

Eight Connective Technologies: Report and Forecast

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In his seminal treatise *The Medium is the Massage*, Professor Marshall McLuhan

declared, "Our time is a time for crossing barriers, for erasing old categories—for probing around. When two seemingly disparate elements are imaginatively poised, put in opposition in new and unique ways, startling discoveries often result."

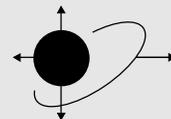
The year was 1967. Now, on the cusp of the new millennium, we are seeing Professor McLuhan's words born out like never before and, possibly in a way, not even anticipated by him.

Steeped in and surrounded by a world in transformation, we're again entering a deeper period of digital innovation. A period when connective and micro technologies are giving rise to startling new discoveries and groundbreaking applications.

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Introduction

In looking at the cresting wave of digital innovation, we've chosen to focus on a cluster of eight connective technologies—technologies that help people cross boundaries between work and play, home and office, and the physical and digital worlds. These eight clusters represent technologies that will critically transform work, and workspaces, over the following decade. They include: Small-Scale Power Systems, Smart Materials, Biometrics, Displays, Voice Technology, Tagging, Peer-To-Peer Networks, and Wireless Technology. And their subsequent innovations herald a world in which context and connection will have profound new meaning; in which people can choose to be more connected, or connected in new and different ways.

To understand the impacts of these technologies, we need to understand the trajectories of the technologies themselves—the ways in which they might interact over the coming decade, as well as the choices that users will make as they incorporate these technologies into their daily lives.

And so we ask the questions: What is this new technology? Why is it important? How is it used or applied? How will it evolve? What about standards—how will it be integrated? What are the key business impacts? And what about roll-out—when will these products enter the marketplace?

The figure in the center of this report presents a forecast for these eight technology clusters and addresses these questions, delivering a concise cocktail of information and an explanation. This is a story—not about technologies—but about the role they will play in a rapidly transforming world. A story we hope will enhance your understanding of, and excitement for, what lies ahead.

Small-Scale Power

The small-scale power supply

is one of the more liberating advancements in next-wave innovation.

These groundbreaking power sources are long lasting, eminently portable, flexible pieces of microtechnology, some of which can even be printed on paper.

Small and micro-thin, these mini batteries may be rechargeable, and sometimes even transparent.

Through processes akin to lithography and silk screening, electrolytes, cathodes, anodes, and conductors can be affixed or “printed” on paper or other more durable substrates. These new, open-cell batteries are safe, eco-friendly (they utilize no heavy metals and require no casements); they can be made in virtually any shape, and can be easily integrated onto almost any surface. They can even withstand crushing or bending.

The array of small-scale components currently in development includes microbatteries, transparent solar cells, micro fuel cells, and “parasitic” power systems that are able to convert power from the systems they harmlessly draw from.

Importance

To date, small-scale power supplies have been the missing link in the information revolution—the obstacle to the ubiquitous computing, aware environments, and smart machines heralded as the next big wave of silicon intelligence. Within the decade, however, all this will change.

As the micro-device market grows, coming innovations will redefine the personal uses of power. The individual will now be free from the household and workplace power grids, relying, when desired, on personal (and personalized) mobile power systems. Connectivity, communication, and knowledge management will be forever changed.

Microbatteries—seamlessly integrated into the objects they power—will mirror other integrated circuits on the miniaturization curve, as power itself will become a component subject to Moore’s Law. Costs may be dirt cheap. Vertical and lateral buildout in the industry will swell, flooding the marketplace with a myriad of useful new gadgets and peripherals.

The result—all of these advancements will provide the breakthrough needed to put power wherever we want it, in whatever form-factor we can imagine. Power will be lightweight, fully mobile, inexpensive, and easily pervasive.

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SMALL-SCALE POWER (CONT.)

Uses & Applications

Up to now, various power factors have impinged on the advancement and development of micro devices. Power density, cell weight, battery life, form factor—all of these have proven significant and cumbersome when considered against micro applications. Batteries of the future will need to be miniaturized, untethered, and on-the-move.

With the transformation and miniaturization of stand-alone power, what you could call big, dumb voltage will now give rise to small, smart voltage—batteries tailored specifically to the objects they will power. Small-scale power systems will enhance innumerable new, as well as existing, wireless devices. And uses will run the gamut, augmenting cell phones, laptop computers, communicating cameras, even smart wearables.

Future Innovations

Small-scale power systems will be a driving force for almost all connective technologies, especially for displays and smart materials.

At the systems level, important power-supply developments will be realized when power circuits integrate with other circuits using the same manufacturing technology. As mentioned above, all of these will continue to shrink in size and cost, ultimately supporting a US\$3 billion market in micro-electro-mechanical devices (or MEMS, pronounced “memz”). Small-scale power is projected to achieve nearly 100-percent penetration in the MEMS market.

Many options and uses for small-scale power are on the horizon, so it seems impossible that a single solution, winner-take-all technology will dominate the field. Nevertheless, we do anticipate that some technologies will find much broader application in the coming decade than others. The lineup is as follows:

Microbatteries

The lead technology in small-scale power systems is the microbattery—a very tiny power supply that can be printed on integrated circuits (ICs) like any other electronic component. Production will be low-cost and high-volume. And these batteries can be manufactured in any size, shape, voltage, or power capacity needed.

Pioneered at such places as Brigham Young University, the Korea Institute of Science and Technology, the University of Tokyo, and Oak Ridge National Laboratories, microbatteries are now in active production at several companies, including BiPolar Technologies and Infinite Power Solutions.

The leading edge of this technology is the thin-film lithium ion microbattery, which is not only tiny, but also flexible. Technology has already been developed that allows for printing “caseless” zinc-manganese dioxide batteries on paper or other flexible surfaces.

Power Paper, an Israeli/Hong Kong company currently spearheading many small-scale power advancements, has pinpointed microbattery uses in consumer e-novelties (promo items, stationery, jewelry, and I-wear [intelligent wearables]), medical applications (transdermal drug delivery devices, electro-stimulation patches, and diagnostic microsensors), as well as smart cards and smart tags (enabling technology for security authentication, data storage, and the like).

Micro Fuel Cells

This technology mimics the cell structure existent in all living things. Micro fuel cells produce electricity by electrochemically combining hydrogen and oxygen without combustion. Unlike standard batteries, so long as fuel is supplied, this type of battery will not run down.

These miniature cells offer a non-polluting, non-toxic power source, are “always on,” and have an estimated 20-year shelf-life.

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Micro fuel cells promise 10 times the energy of conventional batteries, while weighing and costing substantially less. For example, a cell the size of an ink-pen cartridge might power a cell phone for up to a month without chargers or adapters.

Motorola is currently commercializing a technology developed at Los Alamos National Laboratory. Another player in this arena is the Microsystems Laboratory at Ajou University in Korea.

Parasitic Power

Using piezoelectric materials, or miniaturized rotary lever motors, parasitic power supplies translate human activity into power to supply their local needs. The most commonly cited examples are shoes that convert walking motion into power for devices worn on the body, as well as keyboards whose key action can generate ample power to run the devices to which they're attached.

This form of small-scale power generation has caught the imagination of several big technology developers, including MIT Media Lab, IBM, and Compaq Computer. At the Electric Shoe Company, the technology is already on the cobbler's bench.

Transparent Solar Cells

Solar cells concentrate light onto semiconductor material to generate electricity. The Graetzel cell, for example, is a small, transparent cell that can be silk-screened on just about any surface to create a solar power source that you can see through.

The technology has been developed in Japan by Toshiba, as well as other companies in Japan, Europe, and Australia.

Swatch is hoping to commercialize this type of technology for use in a new genre of self-powering wristwatches.

Biocatalytic Cells

Biofuel cells utilize biologically-based compounds and natural reactions (such as oxidation) to produce power along standard, miniaturized electrodes.

By employing enzymes, water, and the bioelectrocatalytic oxidation of glucose, an electrical charge can be generated that fuels the cells. Experimentation with photoswitchable biomaterials, as well as magnetic control of the bioelectrocatalytic reaction will give rise to new means of triggering electrical signals.

These cells could be used within information storage and processing systems, as well as molecular machines.

Microwave Power Transmission

An innovation still in development is the use of microwave radiation for power transfer. By employing microwaves, this technology is expected to be used to transfer power from point A to point B in a single beam.

Other Innovations

In addition to the above, many other applications and innovations exist.

Currently in the works from New Jersey-based Dieceland Technologies are disposable cell phones—flexible devices as thin as three credit cards that will come complete with simple dial-out features, and an hour's worth of talking time. Some phones may even be rechargeable, both for power and connect time. Projected retail price: about US\$10.

Visual displays and display screens are typically the biggest energy consumers in a portable device, generally demanding a tradeoff between power use on one hand, and quality, size, and mobility on the other. However, innovations in small-scale power systems, together with the emergence of low-power displays, will change this basic equation. In synergy, advances in these two connective technologies will increase the opportunity to employ innovative applications of mobile displays.

► **SMALL-SCALE POWER (CONT.)**

Integration, however, will prove a significant breakthrough in small-scale power systems—not only at the product level, but also in the manufacturing process. In addition to cost savings and portability benefits, this kind of integration points to the future of “smart power”—integrated “smart cells” that can be continuously monitored, adjusted, and even automatically recharged according to the requirements of the application. Power will be delivered efficiently, when and where it’s specifically needed.

But the real head-turners will be aware environments, and PANs—or personal area networks—supported by personal, mobile power systems, that will interact with the technology and environments around them.

Turner Whitted, an engineer at Microsoft Research, is an enthusiastic proponent of PANs. Whitted’s work incorporates a network of various wearable, interconnected gadgets, all powered by piezoelectric generators (in this case, special shoes—see next section on Smart Materials). Each device connects to a communication “hub” worn either on a special belt or pendant. The hub communicates with very low resolution LCD displays for a variety of specific functions, and can interact with various environmental displays including walls, windows, furniture, etc. (For instance, the hub could communicate information about the user’s state—say, a medical patient’s failing heart rate—and in turn would receive adaptive services from environ-

mental systems that don’t have the power restrictions of body-based gadgets [i.e., the patient would receive the necessary heart electro-stimulation from a machine connected to a hospital’s own power supply]).

Standards

Table 1 presents certain emerging small-scale power technologies, as well as their chief proponents and developers.

Key Business Impacts

- Advancements in small-scale power will increase adoption of, and dependence upon, pervasive wireless devices. For the most part, PDAs and mobile phones have already broken the “same-day” threshold, enabling users to recharge them each evening; the next threshold—a month of uninterrupted usage for small form-factor devices, and a day for higher-power devices such as laptops—will allow business users to depend upon these devices for business critical information and transactions.
- Power will emerge in what were previously inhospitable environs, enabling new applications to come into existence. Remote, wireless devices will provide timely warnings of system failures, and will improve our ability to control far-flung production and transportation systems.

*Table 1
Standards: Small-Scale Power*

Selected Emerging Standards	Proprietary or Open	Significant Proponents/Developers
MicroFuel cell™	Proprietary	Manhattan Scientifics
DMFC	Proprietary	Mechanical technology, Dupont, SUNY-Albany
TFM	Proprietary	Power Paper, International Paper, KSW-microtec

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- Various groups of workers will find that small-scale power provides them with the means to do their jobs differently, and more efficiently. Technicians and repair persons are likely to adopt wearable computers in place of heavy paper manuals. As systems complexity grows—whether in auto repair or server farm maintenance—interactive manuals will alter worker routines and will make “hands-on workers” into members of the knowledge workforce.

Smart Materials

The world of **materials** stands poised on the edge of an evolutionary leap. “Stuff” is getting smarter.

Over the past century, we have learned how to create specialized materials that meet our specific needs for strength, durability, weight, flexibility, and cost. However, with the advent of smart materials, components may be able to modify themselves, independently, and in each of these dimensions.

Smart materials can come in a variety of sizes, shapes, compounds, and functions. But what they all share—indeed what makes them “smart”—is their ability to adapt to changing conditions.

Smart materials are the ultimate shapeshifters. They can also alter their physical form, monitor their environment, even diagnose their own internal conditions. They can also do all of this while intelligently interacting with the objects and people around them.

More boldly, it is highly likely that once smart materials become truly ubiquitous—once they are seamlessly integrated into a webbed, wireless, and pervasive network—smart materials will challenge our basic assumptions about, and definitions of “living matter.”

Importance

In certain respects, smart materials are an answer to many contemporary problems. In a world of diminishing resources, they promise increased sustainability of goods through improved efficiency and preventive maintenance. In a world of health and safety threats, they offer early detection, automated diagnosis, and even self-repair. In a world of political terrorism, they may offer sophisticated biowarfare countermeasures, or provide targeted scanning and intelligence-gathering in particularly sensitive environments.

In general, smart materials come in three distinct flavors: passively smart materials that respond directly and uniformly to stimuli without any signal processing; actively smart materials that can, with the help of a remote controller, sense a signal, analyze it, and then “decide” to respond in a particular way; and finally, the more powerful and autonomous intelligent materials that carry internal, fully integrated controllers, sensors, and actuators.

