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Your Cell Phone Is A Radio

Semiconductors will provide the impetus for more turmoil in the Telecosm.

Inside:

It was time to get a cell phone. It wasn't as simple as it should have been. What's the best rate plan? Which service providers serve my geographic area? Whose network covers areas I frequent? Are developments in the works that will change the choices in a month? Of course. It took me a year to collect the information and to decide. It shouldn't be that difficult. The service provider lost a year of revenue and, even with a huge investment in research, I didn't get what I needed.

Our cell phones—our personal radios—are tethered to one provider's physical network and to one provider's services. In ILEC (incumbent local exchange carrier) fashion, service providers have used wireless protocols to create the wireless version of the local loop (the wires between the customer and the central office). Having achieved the tethered cell phone, the industry is moving "more digital" to ride Moore's-law advances in semiconductors. Moore's law would normally help us cut the aforementioned tether by enabling software-defined radio (SDR). Unfortunately, candidate platforms for implementing SDR, DSPs and microprocessors, fall short. A new solution is emerging while two big industries, semiconductors and telecom, say respectively "consumer handhelds are small PCs," and "the term 'vertical business model' is redundant."

Babel rising

There's an alphabet soup of communication schemes (protocols) lodged between the cell phone and the network: CDMA, TDMA, PCS, GSM, CDMA2000, EDGE, W-CDMA, GPRS, et al. Service providers build their own networks (of base stations) and they provide the cell phones that work with their network. The cost to overlay the country with numerous incompatible wireless networks is mind-boggling. Overlaying the same area with multiple incompatible networks helps make spectrum seem scarce. Spectrum isn't scarce. Any cell phone should be able to talk to any base station. The cell phone should find the nearest base station. If there's a CDMA base station nearby, the cell phone shouldn't be forced to talk to a TDMA base station three miles away. The cell phone and the base station should agree on the best protocol for their circumstances, and they should communicate with the minimum necessary power.

Sound like an impossible dream? It's not. In fact, it's inevitable, but the business will have to change along the way. Just as the semiconductor industry's integrated device manufacturers are fragmenting horizontally (intellectual property cores, system-on-chip designers, foundries, and equipment suppliers) for greater efficiency, telecom's integrated service providers will split into cell phone suppliers, network suppliers, and service providers.

As it is now, a single company provides the service, builds the network, and supplies its customers with cell phones that work with that particular network. A few large cell phone suppliers build protocol-specific cell phones for the service providers. Your cell phone may be wireless, but it is effectively tethered to a vertically integrated business. Imagine what it would be like if the automobile industry had developed that way. You would buy a car from **Ford** (F) only if there were enough Ford fueling stations in your area; the pumps and the fuel at the **GM** (GM) station in your neighborhood aren't compatible with your Ford. Forget getting tires from **Goodyear** (GT) or Firestone; only Ford tires will fit. There may be only a few large tire manufacturers, but they produce custom tires for automobile suppliers, not generic tires for automobile owners. Forget Jiffy-Lube; that stuff's all custom, too, and comes only from the Ford service center. Costs are higher for everyone, including Ford. As Ford expands its dealerships, it has to build a network of proprietary filling stations, parts suppliers, and service centers. The cost of these facilities isn't amortized across the total number of cars in the field; it's amortized across only the Fords.

That's pretty much what today's cellular networks look like. Each service provider has its own protocol (CDMA, TDMA, GSM) and its own frequency band (in the United States, 850 MHz and 1900 MHz).

Cellular networks began as analog radios. Each cell phone in the base station's area got its own 30-kHz-wide analog "channel." The number of mobile subscribers grew and soon there weren't enough channels to go around. The information transfer supporting a voice conversation is low, so assigning a communication channel to a single conversation was extravagant. Engineers digitized the information from several conversations and interlaced or "multiplexed" them on a single channel. For time division multiple access (TDMA), six digital conversations share each analog channel. Each conversation is assigned its own time slot.

Moore's law outpaces demand for performance. Radios are an exception to this rule.

The change from analog to digital had two advantages for the service provider. First, the in-place analog base stations could be incrementally converted to digital as the number of digital users rose and as analog demand fell. In the base station, digital channels could displace analog channels one analog channel at a time. Second, each in-place base station accommodated more users as it converted its channel from analog to digital. More users, more revenue.

