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Qualcomm Excelsior

Emerging as the leader in this network processing space, is our pick from more than a year ago: EZchip

Out in San Diego in November for the North American CDMA Gala, I found myself sitting next to the lanky frame of Irwin Jacobs. Jacobs is the father and champion of Code Division Multiple Access (CDMA) as a technology, a business, and an international standard. An MIT doctorate who holds 11 patents, Jacobs is also the personification of our first paradigmatic company, **Qualcomm** (QCOM), which in its long and finally successful campaign against the global telecom establishment is one of the great entrepreneurial sagas in the history of enterprise.

We have described and celebrated CDMA in many previous letters (see January 1997, June 1998, December 1998, and April 1999). In general, our take on Jacobs has been that despite relentless cavils of captious rivals, despite heavy breathing stories in *Forbes*, the *Wall Street Journal, Fortune,* and other less believable publications depicting him as an artist of hype, turbo-touting his inventions, Jacobs is a scrupulous scientist who excels nearly all other business leaders in fulfilling his prophecies. If he says CDMA will be 20 to 40 times more cost effective than analog cellular, or 6 times as spectrally efficient as GSM, you can take it to the bank. Some of you have. If he tells me that tax cuts will plunge the economy into recession by raising long-term interest rates, I gulp and maintain a straight face.

Until last year, Jacobs's name was rarely mentioned without Andrew Viterbi's. Indeed, Jacobs and his CDMA cause gained luster and momentum from its association with Viterbi and his eponymous decoders, algorithms, books, and publications. Two years ago, however, Viterbi retired from Qualcomm to flog the next new thing, Flarion, which is a vessel of a technology called orthogonal frequency division multiplexing (OFDM). With "flash" and "Vi-turbo" added, it preens as F-OFDM and is directly targeted at Qualcomm's 3G mobile business. Isn't that what we needed—another complex wireless standard with no significant advantages beyond orthogonality to Qualcomm's imperial patents? With flash or without, with or without Viterbi, OFDM essentially translates the discrete multitone technology of digital subscriber line (DSL) into broadband wireless. Hardly an innovation, it is actually more relevant to the fixed wireless applications that Flarion is mostly ignoring.

In any case, there at the cavernous but crowded San Diego Convention Center, I had just given a speech in which I spoke of the power efficiency advantages of CDMA. I ascribed CDMA's superiority to Claude Shannon's insight, adopted by Jacobs and Viterbi, that digital technology allows a tradeoff between bandwidth

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and power. For a particular distance and data rate, you can use more bandwidth and less power or more power and less bandwidth. Qualcomm had thrived by choosing the way of "wide and weak" that would increasingly prevail across all of information technology, from single chip systems with on-board DRAM that would trump **Intel**'s (INTC) Pentiums to GANs (global area networks), such as **Global Crossing** (GX) and **Globalstar** (GSTRF.OB).

For much of the history of wireless, the industry went for an analog paradigm of high-power, narrow-spectrum channels that responded to interference like Rice Krispies to milk, and thus, needed lofty signal-to-noise ratios that restricted battery life to an hour or so.

In wireless technology, power is the central issue. Power use increases in proportion to the frequency and by the square of the voltage. As vendors move to higher frequencies, power budgets burst like Pandora's Pinata. Donning color screens which run at 15 volts, MP3 players that run on 5 volts, and CMOS devices at 1.5 volts, future cell phones will rise and fall in accordance with their success in handling and regulating power.

Qualcomm turned the industry around by choosing the path of low-power broadband signals prescribed by Claude Shannon

When the cellular industry moved to digital, it at first perpetuated most of the flaws of analog. It chose the Time Division Multiple Access (TDMA) system, upheld to this day by the global hoards of GSM and neuralgic old-time dividers **AT&T** (T) and **Cingular** in the U.S. Retaining much of the analog model, TDMA restricts calls to narrow 30 kilohertz bands and time slots that also aggravate interference and require onerous power to overcome it. Gathering the entire signal into one particular slot, TDMA platoons could be wiped out by a single grenade of interference.

Qualcomm turned the industry around by choosing the optimal path of low-power broadband signals prescribed by Jacobs's and Viterbi's legendary teacher, Claude Shannon. A lifelong juggler and master of the mathematics of keeping balls or calls aloft, Shannon saw clear limits to the strategy of throwing objects higher or harder as a way of keeping many in the air at once. Maybe you just spread out the jugglers and allow them gently to share the space. Minimizing power usage by complex power management schemes and spreading multiple calls over the same 1.2 megahertz of bandwidth, Jacobs and Viterbi upheld Shannon's rule of wide and weak.

Presumably misunderstanding my talk, which suffered from on-the-fly bandwidth compression when shortened at the last minute from 40 to 20 minutes, Jacobs strode to the podium to correct my apparent misrepresentation of his admittedly powerful technology. "Wide and weak," indeed. Shannon, he said, showed that more bandwidth entails more power; you cannot send more bits for nothing. He proceeded to tell the enthusiastic crowd of CDMA proponents of the imperial advance of the technology through Asia, from Korea to China, and its impending breakthroughs for data in the U.S. and Latin America.

