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Sillibits and Lambdas Galore

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Terry Turpin comes on lean and hungry like some hybrid pioneer and Ponzi, pirate and hermit. With black eye patch, dark hair, nickel stock, ruddy cheeks, and soft sinuous voice, he has the intensity of an aging engineer emerging from a long siege in a spooky spectral wilderness with a new invention and a prophetic sermon. Last week, at the National Fiber Optic Engineering confab in the cavernous Baltimore Convention Center, where the throngs were intoxicated with the promise of sending 40 billion bits down a single fat wavelength of light, he was talking tens of thousands of slim lambdas instead. Some people think he is a "conference crank."

Down the road in Columbia, Maryland, Turpin has a company called **Essex** (ESEX) that he is edging into the public markets like a hermit crab, using the beached corporate shell of a defunct insurance consultancy. The stock symbol, ESEX, shows the full broadband power of wavelength division multiplexing (WDM). Entered into a Google search, it yields 3,460 colorful lambdas, defying the common notion that e-business is dead. Anil Khatod, the retiring optical chief of **Nortel** (NT), may not be worried. But Turpin is not a crank. He is a cagey consort of such photonic sages as Fred Leonberger of **JDS Uniphase** (JDSU) and Paul Green, virtual inventors of WDM.

Turpin tells us that he has already reduced the spacing between lambdas in his Hyperfine system to 250 megahertz or 0.002 nanometers, approximately 400 times smaller span than Nortel is currently pitching. More important is Turpin's claim that as the wavelengths move closer together in spectrum space, they line up and behave better. They use a fraction of the power, keep their shape and shelf-life longer than Cher, shun tricky polarization effects like George W., suffer less crosstalk or four wave mixing than the Pope, and can be added or dropped as readily as a Lewinsky diet.

Turpin's insight, if I fathom it through the stealth, is self-alignment. He repeats in the Telecosm what Federico Faggin accomplished in the microcosm with the self-aligned silicon gate. Before Faggin, it was necessary to align a metal gate with exquisite accuracy on top of a transistor's electronic channel. After Faggin, the gate was self-aligned. Rather than creating the two termini (source and drain) of the channel first and then putting the gate precisely between them, Faggin deposited the gate first and it served as a mask to define the positions of the source and drain. Turpin uses an apparently similar strategy in optics. He uses the center frequency of the laser not to define the channel in the usual way of WDM but to define the center spacing between two sidebands. The sidebands form the channels that carry the bits. This system, according to Turpin, will allow the creation of channels separated by as little as a few Hertz or

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picometers. In the past such aggressive claims for the ultimate capacity of WDM were made only by Simon Cao of **Avanex** (AVNX), also an exponent of self-aligned lambdas and several years ahead in the creation of products.

Nonetheless, enthralling the industry in Baltimore was the image of a few fat lambdas, undulating on stage under the direction of the Nortel baton at a rate of more that 40 billion vibrations a second. This is the dream of OC-768 (40 gigabits per second). In cost per bit, in power usage, in bandwidth efficiency, this Nortel vision is hard to beat. It crams more bits in less spectrum space than anyone ever dreamed in the dawn of WDM ten years ago.

If optical bandwidth were scarce and connectivity abundant, OC-768 would be the way to go. Optimize bandwidth—the total carrying capacity of the fiber—and let connectivity take care of itself, with a few hundred multi-terabit routers like the "n-dimensional **Cisco** (CSCO)-killer super-switch" being developed by Internet pioneer Larry Roberts at **Caspian**. For a million dollars or so you can even link to the Net. But if bandwidth is abundant—did we hear somewhere rumors of a bandwidth glut?—then the appropriate strategy is to waste bandwidth to achieve connectivity, growing lambda links to the Net for a few dollars from the backplane of your notebook computer. Rather than terabit routers with racks on racks of lasers, transponders, muxes, demuxes and remuxes, mazes of electronic microchips and buses and cross-connect switch fabrics, all active devices gorging power, WDM lambda channels are wavelengths of light. They can be self-aligned, merged, and separated down the fiber with passive arrays of lenses, mirrors, and prisms that use no power at all.

In cost per bit, in power usage, in bandwidth efficiency, Nortel's electronic vision is hard to beat

Turpin's basic expertise is recherché signal processing, which he used to perform for the spooks at the National Security Agency. For Turpin and Essex, stealth mode comes naturally. Turpin's Essex project does not rely on stealth, however, but on Fourier transforms that can translate any broadband signal into a set of narrowband channels, any fat wave into many lean lambdas. An OC-768 lambda can morph into sixteen OC-48 lambdas or 40 one-gigabit Ethernet lambdas. As long as the total power on the fiber does not increase, dispersion and non-linearities remain under control and thousands of lambdas on thousands of fibers across the country offer the promise of myriad connectivity.

But who is this on the phone? It is Anil Khatod of Nortel with a different mode of self-alignment, realigning his company outside the paradigm of the Telecosm. Giddy with the vindication of Nortel's removal from our list and free of $19.2 billion of cockamamie good will from purchases such as Xros and Qtera, Khatod fingered an incriminating old GTR (GTR, February 1997). In it, I had predicted the failure of OC-192 SONET. Had not Nortel seized 90 percent of the optical transmission market by moving first to these complex 10 gigabit per second channels? Remember those Glory Days when Nortel sold $6 billion worth of OC-192 equipment in the first year. Now Nortel would win again by moving first to OC-768 at 40 gigabits per second. And 80 gigabits. Then to OC-3072. However many sillibits per second you want. Forget all those extra WDM lambdas. That's cheating. Real men will lift scores of TDM gigabits on single wavelengths. It would be so hard and exacting and costly—just think of the non-linearities and the polarization mode dispersion and the capex dollars all rising exponentially—that no one else could do it, and no one else could connect to it. Nortel would win a new monopoly end to end. And the paradigm would die. What did we think of that? We heard strange cackling at the other end of the line. Perhaps it was Khatod, leaving Nortel for unnamed "other opportunities."