Moving to digital also benefited the users. The base station's increased capacity meant better access (fewer times when no service was available). The digital cell phone's battery lasted longer, because, unlike the on-all-the-time analog cell phone, the cell phone's electronics listened and talked only during its time slot.

While digital had advantages, it brought complications. The network couldn't be converted overnight. Roll out digital cell phones and base stations in Chicago and peripatetic digital subscribers can't use their new cell phones in Lubbock or Mobile or anywhere else that is on the waiting list for network conversion.

One solution to this dilemma is the "multimode" phone. Build a cell phone that has both: a digital channel and an analog channel. That's not a perfect solution. Analog and digital circuits are different animals. Manufacturers essentially cram both circuits into a single case. It's bigger, heavier, it costs more, and its battery doesn't last as long.

Time-sharing analog channel slots with digital conversations increased the capacity of the base station by a factor of six (TDMA) or eight (GSM). But multiplexing time slots isn't efficient either. Voice conversations are sporadic surges of words and lots of silence. The time slot is at regular intervals. So the silences waste the slots. Spread-spectrum signaling, such as **Qualcomm**'s (QCOM) CDMA (code division multiple access), is more efficient.

CDMA transmits information and it ignores silences. Spread spectrum does what it sounds like; it spreads the signal across its available spectrum. Unique codes, instead of unique frequencies or time slots, keep signals apart. Each transmitter uses a unique code to spread the information in the signal across a range of frequencies; the corresponding receiver uses the same code to "de-spread" the signal. Other users in the base station's range get their own unique codes. Your unique code is applied to all signals arriving at your receiver. It de-spreads your signal. Your receiver attempts to de-spread all the incoming signals with your unique code, but if the codes differ, the result looks like noise and is thrown out. The number of users the base station can talk to depends on the code-processing power of the base station. The base station doesn't run out of time slots for users; additional users just contribute a little noise. The base station saturates gracefully rather than abruptly. Cool stuff. Service providers build CDMA networks on top of their old analog networks. Spread spectrum faces the same build-out situation that digital time-multiplexing faced, so multimode cell phones have an analog circuit and a spread-spectrum circuit.

Converting an analog base station to CDMA isn't as easy or as incremental as it is for TDMA. TDMA squeezes six digitized conversations into what was once a single analog channel, so service providers can convert base stations one analog channel at a time, if they wish. CDMA, instead of cramming digitized conversations into narrow channels, spreads them across spectrum that would have been occupied by more than forty analog channels. Base stations forfeit large chunks of analog channels to make room for one CDMA spread-spectrum "channel." But each such CDMA channel supports many more digital users than the number of analog users it displaces.

In the United States, we now have analog networks, TDMA networks, CDMA networks, and even GSM networks. Further, many service providers compete. My CDMA phone won't work in Detroit unless my service provider has an agreement with Detroit's CDMA service provider. There's more. The protocols aren't fixed in number; there are a bunch of them—and they're evolving. Networks in other countries differ too. And they occupy different frequency bands. My cell phone won't work overseas (different protocols, different frequency bands); I'm lucky if it works for most of my domestic travel (different networks, different protocols, different service providers).

The spectrum allocation that began with the cellular band is now joined by the PCS (personal communications services) band. More protocols and more incompatible networks. Cram more stuff into the multimode, multiband cell phone. What a mess! Things aren't getting better, they're getting worse. We need standardization; we need the attributes of the PC market to invade the cell phone market.

Been there, done that

Years ago, the U.S. Department of Defense (DoD) saw this coming in its radio networks. Each of the armed services had grown its own communication networks independently and incrementally. In the old days, the services *operated* independently. For modern warfare, the watchword is "joint." Now, the armed-service chiefs recruit, train, and equip their forces. Operational commanders control joint forces from all the services that are deployed in their geographic area. Now we have a problem. The army's radios not only don't talk to air force or to navy radios, they might interfere by using the same spectrum. Some army radios can't even talk to other *army* radios.

Military equipment stays in the field a long time. Many of the air force's pilots fly airplanes that are older than they are, and most of the navy's ships are older than their crewmembers. Communication systems deployed in the '70s are still around today. The services have thirty to forty incompatible communication systems.

Maintenance and repair of old gear becomes a nightmare. Military electronics was once a significant portion of the semiconductor market. Today, it's insignificant. Try to find mil-spec replacement parts for a thirty-year-old radio. What to do? The services can't get components for old radios, and they can't afford wholesale replacement of a few thousand very expensive, mil-spec radios.