Qualcomm's Chinese fortune

Almost three months later, the advance of CDMA continues relentlessly, with an astounding total of 4 million users of the first real 3G technology, CDMA2000, in Korea less than a year after launch. In December 2001, China's Unicom launched its nationwide CDMA service with some 500 thousand pre-registered users. Although takeup was inhibited by lack of phones, Qualcomm has licensed 19 Chinese companies to produce equipment.

By contrast, after resolving on a 3G system called WCDMA (wideband CDMA) that is even wider and weaker than CDMA2000, and after repeatedly declaring themselves far ahead of the U.S. in 3G, the Europeans and Japanese have foundered. Based on Qualcomm patents but with a pastiche of other dubious intellectual property from favored EEC suppliers, WCDMA ventures have incurred one setback after another. After many claims to have the first 3G system in the bag, **NTT DoCoMo** (NTDMY) confesses to reach some 30 thousand customers with a service at 64 kilobits per second, too slow for 3G specs of 144 kbps. The interim fix for Europe and AT&T, GPRS, offers less than half the data rate of CDMA2000, no added voice capacity, and greater costs. It now appears that the merely half-Qualcomm WCDMA technologies will fall ever farther behind the full Qualcomm spreads, which by the way is just what Jacobs has been predicting for several years.

The GSM proponents currently relegate this Korean news to peer-to-peer terminals on the SETI (Search for Extra-Terrestrial Intelligence) network. But they will be hard pressed to avoid noticing Qualcomm's up-to-2.4 megabit High Data Rate Technology, clumsily renamed CDMA 1X EV-DO, when it is exhibited in Seoul in June during the World Cup Soccer Championships, the largest international event in Korea since the Seoul Olympics of 1988. Currently the leader in CDMA handsets, including one with a color screen and digital camera exhibited at Telecosm 2001 in November, Korea's **Samsung** is now entering the arena with CDMA PDAs and is likely to prosper with the expansion of the system. Korea's SKT points out that the EV-DO service will reduce time to receive an MP3 song from the current 4 to 5 minutes to 10 seconds and a digital picture from a minute to a second or so.

Soma & Narad blow open local loop

As an answer to OFDM, moreover, **Soma Networks** (see *GTR* March 2001) emerged triumphant from severe tests of its Qualcomm-based 5 megahertz CDMA wireless local loop technology. Shunning the European pastiche of WCDMA, Soma created its own 5-megahertz CDMA system that combines a peak data rate of 12 megabits per second with flawless IP voice. Early last year, Soma executives observed that spurring OFDM's proponents was chiefly the desire to swivel around Qualcomm patents. Unless AT&T "Angels" and zigahertz hype of OFDM could propel the system out beyond the Shannon limits into SETI country, Soma would prefer to pay the money and be first into the market with broadband wireless using the most robust and fully debugged scheme available on earth. Sure enough, they are going to be first into the market. Showing the only fully robust wireless last mile technology, Soma has won blockbuster customers in Asia and the United States that will be announced in March. Together with **Narad Networks** (see, *GTR* June 2001), Soma is going to break the broadband local loop wide open even without government subsidies and counteract the recent possible slippage in Internet traffic growth limned by Larry Roberts in these pages.

CDMA continues to thrive because it is wide and weak. Although no one allegedly believes that you can send more bits for nothing, Shannon asserted that you can send more bits to get more communications capacity in less spectrum with less power. In wireless, power is king and free lunches are common on the spread spectrum scene even if Jacobs remains convinced that he somehow pays for them, perhaps in his humongous tax bill as number 136 on the Forbes 400 list. Shannon began his canonical paper on "A Mathematical Theory of Communication" by citing modulation schemes that "exchange bandwidth for signal-to-noise." Asserting this tradeoff are all of Shannon's calculations on the value of redundancy and the efficacy of coding to overcome the energy of noise in a channel.

CDMA's free lunch trick

In theory, analog is far more efficient than digital is. Most phenomena in an analog world—sounds, images, temperatures, organisms, and galaxies—are their own simplest representations. As Shannon pointed out repeatedly, a continuous analog signal contains infinite information and cannot be captured perfectly by any digital code. Spread through time and space like any physical phenomenon, with every point on the curve marking a feature of the object, an analog signal is an incomparably more accurate and succinct carrier of information than a digital signal. But its very precision and wealth of information—much of it of no value to the human ear in a telephone conversation—renders it impractical in crowded and noisy phone channels.

With the simple but relatively crude on-off codes of binary communications, severed from analog time and liberated from the burdens of beauty, digital systems gain huge flexibility advantages. The genius of CDMA was to maximize this flexibility by using bandwidth (digital codes, redundancy, power control, soft handoffs, rake receivers—bandwidth wasters all) to compensate for the noise in a wireless channel while minimizing demands for battery power.

Measured in Hertz or cycles per second in analog mode, bandwidth is spectrum. In digital mode, bandwidth is bits per second. The CDMA free lunch trick is to translate greater use of digital bandwidth into smaller use of spectrum. While each CDMA signal uses between 6 and 40 times more bandwidth than a typical TDMA or analog signal, CDMA's systemic efficiencies—sharing the spectrum among hundreds of users—makes it roughly 25 times more spectrally efficient than analog and 6 times more spectrally efficient than TDMA or GSM.