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► **SMART MATERIALS (CONT.)**

Taken together, these three types of smart materials will form the foundation of a rapidly growing market in micro-electro-mechanical sensors—a market that is estimated to reach US\$3 billion by mid-decade.

Uses & Applications

The components of the smart materials revolution have been finding their way out of the labs and into industrial applications for the past decade. As yet, they fall into several classes and categories: piezoelectrics, electrorestrictors, magnetorestrictors, shape-memory alloys, and electrorheological fluids.

What these materials all have in common is the ability to act as both sensors and actuators. In some cases, when a force is applied to these smart materials, they “measure” the force, and “reverse” the process by responding with, or creating, an appropriate counter force. In other cases, the materials are populated by sensors that detect environmental conditions within the material itself. When conditions cross designated thresholds, the materials then send a signal that is processed elsewhere in the system. For instance, “smart concrete”—under development at the State University of New York at Buffalo—would be programmed to sense and detect internal hairline fissures. If these conditions are detected, the smart material would alert other systems to avoid a structural failure.

Smart materials are currently used for a growing range of commercial applications, including noise and vibration suppression (noise-canceling headphones); strain sensing (seismic monitoring of bridges and buildings); and sensors and actuators (such as accelerometers for airbags). A number of companies, including The Electric Shoe Company and Compaq, are also exploring the use of smart materials. The Electric Shoe Company is currently producing piezoelectric power systems that generate electric power from the body’s motion while walking. Compaq is investigating the production of special keyboards that

generate power by the action of typing. (See the Small-Scale Power section on page 3 for more on piezoelectric systems.)

Descriptions of applications for the smart materials mentioned above suggest that their impact will be broadly felt across industries.

Piezoelectrics

Piezoelectric materials produce an electrical field when subject to a mechanical strain. Conversely, if an electrical field is applied to them, the material is stressed. Thus they can be used to generate low levels of power from simple mechanical motions or to deform surfaces in response to electrical signals. An excellent example of this is the application of smart materials in snow skis. Piezoelectric elements adjust the stiffness of the skis in response to conditions on the slope by damping shock and optimizing performance throughout a run.

Magnetorestrictors

These materials behave much like piezoelectrics, in that they are reciprocal devices that can both “receive” and “send” information within the systems that they inhabit. However, unlike piezoelectrics, magnetorestrictors respond to a magnetic field rather than an electric field. As such, they produce a magnetic field when strained.

Applications for magnetorestrictors include machine tools, transducers, and sonar systems. Magnetorestrictors can also be used for vibration control (in factory equipment or automobiles), fuel injection systems, and the reconditioning (relining) of aged water and sewer pipelines.

Shape Memory Alloys (SMAs)

This special class of adaptive materials can convert thermal energy directly into mechanical work. For example, smart shape memory alloys can be “pro-

▶ **SMART MATERIALS (CONT.)**

grammed” to adopt a specific shape when the alloy reaches a designated temperature (say, 100° Fahrenheit). This same alloy can then be manipulated or mechanically deformed to adopt a different shape when not in this designated temperature (say, when the material is at 50° Fahrenheit). In turn, when the alloy is heated above a critical transition temperature (approaching 100°), the material will “remember” its earlier shape and restore it—effectively converting the heat into mechanical work.

Alternatively, SMAs can be trained to exhibit two shape-memory effects. In this case, heating the SMA results in one memorized shape while cooling results in a second, different shape (manipulation could then occur at a third, variable temperature).

Shape Memory Alloys are currently used in various military applications. For instance, vibration-dampening SMAs, when deployed on supersonic fighter planes, decrease vibrational stresses on materials, thereby increasing the life and viability of the aircraft. SMAs can also be used preventively, to sense when materials are reaching critical failure limits.

Commercially, SMAs can be used for vibrational dampening effects on various factory machinery—say, within a component that holds a die-cutting laser. In this case, the drop in vibrational interference radically increases the laser’s accuracy. SMA devices could also enhance fire detection equipment, or any other component or situation in which a change in temperature could trigger a necessary mechanical action. Of particular interest is potential application in surgical situations where device longevity, simplicity (ease of use), and biocompatibility could all be benefited.

Electrorheological Fluids

These materials represent fluid suspensions—emulsions wherein the smart material is dispersed, though not dissolved, within a liquid solution. When subjected to an electrical field, these suspensions experience

reversible changes in rheological properties such as viscosity, plasticity, and elasticity. These reversible changes take place because of controllable interactions that occur between various micron-sized “smart-particles” suspended within the emulsion.

Looking to the automotive industry, commercial advances in smart hydraulic fluids, networked car suspension systems, and smart shock-absorbers are already in development. Applying the above described interactions to, say, the smart shock-absorber, a sensor at the front of the car detects variations in the road surface. That signal is sent to a processor that determines whether the shock absorber should be more or less stiff. By altering the electrical field in the shock absorber, the viscosity of the ER fluid inside is also changed, tuning the suspension within milliseconds to match road conditions. Technological applications have been proposed for ER fluids in automotive clutches and valves, servo drives, dampers, and brakes.

Future Innovations

Consumer applications of smart materials in the coming decade will emphasize comfort and safety: noise canceling (headphones and car interiors) as well as vibration canceling applications (car suspension systems) will no doubt be early winners, with some products already in the market. Industrial applications will provide increased control, consistency, and efficiency of distributed processes (for example, the management of print production at multiple international sites from a single, central location). In both cases, the magic of the materials will be largely behind-the-scenes and invisible to all but the engineers who design and maintain the systems.

In the short term, smart-material adaptation will play out primarily as simple sensor-actuator responses to environmental stimuli. In the longer term, as the technology evolves, materials that self-diagnose and self-repair will find applications in everything from

very small biomedical materials (internal components may someday automatically clean your arteries when necessary, or alert you of an oncoming bout of the flu), to very large-scale building materials that provide economies and efficiencies in an increasingly resource-constrained world.

Another potential breakout in this technology is the use of deformable materials to create tactile user interfaces. Such developments may come in the form of flat-screen components (a flat screen that is both display and keyboard combined) that work in tandem with the subject matter they present. For instance, as you sit at your screen-unit and link to your online banking accounts, unique keys that are context sensitive will beckon, raising up from the deformable screen surface, allowing you to perform specified commands and functions. As the task changes, so will the keys that present themselves.

The big commercial growth area for smart materials over the next decade is likely to be actively smart materials supported by a wireless infrastructure. This type of system will enable remote analysis and control of a wide range of sensors and actuators in many different environments. In some cases, these systems will be used to avoid sending workers into hazardous environments, but in others companies will deploy actively smart materials because they will be cost-effective. By decade's end, intelligent materials will be routinely deployed in biomedical, military, and space applica-

tions. In these latter fields, it's likely that the costs of innovation, and subsequent diffusion of the technology, will be subsidized by Government.

Also by the end of the decade, watch for consumer markets in security and health applications to really come to the fore. Smart materials may act as sensors in these applications, notifying connected systems of abnormalities. Today's relatively heavy heart monitor provided by cardiologists simply records signals for later analysis: smart materials will be capable of both sensing and transmitting anomalies in real time, thereby facilitating emergency response and treatment.

Current military applications also hint at future possibilities for commercial applications. Smart armoring of tanks, designed to diffuse the impacts of missiles, suggests strategies for shipping containers that protect their contents against damage. "Smart dust," a new intelligence-gathering tool that employs a cloud of thousands of networked, floating camera-sensors (each "mote" is one millimeter square), spearheaded by Kris Pister and Randy Katz at University of California at Berkeley, hints at the future development of sensor arrays that could be deployed and utilized in environments that are hostile or dangerous to humans (such as the radioactive core of a nuclear reactor).

Standards

Table 2 presents certain emerging smart materials technology standards, including chief proponents and

*Table 2
Standards: Smart Materials*

Selected Emerging Standards	Proprietary or Open	Significant Proponents/Developers
VAMAS	Open	International group creating pre-standards for materials that are developing more rapidly than standards bodies can respond
Intellisuite™	Proprietary	Corning, Raytheon, Lucent

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► **SMART MATERIALS (CONT.)**

developers. Currently, the smart materials market is small and fragmented. An international effort, known as VAMAS, is seeking to establish standards for the measurement and performance of smart materials. The objective is to expedite the pace of product development, thereby enabling trade in newly created smart materials.

Smart materials are produced today principally through contract manufacturing. We expect this trend to continue as the benefits of “on-the-fly-design” and product customization are most easily achieved through the outsourcing of manufacturing. Computer-aided design for smart materials could emerge as an important realm for strategic control: one such product, Intellisuite™, acquired by Corning through an acquisition, has this potential.

KEY BUSINESS IMPACTS

- Smart materials will be adopted early-on to serve as remote sensors, especially in hazardous and difficult-to-access environments. Consider oil and gas pipes lined with a smart material that can sense changes in pressure (to indicate leaks) or detect contamination and impurities.

- Information workers get little exercise, and are subject to physical ailments arising out of their usage of computers and poor posture. Smart materials will soon emerge to improve posture and to stimulate lazy muscles, thereby addressing the legal liabilities that employers incur—and perhaps reducing the health care costs within the knowledge industries.
- Together with IP version 6, the world of inanimate objects will become connected to large inventory databases. In some cases, this will enable companies to better monitor their assets; over time, smart materials will cause these objects to be “remotely addressable” to reduce the need for human service calls, and to more efficiently manage end-to-end mechanical processes.
- Smart materials will further improve quality, tolerances, and ultimately reliability in manufactured goods. For example, the ability to control how these materials machine other materials creates a “sense and respond” loop that can work around natural imperfections.

Biometrics

What was not long ago the stuff of science fiction is poised on the brink of omnipresent reality.

Biometrics—the measurement or statistical analysis of biologically based attributes—is one of these technologies.

At present, biometric identifiers—the categories of measurement—encompass two distinct areas. Phenotypic measurement—which focuses on physical (visible or audible) properties—is confined to what can be externally observed (or heard) in a human subject. For example, facial features, eyes, hands, fingerprints, speech patterns, or the way you pen your signature. Genotypic measurements focus on genetic traits and characteristics—your unique DNA coding or “genetic signature,” as it can currently be measured and observed.

Simple biometric systems are designed around the concept that phenotypic and genotypic identifiers, when taken separately or together, can distinguish one person from another with a level of accuracy that can be specifically tailored to any given system. For instance, a fingerprint might be all that’s needed to gain a driver’s license, whereas a chromosomal reading coupled with a retina scan would provide the deeper level of verification needed to gain entry into a secured section of a research facility.

To create a working biometric system, scanning technologies are combined with pattern matching algorithms that are themselves linked to databases of existing scan samples. This array allows either verification of a known person, or identification of an unknown person. In verification systems, the captured sample is statistically compared to a stored sample, and an algorithm determines whether the number of common features is sufficient enough to accept the user. In identification systems, the sample is compared to all patterns in a broad database, and any samples that meet a programmed threshold are considered matches.

This sort of cross-referencing becomes crucial when considering the fact that not all biometrics are foolproof. There’s no certainty associated with biometric pattern matches; rather, biometrics is based upon statistical corroboration of observed phenomena. Variations in environmental conditions, and human interaction with those conditions, can absolutely affect scan outcome. For instance, a manual laborer or construction worker may have a high incidence of error with, say, a finger scan, as her/his skin

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► **BIOMETRICS (CONT.)**

is most likely cracked, cut, or scarred. Similarly, voice scans can be affected by a cold, or by the acoustics of a room. And although genotypic measurements (DNA testing) can be much more accurate, they, too, are fallible.

It bears mentioning that there are obvious gray areas when it comes to widespread public acceptance of these technologies, both due to biometrics' perceived and potential invasiveness, as well as their inherent, potentially grave implications when considered against civil liberties and privacy. If law enforcement continues to develop biometrics that raise concerns for citizens, the public may increasingly balk at their widespread implementation. For instance, if hidden cameras are capable of facial pattern matching—and subsequent remote identification of any person—the public may be unwilling to give up biometric data for fear of how it might be used.

The threat of terrorism may end up balancing public interest in privacy with the threat to physical security. Security can likely be enhanced less obtrusively with biometric technologies than with a panoply of identity cards, databases, and checkpoints.

Importance

When the world becomes a manipulable, distributed, information-rich environment, biometrics offer the simplicity of a customized user interface that provides context-appropriate, private information access, even in public spaces. The vast and rapid expansion of information in our daily lives will drive the acceptance of biometric systems that provide convenient access to private information whenever and wherever we need it.

In contrast to biometrics, traditional methods of verification offer rigid, “black-and-white” results: when someone enters a PIN code at an ATM, the machine confirms whether the code is correct or incorrect. The ATM cannot, however, confirm that the per-

son using the code is the rightful owner. By contrast, a biometric system wouldn't be able to verify the code, but it does verify the identity of the person linked to that code with a high degree of accuracy.