Enter software-defined radio

In the late '80s, the U.S. Air Force began experiments with software-defined radios. Instead of using physical components to create and to detect signals, a software-defined radio (SDR) does it with software. By careful design, and through software configuration, a single physical design might replace a dozen or so legacy radio designs. **Motorola**'s (MOT) SpeakEASY project, sponsored by the air force, was the vanguard.

The DoD has seen *generations* of SDRs. It's an almost-intractable problem, made that way by the plethora of legacy radios, by interservice rivalries, by funding uncertainties, by the agglomeration of requirements in a joint-services project, and by the need to develop the necessary standards.

Nevertheless, technical progress has made SDR feasible for DoD. But, component obsolescence, the proliferation of legacy systems, and the rise of joint-service operations are making SDR *necessary*.

So what do military radios have to do with cell phones? A lot. By its nature, the military doesn't build fixed networks, so its work on SDRs emphasizes mobile radios. Cell phones are mobile radios.

SDR concepts enable the aggregation of radio-chip-set suppliers' once-incompatible offerings. Instead of separate chip sets to handle each protocol in the alphabet soup, a single chip set with higher volumes and lower cost benefits the supplier and the customer. SDRs offer both the interoperability with legacy systems and the path to the future.

An SDR-enabled cell phone can talk to any base station. SDR concepts also apply to the base station. Suppliers build one higher-volume, lower-cost software-defined base station. It's better for the supplier and it's better for the network provider. The base station can define its channels to match the protocols of the cell phones in its area. The base station's radios can evolve with the development of popular protocols, which makes network upgrades cheaper. Cheaper radios, cheaper upgrades, better service, more users. The radio's software makes it adaptive.

If everyone benefits, why hasn't it happened?

Part of the reason is that the standards that would make it practical are still evolving and part of the reason is that microprocessor- and DSP-based designs won't be good enough.

Supply versus demand

In most technology areas, semiconductors improve faster than the demand for them grows.

Hard disks illustrate differences in the growth of supply and demand. The PC's hard disk capacity grew at about 60% per year. Hard disk capacity started well below what users wanted, but it grew faster. When the 5½-inch hard disk's capacity overshot the market, users bought cheaper, lower-capacity 3¼-inch hard disks.

The PC handily demonstrates supply and demand. When the PC first came out, its performance was well below what people wanted. The performance of the PC's microprocessor improved with Moore's law (doubling the number of transistors every eighteen months). The demand for performance among early adopters rises with time. But late adopters, with modest applications, smear the demand for performance across a range. Leading-edge PCs dominated the market until the PC's performance overshot the needs of more and more users. The PC's performance is good enough for a substantial portion of customers. "Value PCs" now dominate the market.

The hard disk and the PC show the interplay between supply, enabled by technology progress, and demand. For

TELECOSM TECHNOLOGIES

As you know, Nick Tredennick and Brion Shimamoto, former editors of our Dynamic Silicon letter, are bringing their unique insights to the Gilder Technology Report. In addition to big-picture thinking, Nick and Brion arrive with detailed knowledge of companies they've been following for years. Some of their favorite companies have long been favorites of the GTR. National Semi, for instance, or Altera, where Nick was chief scientist. Others will be new to GTR readers. Given this new material and the state of the technology and stock markets, we feel the best method for keeping our readers informed is to provide news and analysis on the impact stories each month. This means not every company "on the list" will appear in this space each month. But the information most important to your business and investment decisions will.

Ciena (CIEN)

METRO WDM PLATFORMS

JANUARY 17: 6.20 52-WEEK RANGE 2.41-14.30 MARKET CAP: 2.7B

Ciena announced results of its tender offer for all of the outstanding 5% Convertible Subordinated Notes due October 15, 2005, originally issued by ONI Systems, and assumed by Ciena in its acquisition of ONI in June 2002. The aggregate purchase price for all of the notes will be approximately $139.2 million. As a result of the tender offer, approximately $48.3 million in aggregate principal amount at maturity of notes will remain outstanding. Ciena estimates it will save approximately $15.5 million in future principal payments as a result of this repurchase.

Essex (ESEX.OB)

OPTICAL PROCESSORS

JANUARY 17: 3.40 52-WEEK RANGE 1.50-6.50 MARKET CAP: 26M

The U.S. Department of Defense awarded the company an additional $3.7 million to be used toward design completion, prototype fabrication, and testing at MIT/Lincoln Labs of an optoelectronic radar processor by late 2003.