Shannon concluded that "although [digital] requires an initial increase of bandwidth for each channel, the resulting 'ruggedness' permits many routes originating from, or converging toward, a single terminal to occupy the same frequency band." Shannon saw that wide and weak digital signals could share the same bandwidth, while analog signals would be destroyed by interference. In an imperfect world, the potential physical perfection of analog is its downfall. Working on the physical layer only in coarse binaries, with large tolerances, the digital method attains perfection only on the level of symbolic abstraction.

Wide and weak becomes increasingly important as new systems using more bandwidth even than QCOM's, roll out in Europe and Japan

The issue of wide and weak will become increasingly important in coming years as new systems that use still more bandwidth even than Qualcomm's roll out in Europe and Japan. The established 3G technology, for example, is termed Wideband CDMA, and it uses 3 times the bandwidth of Qualcomm's system (though WCDMA claims a 5 megahertz span, in fact, it uses just 3.8 megahertz). Qualcomm will collect royalties from WCDMA, but will likely make less money unless it can excel rivals in contriving WCDMA chips despite its lack of enthusiasm for the system. Attracting attention over the last decade and precipitating intense debate at the FCC has been a system called ultra-wideband (UWB) that uses radically less power per bit even than WCDMA and claims speeds of 100 megabits per second while not interfering with anyone. Its own proponents used to acknowledge that UWB would not be a player in communications for a decade, which is a polite way for pessimistic marketers to say never. Now **Time Domain** and **Xtreme Spectrum, Inc.** are touting their technology as a communications panacea. Wide and weak continues to advance.

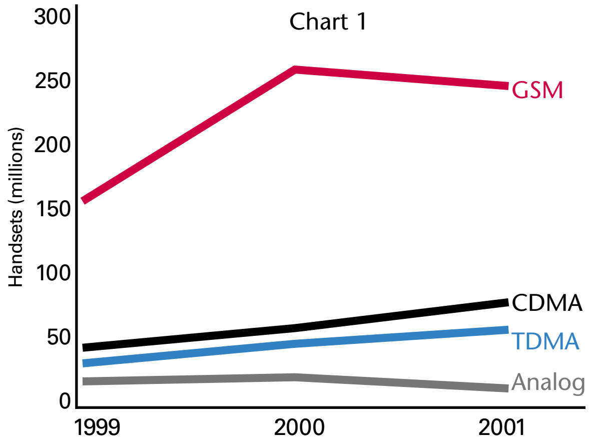
The A, B, C's of wireless LANs

A more important new wide and weak technology is wireless Ethernet. Under the IEEE rubric 802.11b, the so-called Wi-Fi local area network system has emerged in the unlicensed bands where wide and weak is the only approach allowed by the FCC. Specifying the ISM bands (for industrial, scientific, and medical applications), part 15 of the FCC code permits use of spectrum at 900 MHz, 2.4 gigahertz, and 5.8 gigahertz for devices that emit less than 1 Watt of power. For these applications, the FCC mandates use of spread spectrum technology such as CDMA direct sequence or Bluetooth frequency hopping that diffuses power across the band in order not to interfere with others. At present, the FCC does not permit the use of OFDM in the 2.4 gigahertz band.

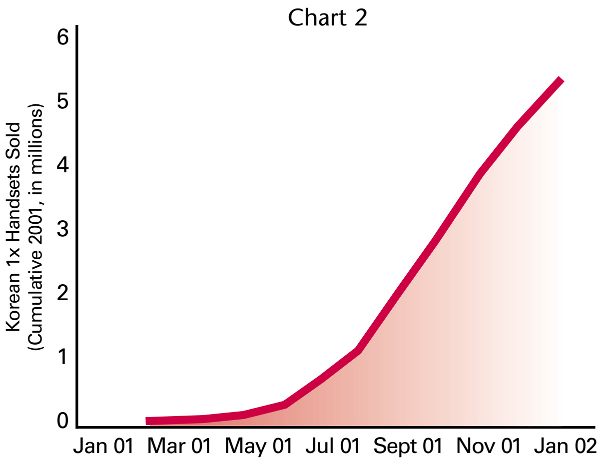
On the surface, Wi-Fi is a complement for 3G mobile networks rather than a rival for them. Like a cordless

3G LEAD BOOSTS CDMA

Leading indicator: CDMA handset sales accelerate



CDMA 2000 takes off in Korea



While European GSM and Japanese WCDMA staggered beneath a series of weighty, wireless setbacks, the pace of CDMA handset sales, a leading indicator for network growth and carrier revenues, continues to increase. (Chart 1)

Much of that boost came from Korea, where nearly 5 million of the new 3G CDMA2000 handsets were sold in the last 6 months of the year. CDMA2000 doubles voice capacity and offers 150 kbps of data, making Korea's the first real 3G roll-out in the world. (Chart 2)

About 45 percent of the CDMA2000 handsets sold in Korea included color display screens. Graphic and multimedia applications are growing fast, with color phone users on average spending twice as much each month for data transmissions. (Users are charged per packet.) Translation: give them bandwidth and they will use it even if they have to pay. (Chart 3)