Chorum signs TDM pact

Nortel won the bit rate debate two years ago and effectively began turning out its own lights. It's hard to argue with history, and so today TDM (time division multiplexing) has become the zeitgeist of telecom. TDM compresses messages into ever smaller time slots rather than packing them loosely in their own lambdas with WDM. Last week's National Fiber Optic Engineers Conference (NFOEC) in Baltimore shouted TDM ascendancy. Meeting with company after company and attending one technology session upon another convinced us that despite the protests of a few "conference cranks," e.g., us, the only industry-wide question remaining on 40 Gbps (OC-768) technology was *when*, not if. Even some of our own GTR companies have signed on, such as privately-held **Chorum Technologies.** In Baltimore Chorum announced a wide passband multiplexer capable of handling 40 Gbps at a broad 100 GHz spacing, thus filtering many fewer lambdas than is possible using the company's current line of commercial multiplexers.

Indeed, if Nortel is right—if it is less expensive to communicate over the Internet at higher bit rates—then that is what the Telecosm *should* be focused on. In such a scenario, WDM—sending many different colors of light down a fiber concurrently—merely serves as a booster for TDM, increasing bandwidth by adding virtual fibers. Ultimately, the goal would be one 50 THz (OC-786,432) optical channel in a strand of **Lucent** (LU) AllWave fiber, equaling the total bandwidth in the glass.

Nortel assures us that the industry can ascend both the TDM and WDM technology curves simultaneously. But you can't, anymore than you can go uphill and downhill at the same time.

TDM and WDM are ultimately incompatible communications paths. Bit-based, electronic-centric TDM ultimately limits channel counts. Circuit-based, optics-centric WDM ultimately limits bit rate. For a while, at optics' inception and when TDM was already climbing a mature Moore's law learning curve, it appeared as though you could travel both technology paths: advancing from 2.5 Gbps to 10 Gbps while doubling channel count as lambda spacings dropped from 200 GHz to 100 GHz. This approach worked because WDM channels that wide can easily hold OC-192 bitstreams of 10 gigabits a second. But the increase to OC-768, 40 gigabits, is not compatible with the next natural step in WDM, reducing spacing to 50 or even 25 gigahertz for another doubling or quadrupling of channel count, as offered today from such companies as Avanex, Chorum, JDSU, and even Nortel itself. To accommodate 40 Gbps, such cutting-edge networks would have to tear out lambdas. The prospects for WDM get much worse at 160 Gbps (OC-3072). Already on Nortel's backburner, these TDM rates conflict with WDM channel counts already available in many networks. You can no longer blaze the TDM and WDM trails simultaneously. More time slots make lambda optics more difficult and conversely more lambdas make packing and unpacking time slots more difficult.

Recently the most fruitful endeavor in optical communications has been to eliminate costly electronic restoration of optical signals that degrade in various ways as they traverse the fiber. Repeated quadrupling of the bit rate surrenders all those gains since shorter, faster TDM signals naturally tend to get lost in the multi-billion-bit-per-second blur. For instance, the blurring of bit pulses caused by chromatic dispersion increases by the square of the bit rate as pulses are squeezed closer and closer together in ever smaller time slots. Increasing the bit rate four times, from 2.5 gigabits to 10 gigabits worsens chromatic dispersion sixteen fold. And OC-768 (40 gigabits) suffers dispersion problems *256 times* as great as 2.5 gigabits does.

At 40 Gbps, Corning needs glass cleaner

For advanced networks employing **Corning**'s (GLW) newer LEAF fiber, dispersion renders a pulse unreadable after it travels approximately 4,000 kilometers at OC-48. But at OC-192, that same pulse degenerates within a mere 250 kilometers without dispersion compensators such as the Avanex Powershaper. Tightfisted OC-768 offers only 15 kilometer transmission links. The older and much more common SMF (standard single-mode) fiber fairs worse, with maximum transmission distance dropping from 930 kilometers to 3.5 kilometers. Therefore, even in shorter-reach metro networks 40-gigs of time slots present a formidable challenge, almost certainly requiring a fresh build-out of latest-generation fiber.

Another dispersion angst, polarization mode dispersion (PMD), occurs when light travels faster in one polarization plane than another. (Lightwaves can be split into two components at right angles which travel independently.) Though unnoticed at OC-48, PMD poses a powerful challenge at OC-768. Caused by infinitesimal asymmetries in the fiber core, PMD comes and goes in a completely unpredictable fashion, changing dynamically with environmental fluctuations such as temperature or the rumbling of a truck overhead or the passing of a train nearby. PMD variations can occur in a few milliseconds in real-life networks, requiring continuous tuning to within 100 microseconds. Worse, at 40 gigabits per second, chromatic dispersion *also* begins to respond to environmental elements, requiring dynamic tuning.