Equinix (EQIXD)

SECURE INTERNET BUSINESS EXCHANGES

JANUARY 17: 5.37 52-WEEK RANGE 4.98-7.95 MARKET CAP: 46M

DONE DEAL—Equinix has completed the merger and financial transactions first announced by the company in October. The success of this deal landed Equinix a $30 million strategic investment, $26 million of cash from Pihana Pacific's balance sheet, and an immediate presence in the Asia-Pac Rim, the telecom world's fastest growing region. Equinix also enacted a 1 for 32 reverse stock split bringing the company's stock price in compliance with Nasdaq initial listing requirements.

KEY

DEBT WARNING · CASH RICH · INTELLECTUAL PROPERTY · IPO WATCH · NEW ADDITION TO LIST · MERGER & ACQUISITION · TECH BREAKTHROUGH · ADDITIONAL FINANCING · CUSTOMER WIN

Sprint PCS (PCS)

NATIONWIDE CDMA WIRELESS NETWORK

JANUARY 17: 4.49 52-WEEK RANGE 1.75-18.38 MARKET CAP: 4.5B

1X UPDATE—Sprint PCS continues to work with content providers to deliver fun and informative offerings such as Google's image search and Rhapsody's 411 music information services to its Vision customers that now number over 400,000. Further evidence of a growing mobile data market came from London-based Informa Media Group citing royalties from ring-tone sales in 2002, up 58 percent from the previous year and suggesting that the overall market is over $700 million annually, and quite possibly as high as $1 billion.

Meanwhile, Cingular proudly announced that it has deployed GSM/GPRS to more than 50% of its subscribers with plans to cover 90% by the end of 2003, completing the overlay by mid-2004.

Qualcomm (QCOM)

CDMA INTEGRATED CIRCUITS, IP, SOFTWARE

JANUARY 17: 36.80 52-WEEK RANGE 23.21-46.85 MARKET CAP: 29B

FOLLOW THE LEADER—An extremely positive development for the continued success of CDMA in the world's largest market is the announcement of a joint venture between China Unicom and Korea's SK Telecom. China Unicom has enlisted SK Telecom, the world's leading authority on commercial mobile data networks, to assist the company as it begins the rollout of its CDMA2000 1x network. Having launched the world's first CDMA2000 1x network in October 2001, SK Telecom possesses the deepest understanding of the technology and subsequent services that can drive uptake as well as operator's average revenue per user.

Broadcom (BRCM)

BROADBAND INTEGRATED CIRCUITS

JANUARY 17: 17.41 52-WEEK RANGE 9.52-49.43 MARKET CAP: 4.8B

A recent UBS Warburg CIO survey showed continued strength for the WLAN market in 2003 and beyond. Out of 85 respondents, 6 indicated they had already implemented a WLAN; 11 indicated they would deploy in the first half of 2003; and an additional 11 have slated adoption for the second half of 2003.

What Up g: Broadcom has won placement in several 802.11g solutions including Linksys, Melco, Buffalo, and the second coming of Apple's deified WLAN offering, AirPort Extreme.

MEAD'S ANALOG REVOLUTION

NATIONAL SEMICONDUCTOR (NSM)
SYNAPTICS (SYNA)
SONIC INNOVATIONS (SNCI)
FOVEON
IMPINJ
AUDIENCE INC.
DIGITALPERSONA

COMPANIES TO WATCH

ATHEROS
BLUEARC
COX (COX)
ENDWAVE (ENWV)
POWERWAVE (PWAV)
SAMSUNG
SCALE EIGHT
SYNOPSYS (SNPS)

Altera (ALTR)

PROGRAMMABLE LOGIC DEVICES

JANUARY 17: 12.39 52-WEEK RANGE 8.32-25.82 MARKET CAP: 4.7B

While presenting at this year's software-defined radio forum, technologists from Altera focused on leveraging the company's Stratix and Stratix GX device families in system-on-a-programmable chip (SOPC) solutions used for SDR applications.