In the near term, the limits of both current systems and biometrics suggest that the most successful verification and identification systems will be those that combine elements of each—say, a biometric scan plus some kind of possession ID or code. Grafted onto the example above, the ATM machine would not only be able to discern whether the card owner had simply forgotten her code, it would also be able to tell if the individual using the code was an imposter, even if the code was correct.

Uses & Applications

Biometrics—while often thought of in terms of security and control—will win over the hearts of consumers through convenience and customization. Consequently, we forecast the rapid adoption of relatively non-intrusive biometric technologies where individual users gain convenience and simplicity in return for the perceived loss of privacy.

Biometric applications offer superior convenience, primarily when they replace verification and identification strategies that require either exclusive knowledge (such as PIN codes), or possessions (such as a driver's license). Systems that combine two types of biometric scans significantly increase reliability (i.e., a finger scan combined with a retina scan), and will thus be more readily accepted by their sponsor organizations or corporations—though systems with this type of complexity will also be more expensive to implement.

There are really two customers for the biometric application: the person being screened and the screening organization. The historic association of sophisticated ID technology with law enforcement and the criminal justice system has impaired the use of biomet-

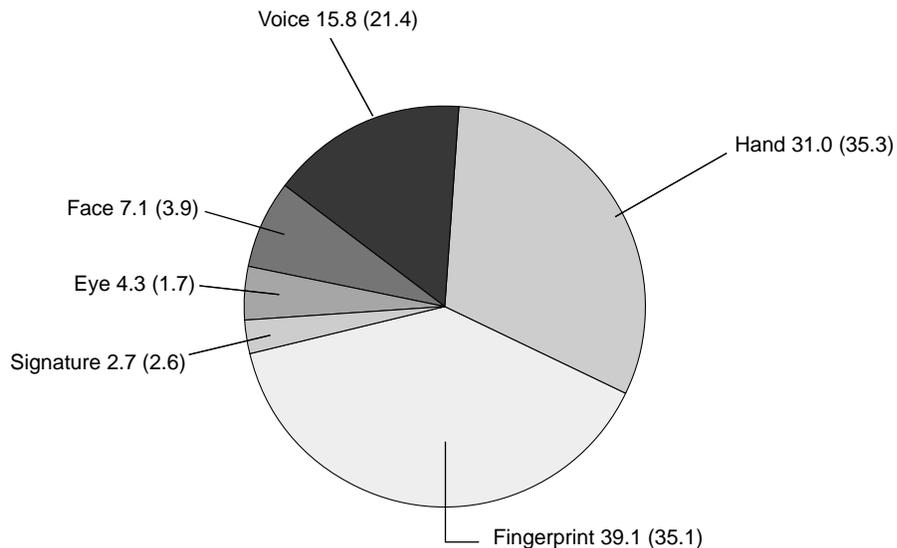
rics for business and personal applications in the past. Studies demonstrate that people generally shun biometrics when they have a choice. As such, trust and relevancy (via PR and beneficial functionality) will need to be part of development. Government involvement cannot hurt the establishment of trust: by establishing rules for the usage and protection of biometric data, the adoption of biometric technologies can be expedited.

The component technologies for biometrics currently include hardware for scanning faces, eyes, hands, signatures, fingerprints, and speech patterns, as well as software for pattern matching. Finger scanning and hand geometry technologies (hardware and software) account for the lion's share of biometric systems currently sold around the world. These two technologies will likely continue to dominate general applications that garner mass appeal. Probably the first applications to receive broad-based acceptance will be systems that

employ finger scanning or hand geometry together with a possession ID (such as a smart card). Indeed, some possession IDs are now being designed with inexpensive, on-board biometric sensors that integrate both technologies to provide quick verification. Fingerprint sensors are now being designed into smart cards, for example. Expect the continued integration of biometric sensors into the pervasive, networked devices filling our pockets. As a result, these PDAs, mobile phones, and other devices will continue to be personalized, as they will only work for the authorized owner.

Price/performance progress in both hardware for image acquisition and software for pattern matching is quickly expanding the possibilities for biometric development. As the price/performance ratio continues to improve, biometric technology will be integrated into computing and communication devices as well as consumer electronics. (See Figure 1 and Figure 2, p.16).

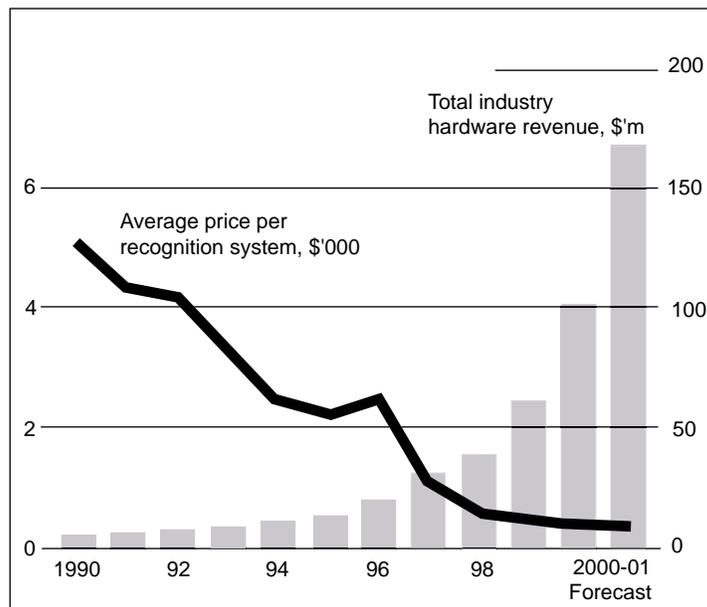
Figure 1
Biometric Technologies' Market Share
Percent, 2000 (1998)



Source: Biometrics Technology Today, *The Economist*, Sept. 7, 2001.

► BIOMETRICS (CONT.)

Figure 2
Biometric Metrics



Source: IBIA, *The Economist*, Sept. 7, 2001.

Future Innovations

The biometrics industry will focus on developing large-scale vertical applications that protect individual privacy. Even so, it's a safe bet that consumer adoption will depend on trust—whether that's confidence in a known and trusted brand, or an endorsement by a democratic government. While vertical applications will be easier to implement, certain horizontal applications (such as biometric authorization for mobile phone usage) are subject to network effects, and will proliferate rapidly.

Widespread integration of phenotypic biometrics into computing and communications devices will herald the first boom in the market. (By contrast, genotypic systems won't become commercially significant until the end of the decade, at which point they'll begin to play a larger role in advanced applications.)

Personal choice will also be key. There are already

hopeful signs that biometric applications can give people the choice to either use the system, or not, based on the system's value to them. For example, the U.S. Immigration and Naturalization Service has recently installed hand scanners in nine U.S. international airports. By using one of these scanners, a frequent traveler can pass through a customs checkpoint quickly, as her identity can be verified via biometrics. But the choice to utilize this scanner is entirely up to the individual. In Holland, iris scans are being embedded into the passports of some asylum seekers—not for reasons of security—as these immigrants have agreed to participate to avoid lengthy paperwork.

To gain widespread acceptance, biometric technologies will need to demonstrate quick and easy sample capture as well as consistent accuracy. Verification systems will most likely emerge more quickly than identi-

fication systems for a number of reasons. First, the technology is easier to implement because the user voluntarily provides the sample, and the database is likely to be significantly smaller. Second, identification systems are more likely to be associated with law enforcement and are less likely to earn the confidence of users.

While several component technologies are currently available for capturing biometric information (e.g., finger and retinal scanners, hand geometry readers, and high resolution digital cameras for visual recognition) the breakthroughs will come from combining these components into cost-effective, secure systems.

For the near term, the most significant biometric components will be finger- and hand-scanning hardware and related software.

Shifting from the consumer's perspective to that of the screening organization (or developer), the most significant challenge may be in justifying the cost of deployment with low initial cost savings. Biometric applications are likely to result in cost savings, by reducing fraud and eliminating manpower needs. But early deployments will need to be justified on the basis of delivering added value to the people being screened, not necessarily on rapid initial ROI.

In the longer term, watch for technological breakthroughs in the gray area between acceptance and rejection of biometric pattern matching. New logic here—perhaps driven by the involvement of democratic governments and emerging security challenges—could greatly increase accuracy and reliability and cut the cost of the systems.

Putting it all together, the most successful early biometric applications will be those that provide convenience to the individual user, offer a choice to bypass the biometric system when desired, come from trusted brands or democratic governments, and do not penalize the user for false accepts or false rejects.

Standards

Table 3 presents certain emerging biometric technology standards, with a breakout of chief proponents and developers. Biometrics are subject to network effects, and the greater convenience that they provide (through pervasive access points) will result in accelerated adoption. For this reason, we believe that the dominant biometric standards will emerge quickly, and in the near future.

*Table 3
Standards: Biometrics*

Selected Emerging Standards	Proprietary or Open	Significant Proponents/Developers
Eigenface algorithm	Proprietary*	Viisage, MIT, Lau Security
BioAPI	Open	Compaq, Gemplus, Veridicom
BAPI/SecureSite	Proprietary	I/O Software, Atmel Grenoble, Ethentica, Intel, Microsoft
NCITS/B.10.8	Open	Gemplus, Motorola, Philips
OpenTouch™	Proprietary	Veridicom, RSA, Lucent, Xcert

*An open version of the software was released by the MIT Media Lab; however Visage licensed the algorithms, and is developing a proprietary offering on this platform to establish as an industry standard.

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► **BIOMETRICS (CONT.)**

KEY BUSINESS IMPACTS

- Biometrics will enable automated systems that have been designed and built over the past 10-20 years to be extended to individual users. As a result, human mediation (in the form of customer support) will become less important as these systems encourage individual users to take on some additional tasks in exchange for convenience. By analogy, the advent of ATMs significantly reduced the need for human mediation in banking by enabling individuals to undertake simple transactions without having to wait in line during normal business hours.
- Individuals will be able to access personal and enterprise data from remote locations more quickly and with a higher degree of security. Biometrics can be used to provide individuals with access to pri-

vate information through a familiar, network-based user interface across a wide range of information devices. Everyone from road warriors to soccer moms will take advantage of the omnipresent network to find and use information where and when it's needed by validating their access through biometrics.

- Companies need to consider how they can further “personalize” their technologies. Manufacturers of both consumer electronics, and information technologies, can expand the market for their technologies when individuals need or require their own devices. As device-based storage increases, biometric access is also likely to grow in importance as it will provide a secure gate to this valuable information.

They're both useful and pervasive: our computer screens, monitors, televisions, PDA touch screens, cell phone displays, LED watches ... **displays**. So pervasive, we frequently take them, and the technology behind them, for granted. So let's start with the basics.

The CRT, or cathode ray tube, is the most widely used technology that both computer monitors and televisions continue to utilize. This vacuum tube—comprised of a magnetically activated, electron emitting “gun” at one end, and a larger, planar surface that intersects with a screen on the other end—fires electrons toward phosphorescent material encased within the screen. When bombarded by these specifically targeted electrons, the phosphorus glows and gives rise to an image.

Unlike CRTs, standard flat screen displays utilize thousands of active, individual pixels. Each one of these is a distinct, tiny “bulb,” outfitted with its own transistor, that can either be turned “on” or “off” to create an image. Because of their thin, light characteristics, flat screen displays are the visual interface of choice for portable devices. These displays utilize several different types of technologies, depending on their function. These include: Active Matrix LCD (Liquid Crystal Diodes, or AMLCDs, such as those used in digital watches); Plasma displays; and Electroluminescent displays. AMCLDs sandwich an active, sensitive material between two pieces of glass and place a separate transistor at each pixel: the active material “twists,” becoming dark or opaque when exposed to an electronic charge. Plasma displays use an active gas in place of the liquid found in AMLCDs. This gas glows when voltage is applied. Electroluminescent displays, like plasma displays, utilize a phosphor like film that glows when charged.

Both CRTs and flat screen displays can be used to produce monochrome (single color), grayscale (many varied gray tones or “values”), and of course color images (though the image can be of varying resolution—see the pixel discussion above).

This is all representative of standard display technologies—many we've taken for granted. But all of this is about to shift. The technology that's behind what you see, and how you see it, is changing ... radically.

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► **DISPLAYS (CONT.)**

Importance

Computer-screen technology has already surpassed standards for broadcast television, and has even pushed the standards in this arena (take HDTV, for example). But again, we stand poised to take a new jump in standards, applications, and quality. For very soon, displays will be cheap, and even printable with low-cost technology. Their worldwide scope and myriad applications will require us to redefine our approach to everything from knowledge management to definitions of public and private spaces. As a result, these combined advancements will usher in a creative (and economic) revolution comparable to the advent of the personal computer, or the birth of the World Wide Web.

In the future, anything can be a display.

The flexibility and low cost of these new technologies will make displays an active design element: wine labels that “talk” to you; clothing tags that display ads for like items; pants pockets that are part wearable storage medium, part visual display; smart cards that deliver email reminders, or announcements specific to the individual user; ubiquitous interactive displays that live in public spaces and places ... All of these are representative of the initial changes that will take place. Just as desktop publishing transformed printing from an exclusive trade to a common office skill, the coming new display technologies will likely transform the manufacture of these components from high-volume, high-tech assembly, to small-to-medium volume, service-driven custom production runs.