Rolling down a Moore's law trajectory, the cost of SONET regenerators continues to fall, and Nortel could keep its more costly OC-768 optics to a minimum and instead add regen sites to decrease optical transmission distances. In a TDM-centric network, power and cost savings are achieved electronically through higher and higher bit rates. Each fourfold increase in bit rate lowers power consumption per bit (and even lowers total power consumption per fiber if Nortel is to be believed) and reduces cost per bit as the number of lasers along with laser footprint drops by 75 percent.

Nortel has thrown up its hands on optics and is tempting the Telecosm with the same apple

Nortel's captive carrier customers have told the Canadian communications giant that they find network power consumption as much a burden as network costs. Therefore, Nortel looks to higher bit rates to reduce both. After performing power and footprint calculations based on its HDX multiterabit switch, Nortel informs us that OC-48 technology consumes 288 watts (W) of power for every one gigabit of capacity. But Nortel promises even better times ahead at OC-768, where they project reducing per-gigabit power consumption to "well below" 10 W, resulting in a per *lambda* power drop to much less than 400 W (10 W/Gb x 40 Gb), lower by 44 percent than even the 720 W of an OC-48 lambda.

For 30 years in the microcosm chip makers have reduced power consumption per transistor even as the total power consumption per-chip rises. In the Telecosm, Nortel can lower both—per-bit power consumption and total power consumption—even though time-compressed light pulses at OC-768 are one-sixteenth the size of pulses at OC-48 and hence require sixteen times the launch power to traverse the same fiber distance before attenuating into unreadable blips.

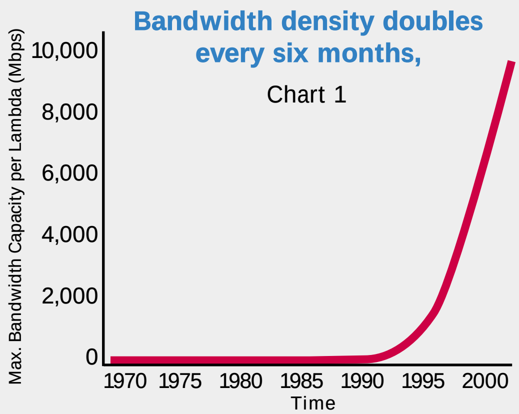
Nortel has discovered its fountain of youth—efficiencies of power which will push TDM innovation far into the future. We are warned never to bet against Moore's law—indeed, electronics is moving ahead at such a tremendous pace that Moore's law actually understates advances in silicon. Microprocessor clock rates of 10 GHz today will soon surge to 60 GHz and beyond, antes **Intel** (INTC). Why not 250 gigahertz? counters IBM. With hundreds of gigahertz electronics, why bother with crude handcrafted optics? Why add power-consuming lambdas? At OC-768 you have one laser (compared to 16 at OC-48 for the same total bandwidth), one modulator, one connection, and a lot fewer transponders, lasers, splices, and couplers resulting in fewer glitches. Digital electronics is simply more reliable, argues Nortel, than the tricky mirrors and exquisite analog accuracies of WDM lasers and modulators.

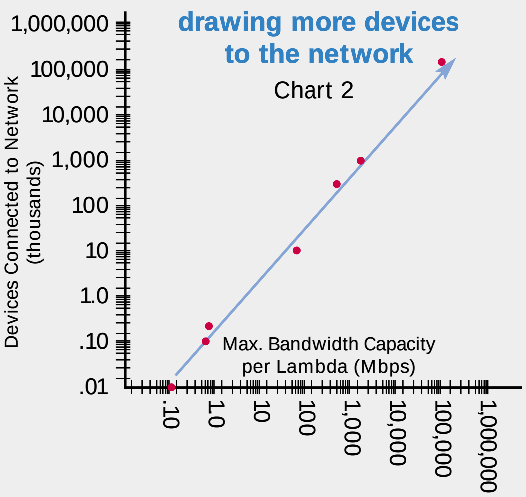
Nortel has thrown up its hands on optics and is tempting the Telecosm with the same apple.

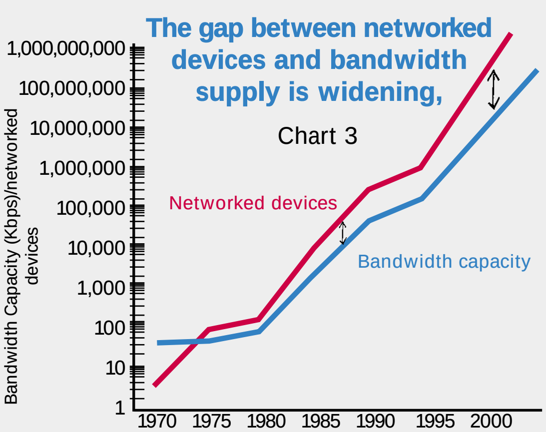
Nortel crams for finals

Unfortunately for Nortel, optics brings a disruptive price model to the industry, and Nortel has fallen victim to a classic case of what Clayton Christensen calls "cramming," where established firms, rather than miss a disruptive technology, endeavor to "cram" it into their existing business model. In trying to make the disruptive technology as good or better than the established one, they fail. Against the assured efficiencies and sustained advances of a mature technology, the new is never good enough. For Nortel, WDM will never achieve the efficiencies of TDM.

GLUT? WHAT GLUT?