EZchip (LNOP)

10 GIGABIT NETWORK PROCESSORS

JANUARY 17: 5.30 52-WEEK RANGE 3.79-16.45 MARKET CAP: 38M

EZchip announced the availability of its QX-1, 10-Gigabit traffic manager, to be offered as an optional companion to its NP-1 network processor. Also, in an effort to increase the flexibility and customization of its offering, the company will make the QX-1 available as an ASIC (Application Specific Integrated Circuit) or as a core for application in FPGA (Field Programmable Gate Array).

Terayon (TERN)

BROADBAND CABLE MODEMS, HEAD-ENDS

JANUARY 17: 2.57 52-WEEK RANGE 0.86-9.35 MARKET CAP: 188M

GET SYMMETRICAL—The growth of symmetric services, such as peer-to-peer file sharing and cable telephony, has altered the ratio of upstream to downstream traffic to one approaching parity from a substantial downstream bias only a couple of years ago. This transition will continue to drive adoption of the symmetric DOCSIS 2.0 standard, primarily benefiting Terayon.

National Semiconductor (NSM)

SINGLE-CHIP SYSTEMS, FOVEON IMAGERS

JANUARY 17: 14.79 52-WEEK RANGE 9.95-37.30 MARKET CAP: 2.7B

Taiwan's BenQ, the world's second largest LCD monitor manufacturer, has been added to the growing list of OEMs utilizing National Semiconductor's Geode processor-based Smart Display reference design. Smart Displays, through the use of 802.11b wireless networking technology, allow all data and applications to reside on the home PC yet remain instantly accessible from any room in the home. National's Geode processor incorporates the microprocessor, graphics, and interfaces used to drive a Smart Display device. The reference design also includes National's power management, audio, and display solutions.

Synaptics (SYNA)

TOUCH-SENSORS, FOVEON IMAGERS

JANUARY 17: 7.70 52-WEEK RANGE 3.13-20.75 MARKET CAP: 180M

Microsoft's cessation of support for the Windows 95 and Windows NT 3.5x operating systems as of December 31, 2002, has been whispered about as a possible catalyst for corporate spending. However, many believe the PC replacement cycle along with the massive installed base of 1998 and 1999 PCs to be mythical. As this argument plays itself out, Synaptics will benefit from the fact that notebook sales have continued to grow better than desktop PCs.

IPod Ovation: Major retailers have suggested strong CQ4 demand for Apple's iPod for which SYNA supplies the wheel interface.

Transmeta (TMTA)

MICROPROCESSOR INSTRUCTION SETS

JANUARY 17: 1.24 52-WEEK RANGE 0.74-4.47 MARKET CAP: 164M

Transmeta limped its way through another quarter reporting Q4 02 revenues of $6.1 million, up dramatically when compared to Q4 01 revenues of $1.4 million. The company received a boost from stronger than expected demand for Tablet PCs: specifically, HP's critically acclaimed Tablet PC TC1000 using Transmeta's new 1GHz Crusoe TM5800 processor currently selling worldwide. Going forward, Transmeta announced that it has received first silicon for a new enhanced security version of the Crusoe TM5800 and expects volume shipments in the second half of this year. We will be watching for meaningful design wins.

Intel (INTC)

MICROPROCESSORS, SINGLE-CHIP SYSTEMS

JANUARY 17: 16.34 52-WEEK RANGE 12.95-35.15 MARKET CAP: 108B

CENTRINO INSIDE—Intel's mobile processor and 802.11b Wi-Fi chipset formerly known as Banias and Calexico, respectively, have become one. Branded "Centrino," the mobile computing platform was a central theme of COO Paul Otellini's during the Q4 conference call. The first generation of Centrino is slated for the first half of this year and will be made up of a microprocessor and 802.11b chipset. Going forward, Intel quickly plans to incorporate an 802.11a/b multimode solution, integrated graphics chipset, and software designed to facilitate user connectivity to access points.

Exemplary Execution: Intel reported a very strong quarter with revenues of $7.2 billion, up 10% sequentially. Microprocessor ASPs increased and the company believes that it gained market share in microprocessors, chipsets, graphics, motherboards, flash memory, PDA microprocessors, and LAN-on-motherboard gigabit Ethernet connections.

Flextronics (FLEX)

CONTRACT MANUFACTURING

JANUARY 17: 7.85 52-WEEK RANGE 5.47-24.59 MARKET CAP: 4B

Flextronics has positioned itself as the primary beneficiary of the accelerating trend toward mobile phone outsourcing. Estimated at 7% of total units in 2000, this market has quadrupled and is now believed to be in the 25-30% range for 2002. The company produces close to 15% of the world's mobile phones, manufacturing an estimated 80% of all Sony-Ericsson phones as well as several models for Motorola, Alcatel, and Siemens.

