ROGER ALLAN
Contributing Editor

Wireless sensing spawns the connected world

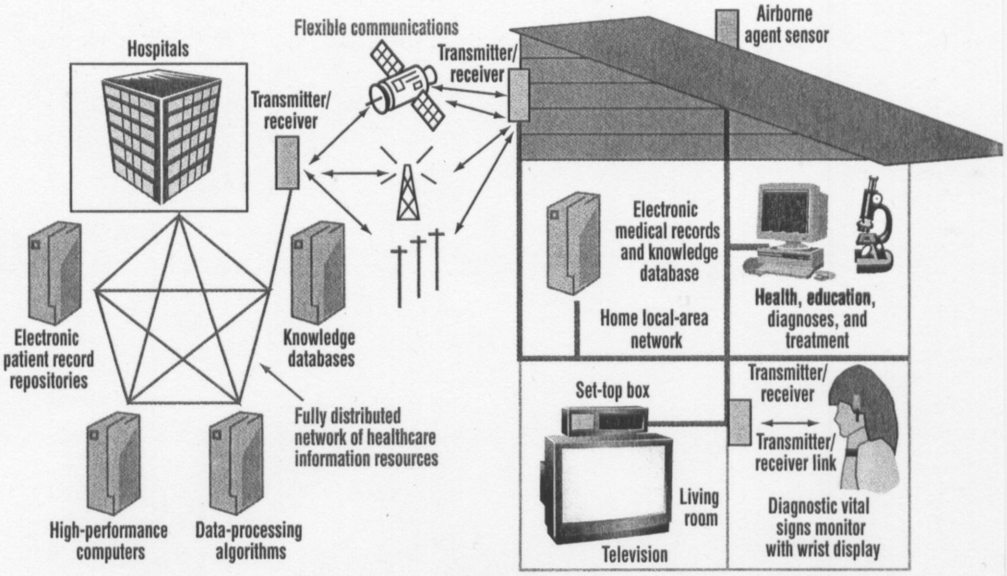
Innovations in sensing, wireless communications, and computing technologies foreshadow ultra-intelligent environments and enhanced lifestyles.

Seamless connectivity between people, objects, and events—such a climate once seemed so daunting. Not any more, thanks to rapid-fire advances made in sensor, computing, and communications technologies, let alone the pervasive use of the Internet. Entirely new applications will embed computing power and wireless communications in our daily lives.

Advances in both telecom and the Internet will converge to deliver ubiquitous wireless sensor networks and pervasive computing *(Fig. 1)*. Professor Dipankar Raychaudhuri, director of the Wireless Information Network Laboratory (WINLAB) at Rutgers University, sees five key changes:

- In frictionless capitalism, consumers can find goods and services by consulting their PDAs as they walk through town. They also can go into stores and purchase these items without the need for any cashiers.
- Smart transportation systems can route vehicles around traffic jams in real time. They also can provide collision-avoidance feedback with augmented reality displays. On top of that, they can guide people to their parked vehicles in a crowded garage or parking lot.
- Airport logistics and security systems can enable passengers to board their planes, find their lost bags (via RFID tags), and be screened for unusual patterns, all with minimal interruption.
- Smart homes will play a key role in assisted living for the disabled and elderly *(Fig. 2)*.
- Workers in smart offices will be able to quickly and accurately search for physical objects, documents, and books. They will also be able to maintain "lifelogs" of stored events by location and/or time and date.

The cell phone will play an important role in the real-world application of many of these scenarios. Customers could use their phone, for instance, to pay for food at the grocery store, eliminating the need to carry cash or a credit card. Motorola's M-Wallet cell phone is an indicator of how these capabilities will be incorporated into the designs of third-generation (3G) handheld devices. With the M-Wallet, users can pay bills, conduct money transfers, and complete point-of-sale (POS) purchases.