Moore's law says that computer power doubles every eighteen months. Total network bandwidth has been growing at a rate at least three times that, doubling every six months on average (chart 1). Abundant bandwidth consistently draws more devices to the network (chart 2).

Billions of devices, from embedded microprocessors in all the machinery of modern life, to hundreds of millions of hand-held wireless teleputers, will flock to the network, creating billions of new network nodes (terminals attached to the network).

Since the early 1970s, the number of networked devices has been growing faster than the bandwidth supply. The gap between number of networked devices and the collective pool of network bandwidth is widening (chart 3).

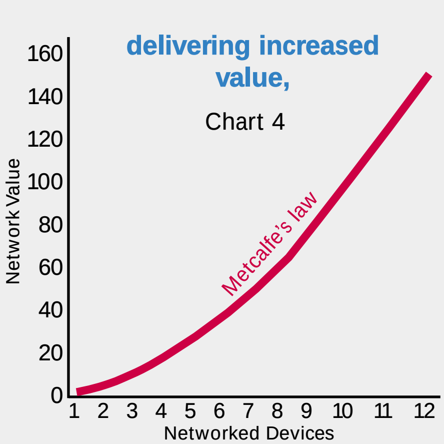
Metcalfe's law, the value of a network is proportional to the square of the number of devices attached to it, implies that the more terminals attached to the network the greater the traffic *per terminal* (chart 5). Add two more phones to a two-phone telephone network and the traffic on the first two phones will increase as well. A town with only one lawyer doesn't need any; a town with two lawyers soon needs four. With networks, unlike lawyers, this creates a virtuous cycle of growth. Abundant bandwidth lures more devices onto the Net, more potential connections means more traffic generated by the original devices, and the greater utility of the Net attracts more devices still.

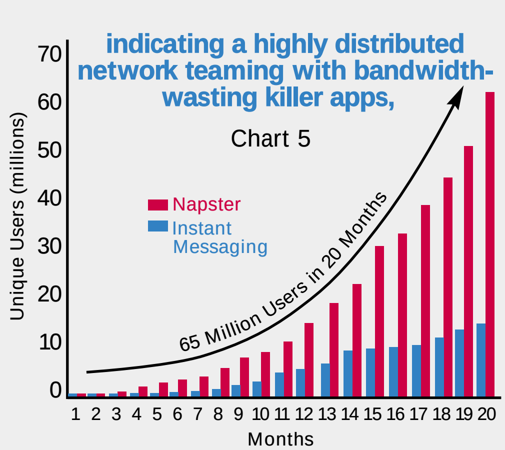
As broadband flourishes, computers will disaggregate across the Net. As cheap abundant bandwidth makes sharing data and functions across the Net *possible*, users discover that ever broader sharing schemes become *optimal*. This is happening right now with the revival of bandwidth wasting peer-to-peer Internet architectures exemplified by Napster and instant messaging (chart 4).

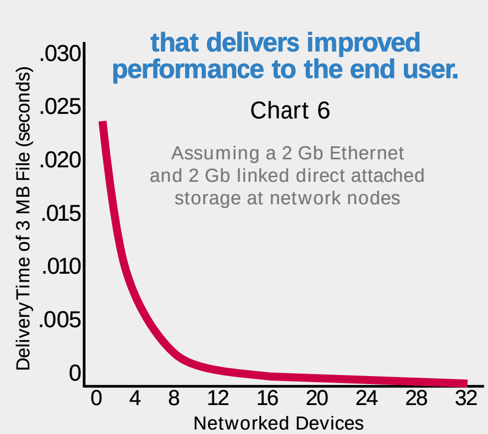
As the number of terminals rise, the power of reaching them soars. Peers will develop dynamic workgroups for real-time instant messaging, file sharing, and teleconferencing. For example, as the amount of on-Net content climbs, individuals and workgroups will tap into the surplus disk space attached not only to their own devices, but the devices of their peers and larger centralized storage nodes maintained by companies like Mirror Image, and waste bandwidth to retrieve and propagate that content.

The broader the sharing the better for the end user and the greater the bandwidth demand. If one Napster user has a 3 megabyte MP-3 file directly attached to her system via a 2-gigabit fibre channel link, the optimal delivery time of that file would be around 0.0012 seconds (3 MB/2 Gbps). Adding a peer to the network, with the same MP-3 file stored across a similar fibre channel link, and 1.5 megabytes of the song can be uploaded from each peer. If the network connection is faster than 2 Gbps, the file will be delivered in less time than if the lone music lover had loaded the file from her own storage bin. Increasing the network to four peers uploading the same file and delivering it across the same network would cut total delivery time in half yet again. Neglecting speed of light latencies, every doubling of network peers would theoretically improve file delivery times by a factor of two (chart 6). - Mary Collins

Chart Source: Chris Kwak and Robert Fagin, Bear Stearns







Nortel believes history supports its thesis, but it commits the fundamental error of ignoring paradigms. Five years ago, when Nortel began spearheading the development of 10 Gbps (Gigabit per second) data rates, TDM was still what Christensen calls a "sustaining technology," necessary to satisfy existing telco customers. Indeed, TDM *was* bandwidth; everywhere you looked capacity was expanded through TDM by compressing messages into ever smaller time slots and processing and switching and routing them electronically, bit by bit, around the network. WDM boosted bandwidth by creating several more 2.5 Gbps "fibers" on a physical strand, but the network was still accessed, switched, and defined by time slots.