Xilinx (XLNX)

PROGRAMMABLE LOGIC DEVICES

JANUARY 17: 22.59 52-WEEK RANGE 13.50-46.57 MARKET CAP: 7.4B

Xilinx reported revenues of $283 million, up 2% quarter-over-quarter. On a year-over-year basis, revenues grew 24%. Revenue from the communications category declined another 11% q/q after already declining 9% in the previous quarter. This continued weakness in the communications was offset by strength in the storage and server category, up 41% y/y.

most applications, Moore's-law improvements in semiconductors outgrow the demand for performance over time. *Radios are an exception to this rule.* The performance requirements of new protocols (2nd generation, 2.5G, 3G, 4G) are growing faster than the Moore's-law pace. *The performance of digital signal processors (DSPs) is falling behind.* Microprocessors and DSPs continue to get faster, but the critical metric is cost-performance-per-watt. Cost-performance-per-watt means the same or lower cost with more absolute performance at the same or lower power. And there, microprocessors and DSPs are falling behind requirements.

Speaking of DSPs

Advanced DSPs, which can no longer meet requirements with only instruction-based processing, are adding special-purpose hardware. **TI**'s (TXN) recently announced TMS320C6416 digital signal processor, which is intended for 3G applications, sports two specialized, on-chip coprocessors (the Viterbi decoder and the Turbo coder and decoder). General-purpose processors are employing specialized hardware to meet performance requirements. Unfortunately, these custom modules differ by protocol, narrowing their usefulness, and therefore the market, for a particular implementation. DSPs are morphing into application-specific integrated circuits (ASICs).

Vertically integrated service providers built today's cellular networks.

Specialized DSPs buck the trend toward multimode, multi-band radios. These multimode, multi-band radios need both performance (cost-performance-per-watt) and flexibility.

DSPs specialize to meet the performance requirements of an application, but they forfeit flexibility and market breadth in doing so. DSPs and microprocessors can't do the job. The difficulty is in the way the problem is being solved. Since the introduction of the microprocessor in 1971, their use has grown from nothing to billions of units a year. The microprocessor brought the computer's problem-solving method to embedded systems. Its Moore's-law improvements expanded both the range of its application and the scope of its duties within an application.

Universities have now trained generations of engineers to build systems and to solve problems by writing programs for instruction-based processors. This works for most applications because the processor's performance is good enough. But the inherent problem with instruction-based processing is that *it is simulation*—it's not the direct implementation of the function. Before the microprocessor, the engineer designed both the structure and the procedure. After, the microprocessor provided the structure and the engineer provided procedure within that structure. This is not bad in itself. What is bad is that an appreciation of the inherent inefficiencies of instruction-based solutions is all but lost engineering lore. It will take time to relearn.

The largest contributor to raising the performance of DSPs and of microprocessors is clock frequency. Doubling frequency doubles performance. But doubling frequency also doubles power dissipation. Were it not for decreasing power-supply voltages, power dissipation would soon get out of hand. Halving the supply voltage allows circuits to run four times as fast for the same power. Unfortunately, there's a limit to how far the supply voltage can decrease—the transistors stop working. We're close to that limit and can no longer trade voltage for performance.

Whence the new leading edge?

Cell phones must meet escalating cost-performance-per-watt and flexibility requirements. DSPs and microprocessors are running out of room to trade voltage for performance.

Application-specific integrated circuits, with their efficient direct implementation of functions, can meet the performance requirements of advanced protocols, but ASICs lack the necessary flexibility.

Future generations of cell phones need the performance and the power efficiency of custom hardware and the flexibility of programmed solutions, at the cost of generic components. Cell phones need custom hardware "paged" into general-purpose chips. That sounds like programmable logic. But general-purpose PLDs, such as those from **Altera** (ALTR) and **Xilinx** (XLNX), won't do. The overhead transistors that support all-purpose interconnect and that support programmable input/output (I/O) functions make general-purpose PLDs impractical for cell phone applications. General-purpose PLDs are too big, their logic is too slow, and they are not built for fast (microseconds) reconfiguration.

DSPs and microprocessors can't do it, ASICs can't do it, and PLDs can't do it.