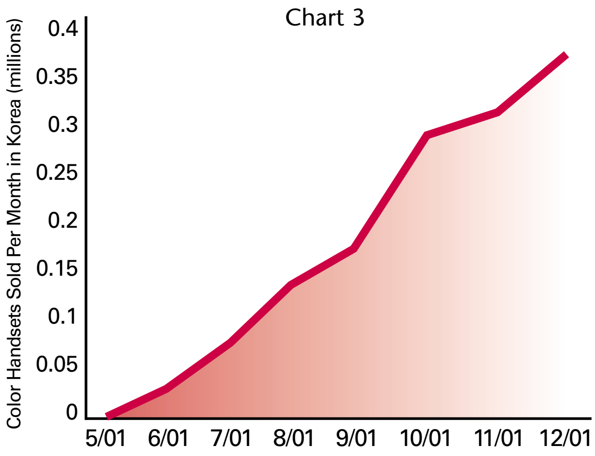
Europe's GPRS system, a GSM interim technology, is really "generation 2.5" with half the data rate of CDMA2000 and requiring a much more expensive network upgrade. For real 3G, the Europeans await WCDMA.

Japan's experience suggests the wait may be long. A series of software glitches delayed NTT DoCoMo's launch of its WCDMA service, which for now is also sub-3G running at only 64 Kbps. Subscriber interest has been thin.

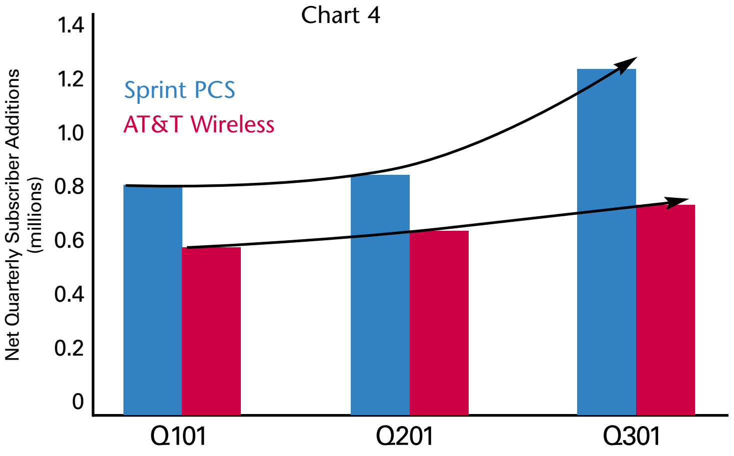
Sprint PCS, still the only major all-CDMA carrier, continues to be by far the fastest growing, taking market share compared to AT&T and other non-CMDA rivals. Every major carrier to report 4Q numbers so far has fallen short of estimates, Sprint reporting 1.1 million net new customers vs. estimates as high as 1.3. At 325,000 additions, Cingular fell far short of an estimated 700,000. At this writing AT&T has not yet signaled any shortfall from estimates of 900,000 and delivers the real numbers January 29. (Chart 4)

— Mary Collins and John Hammill

45% of Korea's 3G phone buyers go for graphic-friendly color screens



CDMA Sprint continues as growth leader



Data Sources: SG Cowan, Merrill Lynch

phone, its reach is about 150 feet radius from an access point. It can accommodate portable but not mobile users. Its initial capacity is 11 megabits per second, which with wireless overhead makes it tantamount to an ordinary office Ethernet. Because the 2.4 gigahertz band favored by 802.11b is crowded with other emitters, from microwave ovens to the new Panasonic cordless phones and Bluetooth personal area networks (PANs) of up to 30 feet, Wi-Fi's ultimate capacity is limited. But also approved by the IEEE in September of 1998 was 802.11a, which is a 54 megabit per second wireless Ethernet in the 5 gigahertz band with 4 times more channels, offering room for even wider and weaker advantages.

While leviathan companies around the globe are litigating for exclusive spectrum rights, Wi-Fi is spreading like wildfire with shared spectrum. Some 200 companies are producing access points and network interface cards. Such new players as **GRIC** (GRIC) and **Boingo** are contriving national roaming systems to knit together the thousands of hotspots at airports, hospitals, offices, and even residences. Want gigahertz surf with your grande skim latte? **Starbucks** (SBUX) has announced that some 500 of its cafes will have wireless LANs by the end of 2002 and that all of its shops will be wirelessly equipped by next year.

Sprint complements Qualcomm

Frustrated by all the politics and bureaucracy in the cellular bands and by the huge costs of exclusive spectrum licenses, entrepreneurs are going wide and weak in order to roll out services in unlicensed spectrum. Rather than litigating for an edge in high-powered mobile services, Wi-Fi pioneers are sharing low-powered bandwidth.

Sharing makes interference the crucial issue. Ideally, customers would use smart software radios that can scan the conditions of available channels and move to the least traveled paths. Adopting a model and mandate based on exclusive spectrum assignments, however, the FCC regards software radios as the computer industry sees hackers: possible violators of their turf and space. For example, prohibiting adaptive frequency hopping, the FCC requires Bluetooth personal area networks to hop mechanically across the entire 2.4 gigahertz band, stomping on anything in their path. Bluetooth is prohibited from avoiding current users of its spectrum space. But adaptive hopping is feasible and it would eliminate the much-discussed threat of Bluetooth interference with Wi-Fi.