Following the law of exponentials, lambdas were increasing relatively slowly in absolute numbers in the early days of WDM. Scarce wavelengths precluded a transparent all-optical network in which untouched bits flow seamlessly through Corning glass. At 40-channels and 2.5 Gbps, WDM could avail us of only two thousandths of the 50 terahertz of bandwidth on Lucent's AllWave fiber or Corning's SMF 28e counterpart. When spectrum is scarce, it makes sense to chop it up into time slots and switch it. Hence, the technological marvel of the "opaque" network, an edifice of electronic switching and grooming (filling each lambda to capacity) and routing of individual bits through a complex maze of never-ending electronic nodes.

Still in TDM undershoot, held back by bandwidth scarcity, the Telecosm was willing to tolerate the enormous expense and burden of multiplying electronic regenerators, routers, add-drop multiplexers, grooming switches, and more powerful transmission lasers as well as the increased challenge of managing feistier fiber distortions of light pulses. The most demanding carriers required improved functionality of TDM to satisfy their customers' appetite for bandwidth. When commercial deployment of **Ciena**'s (CIEN) MultiWave WDM transmission system migrated from 16 channels in the spring of 1996 to 40 channels in the **Sprint** (FON) network two years later, more than doubling spectrum usage, the bandwidth increase from WDM alone could not fill customer demands at 2.5 Gbps. Ten Gbps on channels spaced hundreds of GHz apart were not only feasible but desirable.

But lambdas need no longer be separated by hundreds of GHz, and all the signs are pointing to WDM ascendancy—perhaps a daunting prospect for an industry almost unconsciously traversing a sustaining TDM trajectory. Leaving a well-known path of advance, especially in a downturn, might seem intimidating. Sustaining innovation maps a more comfortable route, and for an industry in depression anything else might look like a threat.

David Gelernter tells us that no matter how certain its eventual coming, we normally fail to envision an event whose exact time and form of arrival are unknown. We tend not to believe in the next big war or economic swing. We certainly don't believe in thousands of lambdas on a fiber. Because we don't believe in technology change (we only say we do), we accept the inconveniences of electronic latency in the network, of burdensome power and space consumption, and of complex bit shuffling at node after node. In some cases we barely even notice the defects instead of demanding that they be fixed.

Confined to this box, Nortel commits the fallacy of circular reasoning. It presupposes the TDM paradigm, then demonstrates how higher bit rates decrease costs, thereby proving the TDM paradigm. Because the time slot paradigm presumes that any lambda must be a hopped-up, high-bitrate lambda—demanding multiples of laser power and costly electronic support—the multiplication of lambdas by WDM strikes the TDM camp as merely a path to higher costs. For Nortel, breeding lambdas will always multiply SONET regenerators, proliferate switching ports, consume more power, pose connectivity headaches, multiply lasers and therefore network failures, and make optics more difficult and costly. Transfixed by these proliferating horrors, they cannot accept that going all the way with WDM, to lambdas numbered not in dozens but in thousands, makes the SONET burden, and eventually all the others, drop away.

Even as Nortel arduously advances electronic technology, David Huber and Simon Cao will be busy eliminating electrons from the network

Compounding its denial, Nortel sets up the feasibility straw man, as if critics say that OC-768 is impossible rather than foolish. But the feasibility of OC-768 or for that matter of OC-3072 is not at issue. Nortel can do it. The Telecosm can do it. But WDM will render it impractical, unnecessary, and onerous.

Corvis's express lambda lanes

Concerns about power efficiency, for instance, become worrisome only in networks replete with electronics switches, add-drops, and regens. **Corvis** (CORV) founder and optical guru David Huber informs us almost anticlimactically in his typically mild manner that along an average Los Angeles to Washington DC link in an OC-192 opaque network, like Nortel's, bits will pass through 17 SONET regenerator sites and five electronic switching sites for a total of 48 O-E-O (optical to electrical to optical) interfaces. In a Corvis transparent network, continues Huber, that same link requires only four optoelectronic conversions. Thus Corvis has essentially transformed 5 switching and 15 regen nodes into zero-watt transceiver sites.

As Nortel advances its OC-768 technology over the coming years, David Huber and other optical gurus such as Simon Cao will be enabling networks to eliminate all SONET regenerator sites and electronic switching nodes on links of all distances, but chiefly in the lower billions of bits per second. Along with the sites go the infrastructure costs of the lasers and air conditioners and inventory and maintenance and cramped central office space. If Corvis enables networks without electronic regeneration, the major excuse for Nortel's time slot efficiencies vaporizes.

In addition to higher network build-out and data transport costs, Nortel will also be saddled with inferior quality of service (QoS). Passing through electronic mazes adds delay (or latency) regardless of distance. In a Corvis network of seamless lightpaths, these delays vanish along with the O-E-O interfaces that cause them. In the course of its 15-week start-to-finish build-out of **Broadwing**'s (BRW) national all-optical backbone, the carrier suffered a fiber cut in its old network and asked Corvis to light a portion of the all-optical installation to make up for the cut. Broadwing's customer, a Forbes 100 software firm, called the networker immediately and told Broadwing: "Whatever you did, don't change it back!" so sharp was the improvement in network quality.