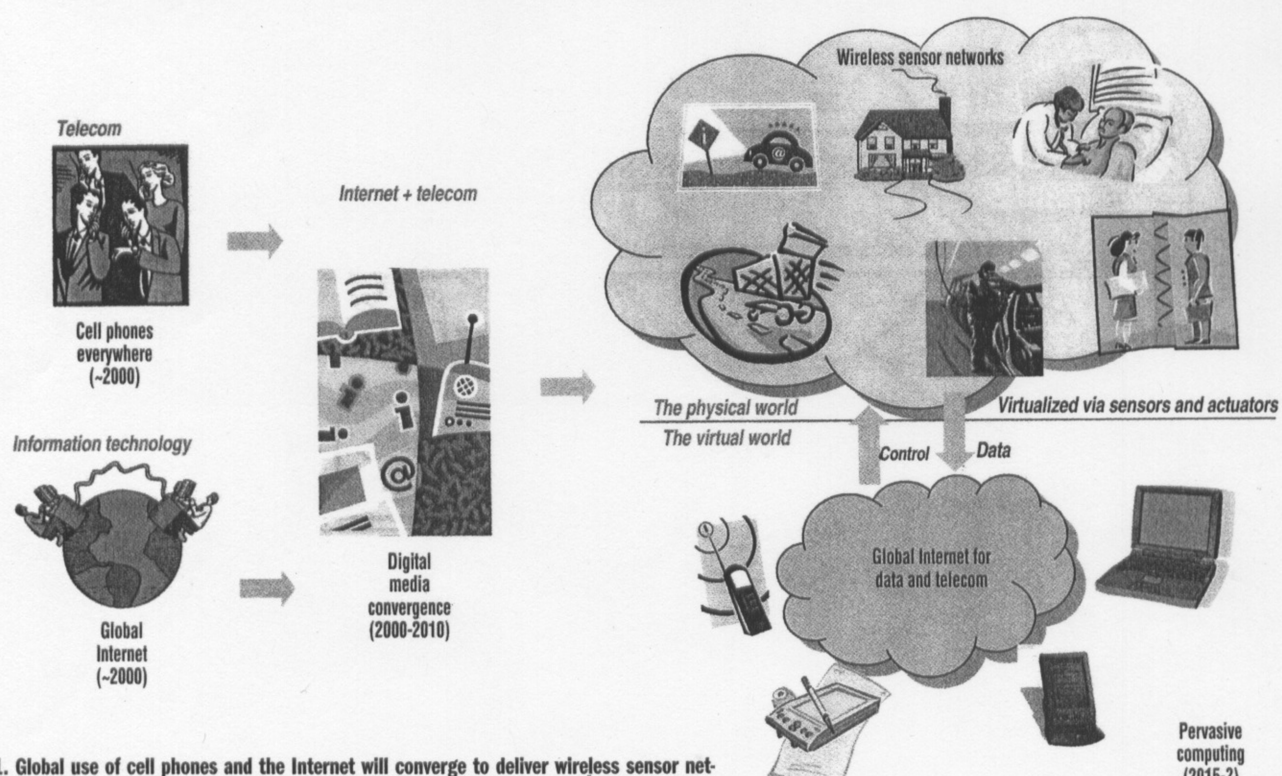


2. Healthcare delivery in a typical smart home will take advantage of ubiquitous wireless sensing, computing, and communications. ***(Courtesy of the University of California at Berkeley)***

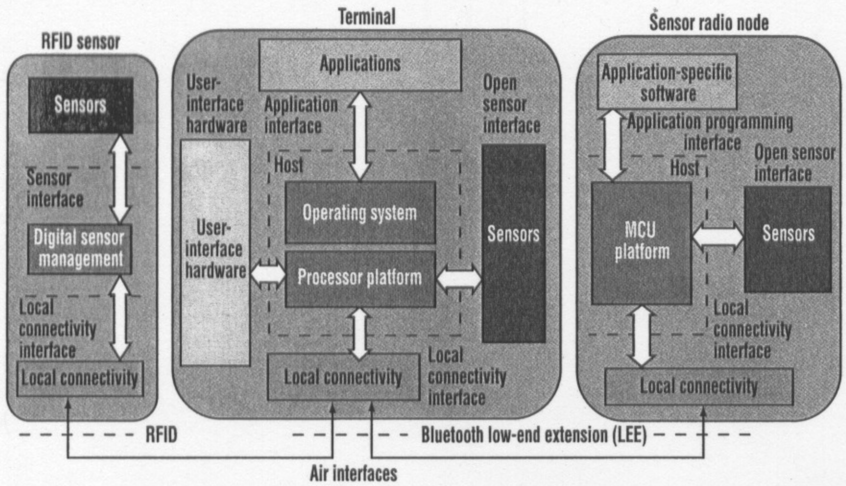
The MIMOSA (MIcrosystems platform for MObile Services and Applications) consortium has set its sights on an open technology platform for ambient intelligence centered around mobile-phone technology. This organization, which comprises 16 member partners in eight European countries, is funded by the European Union's Sixth Framework for Research and Technological Development *(Fig. 3)*.