In an extended technology recession, guerrilla wireless is the way to go. Pushed by thousands of entrepreneurs without centralized organization or funding, Wi-Fi advances incrementally, LAN by LAN. For the next 3 years, it is going to be the focus of energy in wireless. Just as terrestrial Ethernet prevailed in wireline, so will wireless Ethernet prevail in the wireless arena.

Qualcomm's great advantage is that its CDMA technology fits the wide and weak paradigm. In a key step toward smart radios, Qualcomm has announced development of a technology that can bypass the intermediate frequency stage and go directly to baseband digital processing from any radio frequency. To dominate the new era, Qualcomm will have to lead in frequency-agile and smart radio technology.

Qualcomm has long led in exploring hybrid and adaptive technologies. The Koreans too are pioneering in hybrid systems that allow swift movement between 3G mobile wireless and hotspot LANs. But the largest markets for wireless data are in the U.S. Qualcomm's systems must be seamlessly adapted to the spread of Wi-Fi. Sprint is already demanding such technology from its suppliers. Indirectly participating in a $15 million investment in Boingo, **Sprint** (PCS) regards Wi-Fi as a complement to the 3G wireless cellular data. **Sprint** (FON) is an increasingly important force in the development of wireless local loop technology.

Wide and weak across the Telecosm

For a decade, we have been following the emergence of software radios—smart wireless systems that can seek out the least congested parts of spectrum and move to them. This dream is likely to be fulfilled first in the unlicensed bands, where hybrid access point radios are already being developed to allow easy movement from the 2.4 gigahertz band to the 5 gigahertz band as needed. Soon all radio systems will hop adaptively, avoiding crowded channels. Systems that treat spectrum as an ocean rather than as "waterfront property" are likely to prevail, and they will necessarily be wide and weak technologies.

The substitution of bandwidth for power—Shannon's wide and weak paradigm—manifests itself across the Telecosm. It forecasts the failure of the digital subscriber line in competition with the larger bandwidth of cable. Cable could always substitute more bandwidth for power. As Narad today demonstrates, cable coax can carry up to 5 gigahertz of spectrum. Wide and weak secured the success of CDMA in wireless telephony. The issue that remains is chiefly how wide and how weak. WDM optics with its low power and waste of bandwidth also follows the Shannon paradigm. Here the issue arises whether the power efficiencies of using many low-powered lambdas compensate for the bandwidth costs. This issue is central to the question of whether a move to 40 gigabits per second (OC-768) from 10 gigabits (OC-192) will confer large benefits on the companies that achieve it.

Systems that treat spectrum as an ocean rather than as "waterfront property" are likely to prevail, and will be wide and weak technologies

Now **EZchip** from **Lanoptics** (LNOP) is bringing the wide and weak paradigm to the next generation of network processors.

For decades, the bandwidth outside the computer was tiny compared to the bandwidth inside the computer. Intel and **Motorola** (MOT) processors or ASICs designed by telecom equipment makers were plenty fast for network line speeds rated in kilobits and megabits per second. The network of slow copper telephone lines was the bottleneck. As we have written for years, however, optical bandwidth is now outpacing Moore's law of microchips. Optical power, measured in lambda-bit-kilometers, doubles every 5.3 months, 3 times the doubling rate of silicon computer power. We predicted this trend would move the bottleneck to microchips. Indeed, with SONET line speeds increasing from OC-12 (622 Mbps) to OC-48 (2.5 Gbps) to OC-192 (10 Gbps) in the last 6 years, and Ethernet moving from Fast (100 Mbps) to 1 gigabit to 10 gigabit in just 4 years, bandwidth is booming. Silicon, consequently, is reeling. We can now send terabits of data down single fiber threads. But we find it increasingly difficult—and expensive—to read, sort, route, and prioritize this information, a job necessarily relegated to electronics.

With a superior design and order-of-magnitude cost and performance advantages, EZchip is poised to prevail

CORV saves BRW capex

This reversal yields at least two new paradigms. The first is the all-optical network. Move those costly and slow electronics out of the core network entirely. Waste bandwidth. Use lambdas to create a new network topology, physically connecting every node with pure light, instead of logically connecting them with statistical multiplexing. By using **Corvis** (CORV) all-optical WDM equipment to build a new nationwide fiber network, **Broadwing** (BRW) saved some $400 million in capex alone—almost all of it in various forms of eliminated electronics.

But electronics can never be removed from the network entirely. They remain important—they gain new importance, in fact—at the edge of the Net. In edge routers and enterprise networks, for instance. Or even on your desktop or palmtop. Wherever they are, they must be small and fast. The second paradigm, therefore, is single-chip systems. Today, the reading and routing of data packets is performed mostly by customized, hardwired ASICs built into large **Cisco** (CSCO), **Ciena** (CIEN), **Lucent** (LU), **Juniper** (JNPR), **Nortel** (NT), **Extreme** (EXTR), **Foundry** (FDRY), and **Riverstone** (RSTN) boxes. But the Internet is ever-changing and ever-growing. The Net is becoming central, as routers and switches necessarily multiply and shrink and push outward toward the edge. Thus, the trend—just as it was when Intel rendered the PC central and mainframes peripheral—is toward programmable single-chip processors.