With bandwidth a replacement for grooming, Ciena's CoreDirector electronic switches do you no good

The implications of the all-optical network go beyond the elimination of SONET. Corvis has demonstrated in its network models what we have been preaching for years, that the most cost-effective, most efficient optical networks waste bandwidth. In Corvis language, when network traffic exceeds the capacity of merely one lambda on a data link, the network scales best by provisioning new lambdas for new links rather than conserving bandwidth by aggregating bits and switching old lambdas. Between major network hubs, Corvis establishes semi-permanent express lambda lanes, which seldom need switching, as the most cost-effective solution to network management. When wires are cheaper than switches, there is scant need to switch at all.

It will be increasingly more cost-effective to run an all optical network at 2.5 gigabits per second than a hybrid network at 40 gigabits per second. With many partially filled lambdas, the most "efficient" photonic networks will operate at fraction of capacity. Carriers will get rich on bandwidth "glut."

There is a trade-off between packing lambdas efficiently (grooming) and wasting them for connectivity. With bandwidth a replacement for grooming, Ciena's CoreDirector electronic grooming switches, for example, do you no good. To assure that every lambda is filled to the brim entails complicated and costly network management and statistical multiplexing equipment. So Corvis manages a relatively static core where "express" lambda circuits are preoriented, deploying perhaps a half dozen of Huber's all-optical switches. At a capital cost approximating the CoreDirector, Corvis saves core networks $2 million or more in upfront costs by deploying fewer switches. Add to that per port savings of $40,000 to $100,000 and with hundreds of lambdas the savings amount to tens of millions more dollars.

Because of the resistance of some carriers to all-optical networks, trust will be built up only when the economics become so compelling that they have no choice—as when an insurgent carrier forces the issue. With the completion of its Corvis-built 160-channel, transparent WDM backbone network, Broadwing has taken up the challenge. Corvis's advances in distributed Raman amplification have been key in enabling optical signals to travel coast-to-coast on Broadwing's network and still be able to distinguish the 1s and 0s.

Discovered by an Indian physicist early last century as he contemplated enigmatic light patterns on the waves near his ocean liner, Raman effects feed on the curious affinity between sound and light, phonons and photons. Struck by resonant wavelengths, as in lasers, atoms will emit photons. Other non-resonant but contiguous wavelengths excite heat and "sounds" which exert indirect effects, including vibrations in the infrared domain of fiber optics. These phonons can boost optical signals across the entire 50 terahertz fiber band. Superior to the prevailing Erbium Doped Fiber Amplifiers (EDFAs) in bandwidth, Raman amplifiers also have the advantage of enabling distributed amplification diffused through the fiber or amplification of the signal where it is weak rather than near a noisy pump laser. Thus it amplifies less noise. The redoubtable Simon Cao of Avanex used to believe that Raman was complex and unnecessary—that power shaping of the signal could suffice—but this month Avanex broke new ground by announcing the first Raman amplifier designed for metro networks. Employing a hybrid Raman/EDFA architecture, the PowerExpress Raman offers the flexibility to adjust pump power to optimize Raman noise suppression.

Broadwing sends its SONET sisters packing

Unlike its incumbent-carrier competitors, Broadwing can actually build its bottom line as it builds its network. Lighting a lambda is not a multimillion dollar SONET project; the carrier can simply turn lambdas on as needed by adding cards to each end of the link. By using gain-flattening algorithms Corvis avoids sending technicians into the field to tweak each amplifier to accommodate the new lambda(s). And although it takes more effort to light a whole new fiber since new amplifiers and switches and dispersion compensators need to be deployed, Corvis was able to install Broadwing's entire national network in only 15 weeks.

Meanwhile, just to light a new lambda (not a new *fiber*), Broadwing's SONET sisters might make use of Lear jets (actually done by one company) to do a coast-to-coast drop of circuit packs at every network node for the electronic switches and SONET regenerators required for each new lambda. And with the increased capacity, latency actually becomes worse.

Today, Broadwing's all-optical Corvis-built network can scale to 160-channels, and Corvis hints at 700 channels available by year's end for anyone who can use it. In a broadband WDM domain, bandwidth scales in lambdas instead of bit rates—and as Corvis has shown us it scales far more cost effectively and elegantly than TDM. Nortel claims that most network failures are in optics. But millions of lightstreams, such as those envisioned and enabled by Avanex and perhaps some day by Essex, are more reliable than a few hundred. Quality of service comes from wasting bandwidth and proliferating lambdas.

A rift at **Williams Communications** (WCG) highlights the significance of Broadwing's anti-telco, all-optical feat. It seems half of Williams's usually forward-looking technology team, still intrigued by big switches and fancy QoS complexity, is preventing full deployment of the Corvis express lambda network.

Hostile takeover confronts 10-gig

Nortel's troubles aren't over. It also commits the error of comparing next-year's innovation with today's technology, including next year's costs with today's costs. According to a well-established rule of thumb, a carrier will not move to OC-768 from OC-192 unless the higher bit rate is no more than 2.5 times the cost of the lower rate. When Nortel orchestrated the drive to OC-192 from OC-48, the price of 2.5 Gbps had stabilized. Optics was young. It was still young when Nortel was the only 10-gig supplier and could charge whatever it pleased. But this year the price of OC-192 has already dropped 30 percent and will be cut in half by year's end. The pace will not slacken next year. This is a radically different price model than prevailed at the time Nortel introduced OC-192.