Predominantly, we’ll see two kinds of applications: displays that allow people to interact more efficiently and intelligently with objects (such as gauges, appliances, and manufactured parts); and displays that make information more interesting, more current, and/or easier to access (such as electronic paper and wearable computers and displays).

In addition, displays will up the ante for knowledge management: no longer can IT services or knowledge brokers assume a universal device. Rather the world of knowledge management will become increasingly opportunistic, driven by consumer pull rather than producer push. Further, the very formats for knowledge will proliferate. Not bound by a flat rectangular screen, all of our rules for knowledge handling—from content and editorial to database design—will be rewritten. Messages transmitted on a jacket pocket, eyeglasses that double as information display screens (when desired), the interior of a car windshield that plots alternate routes in heavy traffic—any or all of these could be future examples of opportunistic, consumer-benefiting displays.

New display technologies will also challenge some of the basic foundations of intellectual property and business capital. On one hand, these technologies can provide a tighter coupling between content and display, so that the display itself becomes a filter, a gatekeeper, and a “watermark” for the content it presents. On the other hand, the ubiquity of displays—and the likely repurposing of them—creates a world in which enforcing copyright laws might be impossible.

Uses & Applications

Following on the exciting trends since the emergence of the thin film transistor LCD displays 12 years ago, new display technologies are poised to flood the marketplace. The innovations cover the gamut from large wall-size displays to the tiniest of screens for micro-sized applications. All of these technologies have something in common, however: their advancements are bringing the cost of displays down, and fast. Additionally, combined with breakthroughs in battery technology, displays are becoming much more portable, flexible, and lightweight.

In the near term, display technology advances will show up in smart cards and/or credit cards, and in

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small, hand-held devices. The credit card could, in fact, become an e-mail reader, or even a personalized portal to news and information such as stock quotes, sports scores, and bus or train schedules.

At the component level, multiple display technologies are simultaneously converging on better performance, cheaper manufacturing, and thinner, lighter, more flexible substrates. These new technologies will produce displays that travel well, consume less power, and can be molded and folded to a variety of shapes and sizes. The big developments here will be organic light-emitting diodes and polymers (OLEDs and OLEPs) that are flexible, durable, lightweight. The development of flat CRTs, the further enhancements of Active Matrix LCDs, as well as electronic paper and ink will all play a part in radical display advancement.

Here's a detailed breakdown of these emerging technologies:

Organic LEDs (Light Emitting Diodes) and LEPS (Light Emitting Polymers)

Our top pick for breakthrough technology is the category of organic light-emitting devices, primarily plastic polymers. OLEDs have the unique characteristic of being transparent when switched off; when turned on, an OLED can emit up to 40 lumens per watt—as much as a fluorescent tube! A big player in OLED technology is Universal Display Corporation. Their three related technologies—transparent, stacked, and flexible OLEDs—each take advantage of different aspects of organic light emitting diodes.

Electronic Ink and Paper

Like OLEDs, electronic ink and paper are poised to turn both traditional displays and print publishing upside down. These technologies work by encapsulating millions of microscopic plastic spheres (which are today monochrome, but will eventually become color) in a thin, flexible material. Each sphere is encoded

with a separate electrical charge corresponding to each of the two colors (for instance, positive for black, negative for white). When selectively exposed to a charge, the plastic spheres will display the color (or exposed side) that matches the charge.

For the user, electronic paper overcomes the limitations of traditional displays to present several advantages: a wider viewing angle, good readability (in dimly or brightly lit environments), lighter weight, and better portability. Electronic paper can also hold an image independently, without draining power (they require no power in a static state). For the publisher, electronic paper offers the advantages of scalability to large sizes, support for curved designs, and adaptability to both glass and plastic surfaces.

E-Ink, based on research done at the MIT Media Lab, has garnered significant visibility as the leading developer of this technology. But E-Ink isn't alone in this space: Xerox has also spun off a company called Gyricon Media, which is currently working with 3M to develop an electronic paper, based on proprietary technology.

Active-Matrix Liquid Crystal Diodes (AMLCDs)

This technology represents the current leader in flat-panel display capability, and promises a steady evolution toward higher resolution, dramatically reduced production costs, lighter weight, and flexible form factors.

IBM has already produced an AMLCD display with a resolution of 200 ppi, putting it near the limit of the human eye's ability to resolve images. High resolution is particularly important for small displays, such as PDAs, cell phones, and watches. Hi-res displays such as this could open up new possibilities in 3D user interface design, or be used in new applications where this level of resolution is required, such as radiology. Because high-definition displays require less space, it is suddenly possible to pull together various smaller

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► **DISPLAYS (CONT.)**

formats of information onto the same screen (thereby increasing efficiency, or even desktop space).

Alien Technology has developed a new manufacturing technique called “fluidic self-assembly” (FSA) for quick, easy assembly of the component parts of flat-panel displays. FSA eliminates the need to fabricate pixel transistors on large sheets. In fact, it eliminates the need for glass, which can be replaced by thin, light, flexible, low-cost, easy-to-handle film. This manufacturing breakthrough means that inefficient batch production of glass panels can be replaced by a continuous-flow process.

Flat CRTs

The venerable CRT is finally getting thinner, lighter, and less expensive to produce. Silicon Valley start-up Candescant Technologies is developing the ThinCRT—a flat-panel display based on CRT technology but with a slim form factor, a lighter product weight, and significantly low power requirements. Using existing manufacturing techniques and tools, Candescant hopes to provide the necessary high volume that will drive down costs for flat-panel CRT displays for a variety of applications. Venture-backed, Candescant’s substantial investments range from research to manufacturing as they seek to create demand for an entirely new technology.

3D Technologies

Our quest to mimic human stereoscopic vision in the world of displays continues to inch forward. Until now, 3D displays have required special (usually clunky and cumbersome) headsets or goggles that in turn provide the separate perspective-views (one to each eye) needed to recreate stereoscopic sight.

Philips has gotten rid of the goggles. Their 3D-LCD technology uses a lenticular screen over an LCD display to show different images simultaneously to each eye. The resulting 3D display can be viewed by many people over a wide angle.

Future Innovations

The horizon for display applications is a crowded horizon indeed. In a world where anything can be a display, graphic and industrial designers will be adding information content to objects of every type and size. While some of the applications will expand the current range of productivity tools, far more will expand the opportunities for entertainment and especially marketing—both to targeted users and ad hoc users in a ubiquitous computing environment.

The results will be nothing short of radical.

The near-term applications of this expanding technology will put lighter, more flexible information and communication devices into consumers’ hands. Starting around 2004, displays will most likely break out of their “device” identity and become increasingly integrated into objects ranging from consumables to furniture. Every label, sign, and package will become an opportunity for broadcast or interactive communication with the consumer. Displays will provide new opportunities for high-end brands to distinguish themselves in clothing, household goods, and more. (Display kitsch will become a category all its own.)

Combined with tagging, wireless communication protocols, and small-scale power systems, the proliferating displays will evolve into lively visual surfaces that permeate our daily lives. Combined with voice technology, they will talk to us in passing, engaging us like so many street merchants and mendicants. Combined with smart materials, they will show signs of a new kind of sentience. The world of human-made objects will begin to crackle with expanded information and intention.

LED technology might also be grafted to a wide range of lighting applications. Already, LEDs are finding their way into flashlights, emergency lighting, and signage programs. By the end of this decade, we may see a shift in various lighting applications—applications that trace their origins to displays.

Standards

Display technologies might become an example of competing standards peacefully coexisting. Each technology could serve a significant new market, and develop the volumes necessary for its survival—or not. What is certain is that displays will appear in entirely new places, and that there will be an explosion in the display market to address these broad requirements. Pay attention to thin, low-power, flexible displays (there are at least three significant approaches in this emerging segment). E-ink, Gyricon, and Visson are each competing for this nascent market by developing alliances, building beta solutions, and advancing their respective technologies in parallel.

Table 4 presents a portion of this work, with a breakout of chief proponents and developers.

Key Business Impacts

- New display technologies will enable the emergence of entirely new industry segments and new product offerings. Omnipresent retail displays will prove the missing link. Consumers and systems will become intimately bridged, bringing new opportunities (and efficiencies) to supply-chain and customer-relationship management. The transportation industry is likely to attach displays to everything

that moves, and together with tagging, will greatly increase its ability to offer multi-tiered customer service, and to manage system-wide logistics.

- With the advent of MTV, pervasive jump-cutting, and television screens that are crowded with formidable amounts of data at any given moment, we are proving our ability to assimilate large amounts of information at a glance. Individuals already accustomed to multi-tasking will happily manage multiple displays in their daily lives. However, the proliferation of displays won't in any way simplify our lives (or alleviate information overload). In fact, they may serve to make our many personal and business tasks more difficult to manage. Once again, the demand for tools that can integrate, winnow, and manage information in a meaningful (and efficient) way is certain to explode.
- Publishing will be redefined by new display technologies. Just as the VCR did not eliminate demand for movie theaters, new display technologies will not replace books, magazines, and newspapers any time soon. However, our expectations for where and how we'll receive information will drive new formats for publishing, new rules for intellectual property management, and new types of information that we'll both expect, and pay for.

*Table 4
Standards: Flexible Display Technologies*

<i>Selected Emerging Standards</i>	<i>Proprietary or Open</i>	<i>Significant Proponents/Developers</i>
Electronic ink™	Proprietary	E-Ink, Motorola, Philips, Lucent
SmartPaper™	Proprietary	Gyricon Media, Xerox, Thomson-Leeds
Electroluminescent	Proprietary woven structures	Visson, Philips, Profilo Telra

5

e Technology

A Talkative Information Universe??

One Language?

The rest of the world?

Domains with limited people

- Military
- Corp/Orgs

Domains with limited content

- Stock quotes
- Sports scores
- Airline info

Hands-off Device Control Autos + Cell-phones

VOICE PORTAL

INTERNET

TellMe Hey Anita BeVocal

Speech Recognition

Speech Synthesis

Only one mistake percents!

That should be "per sentence"

6

Tagging

Broker Relationships Across Boundaries

PRIVACY

Shopping assistance

- Cue:cat

Matchmaking (MIT)

Cross-media info linking

- Radio/Web links (Sony eMaker) (I-tag)
- Localized Taxi ads

Drive-Thru services

- Tolls
- Gas
- Fast foods
- Groceries?

Physical Object Tags

Digital Content Tags

RFID Threshold: <\$.50/label

Wireless Connection + Remote Database + Barcodes + Pattern Matching + GPS + Clock

7

Peer-to-Peer

The Network Becomes The Computer—And Anything Can Be A Node

Intellectual Property At Risk

Group Collaboration (HP, Intel, IBM, Groove)

Device Infrastructure (Endeavors Magi)

Peer-amid Marketing (Lightshare)

SETI@home

Dynamic System Configuration (Consilent)

Corporate & Consumer Processing Exchange (Central) (Juno) (MojoNation)

FAULT TOLERANT

Fully-distributed open systems (Gnutella)

Central server for content index (Napster)

Fully-distributed protected systems (FreeNet)

DECENTRALIZED NETWORKS

- Distributed content
- Distributed processing

Network File Sharing Architectures

Network Resource Sharing Architectures

Copyright Protection (Flycode)

Encryption

8

Wireless Standards

Assure Connectivity Anywhere

Have/Have-not Gap

3rd World Leapfrog

New Use Scenarios

Telemetry

- Automated Wireless Monitoring
- Industrial systems
- Pipelines
- Home appliances

Exploit Multiple Wireless Standards

- Standard-neutral systems

Multiple Device Standards

From Residential Gateways TO Personal Mobile Gateways

Swarm Networks

Fixed wireless broadband

PAN Bluetooth

LAN 802.11

WAN

WAP

2005: Bluetooth chips <\$3.00 each

Voice Technology

You might picture the world of Gene Roddenberry's *Star*

Trek, wherein the intrepid chief engineer, Mr. Scott, routinely carries out complex technical feats with a series of voice commands. Or you might imagine your computer actually carrying out some of the more ... colorful directives you give it. Whatever the case, while we may not yet be able to incite phenomenal technical achievements (or capricious computer functions) with a word or a phrase, the nascent stages of this technology are already at hand.

As it currently stands, virtually all speech recognition programs work in basically the same way. The user speaks into a microphone of some sort (either a hand-held or built-in mic, or a headset). This microphone is attached to the system either via hardwire connection, or a wireless proximity broadcast frequency (like an RF, or radio frequency, mic). The mic then translates the speaker's audible sounds into distinct electrical signals, which are in turn translated by the computer into a binary data stream (a series of 0s and 1s). The system's software, via voice synthesis algorithms, then examines the code, looking for patterns it can pinpoint as specific, identifiable sounds. Each distinct data pattern is compared against an embedded dictionary: here, patterns that contain the same sounds in the same order are deemed "matches," and each match is assigned a probability that it is the correct choice. Items assigned the highest probability are presented back to the user (either by appearing as written text on a display, or, in some cases, as audible words spoken by the machine).

