

Mobile phones work only in some areas, and they become obsolete rapidly, as new features are developed. Flexible software in phones and wireless networks could change all that.

The great wireless revolution, which took off with the spectacular spread of cell phones in the 1990s, and which is supposed to bring broadband Internet to the gadget in your pocket, is in trouble.

Demand is soaring, forcing makers of wireless equipment and network operators to invest billions to meet humanity's inexhaustible thirst for getting connected anywhere, anytime. Global sales of mobile phones soared from seven million in 1990 to 700 million last year and are projected to reach 1.7 billion in 2005. More and more users expect their phones to deliver very clear voice signals and to pick up their e-mail, albeit slowly.



Illustration by Stephen Sheffield

But as frustrated callers know, communicating with mobile phones is tricky. The problem: today's wireless networks use a maze of incompatible transmission standards, so road warriors aren't guaranteed a dial tone when they travel. U.S. wireless operators alone use three competing standards, and just one of these is compatible with the leading standard in Europe, which itself has several variants. Most Asian wireless networks are built to another standard. This radio-wave Babel prevents most mobile phones in the United States from being viable elsewhere. It also limits U.S. manufacturers' economies of scale against foreign competitors.

The wireless revolution's troubles go beyond conflicting standards. Consumers consistently expect more advanced features, so models that were state of the art in, say, 1995 will seem antique by 2003. By then, almost all new mobile phones will offer some form of Internet access. Millions of people in Japan, for example, snapped up i-mode, a service that lets them use cell phones to send text messages, buy stocks and check sports scores. Worldwide, companies are spending billions to build a new network, usually referred to as "third generation," or 3G, that is expected to bring broadband—detailed Web pages, music, even video—to your mobile phone.

However exciting for consumers, these advances carry a price, since there's currently no easy way to upgrade mobile phones, or the base stations that carry their signals to the network, without changing hardware. Moreover, the wireless industry can't predict which offerings will be winners; the consequences of failing to guess right can be devastating. Last year, European

wireless operators spent heavily to offer phones equipped with a format known as Wireless Access Protocol, only to find the buying public impatient with their slow download speed. Demand was limp.

Small wonder that wireless companies are looking for ways to make their networks flexible, so as to avoid costly retrofitting as demand changes. A technology first developed by the military and now being pursued by several technology leaders could be the key. The technique is known to experts as software-defined radio, or SDR. ("Radio" refers here not to AM or FM, but to any equipment that communicates through the airwaves on radio frequencies, as cell phones do.) The advantage offered by this new approach is that it shifts the workload of wireless units from dedicated components to software that can be reprogrammed to work on a different standard or add applications. That's entirely different from today's mobile phones and base stations, in which virtually all signal processing is carried out by electronic circuitry designed to do one and only one thing.

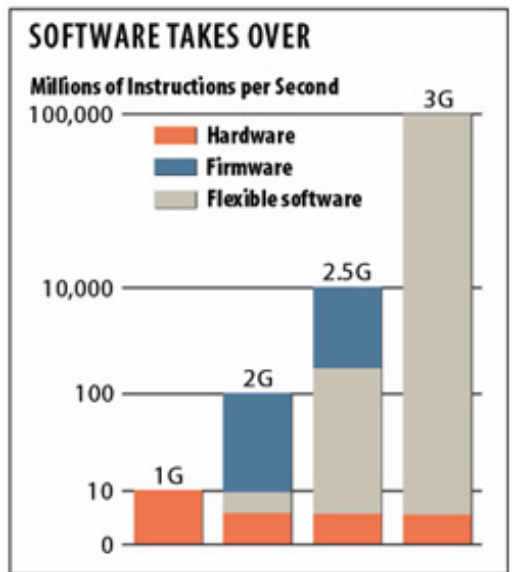
The migration toward wireless networks that are adaptable due to their use of reprogrammable software "is one of the most important trends in technology today," says analyst Craig Mathias of MobileInsights in Mountain View, CA. James Gunn, of the Dallas-based consulting firm Forward Concepts, calls this trend the "revolutionary next step" that wireless technology needs.

Flexible software could also help solve another basic problem for the whole wireless enterprise: scarcity of spectrum (or bandwidth). As the demand for wireless communication explodes, there is an accompanying dearth of the necessary frequency channels. The Federal Communications Commission recently concluded that networks using reprogrammable software could ease that shortage because they could seek out and use temporarily unoccupied channels. Last December, the FCC proposed rules for its licensing of equipment and software in order to speed up U.S. adoption of the technology.

More like a PC

The first cell phones relied on dozens of hardware components. In the past 15 years, programmable chips have been added, but their function is set immutably at manufacture. Today, dedicated, single-purpose chips do most of the work in mobile phone handsets and base stations; these chips are made as simple as possible to keep costs down.

Given the mishmash of conflicting standards and the uneven advent of the next generation of broadband wireless, manufacturers such as Motorola are starting to see dedicated components as a liability. A manufacturer that guesses wrong about the future standard will find itself with a lot of useless junk in its warehouses. As Ken Riordan, of Motorola's Personal Communications Sector in Libertyville, IL, puts it, "If you commit your solution to hardware, and you get it wrong, then you're going to be in a very jeopardized situation."