MULTIMODE LOW-POWER SENSORS IN DEMAND • There's a lot of demand for sensors that can measure more than one parameter while dissipating a lot less power. "Sensors, in general, do not have enough output power and range to make it [survive the transition] into a wireless world," says Rutgers University's Raychaudhuri.

One proposal uses sensors in a pulsed-output mode to minimize power dissipa-



1. Global use of cell phones and the Internet will converge to deliver wireless sensor networks that tie the physical and virtual worlds with pervasive computing. ***(Courtesy of Rutgers University's WINLAB)***



3. The MIMOSA consortium developed an overall architecture specification for a mobile-device-centric open technology platform for ambient intelligence. ***(Courtesy of STMicroelectronics)***

tion. One thing is clear, though. For untethered electronics, a low-cost, reliable alternative to the battery has yet to be found. Until then we must rely on improvements in battery technology, which have their limits *(see "The Promise Of Harvested Energy," p. 55)*.

Intelligent microelectromechanical-system (MEMS) sensors are being developed to address these problems. In a joint effort, the University of Florida and Freescale Semiconductor foresee the possibility of a very low-cost MEMS motion sensor that dissipates a mere 1 mW, giving it the potential to operate continuously for up to one year. It's so sensitive, it can sense sounds as well as motion. Compatible with a standard IC process, the device can be planted inside helmets and clothing to monitor the body movements of athletes and home-care patients.

The Rutgers University WINLAB is working on a multimodal wireless sensor (MUSE) multichip module that includes a sensor, the RF communications circuitry, a modem, a CPU, and supporting circuits *(Fig. 4)*. Integrated with low-power transceiver designs, applications are initially targeted at medical heat-monitoring applications. Ultimately, it will be used in a wide range of other applications that call for a sensor, including heat, light, motion, and water-flow.

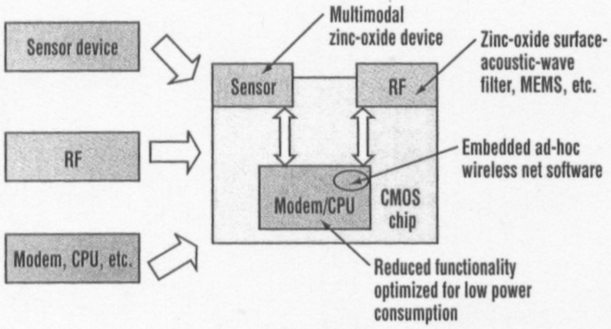
The tunable MUSE device consists of zinc-oxide materials, and it can be programmed to operate in dual modes (acoustic and ultraviolet optic). It can also be reset to increase sensitivity for liquid and gas sensing. First-generation implementations will be in system-on-package (SiP) and system-on-a-chip (SoC) configurations. A single-chip prototype is slated to debut sometime this year.

Minimizing sensor power-dissipation levels and maximizing output levels (and thus transceiver range) are, of course, two key goals for designers. However, efforts also are under way to minimize transmitted sensor data loss and maximize sensor output information content via smart MEMS sensors.

With the two latter goals in mind, the National Center for Supercomputing Applications at the University of Illinois Urbana-Champaign developed a thermal infrared (IR) wireless MEMS sensor that calibrates cameras. The work was jointly performed with Crossbow Technology, using its MICA sensor hardware, and Indigo Systems Inc. with its thermal IR cameras.

Nokia's Bluetooth low-end extension (BTLEE) radio concept seeks to improve Bluetooth transmissions and lower costs. It complements Bluetooth by allowing small devices (those limited in battery power, size, weight, and cost) to have wireless connections to mobile terminals without adding yet another radio to those mobile terminals. Nokia developed a BTLEE radio system to demonstrate the concept's feasibility and expects to push out products next year.