Importance

In the past few years, voice recognition technology has evolved to the point where it is now efficient, affordable, and practical for everyday use in many diverse applications. These applications, for the moment, intersect with areas such as dictation and transcription, as well as voice-activated phone services, and other Web-like phone systems. But the true impact of voice technology will be born out over the next decade.

As devices become smaller, voice recognition technology will become increasingly more important. Many of the most commonly used devices will either have no keypads at all (i.e., nothing that would lend itself to typical typing-style interaction), or displays that will be too tiny to function as touch-screens. Voice interaction will be vital for these systems and their applications.

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► **VOICE TECHNOLOGY (CONT.)**

Furthermore, and more immediately, voice technology promises to cut costs for many businesses—either by reducing transcription time and costs, or by streamlining call centers that have traditionally been staffed by only human operators. Many applications in manufacturing, journalism, law, elder care, and medicine (hospitals, emergency rooms, doctors’ offices) promise to bring new efficiency to report writing, data analysis, and records keeping.

There are a number of applications that could make the world much more accessible and navigable for persons with either physical, or learning disabilities, as well. (Proponents of this field herald voice recognition and voice activated technology as “the great equalizer.”) Whether it means that a dyslexic teenager can gain self esteem and admittance into college, or that a quadriplegic can send email, or operate a complicated household appliance, the possibilities here are exciting, and manifold.

Voice-enabled systems will also be key in the mobile commerce (m-commerce) boom. Already, a harried stay-at-home dad can change diapers while simultaneously ordering more of them through his headset, and a businesswoman can order flowers for her husband on the fly. But soon, voice recognition technology will expand these possibilities to a host of more complex and pervasive systems that will enable a boom in m-commerce technology and economics.

Uses & Applications

Likely near-term applications for voice technology remain restricted to two classes. The first includes applications where the substantive content of the domain is limited and the user speaks commands or responds to prompts, so questions and answers are easily structured. Examples of this include United Airlines’ voice-activated flight tracking service (delivered over the phone), and stock quote services, such as

that delivered by Charles Schwab Corporation (through which clients can check their portfolios, and individual stock performance, at any time over the phone). The second class of voice technology includes application domains where the subject matter is limited (such as in the military, or among employees of a particular organization); in this case, the system and the users can be trained to understand each other.

Initially, systems that are somewhat limited—in scope, requirements, or users—will have the advantage. With less complex task sets, and a smaller, more manageable dictionary, the system’s information becomes more focused, more finite, thus making pure voice recognition (human to machine) possible without the need for additional human operators. However, as soon as the goods, services, or information exchanged reaches a certain level of complexity, an extremely sophisticated system is needed; such a system would need to deal with a range of variables including dialect and accents, linguistic context, environmental factors, and varying vocabularies. Currently, for instance, it’s close to impossible for voice recognition programs to distinguish between the word “hear” and “here.” This sort of intelligence will be necessary for sophisticated interactions with machines. These sorts of highly advanced systems are still in development, and their widespread adoption is not expected to happen within the next decade.

Current voice technology focuses on the areas of dictation, transcription, translation, and command prompts.

Early dictational voice recognition programs demanded that users speak slowly and very deliberately. Words would then appear on the screen (after a bit of a delay) one at a time. Current software, however, lets users speak conversationally, and brings their words to the screen almost in real-time. (This evolution has been absolutely tied to the expansion of com-

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► **VOICE TECHNOLOGY (CONT.)**

puter RAM, the advancement of processor speed, and the extraordinary growth of low-cost storage.)

Even so, voice recognition algorithms boast only about a 90% accuracy rate out of the box. (This translates to about one mistake per sentence.) Training can bring that rate up a bit, usually by reading to your computer—allowing it to learn the idiosyncrasies of your voice and speech patterns. But even meticulous training can't shield you from interference from ambient noise, a bad microphone, or unrecognized speech vagaries (such as incomplete or fragmented sentences, or poor grammar). Accuracy and scalability remain the big obstacles to wide-range commercial development; however, an enormous amount of capital is being funneled into this technology. Applications will continue to develop in domains where voice recognition algorithms are 'tuned' to a substantive domain (such as medical radiology), and the users employ similar jargon and grammar (as in banking).

Voice portals are telephone-based, voice-activated systems that operate very much like a Web portal, and are one of the hottest areas of competition today. Consumer-side developers include Tellme and BeVocal, two companies from Santa Clara, California, that launched voice portals early in 2000. Consumers dial in on a toll-free number and, with voice prompts, request information such as traffic reports and sports scores. The businesses have evolved to function as application-service providers as well as carriers. (Live operators must still be available to handle more complex requests.) The voice portal offers the potential of becoming the personal concierge and the one-stop shop for a wide range of transactions. One company, Sound Advantage, is promoting a service that provides access to email and faxes by phone (a server on the network reads email messages to callers). We expect continued improvement in the voice recognition technology employed by voice portals, and the emergence

of an ASP-like model to offer and customize this technology for enterprises. Today's financial and travel service providers are likely to resell voice portal services to maintain their customer base, and to expand into new service areas.

Among top contenders to license core voice-recognition engines are voice-interface-software makers such as SpeechWorks International Inc. of Boston, General Magic of San Francisco, and Nuance Communications of Menlo Park, California. Human language technologies continue to be a focus at IBM and Microsoft, as well.

While intent has orbited around developing voice-recognition capability for things like controlling your cell phone and other gadgets hands-free, managing such auto-based systems as stereo and GPS/direction services, or making your computer more accessible if you're all thumbs on the keyboard, the technology is also making its way into a range of applications for people with disabilities.

Some might still call it an underground movement, but determined developers are working to help people with impairments ranging from paralysis to repetitive stress injury (disabilities that make typing painful or impossible), while also giving people with dyslexia a much needed advantage, as well. Recent legislation in the United States may help to expedite the development of voice technology for the disabled: to do business with the U.S. Government, information technology vendors will need to redesign those products that cannot be used by physically impaired individuals.

Future Innovations

While visions of "voice surfing" dance in the heads of speech recognition experts, a general-purpose voice interface to the Internet probably won't leave the labs in the coming decade. Even devices at the level of IBM's ViaVoice are still somewhat limited tools, as

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they're not yet able to produce documents that are near perfect on the first dictation, and they're still unable to transcribe long email messages. While dictation may get most of the visibility, one of the more important advancements in speech recognition will be the ability of systems to perform functions based upon common language. The Web navigation capabilities embodied in IBM's "Home Page Reader," designed for visually impaired Internet users, begin to offer some of the nuanced facilities necessary to make machines function by voice command.

Voice interfaces to well-defined domains of information will most likely proliferate over the coming decade, creating an increasingly talkative information universe, even an integrated voice ecosystem. Advances in small-scale power and wireless infrastructures will spur even greater innovation, possibilities, and markets. Concurrently, the 10-year horizon promises the birth of both natural language software (the kind that can understand many complex and idiosyncratic sentences), and broadband data speeds that make online video ubiquitous. Development here will be exciting.

In the nearer term, watch for the breakout use of remote voice interfaces in Europe and Asia, where the wireless infrastructure is more complete, and cell phone penetration is greater.

At the systems level, the current Holy Grail is a voice portal to the Internet that integrates voice recognition algorithms with a networked telephone infrastructure. Big issues here are the reliability of algorithms over such a large domain of content and users, as well as basic problems with the scalability of such systems. As mentioned above, accuracy and scalability remain two significant challenges in the coming years.

Social impacts may be largely geographical, with early adopters and ready infrastructures in Europe and Asia possibly taking the lead. The result may be a shift

of certain kinds of cultural know-how to these regions. In the meantime, however, watch for a steady increase in the percent of daily interactions with automated voice systems.

Standards

Table 5 on Page 30 presents emerging standards in voice recognition hardware, software, and network technologies, with a breakout of chief proponents and developers.

One technology to note is VoiceXML. Like HTML before it, VoiceXML is a simple programming language for creating voice-user interfaces, particularly for the telephone. Based on the World Wide Web Consortium's (W3C's) Extensible Markup Language (or XML), VoiceXML leverages the Web paradigm for application deployment and development. It uses speech recognition and touchtone (DTMF keypad) for input, and pre-recorded audio and text-to-speech synthesis (TTS) for output. Like HTML, it shields users from the complexities embedded within the programming language.

VoiceXML builds voice-enable Web applications, and can be used as an open-architecture means for building interactive telephone services. (This is the language behind voice portal technology.) Other applications include voice-enable intranets, notification systems, and voice-enabled home appliances.

Key Business Impacts

- Sophisticated voice-enabled applications will begin to reduce business' reliance on humans for interaction with customers within the next three to five years. While the cost of the technology probably won't allow for overall cost savings to the business, it will provide customers with faster and more effective responses than today's call centers are capable of providing.

▶ **VOICE TECHNOLOGY (CONT.)**

- The continued integration of computer and telephony technologies is further facilitated by voice recognition, and will provide the impetus for “one-line solutions” on corporate and government campuses.
- Voice portals are surfacing as one of the first service sector businesses to effectively take advantage of voice technology for cost savings. Beyond the

current financial market fluctuations, voice portals will become an important technology for most businesses. In just three to five years, voice recognition and voice portal technologies will emerge as a core element in communicating with mobile workers, and in improving the quality of customer relationship management.

*Table 5
Standards: Voice Technologies*

Selected Emerging Standards	Proprietary or Open	Significant Proponents/Developers
VoiceXML (VXML)	Open	No competing markup language efforts! AT&T Wireless, BeVocal, IBM, Intel, Lucent, Motorola, Net2Phone, Sprint, VoiceGenie
Internet Voice Mail (aka, VPIM v3)	Open	3Com, Cisco, Nortel, Telstra,
Speech API (SAPI) [™]	Proprietary	Microsoft
ViaVoice [™]	Proprietary	IBM, Avaya, Fujitsu, Sony, Virage, VoiceRite
Speech Application Language Tags (SALT Forum)	Open	Microsoft, Cisco Systems, Comverse, Intel, Philips and SpeechWorks
FreeSpeech [™]	Proprietary	HeyAnita, Dialogic, FedEx, Net2Phone, Sprint, Vodafone
MicroREC [™]	Proprietary	VoiceSignal, GE, Hasbro, Hitachi, Mattel

We've all been there—

trapped in a slow-moving line at the cash register, late for an appointment, virtually powerless as our time slides through the hourglass unimpeded.

By as soon as 2005, however, this experience may be a relic of the past.

The pervasive UPC (Universal Product Code) bar code—publicly inaugurated on a June morning in 1974 in Troy, Ohio—has since become an omnipresent emblem used for categorizing, pricing, and requesting payment for everything from automotive oil to zydeco CDs. But a new phenomenon stands ready to dwarf this familiar technology. “Smart tags” (RFID tags, smart labels) are coming. And their effect on the manufacturing, distribution, and consumer/retail worlds will be nothing short of revolutionary.

“Tagging” (the use of labels to describe or identify an object) forges the link between information and the physical world. It binds data to time, place, and objects. As such, it’s the ultimate broker—across media, tasks, locations, accounts, ... even across a crowded room. With increasing frequency, we’re learning that objects can be physical or digital, and tags can refer to one or the other—or both.

Tags may be either physical or electronic, embedded in objects, or read from coordinates in time and space. When integrated with databases, software for pattern matching, wireless protocols, GPS or other location identification technologies, tags provide a way to quickly make connections between objects and events in time and space.

Radio frequency identification (RFID) tags are basically intelligent bar codes that can talk to a networked system via frequency waves. Once limited to tracking livestock and freight cars, RFID technology is now penetrating a host of various markets. Theoretically, this system can be used to track any product or component—large or small—from cradle to grave—from the item’s inception and production to its final resting place—within the walls of a building, on the shelves of a retail store, or even within a consumer’s home.

Essentially minuscule two-way radios, RFID tags/labels/etc. are comprised of a miniature silicon microprocessor, conductive metal or ink, and an antenna. Using a designated spectrum of the UHF (ultra-high frequency) band, the tags and labels can, for instance, be affixed to a

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► **TAGGING (CONT.)**

perishable item (like a piece of fruit), and then set like a thermostat—sending vital information about ambient temperature, or the item’s viability (i.e., when the fruit is too warm, or about to go bad). Source tags (tags that are embedded into items at the point of manufacture or packaging) can be woven into garments, or invisibly embedded within paper labels, cardboard, or blister packaging. During manufacturing, tags can send information details about production options and specifications. In fact, the tagging components are so tiny, they could be placed virtually anywhere in or on a product and be invisible to the naked eye.