Opportunity

QuickSilver Technology, a Silicon Valley pre-IPO startup, thinks it has a solution to this dilemma. I agree. QuickSilver designs programmable logic chips specifically to go into cell phones. (This isn't quite what QuickSilver says, but it's close enough. QuickSilver may license designs and development tools to third parties that build chips.) That reduces the tremendous overhead of general-purpose I/O and of generally programmable interconnect present in general-purpose programmable logic devices. Instead of implementing functions as instructions running on a general-purpose processor or as custom hardware modules, QuickSilver breaks functions into "algorithmic elements." View these as small, custom hardware macros that are aggregated to build direct implementations of larger functions. Paged configuration of algorithmic elements offers the flexibility of programming with the efficiency of custom logic.

Where we're going

Your cell phone is portable, so it wants long battery life. It's a consumer item, so it has to be low cost. And it's a complex digital radio, so it needs good performance. The ultimate cell phone could talk to any base station using any protocol. It could load updates, protocols, or services over the air. It could accommodate new protocols. It would be agile enough to change protocols (such as moving from a TDMA base station to a CDMA base station or to a Wi-Fi network) *during a call*.

The base station plugs into the power grid, so power conservation isn't critical as it is for a cell phone. It's also not a consumer item, so it's not as cost-sensitive. The primary design objective of the base station is performance. It's designed to dig out weak signals from moving cell phones.

The ideal base station would *adapt* to talk to any cell phone in its area. It would dynamically allocate its channels to match the mix of users. And it would have the flexibility and the resources to upgrade to new protocols through its connection to the network.

In the beginning, voice dominated transmissions. Voice signals digitize to a rate of 10- to 16-kb/second—a low-data-rate signal. And they tolerate error rates of one bit in a thousand. Data traffic is increasing (multimedia, web pages, data files). Data rates for these transfers want to be as high as they can be. Nothing is too fast. And they demand error rates better than one bit in a million.

Vertically integrated service providers built today's cellular networks. These networks cost too much to build, they cost too much to operate, they cost too much to maintain, and they don't work as well as they should. This situation isn't good for the users and it isn't good for the service providers. The service providers' current vertical orientation will fragment horizontally to look more like the PC business.

Forces driving the horizontal fragmentation include semiconductor progress, advancing communication protocols, vastly more cell phones, and the transition of channel content from low-bit-rate voice to high-bit-rate data.

It's not just cell phones that will communicate; it's *everything*. Bluetooth and 802.11x are communication protocols for smart devices. Soft radio implementations will enable smart devices to configure themselves to match any protocol that's handy for connecting to the network.

The industry won't tolerate vertically integrated service providers that cling to charge-by-the-minute business models based on voice traffic. Independently operating smart devices and their data transfers will dominate network use.

Wrap

Analog circuits don't scale well, so Moore's-law progress favors digital logic, which does scale well. (Transistors in digital circuits are either on or they are off, so their operation is relatively insensitive to the transistor's material characteristics or to its size. But transistors in analog circuits operate in the linear region *between* on and off. There, the operation is very sensitive to the transistor's characteristics and to its size. The operation of analog circuits depends on the characteristics of resistors, capacitors, and inductors in the circuit. These devices are usually outside the chip and do not scale easily. In addition, design tools support digital designs, but not analog designs. Digital circuits move from one semiconductor process to the next without the labor-intensive redesign that accompanies analog circuits.)

A hitch in the transition from mixed analog and digital to the all-digital radio is that processing requirements rise faster than the DSPs and microprocessors of today's digital implementations improve. Compensating for the lack of general-purpose computing power, by adding custom processing functions, won't work because it forfeits flexibility and because such customization narrows the range of application for the chip, making it less cost-effective.

Instruction-based processing, which simulates functions, is inefficient; it uses too much power and it lacks performance. A custom implementation, such as an ASIC, is power-efficient and is fast enough, but is too expensive. An ASIC-based implementation is inflexible; it cannot adapt to new protocols and it cannot be patched or upgraded in the field. What is needed is the flexibility of instruction-based programming and the implementation efficiency of an ASIC. Instruction-based processing is one-dimensional in the sense that the primary way to increase performance is to speed instruction execution, which correspondingly raises power use. In direct implementation of logic functions, such as is done in ASICs, designers spend speed (frequency) *or* area (more transistors) for performance. Direct implementation of a logic function can be hundreds or thousands of times faster than its instruction-based equivalent. Programmable logic enables the flexibility of paging efficient hardware functions.