EZchip protracts single-chip paradigm

Emerging as the leader among scores of companies spending a total of some $25 billion in this *network* processing space, is our pick from more than a year ago: EZchip. (See, *GTR* September 2000.) It is the most promising solution because it puts memory and processing on the same chip. Embedding memory radically increases its speed—the rate at which data can be retrieved from memory and delivered for processing. Thus, it provides the only workable answer to the dilemma of Intel scientist John Shen, who recited the *GTR's* memory mantra to *EE Times*: "My personal view is that memory is the predominant performance bottleneck. CPU speed increases 40 to 50 percent per year. However, memory speed increases at a paltry 5 percent per year. That gap will continue to widen. Today it takes 100 to 150 clock cycles to access main memory for one to two gigahertz CPUs. That could expand to several hundred clock cycles in the foreseeable future."

After delaying for several months to perfect the complex design and tape it out, EZchip has announced eight customers and a sampling date (March 2002) of its flagship NP-1 chip. Manufactured by **IBM** (IBM), the chip gains nearly all of its advantages—less power, less board space, more look-ups, more bandwidth—from IBM's mastery of embedded DRAM technology. From **Texas Instruments** (TI) to **Micron** (MU) and **LSI Logic** (LSI), many macho fab experts have come a cropper on the treacherous intricacies of integrating DRAM cells, optimized for large capacitance, with CMOS transistors, optimized for as little capacitance as possible.

Though numerous devices claim network processor status, real network processors have 4 tasks: classifying packets (identifying and parsing headers and fields); searching IP look-up tables (finding addresses); resolving packets (assigning destinations); and modifying packets (prioritizing, scheduling, tagging, and policing them). Processing 10-gigabit Ethernet or SONET streams at wirespeed, moreover, requires at least 320 Gbps of memory bandwidth—160 gigabits to buffer memory and 160 gigabits to look-up table memory. To perform all of these tasks at 10-gigabit wirespeed is extremely hard. Indeed, while OC-192 optics has been on the market for more than 2 years, only recently have companies been able to craft true 10-gigabit transceivers, and no one has produced a 10-gigabit network processor. EZchip executes all these functions in one large chip—the NP-1. For high-end applications like core routing it will, by summer, add a simple traffic manager, dubbed the QX-1, and it can use some off-chip memory as well.

Power hungry competitors

To get a feel for the size and complexity of the NP-1, compare it to a leading-edge 2.2 GHz Intel Pentium 4. The new Pentium has 478 pins, or external wire connectors. EZchip's NP-1 has 1,247 pins. Pentium 4 has 520 kB of SRAM (an 8-kB Level 1 cache and a 512-kB Level 2 cache). With 4.2 MB of DRAM plus 1 MB of SRAM for microcode, NP-1 has 10 times as much on-chip memory. Pentium 4 has 32 Gbps of memory bandwidth. NP-1 has 500 Gbps. Pentium 4 dissipates 55.1 Watts. NP-1 dissipates just 15 Watts (largely because it runs at 200 MHz, rather than 2.2 GHz). While they are becoming powerful enough to take on some network functionality, like administering simple encrypted VPNs, PC microprocessors are not suited to most high-speed networking tasks. A functional comparison can only be made among EZchip's peers.

While EZchip uses 1 to 10 devices, including external memory, and dissipates a total of some 20 Watts of power, its competition lags far behind. One net processing start-up with products due this year, **Silicon Access**, uses at least 21 chips consuming some 60 Watts. Another vendor's 10-gigabit "network processor" is said to be contrived using 51 chips that dissipate 154 Watts. Competitive offerings from sector-leaders IBM, **Applied Micro Circuits** (AMCC), and **Agere** (AGR.A), due out later this year, require 56, 60, and 76 devices, respectively. Power dissipation might reach 200 Watts. Imagine, then, multiplying these chip-counts and power figures by many, many Ethernet ports per switch, and you quickly reach hundreds or even thousands of chips consuming thousands of Watts. These offerings are less network processors than network mainframes.

Bart Stuck and Michael Weingarten of Signal Lake Ventures show that one line-card produced with such an architecture would manufacture for $10,000, implying an ultimate market price of some $90,000. (Confirmation: One port on Ciena's CoreDirector optical switch prices at $100,000.) EZchip CEO, Eli Fruchter, modestly believes the NP-1 will replace at least 10 components in a typical line-card, enabling a Cisco or Juniper or Ciena to reduce its non-optical component costs by 75 percent. Using Weingarten and Stuck's assumptions, however, building with EZchip saves you closer to 90 percent. Fruchter believes that his company is one generation ahead. Would you believe two generations?

In conjunction with 64 parallel and pipelined "Task Optimized Processors" and patent-pending search algorithms, EZchip's DRAM enables extraordinary access to look-up tables and buffer memory. Multiple busses, each from 256 bits to 512 bits wide, connect at 200 MHz to 4 DRAM cores totaling 4.2 MB to attain its 500 gigabits per second of on-chip memory bandwidth. Multi-chip solutions connect to external DRAM at 64 bits and must endure a longer path as well.