And OC-192 isn't the only kid on the block; OC-48 prices are no longer stable but are sinking fast as well—another sign of WDM ascendancy. Reports that Nortel's 10 Gbps sales are flattening may be confirmed by Ciena, which has seen a firming of its 2.5-gig sales. Many carriers have yet to move fully to OC-192, including Sprint. Corvis tells us that the price of OC-48 transponders is dropping faster than the price of their OC-192 counterparts, such that today four 2.5 Gbps transponders are cheaper than one 10 gigabit per second module. Since Corvis demonstrates that at lower bit rates networks can shun costly optoelectronics and become transparent much sooner, 2.5 Gbps becomes an attractive choice and gigabit Ethernet a beckoning further step.

As we learned at NFOEC, industry visionaries such as Simon Cao and Terry Turpin will soon deal further blows to Nortel's assumption that proliferating lambdas also means proliferating lasers and other discrete optical components such as modulators, isolators, and attenuators. New passive architectures may soon enable integrated arrays of separately tunable modulators and amplifiers fed by single broadband lasers, creating multiple wavelength streams without multiple active devices. Contrary to the TDM assumption, the network will become steadily simpler and cheaper as wavelengths increase.

It is connectivity that is scarce rather than bandwidth. Therefore the appropriate strategy is to waste bandwidth in order to enhance direct and simple connectivity to the networks run by nearly all customers, namely Ethernets. The best approach is to run Ethernet on thousands or even millions of lambdas, mapped as circuits across the Net. With prices dropping fastest for the slowest bitrates, the cheapest networks will offer the most connections.

Awaiting a "firming" of optical components prices, financial analysts show pork-belly brains, blind to the dynamics of technology markets. The accelerating decline of prices in optical technology reflects the acceleration in innovation, clearly discerned at OFC (Optical Fiber Conference) in Anaheim this past March as reported in the April GTR and appearing again last week at NFOEC in Baltimore.

Whether power or transistors or bandwidth, the key abundances of each era tend to end in a near zero price. As the price declines their role in the economy becomes ever more crucial. During the computer revolution of the past 30 years, transistors became asymptotically costless, while creating a trillion dollars of market cap for the industry. As we enter the communications era, the price of bandwidth as measured in cost of bits per second has begun collapsing faster than has the cost of transistors on a chip. These economies are driven by optical innovators such as Avanex, Corvis, and **Lightchip** and new players now moving to the fore.

Perhaps the most surprising news to emerge from NFOEC came at the end when we met with a company called **NP Photonics**, a stealth spinout from the University of Arizona. They have achieved the first major advance in EDFA (erbium-doped fiber amplifier) technology since its inception 30 years ago.

To keep pace with the multiplication of lambdas and power-robbing passive components such as multiplexers and add-drops throughout the network, EDFA designs have added multiple pumps, couplers, longer erbium fiber strands, multiple gain sections, and come in C- and L-band hybrids that complicate the network. EDFA pioneer David Payne of **Southampton Photonics** proposes a proprietary architecture to couple four pump lasers to eight fibers, thereby amplifying eight fibers in a hybrid device to save dramatically on cost and space.

But "dramatic" won't be good enough when confronting the breakthrough spearheaded by the chair of the University of Arizona's optics department, Nasser Peyghambarian. Having overthrown the formidable EDFA paradigm which demands ever-longer doped strands and ever-more powerful pump lasers in return for more amplification, NP Photonics will soon enable tiny EDFAs of far superior functionality and radically lower cost than possible today. Facilitating reductions in the cost of WDM undreamt in Nortel's worst nightmares, their impact will reverberate through the network and among many of our favorite companies such as Corning, JDSU, and **Genoa**, but more next month.

Broadwing lands on list

Broadwing combines an old local Bell company (Cincinnati) with a new generation network (IXC). Resolutely focused on the Telecosm, it is staking its future primarily on the all-optical network, and now particularly on sales of lambda circuits. More than 50 percent of revenues, and 80 percent of revenue growth, now come from data and wireless, and margins on data are rising rapidly thanks to Corvis. Even in its local business more than 80 percent of sales growth comes from broadband. We wish the wireless service were CDMA, but as the fastest growing wireless provider in its market, and with more than 28 percent market share, Broadwing is its own best competitor in the dwindling wireline local voice market. (Because local voice will decline more slowly than long distance voice has, however, robust local cash flow offers protection for now from Telcosm-hostile capital markets.) And while all DSL systems come branded with a sell-by date, at nearly 7 percent BRW boasts better market penetration than any other local DSL provider in the nation, testifying to a commitment to the Telecosm, which also lands them on our list.