Successive generations of wireless technology (denoted by "G" numbers) will shift more processing into software. (Graph by Betsy Hayes)

So more-general-purpose software that can be reprogrammed looks appealing.

No one understands the trade-offs better than Joseph Mitola III, a radio engineer whom many insiders perceive to be the central innovator in the field. Early in life, Mitola became fascinated with computer code; he learned Fortran while attending high school in Providence, RI, in the 1960s. When he got to college—Northeastern University in Boston—he says he was "one of the few who knew how to program anything." Mitola had also tinkered with radios. Combining both interests led to a career creating top-secret radio designs for the military—including the first software-defined radios, which were for military use (see "[The Military Seed](#)"). Indeed, the commercial wireless industry learned of the technology in the early 1990s mainly through Mitola's papers and lectures. His military bosses cleared these for public release, figuring the military could benefit if the commercial world pushed the technology further and brought costs down.

The problem Mitola was trying to solve was similar to the situation that would arise if you had to put a new circuit board in your PC every time you wanted to do a different task—say, switch from Web browsing to a spreadsheet. You'd eventually run out of space inside the box. The same holds true for cell phones. "If you want to cram in four more functions, it means each device has to be about a quarter the size it was before," says Mitola, now at the McLean, VA, office of MITRE, a nonprofit R&D consultancy. But, he adds, chips aren't shrinking rapidly enough to make that possible, given the many standards and functions the wireless revolution demands.

If mobile phones and their base stations *were* computers, new software could download easily through their wires. But wireless communication is fundamentally different. Mobile phones must push signals across the airwaves at precisely the right power level and in the exact transmission format. They must be tuned to receive incoming, powerful signals from one or more channels. Antennas catch irregular analog signals traveling through space on "carrier" frequencies; incoming radio signals must then be converted to an intermediate frequency through combination with another radio wave produced inside the receiver. Then the carrier wave gets subtracted to put the signal in baseband—that is, a power level and speed that ordinary digital processors can handle. While the signal is in baseband, it is translated into a stream of binary ones and zeroes, which are in turn decoded, decrypted and formatted into voice or data.

The first operations to benefit from reprogrammable software are operations in the baseband. In one model of Motorola base station, for example, the software that performs the baseband coding and decoding is reprogrammable, according to Motorola's Riordan.

Next, manufacturers would like reprogrammable software to handle the intermediate-frequency and radio-frequency parts of the job. That's a more difficult technological challenge, in part because silicon—which is by far the most common and least expensive chip material—does not handle radio-wave signals well. Radio-frequency processing of broadband signals will most likely use gallium arsenide chips running 100 *billion* instructions per second, compared to the roughly 10 to 100 *million* instructions per second in single-purpose chips in present-day phones.

The rise in computing complexity is exacerbated by the push to send signals much faster. So-called third-generation broadband wireless service could move data at two megabits per second, a roughly hundredfold leap from the operating speeds of most of today's wireless networks. All these demands mean chips will require lots more power; added power is far more easily obtained in a base station than in a small, lightweight mobile phone.

Still, Mitola says he would like to see a mobile phone that "digitizes the whole signal at the antenna" across widely spaced frequencies. "Then," he adds cheerfully, "other software can do whatever it wants with it." Such a flexible

phone, he says, will be able to sniff out unused channels in the spectrum. Several U.S. chip makers, including big players Texas Instruments and Analog Devices, are pushing to develop the enabling technology. Small firms such as QuickSilver Technology of Santa Clara, CA, and Morphics Technology of Campbell, CA, are also vying for the prize.

To start with, however, manufacturers are putting reprogrammable chips mainly into base stations that relay signals from cell phones to the network. Unlike handsets, base stations have few space or power constraints. For instance, Lucent Technologies, second to Motorola as a supplier of wireless base stations worldwide, has new models that are "smart" (that is, they have a flexibility endowed by software) at the antenna. According to Paul Polakos, director of the company's advanced wireless technology lab in Whippany, NJ, the new base stations can shift among multiple channels, assuming different "personalities" depending on which type of communication is called for—analogue or digital voice transmission, high-speed data, or broadband.

Cramming this kind of software-derived flexibility into lightweight handsets will not be easy. Even Mitola admits that "truly breakthrough technology" will be needed for a lightweight handset to flex among three or four frequency bands and operational modes. Meanwhile, smart, software-programmable wireless sets will find their way into vehicles, which can accommodate larger and heavier systems than people's pockets can. Indeed, one early use of flexible software radio technology will be in radios in police and fire vehicles: public safety agencies' wireless systems are notoriously incompatible. The FCC is encouraging public agencies to adopt this technology. Several firms, such as Vanu of Cambridge, MA, are developing equipment for this market.