Because they have read and write capabilities, the data embedded within an RFID tag can be updated, changed, and locked at any point. And while “passive tags” (non-RFID tags) may have a capacity of only 1 bit of data, “active,” read/write smart tags can carry upwards of 128 bytes of stored information (the equivalent of approximately 70 pages of information). This data can be scanned selectively, pulling out only the pieces of information that are relevant at any given point in the tag’s (or item’s) life. Stated another way, manufacturers, distributors, and retailers will now be able to locate and talk to their products—and the products will be able to talk back—at all stages in the supply chain, even after the item has been purchased by a consumer.

Labels need not be physical devices, however. It’s quite likely that “soft tagging” will have as profound an effect on business and society as tangible tagging. Indeed, this distinction might become irrelevant as knowledge about tangibles and information begins to blur together. A leading soft tag technology is XML (or Extensible Markup Language—a programming language akin to HTML). This simple software language is being used across a wide range of industries to describe bundles of information. XML has emerged rapidly over the past four years due in large measure to its flexibility and openness (it also recognized that

ebusiness providence could only occur if there were standard ways for companies to share information).

Importance

The positive ramifications of tagging technologies will be felt in many different areas. Among these, service to customers will become more targeted and responsive, supply chain inefficiencies will be reduced or even eliminated, safety and performance will be improved, tracking of all sorts will be enhanced, accurate accounting at the cash register will become virtually foolproof, inventory control will be vastly enhanced, and theft deterrence will reach a new level of sophistication.

The laser-like accuracy and tracking ability of RFID tags—in all areas of production and distribution—will reduce these inefficiencies significantly, just as counterfeiting will become close to impossible. (UPC bar codes can currently be easily reproduced on standard copy machines.) Relatedly, it will be harder for even small components to slip through the cracks during production or transport (even tiny things can be located on a per-item basis), as the item’s location, destination, and other areas of “accountability” will all become transparent.

RFID tags can also go where UPCs never could: they can withstand intense cold or heat—even chemical exposure—and their information can be read through up to two inches of non-metallic debris (smoke, grime, concrete, cloth, wood, dust, plastic, or paint). Also unlike bar codes, RFID signatures do not require line-of-sight reading: they are wireless and need not be visible to be detected; moreover, they are read/write capable (as opposed to a bar code’s passive read-only functionality). Even if folded, spindled, or mutilated, RFID tags can still talk to their networks.

Software tags may be even more durable: they reside in networks and on hard drives, and are only called upon when data is transferred or searched. It’s

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difficult to overstate the implications of soft tags; XML and its variants have the potential for building bridges wherever proprietary standards prevent collaboration today.

Even more valuable than overcoming platform and organizational barriers will be the architectural changes driven by XML and other soft tags. Information is seamlessly wedded to an application in current systems architecture: without translation tools, it's difficult—if not impossible—to use information developed in one application on another system using another application. The goal of soft tags is to enable the transfer of bundles of information from one user to another without regard to the application upon which it was created, or the application upon which it will be processed and used. In a world that is becoming more interdependent, soft tags facilitate any sort of collaboration or transaction while allowing each user to choose different systems, and to customize applications for different business models, or even cultures.

Software tags serve as “wrappers” for bundles of information. Pieces of information might be pulled from various data sources to be brought together under the guise of a soft tag. Just as a physical tag might enable you to know what is within a rail boxcar without looking inside, a soft tag can provide similar insights into information bundles. This will undoubtedly enable faster processing and sorting because raw data need not be transferred or searched.

Uses & Applications

Virtually every category of supply-side and retail business will be affected by RFID technology. For instance, this technology is already employed in rail-car location and tracking, luggage and baggage tracking (for both travel and freight), and postal and express-package tracking. Smart tags will also populate all levels of consumer goods, from clothing to

consumables, anti-theft devices, library items, even construction materials (sensors may soon be all around us, directly built into new structures). And because an RFID tag is “always on,” shoplifters wearing a stolen (but tagged) item could feasibly return to the store weeks after their crime, and still be detected.

Tagging applications range from personal bar-code readers and smart cards (used for payments of tolls and other quick drive-thru services), to ID badges that track the location of people and objects in buildings. Some hospitals currently use RFID tagging to keep track of sophisticated mobile equipment as it's shared between hospital floors and departments. In areas of production control, multi-ton cargo containers can be tracked daily to assist in highly efficient loading, unloading, and accurate placement of cargo in the shipyard. And, as mentioned earlier, perishable goods, such as produce, dairy, or poultry will soon be tagged with sensors that will communicate information about the items themselves, just as these same sensors communicate with the shelves or bins on or in which the food is stored.

A host of component technologies will come together to support physical tagging in the coming decade: databases, software for pattern matching, GPS systems, wireless communication protocols, personal bar-code readers, drive-thru purchase devices, smart ID badges, not to mention small-scale power and smart materials (see related sections in this report for more information).

At the system level, physical and digital tags become one and the same. Physical tags are typically sensors embedded in objects and scanned by local or remote devices for purposes of tracking and handling. Digital tags will most likely use XML to build links that propagate across data objects, linking them by content, structure, ownership, or other characteristics.

Some current industry players in physical tagging

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► **TAGGING (CONT.)**

include: Texas Instruments, who, with SCS Corporation, is developing a passive RFID/UHF tag with a read-range of approximately seven feet. Costs should be kept to a minimum as these partners hold to their vision of employing antennas on receiving-dock doors. Tagged containers, cartons, and pallets will then be instantly read as they pass through the dock doors. Texas Instruments has also partnered with Symbol Technologies and Zebra Technologies on a complete UHF offering. Other chief players include Alien Technology of Morgan Hill, California, PhotoSecure of Boston, Intermec Technologies of Everett, Washington (maker of Intellitag), and Power Paper (see the Small-Scale Power section of this document for more on this Israeli company).

Other products include:

BiStatix

This technology, developed by Motorola, has trimmed certain costs of RFID tag production from US\$3 down to only 50¢. BiStatix removes some of the standard RFID electronics (mentioned above) and instead prints the tag's antenna onto paper, using conductive carbon ink.

*FastTrack / I*CODE*

Escort Memory Systems (EMS) utilizes Phillips Semiconductors' I*CODE integrated circuit (IC) in its FastTrack array of smart labels and tags. FastTrack tags are in turn employed by other companies, such as Cultured Stone, of Chester, South Carolina (the company is a division of Corning). Cultured Stone embeds FastTrack smart tags into their molds and pallets, thereby communicating product state and whereabouts to the company's system network.

RFID advances are providing good news for companies in North America. But the challenges in Europe remain. There, UHF use is more tightly designated and regulated (only low-to-mid-range spectrum communication is allowed; tags tend to have a more limited data

storage capacity and shorter-distance reading ratio). A host of regulatory issues will need to be ironed out. In the long-term, global tracking of items is the ultimate goal (see "Standards" for more on all of this). Near-term domestic (U.S. and North American) RFID applications, however, will soon be appearing.

Future Innovations

The future of RFID technology could happily invade every aspect of our lives. Particularly interesting uses of the technology are those that link information across media—for example, tagging a radio program to provide quick access to additional information on a Web site.

The hot spot in the future here is bundling and tagging information itself. Consider, for example, tags that link information to a particular individual becoming the basis for augmented reality applications. Workers in environmentally hazardous situations could have their actions tracked by tags which could identify situations that would be particularly threatening based on each worker's prior performance and traits. Soft tags might contain information about an individual's voice, height and weight, and even experiences, all of which could be drawn upon to simulate their performance in a given scenario. Of course, soft tags also raise fundamentally new privacy issues: information that was previously contained across different systems—but now linked by a tag—becomes much more descriptive.

Other pieces of the puzzle will fit together when the smart-tag networks and their readers are directly connected with existing infrastructure like the Internet. When this happens, and with sensors embedded into buildings, appliances, and gadgets, everything will communicate with everything. In the not-so-distant future, you may be able to "dial home" (via the Internet) before you leave work to see if you've got the ingredients needed to make that chocolate cake you're

craving. Your pantry might then send a signal to your local supermarket. When you arrive to buy your ingredients, a shopping cart will already be loaded for you. (While this type of technology may very well be developed and available as early as 2015, deployment may take a bit longer.)

Standards

Table 6 presents certain emerging standards in tagging technology, including chief proponents and developers.

Because smart tags are already in use, and because their performance and possibilities are rapidly increasing acceptance of the technology, the GTAG (or Global Tag) program—a joint initiative between the UCC, which is based in Lawrenceville, New Jersey, and the European Article Numbering Association (EAN), based in Geneva, Switzerland—was launched in March of 2000. GTAG is not a company, but a consortium of the above bodies, in partnership with Philips Semiconductors, Intermec (the leading auto ID company), and Gemplus (leading supplier of RF tags, labels, and reader components). Their collective goal is to guide the creation of standards in this soon-to-boom industry, clearing interoperability and regulatory hurdles, most specifically in the 862- to 928-MHz UHF range. Their vision is to guarantee the establishment of open, standards-based RFID technology that can be used anywhere in the world.

This work is vital, for, at this point, international

standards for smart tags and labels has focused on those that communicate in the 13.56 MHz band. This becomes limiting when investigating new ways that RFID technology might be leveraged. For instance, GTAG’s proposal (in the 800-900 range) would provide for greater read-range than 13 MHz can provide. Higher frequency means faster data exchange and larger per-item “batch reading” capability. Also, a UHF signal has a narrower beam, which gives rise to less background interference from other near-by systems. The GTAG consortium is expected to publish their guidelines by May of 2002.

Manufacturing specs will naturally flow from these sorts of new parameters, as will new international protocols for performance, data management techniques, and minimal requirements of what a system must do. Once this is put into the public domain, anyone will be able to use it, free of licensing fees.

Relatedly, the International Organization for Standardization (ISO) has, for about three years now, been spearheading a broader effort focused on making higher communication layers independent from carrier-frequency issues. This would allow developers of application software to work independently of the physical nature of, say, the air interface between tag and reader. In this case, advances in tag technology, or use of differing brands, would allow software to remain unaffected.

*Table 6
Standards: Tagging*

<i>Selected Emerging Standards</i>	<i>Proprietary or Open</i>	<i>Significant Proponents/Developers</i>
GTAG*	Open	Gemplus, Intermec, Philips, TI
ISO/IEC JTC1/SC31*	Open	Denso, Gemplus, Matsushita, Philips, Siemens, ST Microelectronics, Symbol, TI

*RFID technologies are for the most part industry specific; however some overarching standards pertain to radio frequency and data transfer.

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► **TAGGING (CONT.)**

KEY BUSINESS IMPACTS

- Physical and soft tags will each create the opportunity for cost reduction in supply-chain operations, principally through greater collaboration with industry partners.
 - Soft tags will enable companies to leverage their existing enterprise data, and to share it more effectively with other companies within their value web.
 - Tagging increases the ability of companies to build end-to-end relationships with their customers, and to move into new service-related businesses that employ information about the product's design, manufacture, current location, performance, and maintenance.
- Smart agents will gain in importance as more information about objects is gathered—and becomes comparable. This is likely to continue to force down prices (and margins) especially in B2B transactions; ultimately, vendors will focus on trust and product services as differentiators.
 - Expect continued growth in dependence on external partners (value web) to provide complete solutions to customers.

Peer-to-Peer

Peer-to-Peer computing isn't exactly new. The idea behind it has been around for at least 30 years. Client/Server hasn't been the only architecture on the computing scene, and an alternative network architecture, now labeled peer-to-peer, has been explored for some time. Of course, the Internet has changed everything, including our understanding of peer-to-peer computing.

Put simply, peer-to-peer (P2P) computing is a user-level, distributed system architecture that makes independent file-sharing and communication a snap. Based on open-source coding, customers with similar interests can link with one another and search each other's computers for desired information. And every client/server on the network can actively choose what information is shared, and what isn't—and can change those designations at any time.

In a peer-to-peer architecture, computers that have usually functioned as clients, instead communicate directly among themselves, acting as both clients and servers, assuming whatever role is needed at the time. Peer-to-peer networks securely tunnel through corporate firewalls, making it possible for safe, encrypted communication to happen both within and between companies. This also allows budding peer groups to set up P2P networks without bothering network administrators for special permissions every time things need to be shared.

Speaking metaphorically, logging on to a P2P network is like wading into a sea of people. But in this ocean, everyone who's a part of it may hold vital information about the topic (or topics) that connects them—the shared “water” everyone's voluntarily swimming in. As you wade in, you put a specific question out over the waves. Every node (every computer or person) that's part of this ocean receives your query in a distributed, chain reaction. Any nodes that have relevant information in turn may choose to pass that data back to you in the same distributed fashion. The lack of a central server creates a fundamentally decentralized network, which provides fault tolerance while also reducing the ability to control the flow of information and resources within the network. In a P2P system, information truly wants to be free.

Across wide horizons, the sharing of computer resources and services happens by direct exchange between systems. P2P services include the exchange of information, distributed processing cycles, and cache storage.

▶ **PEER-TO-PEER (CONT.)**

Importance

Peer-to-peer networking takes advantage of existing desktop computing power and network connectivity, allowing participants to leverage their collective power to benefit the entire enterprise.