George Gilder and Charles Burger
July 20, 2001

TELECOSM TECHNOLOGIES

ASCENDANT TECHNOLOGY	COMPANY (SYMBOL)	REFERENCE DATE	/ PRICE	JUN '01: MONTH END	52 WEEK RANGE	MARKET CAP
FIBER OPTICS						
Optical Fiber, Photonic Components	Corning (GLW)	5/1/98	13.64	16.71	12.60 - 113.33	15.5B
Wave Division Multiplexing (WDM) Components	JDS Uniphase (JDSU)	6/27/97	3.63	12.80	9.55 - 140.50	16.8B
Adaptive Photonic Processors	Avanex (AVNX)	3/31/00	151.75	10.49	6.92 - 174.50	682.3M
All-Optical Cross-Connects, Test Equipment	Agilent (A)	4/28/00	88.63	32.50	25.00 - 80.94	14.9B
Tunable Sources and WDM Components	New Focus (NUFO)	11/30/00	20.31	7.85	5.29 - 165.13	595.6M
Crystal-Based WDM and Optical Switching	Chorum (private)	12/29/00	–	–	–	–
WDM Metro Systems	ONI (ONIS)	12/29/00	39.56	28.45	15.75 - 128.63	3.9B
WDM Systems, Raman	Corvis (CORV)	3/30/01	7.03	4.32	3.00 - 114.75	1.5B
Metro Semiconductor Optical Amplifiers	Genoa (private)	3/30/01	–	–	–	–
LAST MILE						
Cable Modem Chipsets, Broadband ICs	Broadcom (BRCM)	4/17/98	6*	42.26	20.88 - 274.75	11.0B
S-CDMA Cable Modems	Terayon (TERN)	12/3/98	15.81	6.03	2.36 - 81.94	408.5M
Linear Power Amplifiers, Broadband Modems	Conexant (CNXT)	3/31/99	13.84	8.95	6.90 - 57.06	2.2B
Broadband Wireless Access, Network Software	Soma Networks (private)	2/28/01	–	–	–	–
WIRELESS						
Satellite Technology	Loral (LOR)	7/30/99	18.88	2.80	1.03 - 8.50	929.3M
Low Earth Orbit Satellite (LEOS) Wireless Transmission	Globalstar (GSTRF)	8/29/96	11.88	0.33	0.25 - 14.19	36.1M
Code Division Multiple Access (CDMA) Chips, Phones	Qualcomm (QCOM)	7/19/96	4.75	57.95	42.75 - 107.81	43.9B
Nationwide CDMA Wireless Network	Sprint (PCS)	12/3/98	7.19 *	24.15	15.72 - 65.88	22.6B
CDMA Handsets and Broadband Innovation	Motorola (MOT)	2/29/00	56.83	16.56	10.50 - 39.75	36.4B
Wireless System Construction and Management	Wireless Facilities (WFII)	7/31/00	63.63	6.85	3.31 - 84.81	306.8M
Internet Backbone and Broadband Wireless Access	WorldCom (WCOM)	8/29/97	19.95	14.95	13.27 - 49.97	43.3B
GLOBAL NETWORK						
Metropolitan Fiber Optic Networks	Metromedia (MFNX)	9/30/99	12.25	2.02	1.39 - 43.75	1.2B
Global Submarine Fiber Optic Network	Global Crossing (GX)	10/30/98	14.81	8.64	6.70 - 37.75	7.7B
Regional Broadband Fiber Optic Network	NEON (NOPT)	6/30/99	15.06	6.80	3.40 - 71.00	145.1M
National Lambda Circuit Sales	Broadwing (BRW)	6/29/01	24.45	24.45	15.40 - 13.13	5.3B
STOREWIDTH						
Directory, Network Storage	Novell (NOVL)	11/30/99	19.50	5.61	3.44 - 12.75	1.8B
Java Programming Language, Internet Servers	Sun Microsystems (SUNW)	8/13/96	6.88	15.60	12.85 - 64.69	50.8B
Network Storage and Caching Solutions	Mirror Image (XLA)	1/31/00	29	4.14	2.81 - 37.00	439.2M
Disruptive Storewidth Appliances	Procom (PRCM)	5/31/00	25	9.03	4.25 - 60.44	144.1M
Remote Storewidth Services	StorageNetworks (STOR)	5/31/00	27*	16.95	7.00 - 154.25	1.6B
Complex Hosting and Storewidth Solutions	Exodus (EXDS)	9/29/00	49.38	2.08	1.18 - 69.00	1.2B
Hardware-centric Networked Storage	BlueArc (private)	1/31/01	–	–	–	–
Virtual Private Networks, Encrypted Internet File Sharing	Mangosoft (MNGX.OB)	1/31/01	1.00	1.08	0.53 - 18.38	29.1M
MICROCOSM						
Analog, Digital, and Mixed Signal Processors	Analog Devices (ADI)	7/31/97	11.19	43.25	30.50 - 103.00	15.6B
Silicon Germanium (SiGe) Based Photonic Devices	Applied Micro Circuits (AMCC)	7/31/98	5.67	17.21	11.25 - 109.75	5.2B
Programming Logic, SiGe, Single-Chip Systems	Atmel (ATML)	4/3/98	4.42	13.19	7.63 - 21.94	6.1B
Single-Chip ASIC Systems, CDMA Chip Sets	LSI Logic (LSI)	7/31/97	15.75	18.80	13.65 - 68.50	6.1B
Single-Chip Systems, Silicon Germanium (SiGe) Chips	National Semiconductor (NSM)	7/31/97	31.50	29.12	17.13 - 69.69	5.1B
Analog, Digital, and Mixed Signal Processors, Micromirrors	Texas Instruments (TXN)	11/7/96	5.94	31.90	26.26 - 76.13	55.4B
Field Programmable Gate Arrays (FPGAs)	Xilinx (XLNX)	10/25/96	8.22	39.90	29.79 - 98.00	13.3B
Seven Layer Network Processors	EZchip (LNOP)	8/31/00	16.75	9.23	3.69 - 38.44	59.6M
Network Chips and Lightwave MEMS	Cypress Semiconductor (CY)	9/29/00	41.56	23.85	13.72 - 55.75	3.0B
Field Programmable Gate Arrays (FPGAs)	Altera (ALTR)	1/31/01	30.25	28.80	18.81 - 67.13	11.1B

ADDED TO LIST: BROADWING

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