor industry, so we can expect to see massive price drops-as muc h as 30% per year-in photonic network equipment as more modern manufacturing, packaging and interconnection processes come on-line, drawing on the experience and hundreds of billions in capital expended over four decades in silicon integrated circuit manufacturing.

Interface standards Photonic transmission has introduced a new set of analog transmission interfaces into the X.200 open systems interconnection (OSI) reference model of the International Standards

Organization. This set of interfaces is called the photonic layer.

The photonic layer resides between the physical media layer, often called Level 0, and the physical layer, or Layer 1, which involves specifying signal voltage and current levels, waveforms and timing for signals transmitted over the physical media.

The photonic layer is an emerging area for network interface standards, for both information transfer and out-of-band signaling and control. Electronic transmission standards for optical fiber transmission (Sonet and SDH) have been under development since the mid-1980s.

An early example of a photonic network element was the EDFA, an analog amplifier capable of greater than 35 dB gain over a 4 THz transmission pass band centered at 1550 nm.

But a set of standards was missing for determining how to interface this type of equipment with carrier networks, and perhaps more importantly, how to manage the equipment. For example, what types of network management control are needed to determine what types of failure modes? As more photonic telecom devices and systems become cost-effective, photonic analog transmission layer standards can be expected to evolve. Issues such as crosstalk, chirp, bandwidth, decibels, dynamic range, noise figure, rise times, intermodulation products and distortion will be the core vocabulary for this new set of photonic interfaces.

Major carriers suffer a significant optical fiber cable cut on an average of every 10 days, and as more optical fiber is deployed, the average time between major cuts is dropping.

A major optical fiber cable cut means that some or all of the fibers in a conduit are severed, typically by a backhoe. Because optical fiber can carry tremendous amounts of information (a terabit per second of transmission capacity corresponds to more than 15 million simultaneous telephone calls), a major optical fiber cut has the potential to interrupt phone service for large numbers of subscribers.

The need for some type of redundancy has long been recognized, and to date, the proven approach has been to use relays to switch to a backup optical fiber when signal loss is detected on a primary optical fiber. This type of restoration is adequate for some types of point-to-point transmission systems, but it does not provide the flexibility that carriers require for network-level protection.

A step up from unidirectional line protection switching is an optical fiber ring, with two pairs of optical fibers going from node to node using bidirectional line protection switching. Rings were widely deployed beginning in the late 1960s in IBM computer-centric data communications networks and have achieved widespread telecom carrier acceptance based on their reliable operation.

The ring has the advantage that if a cut occurs in the optical fiber between two nodes or if a node fails in the network, relays can use the backup pairs of optical fibers. As long as the time required to fix the cable cut or the failed equipment node is much shorter than the time to the next outage, this approach can be quite cost-effective.

With the advent of photonic WDM over a single pair of optical fibers, the need for protection switching and restoration has become even greater because each optical fiber pair is now transmitting information that is the sum of the information on each of the respective wavelengths.

One approach to handling protection and restoration is to deploy a photonic add/drop multiplexer, in which the information transmitted over each optical fiber thatis added or dropped would use a distinct wavelength. These products are a step in the right direction for developing a truly general purpose ADM that would permit any wavelength on any optical fiber pair to be added or dropped at any network node.

The result of this technology evolution will be networks evolving away from rings and toward more general mesh structures, and this will start within the next two to three years.

Network management The need for network management has led to a standards body, the Network Management Forum, whose members are carriers and equipment vendors, working to provide a set of standards for network management.

These standards are called Telecommunication Management Network (TMN) and encompass the following:

* network element

* element management

* network management

* service management

* business management

By using an out-of-band optical channel to transmit network management information, any frequency impairment on a wavelength channel handling information has the potential to be diagnosed and repaired efficiently. Photonic network management so far has concentrated on network element and element management, but over time, higher level activities will be integrated.

Each equipment vendor can provide its own base network management system, using the legacy character-oriented TL1 or an OSI protocol suite using either CMIP or SNMP stacks.

A software agent in turn manages the network management information specific to the equipment. After two decades of work around the world, a core foundation now exists for the network management of photonic networks. The challenge will be to identify what is unique to purely photonic networks and how to best manage those networks.

One obvious departure from existing optoelectronic networks is that photonic networks are based on photonic analog transmission techniques, and there is as yet no cost-effective capability for photonically processing digital signals in a reliable manner.

Existing optoelectronic networks convert optical signals to electrical signals in a digital format, then draw on 50 years of digital computer technology advances to manage the transmitted bit stream.

On the other hand, a combination of TCP/IP protocols running over a photonic analog WDM system achieves much of the functionality of add/drop Sonet/SDH multiplexing as well as asynchronous transfer mode switching.

The Optical Internetworking Forum seeks to develop new optical data communications equipment for the emerging packet-switched carrier networks. The forum counts AT&T, Bellcore, Ciena, Hewlett-Packard Co., Qwest, Sprint and WorldCom as founding members.

TDM photonic transmission An alternative approach to photonic WDM is ETDM and its newer photonic implementation, OTDM. In this approach, the primary technical limitation is the time required to turn on and off a transistor that in turn modulates a laser, and this can be achieved either purely electrically or via photonics.

Semiconductor device technology has advanced rapidly over the past decade, achieving shorter and shorter switching times. The end result was that until 1995, TDM achieved a factor of four increase in peak transmission capacity roughly every two years (Table 3).

WDM uses a different component-an optical multiplexer-to complement the TDM technology, and during the past three years has far outstripped the transmission capacity gains of TDM. Figure 1 summarizes both trends, the increase in transmission rate due to TDM and to WDM, showing two sets of data: the year that an initial peak transmission rate was announced in a recent laboratory, and the year that that transmission rate was offered in a commercial product. Roughly speaking, five years elapse from the time that a laboratory announces a peak transmission rate until it appears in a commercial product.

Laboratory systems currently can handle 300 times the transmission capacity of a single optical fiber pair. It is important to realize that each transmitted wavelength runs at a different transmission rate, so an OC-192 transmission system over a single optical fiber pair, handling 10 Gb/s, can handle up to 80 times that transmission capacity, or up to 800 Gb/s.

This far outstrips the transmission gains of TDM, while preserving the investment in TDM equipment.

Broadband photonic networks are still in their early stages. This is a story that can be told only once a century, much as the original telephone networks were deployed around the world toward the end of the 19th and beginning of the 20th centuries. Stay tuned.