Peer-to-peer architectures will not only challenge the mold of traditional computing—eliminating the concepts of central servers and remote clients; they’ll also break the boundaries of what can be a processor and/or a data storage device. The network becomes the computer, and anything can be a node—particularly given the anticipated developments in smart materials, tagging, and display technologies.

Unlike the public Web, where you can frequently be steered to stale links, irrelevant hits, or be required to brave the onslaught of ever-more-targeted advertising, P2P networks can offer secured encryption, and access across firewalls, for networks that are alive and specific in their content and intent. And the decentralized nature of a P2P network can also work to guarantee privacy, as well as a running network (it’s much harder to bring the network down when it’s vastly distributed). In a sense, P2P architectures are like the Internet, providing fault tolerance and a healthy dose of disrespect for central authorities.

For large companies, the promise of P2P is threefold. One use of the P2P structure is the highly powerful “distributed processing” network. In this situation, the network taps idle PCs to parse data, thereby transforming their cheap, underutilized processing power into a distributed virtual supercomputer. Also, by linking users directly, P2P can facilitate easy collaboration, allowing the rapid formation of work groups that sidestep barriers such as restricted Intranets or firewalls. And finally, P2P could make information more accessible within companies, by basically (and voluntarily) opening up the desktops of individual participants—allowing staffers to search each other’s virtual desk drawers more freely.

Regardless, peer-to-peer systems are like the Fates escaped from Pandora’s box. We can’t put them back, and they’re going to change the contemporary human experience—not only of information, but of anything the human mind can produce (and maybe some things that only machines can produce). The future of intellectual property—and all that it implies for a knowledge economy—is suddenly up for grabs. Likewise, organizations built on centralized control of resources may find themselves unable to respond to dynamic business conditions.

Uses & Applications

Peer-to-peer applications provide an alternate way to engineer data and secure resources. In the short term, the emphasis will be on managing information. In the longer term, as millions of small, smart objects in the environment become connected in a ubiquitous wireless network, the apportioned processing power of these nodes will transform the network itself into a powerful distributed computer.

The key components of peer-to-peer systems include: new network file-sharing architectures, network resource-sharing architectures, and various technologies for encryption and copyright protection within these architectures. These components will rapidly change the underlying infrastructure of the knowledge and entertainment industries over the next 10 years.

Business applications for P2P networks cover approximately four major categories or scenarios:

Distributed Computing

As mentioned above, P2P networks offer a powerful solution to large-scale processing needs. Using a network of existing PCs, peer-to-peer technology taps the dormant power of an idle computer, utilizing its disk space and CPU to perform huge computational jobs across multiple computers. Results can be shared directly between all peers within the horizon.

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An excellent example of this is Intel's Philanthropic Peer-to-Peer Program, which is focused on utilizing the virtual supercomputer to help find a cure for cancer, diabetes, and Parkinson's disease. More than 900,000 PCs are participating in this colossal effort, and have affected more than 365 million computational processing hours.

Professor David Anderson of the University of California at Berkeley has used the distributed supercomputer model since 1998 to parse incoming radio astronomy data in the search for extraterrestrial intelligence, as part of the SETI@home research effort. More than 3.2 million volunteers participate in this massive effort. (One of the perks: if your PC discovers communication of import or interest, you'll receive partial credit for the discovery.)

Collaboration

As we've discussed, P2P networks empower teams, and individuals, to create working groups easily and on-the-fly, with the focused intent of sharing information across platforms, organizations, and firewalls. This collaboration is real-time, and lends itself to greater efficiency, due to its focused nature, and the absence of false leads, slow download times, and unwanted advertisements (all of which are currently part of the Web environment). Data is fresh, and just-in-time. Productivity is increased, standard network traffic is decreased, and the lack of reliance on email as a file-sharing tool naturally frees up a vast amount of CPU volume on central servers. Information and data files can be stored locally.

Edge Services

Here, P2P networks guarantee that businesses are able to push vital information to the specific points that need it most. For instance, the P2P model lets data move efficiently to intra-company sites in distant geographic locales, acting as a network caching mecha-

nism. Utilizing P2P networks in this way can facilitate standardized training across geographic distances. For instance, in the past, video programming would have been streamed from a distant centralized server, whereas now it can be stored locally. Sessions are unfettered by the usual drawbacks of agonizing stream times, and the P2P network eliminates the need for storage space on a company's main server. Local clients share data over their LANs instead of putting demands on the WAN.

Intelligent Agents

Peer-to-peer computing also allows the dynamic employment of intelligent agents (also called "bots") across a network. These agents live on the local PC, and can find or communicate data, and initiate certain tasks across the distributed system. These tasks might include managing traffic on the network, searching for local files, prioritizing tasks across the network, or pinpointing anomalous behavior (signs of a virus or worm)—thereby keeping these destructive elements from infecting the entire system.

P2P has also attracted the interest of many key high-tech players. Among them, Intel, Sun Microsystems, and Microsoft have all poured time and money into peer-to-peer development. Intel's Peer-to-Peer Trusted Library, unveiled in February of this year, works to beef-up security protection, offering peer ID and encryption to a P2P network. Sun's Project JXTA is a secure, open-code P2P platform software that facilitates interaction between any connected device (cell phone to PDA, PC to server). Microsoft is a significant stake-holder in Groove Networks, a premier P2P collaborative system integral to Microsoft's ".NET My Services" offering that also employs Microsoft's Passport technology. Cisco Systems, Raytheon, Ford Motor Company, and the U.S. Defense Department are all interested early adopters of P2P technology and functions.

► **PEER-TO-PEER (CONT.)**

In the case of P2P, the technology itself isn't the chief barrier to adoption: instead, (and mirroring the plight of ebusiness), it's the business model, as no one has yet figured out how to make money on peer-to-peer applications or systems. For now, the cost benefits are inherent in the system, affording a myriad of cost savings and efficiencies across many categories of business (and computational) functions.

Future Innovations

P2P architectures can already form a network with so many nodes that the network itself develops the power of a virtual supercomputer. And with anticipated developments in smart materials and display technologies, anything can become a node. The proliferation of MEMS-scaled objects will produce an intelligent Web with vast distributed processing power, just as the Web learns to incorporate P2P applications into its own infrastructure. The end-goal here is to create both the usability and immediacy of P2P applications, which also deliver the same widespread accessibility, openness, and democratic access afforded by the Web.

Even so, there may be some tradeoffs. While the peer-to-peer model is fault-tolerant and scales well, it obviously lacks a central control structure. Watch for the development of corporate and consumer exchanges—subnets on the Internet that share processing power or informa-

tion in exchange for benefits or shared goals.

Standards

Table 7 presents certain emerging peer-to-peer technology standards, including their chief proponents and developers.

In August of 2000, a number of companies joined forces and organized the Peer-to-Peer Working Group (P2PWG). This consortium is dedicated to exploring and establishing industry standards for P2P software. There is a clear recognition that P2P computing cannot emerge broadly until there is an assurance of interoperability across platforms and applications. The consortium's member companies include technology heavy-hitters such as Fujitsu, Hitachi, Intel, and NTT, as well as such promising P2P start-ups as Groove, OpenCola, NextPage, and 3Path.

Companies are still somewhat leery of turning large or proprietary projects over to distributed computing models. Indeed, P2P architectures challenge the role of an organization's CIO, and the growing trend towards large, managed outsourcing contracts. Without a governing protocol or single accepted platform, companies risk entering a P2P Tower of Babel. And users would likely adopt collaboration software only if they can talk to those both inside and outside their organization. Watch for standards bodies and protocols that will work to solve these issues.

*Table 7
Standards: Peer-to-Peer*

Selected Emerging Standards	Proprietary or Open	Significant Proponents/Developers
P2PWG	Open	An open standard is now being developed by the Peer-to-Peer Working Group. P2P application developers and processor manufacturers are dominant players on the P2PWG.
JXTA	Open	Sun, Avaki, Improv
Groove Platform	Proprietary	Groove Networks, Avaki, Quidnunc, Microsoft

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KEY BUSINESS IMPACTS

- Culture and computing-architecture are unavoidably linked. P2P architectures challenge hierarchically structured organizations. Depending upon the vertical in which a company operates (as well as its business model) some companies will be injured by competitors who adopt P2P tools early on. Conversely, some industries and corporate cultures are not likely to function efficiently in an environment where authority is highly distributed: instead, they will be best served by continued dependence on rigid structure.
- Facile and expedited decision-making within knowledge-based organizations will result from P2P collaborative tools.
- Look for improved collaboration across company boundaries, especially for those companies who are dependent upon their role in a value web.
- P2P means a changing role for enterprise IT departments, as collaborative applications and authorities will increasingly be under the control of individuals; however, Web services that underpin P2P computing will require the expertise of a central technology group.
- P2P provides a simplified means for pulling together teams of consultants and freelancers, who may come together on their own initiative to bid on projects or temporarily join an enterprise project team.

Wireless Technology

Monday morning. 7:00 a.m. As you leave the house, travel-mug in hand, you double-check that you didn't forget any of the **vital devices** that make up your PAN (your Personal Area Network): PDA (check), cell phone (check), earpiece (check), smart badge (check). The network hub on your belt shows that battery power is fully charged and each of your devices is smoothly cross-communicating. As you walk to your car, hands occupied with your briefcase, today's Wall Street Journal, and your coffee mug, you access your PDA with a simple voice command, "Activate PDA. ... Email. ... 'Jarod, I'm on my way. The report's waiting for you on the printer.' ... End activity. ... Next task ... Print Connective Report to 'Hal.' ... End activity." Then you realize that there's something else you almost forgot. "Activate cell phone. ... Call Amy."

Already, an email message is whizzing from your PDA to Jarod's email queue, which resides on his corporate LAN. The appropriate Word document is currently printing on Hal, your group printer. And, as your PAN processes the message from your PDA, your GPS-enabled cell phone will tag the message with your precise location, as well as the exact time. When Jarod logs-on in an hour, he'll know you radioed in from home, and that you'll be a bit late due to the jackknifed trailer on I-95. And when you arrive, the report will be ready for distribution to the team. But right now, you're busy leaving a voice message for your PTA president about tonight's meeting.

A wireless network permits the transfer of digital data through the air, employing a variety of technologies. These exchanges may include the transfer of data between and among people, between machines, or within (or between) networks themselves. Ultimately, communication will happen in a variety of ways, across multiple domains and devices.

And what makes wireless technologies meaningful to business users is simply put—convenience. As knowledge workers, our increasing dependence on technology has had both bad and good consequences. We seem to have less time to do our jobs, despite the rumored productivity gains from technology. Wireless enables us to take advantage of those discrete, free moments we have, regardless of where we are. And, unlike the production worker, we often think about work away from our work-sites (should we even have one!). Wireless technologies provide one additional and easy way to capture those thoughts and to take action.

Perhaps the real benefits of wireless are less obvious. Expanded machine-to-machine communications are integral to the wireless boom. Telemetry, or the ability to monitor the state of physical systems at a distance—whether they are industrial mechanical systems, or biological environments—is made possible by a combination of functions. Sensors, including smart materials, communicate wirelessly with remote processors that in

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► **WIRELESS TECHNOLOGY**

turn apply pattern recognition algorithms to analyze changes. Remote adjustments to the system might be made, or a service team might be dispatched to prevent a predicted system failure.

Taken together, with the arrival of wireless data networking, our opportunities to integrate personal and work activities, machine-to-machine activities, and even community activities, such as managing school schedules, coordinating sports and recreation, or organizing spontaneous groups for specialized action or activity, will vastly increase. It is social convergence within technical convergence.

Wireless technology is defined by two major categories, and three main domains. The categories include fixed (geographically rooted) and mobile wireless technology. As a rule-of-thumb, the domains are: PANs (Personal Area Networks) that currently communicate within 10 meters of targeted devices; LANs (Local Area Networks) that can communicate within 100 meters of targeted devices; and WANs (Wide Area Networks) that can communicate beyond a 100 meter radius.

As computer networks, the Internet, and wireless communications evolve, their radically expanded integration will raise new challenges for both individuals, and business organizations, who have traditionally thought of networks, devices, their applications, even their processes, as cleanly separated, definable entities. But advances in information technology, microelectronics, and “soft radio” will knock down these barriers and cause us to think about wireless networks differently: they’ll be converged voice and data systems that seamlessly switch among protocols to find the most efficient network manager based upon time and place.

Importance

In business, wireless technology can seamlessly connect employees to corporate data and applications, even if they are geographically dispersed. The benefits

are potentially enormous: real-time updates of warehoused goods, just-in-time supply chain management, improved logistics for customer service, radically increased portability of devices (which, in turn, increases the reach and speed of information), and much more.

But the real test will be in choosing how to integrate wireless technology into business processes. In the past, enterprise networks have adopted new information technologies incrementally, allowing users and the corporate climate as a whole to gradually integrate and adapt to the changes each new technology brings. Wireless information is very different, as this type of mobile, portable, just-in-time data creates the need to think in entirely new ways about corporate resources, employees, and customers—predominantly because these things no longer need to be fixed in geographical space. The entire system becomes moveable, nimble, eminently accessible, thereby increasing the power of the information itself.