Fruchter emphasizes reduced cost and power dissipation, greater port-density, and manufacturing and programming simplicity. But because the product exists only on paper, he may underestimate his device's edge in pure performance. It is difficult to believe, for instance, that alternatives using 50-plus chips can actually deliver on the goal—a faster, more robust Internet. By keeping its packets on-chip, EZchip limits their electronic lives and maximizes their photonic lives. Packets do not get lost. Traffic jams are avoided. Latency is reduced. Fewer components mean fewer points of potential failure. In the microcosm, smaller is better.

The difficulty in designing network processors derives from their broad flexibility and applicability, but that also points to their large potential market. Just as Intel Pentiums are used in $1,000-desktops and high-end servers alike, net processors may someday find themselves in everything from small firewall boxes to large core routers. Outside the domains of the all-optical network but everywhere on its edges, no piece of communications equipment that stands in the data path of the Net will be immune—from storewidth appliances to 3G wireless base stations. Cahners In-Stat projects network processor unit sales will increase from approximately 2 million this year to over 20 million by 2005. In the same period, revenues from these sales are expected to vault from $1 billion to over $10 billion. The size of the market will depend on how cheaply the chips can be made. But with a superior design and order-of-magnitude cost and performance advantages, EZchip is poised to prevail. We now know that the design works on simulators, that applications engineers have been using its software development tools for a year and that IBM is ready to make the chip. The question remains whether this large, complex device, with its tricky embedded DRAM, will work in the real world. We will find out in March.

Spacewidth galore from Hughes

Reaching the earth from 23 thousand miles away, widest and weakest of all are satellite signals. Although cellular bandwidth is improving, the technology continues to face a constraint of coverage. For coverage, the technology of choice is satellites. From San Diego, with various stops, I came to Washington to speak to a meeting for the current **General Motors** (GM) subsidiary **Hughes Network Systems** that is now launching its Spaceway technology. Probably to be absorbed by **Echostar** (DISH) and renamed DirectWay, the Hughes venture includes DIRECTV and DirecPC (which provides me access in the remote reaches of the Berkshires).

In its current form Spaceway consists of 3 geostationary satellites that can cover North America with a collective throughput of 30 gigabits per second. In *Telecosm*, I wrote that Spaceway would be trumped first by Globalstar and then by Teledesic. The prospects for both are now attenuated, though Jacobs in San Diego described enthusiastically the prospects for Globalstar as an airplane security tool.

EZchip believes the NP-1 will enable a CSCO or CIEN to reduce non-optical component costs by 75 percent

No satellite system can compete with fiber for bandwidth (one fiber cable after all can hold a few petabytes per second; Spaceway can process 9.7 petabytes per *month*). But satellites can aid in storewidth by feeding caches simultaneously around the globe. And satellites can offer *spacewidth* galore, covering the entire face of the earth at a cost thousands of times less than fiber and cellular can. For a total outlay of $1.5 billion, Spaceway now has a window of opportunity to provide coverage for all remote areas of the U.S. As I predicted, DIRECTV has become the chief source of digital television coverage, with some 16 million households covered by the Echostar-Hughes team. Spaceway can become the chief source of broadband Internet coverage in the remote areas of America.