WIRELESS NODES GET A BOOST • The power problem goes beyond available



4. The MUSE project integrates multimode sensing, computing, and communications circuitry onto one chip. (Courtesy of Rutgers University's WINLAB)

sensor output power levels and high power-dissipation levels. The power needed for wireless transceiver nodes also is a concern. BitWave Semiconductor proposed using software-defined radio (SDR) to deal with this problem. The company points to its Softransceiver concept as an example of a viable SDR solution that enables seamless global wireless connectivity *(Fig. 5)*. The SDR concept minimizes circuit hardware costs. Instead, it relies on software changes to program or "tune" a circuit to a specific application.

A group of researchers at the University of California at Berkeley came up with a 2.4-GHz wireless transceiver that dissipates only 200 μW. Kris Pister, founder and chief technology officer of Dust Networks (and who coined the term "smart dust" while heading R&D efforts at Berkeley), lauds this work as an important step toward low-cost wireless sensing hardware. Dust Networks is working on low-cost wireless sensing software to complement the technology.

"Berkeley's work is all about low-cost hardware. At Dust Networks, we're

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working on low-cost software," says Pister. "We came up with communications protocols that keep wireless radios off 99.995% of the time. Low-power software running on low-power hardware is what we're looking for. At that point, power consumption goes down into the single-digit microampere range."

To give users better tools so they can move quickly while developing their core applications, Jennic Ltd. recently showed off its IEEE 802.15.4/ZigBee transceiver modules. The JNS5121MOxxx devices provide minimum bill-of-materials (BOM) costs with minimum engineering time spent on RF circuit design and test development.

Yet the world of ubiquitous sensing, computing, and communications lacks standard software platforms. Adoption of the Tiny Operating System (TinyOS) developed at the University of California at Berkeley has helped, but it's only the beginning.

Now, sensor network designers are starting to build on the TinyOS concept. Crossbow Technology's MoteWorks software/hardware wireless mesh development platform uses TinyOS. It supports rapid, flexible, and open designs based on the IEEE 802.15.4/ZigBee standard.

At WINLAB, the open-access research testbed (ORBIT) system facilitates a broad range of experimental research on next-generation protocols and application concepts for wireless networks. A 64-node radio-grid emulator was already released. A full 400-node radio grid is being tested indoors; an outdoor system will be operational shortly. The project involves Rutgers University, Princeton University, Columbia University, Thomson SA, IBM, and Lucent Technologies.

WINLAB also fabricated and tested a novel wireless sensor network known as SOHAN (self-organizing hierarchical ad-hoc network). The laboratory says that

THE PROMISE OF HARVESTED ENERGY

Nature possesses a boundless amount of harvestable energy that can be harnessed to power wireless sensor networks. Potentially, it can eliminate the need for batteries in tethered electronics and solve many power-supply and dissipation problems in one stroke.

Vibration, strain and inertial forces, heat, wind, light, and magnetic fields can all be tapped for this purpose. Piezoelectric materials, for example, can convert mechanical motion into electric currents and vice versa. Magnetic and inductive coils can tap inertial forces. And, thermovoltaic and photovoltaic cells can harvest the energy given off by heat and light.

To successfully harvest energy, one must overcome formidable economic and reliability challenges. The battery industry is fast approaching performance limits in terms of materials and chemistry, which will pose another hurdle. But while the work on energy harvesting is only in its infancy, recent success in the laboratory shows that there's hope.

Perpetuum Ltd. and Innos Ltd. teamed up to develop embedded MEMS silicon microgenerators for wireless communications. The devices feed off the vibrations in the environment to produce consumable energy *(see "Microgenerator Harvests Kinetic Energy For Wireless Devices,"* Electronic Design, *Sept. 15, 2005, p. 28, ED Online 11050).* Each 5- by 5- by 1.5-mm device can produce a few hundred microwatts of energy under certain conditions, which can drive sensors, small microprocessors, and RF transmitters for a complete self-powered system.

The University of Texas at Arlington's Materials Science and Engineering Department, meanwhile, has produced small piezoelectric-based generators to power wireless networks. Powered by 5- to 10-mph winds, the devices can produce up to 50 mW. That's enough to support individual nodes in a wireless sensor network.

The MIMOSA consortium has made energy harvesting—or energy "scavenging"—a major goal. So to that end, energy sources like photovoltaic cells, RF waves, and thermocouples are certainly worthy of investigation.