If you think programmable logic is too slow and that it has too many configuration transistors per net logic transistor to be practical for any radio applications, then you'd be wrong. General-purpose PLDs take too long to configure, they are too slow, and they use too much power for *cell phones*, but general-purpose PLDs can work for *base stations*. The issue is more about flexibility and about function efficiency than it is about conserving absolute numbers of transistors. General-purpose programmable logic devices from Altera and from Xilinx are being designed into software-defined base stations.

Programmable logic can be custom-tailored for cell phone applications. There's no inherent barrier to rapid reconfiguration. Focusing the application on cell phones reduces transistor overhead, making the "custom PLD" faster and more power-efficient.

Your cellular service costs too much and it doesn't do what you want it to do. The industry is struggling to get to 3G and it doesn't seem to be getting anywhere. Meanwhile, Wi-Fi spreads rapidly. What's going on? The industry has two basic problems: one is the way the industry is organized and the other is engineering design.

The problem with the industry organization is that the service providers are vertically integrated; the suppliers of services also build the networks and provide the cell phones. Service providers, like the mainframe computer companies before them, cling to centralized-control, charge-by-the-minute business models. The industry will work better once the vertically oriented service providers fragment into independent network owners, independent cell phone suppliers (there are independent cell phone suppliers today, but they supply the service providers rather than the network's users), and independent service providers. Wi-Fi may lead the way or the fragmentation may happen as the service providers go through bankruptcies, but it will happen as surely as it did when small computers broke the applications-are-tied-to-the-central-computer business model.

The second problem is more difficult. In mobile devices, the demand for cost-performance-per-watt is outpacing Moore's law. This means traditional microprocessor- and DSP-based design methods aren't good enough to build next-generation mobile devices. That means new design concepts and it means retraining design engineers. The good news is that designs based on programmable logic can do the job and that some startups are heading in the right direction.

Soft Radio Scorecard: Who Wins, Who Loses

COMPANY	TYPE OF COMPANY	FUTURE POSITION	THE WAY I SEE IT
Celoxica, MathWorks, Synopsys	Software	Excellent	As radios go digital, the level of abstration for implementing functions rises. Celoxica and Synopsys offer conversion from programming languages to soft hardware. MathWorks' Matlab and Simulink, which offer even higher-level description languages, will gain popularity.
Chartered, TSMC, UMC	Foundry	Excellent	As the digital content of systems increases, use of general-purpose chips increases. Larger production runs of fewer chip types are more profitable. Foundries are the principal suppliers of programmable logic devices (PLDs). The PLD market will continue to grow rapidly.
ADI, GCT Semiconductor, ParkerVision, Qualcomm, Skyworks, TI	Chip Supplier	Good	These companies supply chip sets for direct-conversion receivers. As digital content of radios increases, direct-conversion radios dominate implementations. As intelligent devices penetrate more applications, radios for wireless connection will proliferate.
Altera, Xilinx	Fabless	Good	Radio base station designs will use programmable logic chips. Programmable logic devices will begin to displace microprocessors and digital signal processors in a variety of applications, greatly increasing the market for PLDs.
Motorola, Ningbo bird, Nokia, Samsung, Sony-Ericsson, TCL	Handsets	Good	The handset market will continue healthy growth. Handsets in the field will eventually be replaced with versions based on programmable logic. The emerging high-growth market in China particularly benefits Motorola and TCL.
QuickSilver	Fabless	Good	It will be difficult for programmable logic implementations to gain ground against microprocessor-based implementations, but paged-hardware implementations will eventually displace instruction-based implementations.
Advanced Communications Technologies, AirNet Communications, Chameleon	Base stations	OK	Network buildout continues. Legacy systems with fixed-protocol implementations will convert to software-defined implementations.
AT&T, Sprint, Verizon	Service Provider	Struggle	Vertically organized service providers will struggle to maintain charge-by-the-minute business models as the industry fragments into handsets, networks, and services.

The "position for the future" and "the way I see it" apply only to the topic of the issue. Possible positions for the future are: excellent, good, OK, struggle, and fail. A company that is "excellent" with respect to horizontal fragmentation of an integrated business may, for example, "struggle" with cultural obstacles in another technical transition. A company listed as "struggle" in another issue could be listed as "good" in this issue since issues cover different topics.

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