Future Phones—Smarter Still

Wireless devices that morph through different "personalities" on the fly would be a boon to their users. But at the same time they create policy problems, as new technologies that cross boundaries often do. Historically, the FCC authorizes each piece of equipment for a type of use and specific channel. How should the regulators license mobile phones and base stations that can readily be changed after they're in use? How free should third parties be to load new software into your phone? How will it be possible to distinguish legitimate upgrades of the network from rogues trying to subvert it?

The FCC decided that rules to cover these scenarios were not needed—yet. But it also concluded it should facilitate this technology's evolution. A main reason is the lack of enough spectrum for third-generation wireless services in the United States at present. So equipment that sniffs out and utilizes unused swaths of spectrum could alleviate what the FCC calls the U.S. spectrum "drought."

To do this, however, will require both base stations and handsets to become supersmart—a leap to what Joe Mitola calls "cognitive radio." A cognitive device will not only scan its spectral environment; it will also have built-in memory and maps and positioning capabilities. Those will enable it to react intelligently to its environment.

Over the past two years, Mitola built a crude civilian version of a cognitive radio as a doctoral project for Sweden's Royal Institute of Technology. When this device is outdoors, it configures itself to use the prevailing cellular phone protocol; when carried indoors it switches to the format of the building's local area network. Mitola explains that a more advanced version could "know" that the person carrying it is in trouble and send a distress signal on the local emergency frequency to give rescuers its location.

But mobile phones that reorient to a new channel for temporary use would have to get permission to "rent" that spectrum for some period of time from the official licensee. In a

paper that foreshadowed his doctoral thesis, Mitola proposed a payment system that would employ the signal protocols (*see "Wireless Rent-A-Channel"*). Using such a system, your intelligent handheld would scan the spectrum to find a channel that was not in use at the moment; for example, it might find one that the local fire department had the license to use but was offering for rent. Your radio would bid to rent the channel. The fire department's radios, receiving the bid, could agree—or wait for other bids. But the instant the station's bells rang and the firemen needed their channel back, their radios would bump the renter off. Mitola reckons the channel's owner could regain control in 25 milliseconds—a delay that would be unnoticeable to human speakers. Your cognitive mobile phone would sign off, reckoning and paying a bill for time used, then start scanning for another open channel.

The FCC, in endorsing this vision, has joined forces with an unlikely ally: George Gilder, self-styled seer of the "telecosm" and critic of the FCC for holding back innovation. For years, Gilder has predicted that intelligence will grow at the edges of the wireless telecom network with the result that channels become fluid. Wireless devices and networks that employ flexible software, he says, will "transform the entire world of wireless communications," the way personal computers transformed wired networks.

The swaths of spectrum that are most commercially desirable are often referred to as prime beachfront property. But Gilder wants people to stop thinking of spectrum as some kind of ethereal analogue to physical land. "Smart radios suggest not a beach but the endless waves of the ocean itself. You can no more lease electromagnetic waves than you can lease ocean waves."

Making that ocean available to billions of people could be one impact of flexible software-based wireless networks. But even before we reach this nirvana of spectrum abundance, the technology could make wireless networks more cost effective and future-proof—and keep the wireless revolution rolling.

Deborah Shapley is a former editor of *Technology Review* who specializes in communications. She has written for the *Christian Science Monitor*, the *New York Times*, and *Time* magazine.

Companion Articles

The Military Seed

The notion of controlling most operations of wireless reception and transmission with software evolved during the Cold War. The military needed receivers that could scan the spectrum, sense incoming signals from enemy aircraft or ships and react with countermeasures on the same frequencies. Though this military equipment was heavy and armored—not to mention expensive—one developer, E-Systems in Dallas, saw the commercial potential. When the Cold War ended, the company and its clients at the Pentagon allowed public release of basic principles.



Illustration by Stephen Sheffield

That wasn't the end of the military's role in developing this technology. In post-Cold War operations, different armed services needed to be able to work together more closely, due to budget limitations and because wars were most likely to take place in more confined theaters. The U.S. Defense Advanced Research Projects Agency began the SPEAKEasy project to see how reprogrammable software could help the myriad military radio systems talk to each other. The Naval Research Laboratory, meanwhile, has produced a chameleonlike "information terminal" now used on board some Army

vehicles. This system can adopt any of 12 radio “personalities” from software stored in memory.

Although DARPA works with big defense contractors, much of its largesse is directed at universities. Among its projects on flexible software communications technologies is MIT’s SpectrumWare project. Vanu G. Bose’s research on this project led him to found Vanu, which markets flexible radio designs to the military and law-enforcement agencies.

One DARPA project foreshadows the “cognitive radio” networks prophesied by MITRE radio engineer Joe Mitola. The Small Unit Operations: Situation Awareness System is intended for ground troops entering hostile or empty terrain with no available communications. According to DARPA program manager Paul Kolodzy, troops will be able to “communicate clandestinely in buildings, jungles and mountainous terrain.” Their wireless transmitters and receivers will sniff out available spectrum and then form an intelligent network that might be totally independent of the local authorities’ radio systems, and possibly independent of other U.S. military radio systems operating in a theater. The wireless devices would know where they were, even when “reliable Global Positioning Satellite fixes are not available.” How do they do that? Don’t ask.

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