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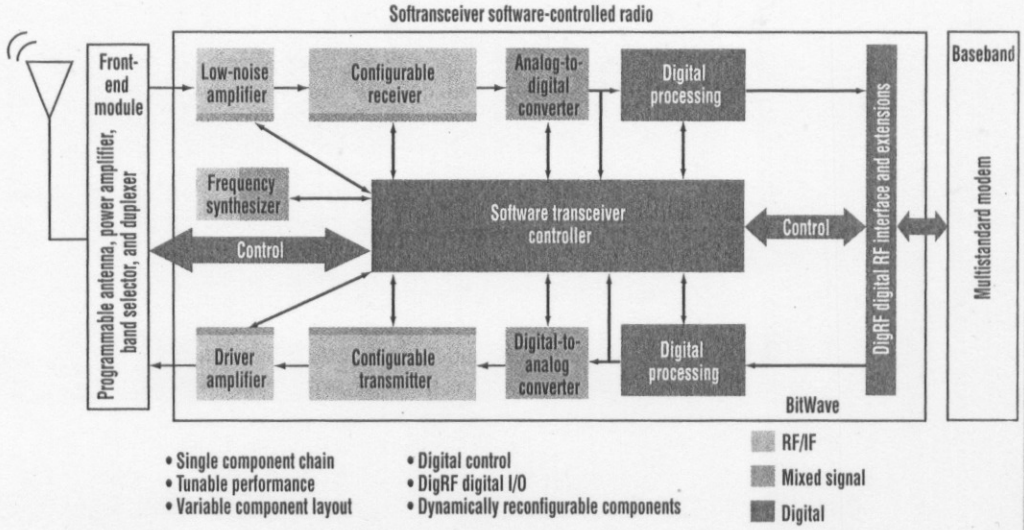
this network, which has been prototyped, offers significant capacity improvements over conventional ad-hoc wireless sensor networks.



5. BitWave Semiconductor proposed using its Softransceiver software-defined-radio (SDR) concept for viable seamless global connectivity.

LOOKING FORWARD • Wireless sensor techniques eventually will mature to permit the seamless interconnection of the physical and virtual worlds. Wireless network technologies like WiMedia Ultra-Wideband (UWB) will enable users to do things like download an entire television show in just one minute. Demonstrations of such capabilities already have proven feasible, so it's only a matter of time before there's wide-scale market acceptance.

With Qualcomm's MediaFLO service, users can receive TV broadcasts on cell phones with a TV decoder. The decoder can also decode video from other sources, such as digital video recorders. Users will be able to download programs from other sources onto their phones and watch them when they're on the go.

The rapid proliferation of low-cost, low-power, radio-frequency-identification (RFID) tags in industrial, medical, and agricultural applications only adds to the seamless pervasiveness of connectivity. All-plastic—instead of silicon—RFID tags have aided RFID advances. Many such tags will debut this year.

Even still, there's a need for new software development and deployment approaches. The industry also must develop the right networking protocols, the organization of network-based services, and techniques for self-organization, self-configuration, and self-maintaining large distributed systems.

Privacy and security issues must be resolved as well. "If a wireless network's architecture is not planned for privacy and security from the beginning, it will never succeed," warns Rutgers University's Raychaudhuri.

New business models are needed, too, so that there's interoperability between devices and services. This will ensure the flexibility consumers demand. Ultimately, though, technology must be shaped to address a wide range of user needs.

The impact of ubiquitous sensors may create some surprises in the long term. Some technology forecasters predict a greater emphasis on analog computing and networking to faithfully interact with the real world of analog sensors. After all, the real-world variables detected by sensors are all analog in nature.

"A modest indicator of this trend is visible today in the audiophile world," says Paul Saffo, director of the Institute for the Future (IFTF). "The most sophisticated audiophile stereo systems available today still rely on old-fashioned vacuum-tube technology. Audiophiles can tell the difference between sound that has been deconstructed into bits and reconstructed as an analog waveform and sound that has remained in analog form all along."

Ubiquitous sensing will rely on computing and communications. In turn, these technologies will depend on the wide-scale deployment of actuators that enable total closed-loop system control. MEMS technology can fulfill this need. ED

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