George Gilder and Bret Swanson
with John Hammill
January 23, 2002

TELECOSM TECHNOLOGIES

ASCENDANT TECHNOLOGY	COMPANY (SYMBOL)	REFERENCE DATE / PRICE		DEC '01: MONTH END	52 WEEK RANGE	MARKET CAP
FIBER OPTICS						
Optical Fiber, Photonic Components	Corning (GLW)	5/1/98	13.64	8.92	6.92 - 72.19	8.4B
Wave Division Multiplexing (WDM) Components	JDS Uniphase (JDSU)	6/27/97	3.63	8.68	5.12 - 64.94	11.5B
Adaptive Photonic Processors	Avanex (AVNX)	3/31/00	151.75	5.90	2.70 - 83.50	392.0M
All-Optical Cross-Connects, Test Equipment	Agilent (A)	4/28/00	88.63	28.51	18.00 - 68.00	13.1B
Tunable Sources and WDM Components	New Focus (NUFO)	11/30/00	20.31	3.81	2.10 - 62.88	289.3M
Crystal-Based WDM and Optical Switching	Chorum (private)	12/29/00	—	—	—	—
WDM Metro Systems	ONI (ONIS)	12/29/00	39.56	6.27	3.50 - 58.63	875.8M
WDM Systems, Raman	Corvis (CORV)	3/30/01	7.03	3.23	1.19 - 30.00	1.2B
Metro Semiconductor Optical Amplifiers	Genoa (private)	3/30/01	—	—	—	—
Optical Processors	Essex (ESEX.OB)	7/31/01	5.90	7.95	2.88 - 8.25	40.4M
LAST MILE						
Cable Modem Chipsets, Broadband ICs	Broadcom (BRCM)	4/17/98	6.00*	40.87	18.40 - 139.50	10.7B
S-CDMA Cable Modems	Terayon (TERN)	12/3/98	15.81	8.27	2.36 - 14.75	567.6M
Linear Power Amplifiers, Broadband Modems	Conexant (CNXT)	3/31/99	13.84	14.36	6.57 - 21.50	3.7B
Broadband Wireless Access, Network Software	Soma Networks (private)	2/28/01	—	—	—	—
Gigabit Ethernet Coaxial Cable Networks	Narad Networks (private)	11/30/01	—	—	—	—
WIRELESS						
Satellite Technology	Loral (LOR)	7/30/99	18.88	2.99	1.03 - 6.34	1.0B
Low Earth Orbit Satellite (LEOS) Wireless Transmission	Globalstar (GSTRF.OB)	8/29/96	11.88	0.17	0.10 - 0.30	18.8M
Code Division Multiple Access (CDMA) Chips, Phones	Qualcomm (QCOM)	7/19/96	4.75	50.50	38.31 - 89.38	38.7B
Nationwide CDMA Wireless Network	Sprint (PCS)	12/3/98	7.19 *	24.41	15.72 - 33.25	24.1B
CDMA Handsets and Broadband Innovation	Motorola (MOT)	2/29/00	56.83	15.02	10.50 - 25.13	33.4B
Wireless System Construction and Management	Wireless Facilities (WFII)	7/31/00	63.63	6.73	3.31 - 45.19	316.0M
GLOBAL NETWORK						
Metropolitan Fiber Optic Networks	Metromedia (MFNX)	9/30/99	12.25	0.44	0.25 - 19.94	339.5M
Global Submarine Fiber Optic Network	Global Crossing (GX)	10/30/98	14.81	0.84	0.38 - 25.88	746.5M
Regional Broadband Fiber Optic Network	NEON (NOPT)	6/30/99	15.06	2.71	1.57 - 19.94	57.8M
National Lambda Circuit Sales	Broadwing (BRW)	6/29/01	24.45	9.50	7.50 - 28.88	2.1B
Internet Backbone and Broadband Wireless Access	WorldCom (WCOM)	8/29/97	19.95	14.08	11.50 - 23.50	41.7B
STOREWIDTH						
Java Programming Language, Internet Servers	Sun Microsystems (SUNW)	8/13/96	6.88	12.30	7.52 - 35.13	39.9B
Network Storage and Caching Solutions	Mirror Image (XLA)	1/31/00	29 .00	2.05	1.00 - 14.13	232.6M
Remote Storewidth Services	StorageNetworks (STOR)	5/31/00	27.00*	6.18	3.65 - 33.63	601.1M
Hardware-centric Networked Storage	BlueArc (private)	1/31/01	—	—	—	—
Virtual Private Networks, Encrypted Internet File Sharing	Mangosoft (MNGX.OB)	1/31/01	1.00	0.65	0.34 - 3.00	17.6M
Massively Parallel Global Storewidth Solutions	Scale Eight (private)	8/31/01	—	—	—	—
Secure Internet Business Exchanges	Equinix (EQIX)	11/30/01	1.65	2.90	0.33 - 7.50	232.1M
MICROCOSM						
Analog, Digital, and Mixed Signal Processors	Analog Devices (ADI)	7/31/97	11.19	44.39	29.00 - 64.00	16.1B
Silicon Germanium (SiGe) Based Photonic Devices	Applied Micro Circuits (AMCC)	7/31/98	5.67	11.32	6.01 - 88.25	3.4B
Programming Logic, SiGe, Single-Chip Systems	Atmel (ATML)	4/3/98	4.42	7.37	5.48 - 18.44	3.4B
Single-Chip ASIC Systems, CDMA Chip Sets	LSI Logic (LSI)	7/31/97	15.75	15.78	9.78 - 26.10	5.8B
Single-Chip Systems, Silicon Germanium (SiGe) Chips	National Semiconductor (NSM)	7/31/97	31.50	30.79	19.70 - 35.10	5.5B
Analog, Digital, and Mixed Signal Processors, Micromirrors	Texas Instruments (TXN)	11/7/96	5.94	28.00	20.10 - 52.50	48.5B
Field Programmable Gate Arrays (FPGAs)	Xilinx (XLNX)	10/25/96	8.22	39.05	19.52 - 59.25	13.0B
Seven Layer Network Processors	EZchip (LNOP)	8/31/00	16.75	6.37	2.70 - 19.25	46.4M
Network Chips and Lightwave MEMS	Cypress Semiconductor (CY)	9/29/00	41.56	19.93	13.72 - 29.25	2.4B
Field Programmable Gate Arrays (FPGAs)	Altera (ALTR)	1/31/01	30.25	21.22	14.66 - 33.60	8.2B

* INITIAL PUBLIC OFFERING

NOTE: The Telecosm Table is not a model portfolio. It is a list of technologies in the Gilder Paradigm and of companies that lead in their application. Companies appear on this list only for their technology leadership, without consideration of their current share price or the appropriate timing of an investment decision. The presence of a company on the list is not a recommendation to buy shares at the current price. Reference Price is the company's closing share price on the Reference Date, the day the company was added to the table, typically the last trading day of the month prior to publication. Mr. Gilder and other GTR staff may hold positions in some or all of the stocks listed.

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