Speaking economically, the third-generation infrastructure, or “3G” vision of high-end broadband applications is already in motion, though the cost of 3G will be immense. Even so, an important point here is that there is incredible potential for economic and technological “leapfrogging.” For instance, cellular phone systems have enabled second- and third-world nations to bypass landline phone networks. (Laying fiber isn’t the only route to high-tech capability when you can jump directly to wireless devices and applications.) Similarly, these less advantaged nations could utilize these new technologies to position themselves as global players in wireless networking.

Speaking from a standards perspective, certain wireless applications cannot function unless everyone in a society participates in the network, and we are likely to see these applications emerge as public goods, supported by governments and utilities. Competing standards have already created “wireless

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► **WIRELESS TECHNOLOGY (CONT.)**

islands” around the world; connecting on the island is generally easy, but traveling to another island requires an investment in an incompatible technology.

Uses & Applications

Let’s begin by stating the obvious. In a wireless world, the networking equipment manufacturer faces a significant decision: if their systems are going to work, they must now employ the same standards that device users will be adopting and purchasing. Likewise, device manufacturers are obligated to make a similar decision on standards. However, in a world where such terms as “globalization” and “location independence” are prevalent, competing wireless standards (especially across geographies) are increasingly at odds with the collaboration imperative. And with the advent of peer-to-peer computing, further degrees of complexity are introduced, as devices will now be expected to communicate effortlessly with one another, sometimes across very different task sets and domains.

At the same time, we don’t expect a one-device-does-everything solution. Rather, we expect an increasingly complex device (whatever its category), working in an increasingly sophisticated application ecology—an ecology in which users segment themselves idiosyncratically: by dimensions such as time and place, technology, tasks, rule sets, and experiential preferences. Multiple-standard devices, new user-interface possibilities that connect multiple devices, cordless telephones that also function as cell phones, 802.11a and 802.11b protocols, next-gen “2.5G” and 3G mobile devices, and Bluetooth are all examples of things that will push complexity in the short-run.

The key to the widespread success of wireless technologies for users is the ability to support multiple devices across multiple domains. Wireless technologies that enable machine-to-machine communication may be less dependent upon standards since they’re likely to be deployed by a company, or within an industry, where

there is a clear business case to be made.

Successful systems will be built around usage scenarios rather than general utility models. Usage-based systems will support multiple technology protocols, and users will expect their devices to work across multiple domains. A leading edge example is the use of peer-to-peer architectures to provide “swarm networks”—networks that eschew installed relay towers and instead turn user devices into local relay receivers and transmitters for “swarms” of users that come together organically.

To exploit the real benefits of wireless, applications will tend to integrate data across home, office, and community, and will effectively employ multiple standards. At the same time, users may choose a variety of applications or devices to segment their use of this data in unique and personal ways. Consequently, in building a device that satisfies individual needs, manufacturers will need to give users the opportunity to personalize their network access tools through modular, swappable technologies. In effect, users will determine which access points to connect to and add the appropriate technology protocol chips to personalize their system (this may even give rise to an idiosyncratic collection of both mobile and fixed devices). The areas to watch include:

PAN

Bluetooth was an early, proposed standard for the PAN. However, component costs and security have slowed its adoption (component cost will impair the widespread adoption of Bluetooth in the short-range wireless space [PANs or LANs] probably until 2004.) Bluetooth’s future market share may also be somewhat eroded by current LAN solutions like 802.11b. (Some naysayers have suggested that Bluetooth has lost to 802.11b, but these are predominately complementary technologies with their own strengths and weaknesses.)

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LAN

Printers have been responsible for both surprises and innovations in the personal computing space. In the mid-1980s, some forecasters enthusiastically declared that PCs would store all of our data, creating the truly paperless office. (As we all know, printers flooded our workplaces and homes with more paper than ever.)

If momentum drives this market, which in turn is subject to the network economics we have seen in recent years, it's likely that 802.11b (and perhaps 802.11a) will dominate wireless LANs—and perhaps broaden their coverage across campuses and neighborhoods. Moreover, significant progress is being made in addressing 802.11b's security vulnerabilities, and we will soon see enterprises adopting wireless LANs as their default infrastructure as a result of the cost savings.

WAN

The convergence of data and voice has resurrected the wide area network—a concept that had fallen into disfavor with the rise of the Internet. Yet the path to converged, high-speed wireless WANs still present many hurdles.

Over the course of the next decade, 3G network build-out is estimated to cost around US\$175 billion for infrastructure alone. Some telco service providers have invested heavily in so-called 3G spectrum licenses, suggesting that they envision a huge revenue opportunity from data.

Political and global pressures compound this business dilemma. In overseas markets, there's a great deal of pressure to steer the transition to 3G networks in a way that won't disadvantage European investment in mobile technology. An interim technology known as GPRS (General Packet Radio Service) offers a mixed data-voice network referred to as "2.5G"—and ensures that Europe's domestic manufacturers Nokia and Ericsson will get the lion's share of infrastructure con-

tracts. The United States' Qualcomm has been immensely successful in advancing its CDMA standard for 3G (with strong support from the Government), and is likely to collect royalties throughout the world for every 3G network installed.

Telemetry

Telemetry will prove to be the big sleeper application in the wireless world.

Telemetry tends to benefit those in control of the data. Up to now, telemetric data has been privately held and centrally controlled by large organizations or corporations. With the wide adoption of wireless networks, telemetric technology could give rise to a new type of "information commons" which would give all of us equal access to information about the state of our physical systems (bridges, buildings, public utilities), even the environment.

Telemetry has many obvious industrial applications, including remote monitoring of manufacturing facilities. But it also has home and workplace applications, particularly in the efficient maintenance of appliances and equipment. The potential for cost savings as a result of these efficiencies is huge, and while not nearly as visible and "sexy" as other wireless applications, the market for these applications is massive. In fact, the potential here is great enough for us to forecast the possibility of a "telemetry breakout" in which such applications become the bread and butter of the future wireless market.

Future Innovations

The future of wireless networking is as uncertain and explosively transformative as was the future of the PC in 1981. We are at the beginning of yet another technological breakthrough, facing as many unknowns as we have in any revolution that has come before. How we'll fully utilize data transfer through the air, what

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▶ **WIRELESS TECHNOLOGY (CONT.)**

wireless broadband might really mean, or bring, how our world will be forever changed (in projected, and surprising, ways) ... these outcomes remain to be seen.

Nevertheless, we can paint two broad pictures of future applications: one in which the human user remains central to the story, and a second in which machine-to-machine communication is paramount, with humans only occasionally getting involved.

Look for the emergence of the fully blown-out personal area network—a network that extends well beyond connecting household appliances, and begins to connect people, in a myriad of ways, to each other, and to a world of multi-functional pervasive computing.

Further out, it's entirely possible that the PAN, LAN, and WAN will become one network carrying data, voice, and video. The hurdle is getting to converged, high-speed wireless WANs from where we are today. While today's network providers seek to control their relationship with you, it remains unclear as to whether they can succeed if the economics of convergence favor multiple providers.

Also, keep your eye on wireless gateways. One possibility—the PDA becomes a mobile, personal gateway device as personal and public wireless objects proliferate.

Market pressures could well determine which technologies will be adopted for wireless WANs. The convergence of information technology promised by 3G infrastructures might drive server manufacturers to invest in financially troubled telcos. Over the next couple years, these computer companies will most likely see their profits decline as revenues stagnate and technology standardizes. Each will have an agenda that will influence the technology choice for wireless WANs.

The issue is not whether some variant of CDMA will be employed in 3G wireless WANs, but rather when. Financially challenged telcos must question what application drivers will justify the investment they must make to deploy 3G, and it's a chicken and

egg quandary. The development of applications—and the identification of user needs—awaits the availability of wireless broadband. What is certain, however, is that financial, political, and economic issues will each play a role in determining which technologies succeed, and whether there will be global standards or a continuation of the fragmentation we have today.

In the emerging global economy, wireless technology has already enabled societies with limited landlines to emerge as leading-edge players in the world of connective technologies. (Witness the innovative economies of Nordic Europe, where lack of landlines, extremely rough terrain, wide population dispersal, and a social culture of early adopters have made it a perfect place for wireless to take hold.) Wireless technology may allow other emerging economies to leapfrog into a high-tech future, while skipping the step of building a wired infrastructure.

Regardless, it's safe to say that the big wireless applications of the future will exploit the ability to connect across the PAN, WAN, and LAN domains. They will create the opportunity for both increased integration of applications across traditional boundaries such as home, work, and community, along with increased segmentation according to new boundaries that will be highly individual and idiosyncratic. In these applications, the users (and their preferred usage scenarios) will be the primary drivers of innovation. At the same time, watch for telemetry applications to ride the growth of wireless markets—for automated wireless monitoring of home, work, and manufacturing environments.

Standards

Wireless standards guarantee that wireless devices—from phones to computing devices to sensors—can communicate within the transmission infrastructure and thereby with other devices. (Table 8 summarizes

the emerging wireless standards and key players to watch.)

Two trends will wreak havoc on any single-standard simple solutions. First, people will come to expect their devices to work across domains. Second, peer-to-peer strategies may make the wireless “network” a much more distributed, malleable, and amorphous entity (much like the Internet).

Plainly put, the wireless world is not convergent, and standards are likely to continue to proliferate. Companies will form coalitions to champion particular standards and will rush to establish themselves as “owners” of the wireless gateway to the home or office (possibly borrowing from utility models of phone, power, and cable television). However, by decade’s end, the gateway is likely to be personal and mobile rather than residential and fixed, and will assure connectivity anytime, anywhere.

In the next five years, no single standard will dominate any of the above outlined domains. And, even after that, (as stated previously) users will expect devices to work across multiple standards and in multiple domains. Additionally, users will make their market choices on the basis of personal communication

needs more than cost.

At the component level, standards will segment into three categories: PANs, LANs, and WANs. Yet the boundaries between these domains will blur, and standards will cross over from one domain to the other. Multiple standards will also exist within domains for the next five to seven years.

Aside from these technological considerations, psychological gamesmanship plays a genuine role in the decision to employ one standard as opposed to another. In some cases, companies have dealt with this challenge by participating in consortia or industry working-groups that seek to drive the adoption of a particular standard (as is the case with Bluetooth, the leading PAN technology). Alternatively, a single company might try to enable a new standard by doing whatever is necessary—including making substantial market investments—to ensure adoption by creating both supply and demand simultaneously. (This is precisely what Qualcomm has done to drive adoption of its CDMA standard for WANs.)

Finally, there are two challenges to this forecast. First, extensions of 802.11 must be backward compatible to ensure that users don’t need to upgrade their

*Table 8
Standards: Wireless*

<i>Selected Emerging Standards</i>	<i>Proprietary or Open</i>	<i>Significant Proponents/Developers</i>
802.11b (WiFi)	Open	Dell, Ericsson, IBM, Intel, Lucent, Motorola, Microsoft, Nokia, Sony, Toshiba
Bluetooth	Open	Ericsson, Agilent, Fujitsu, IBM, Microsoft, Motorola, Nokia, Sony, 3Com, Toshiba
BREW™	Proprietary	Qualcomm, au, AvantGo, Flux, HP, KDDI
J2ME™	Proprietary	Sun, DoCoMo, Motorola, Nextel, Siemens
HiperLAN2	Open	Bosch, Ericsson, Nokia, Sony, STMicroelectronics, Telenor, Xilinx

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► **8. WIRELESS TECHNOLOGY (CONT.)**

existing technology. Second the HiperLAN2 standard emerging in Europe has a distinct technical advantage over 802.11a, in that it supports asynchronous, packetized data exchange and Quality of Service (QoS). Since 802.11a must broadcast in a different radio frequency band, it offers a significant opening to HiperLAN2, depending upon cost and timing. Currently, both of these high-speed LAN technologies will be rolled out at roughly the same time.

Key Business Impacts

- Users of wireless will continue to be frustrated by competing and incompatible standards across geographies for the next five years. Nevertheless, knowledge workers will continue to adopt wireless data technologies—becoming evermore connected and continuing to work longer hours.
- Wireless standards will emerge first with short-range wireless technologies, including 802.11 for LANs and Bluetooth for cord replacement (in offices and cars, and on bodies).

- Organizations that are large enough to build out their own multi-campus infrastructure will find that wireless technologies enable new applications and lower cost services, especially with respect to building and maintaining multiple wired networks.
- Densely populated centers (e.g., campuses and shopping malls) and urban districts will install and employ short-range wireless networks to provide convenience and lower cost communications than are possible on expensive wireless WANs. There will be a growing opportunity to off-load data and voice communications to these wireless LANs to reduce costs and balance periods of peak and high-cost usage.
- Some urban regions will emerge as better places to conduct business, due in large measure to past investments by Government and industry in their communications infrastructure. Data communications, wired and wireless, will favor large companies that can negotiate wholesale access to network capacity.