Bluetooth Creates Personal Wireless Network

Intel Pushes Mobile PC Industry Ahead With Wireless Technology

by Keith Diefendorff

At PC Tech Forum last week, Intel and four other industry heavyweights—Ericsson, IBM, Nokia, and Toshiba—announced a new communications technology that Intel hopes will push the mobile PC industry a giant step forward. The new technology, code-named Bluetooth (after a tenth century Danish king), provides a universal wireless interface between PCs and all manner of electronic devices. If successful, Bluetooth will improve the way we connect personal electronics devices to computers and radically improve connectivity for mobile computer users.

Bluetooth links devices using a short-range spread-spectrum radio operating in the frequency band occupied by microwave ovens. The inexpensive ultra low-power radio creates a secure 1-Mbps serial connection between devices up to 10 meters apart.

The Bluetooth group has already been joined by a dozen other big-name companies in the communications, PC, and semiconductor industries, with more to follow. Products using Bluetooth are expected to appear in late 1999.

Improving Notebook Connectivity

Today's mobile PCs give road warriors the near-equivalent of a desktop PC. They are powerful enough for most jobs, and Intel aims to eliminate most of the remaining performance gap with its Geyserville technology (see MPR 3/30/98, p. 4). USB and 1394 ports give notebooks I/O capability similar to that of desktop PCs without using bulky PCI slots. And the new high-resolution, 14" active-matrix LCD screens are superior in many respects to their desktop counterparts.

The one remaining functional difference—and it's a big one—is the lack of network connectivity. A computer these days is a significantly less useful device when cut off from the Internet or the corporate information network.

Figure 1. No more cables! Bluetooth uses an RF link to connect all your personal devices, such as notebook computers, PDAs, cell-phones, headsets, and digital cameras.

When a phone jack isn't handy (which it rarely is), about the only solutions are to connect your notebook PC to your cell-phone through a PC Card modem or to use a Ricochet-type packet-switched radio-modem. But extra cards, cables, and other attachments are a hassle, especially when traveling. Eventually, cell-phone electronics may be integrated into notebooks, but for now this is expensive.

Integrating a cell-phone into a notebook also raises the question of which standard to integrate: analog, CDMA, TDMA, GSM…? There is no right answer. Eventually, soft cell-phone technology or reprogrammable logic will enable all standards to be implemented, but those technologies are over the horizon. And packet-switched radio-modems, while technically superior to circuit-switched cellular networks for data, have a long way to go before the infrastructure is in place to provide broad coverage. Clearly another solution is needed.

Enter Bluetooth. Bluetooth puts a short-range radio into both the notebook and the cell-phone that allows data to be transferred between them. So, for example, when you click the "SEND" button on your e-mail application, Bluetooth will use the cell-phone in your briefcase to transmit the message to your e-mail server over whatever cell-phone service you happen to use.

The beauty of this solution is that it isolates the PC from cell-phone standards, allowing them to evolve separately. This cleverly sidesteps the dilemma of which cell-phone standard to integrate. But there are other advantages. The short-range Bluetooth transmitter will cost less and use less power than an integrated cell-phone. It also retains the current industry economic model of the service provider subsidizing the cost of the cell-phone. Plus, it permits the cell-phone to be carried and used separately. Thus, Bluetooth provides a less expensive and, in some respects, more convenient solution than integrating the cell-phone.

Not Just for Cell-Phone Connections

Bluetooth is not just a cell-phone connection. As illustrated in Figure 1, it can just as easily serve as a link to a variety of other electronic devices, such as PDAs, digital cameras, GPS receivers, automobile navigation computers, headphones, microphones, and so on.

In essence, Bluetooth simply replaces short cables. Thus, all it really does is make it more convenient to do things you do today, such as synchronizing your Palm Pilot with your PC. Other technologies, such as the infrared IrDA link, have been offered for this purpose. IrDA became widely deployed because it is cheap, but users find it too finicky, so it has not become widely used. Products like Motorola's Envoy (see MPR 3/28/94, p. 18) tried to integrate PDA, e-mail, and wireless modem functions together. They failed because they were too expensive. Bluetooth, on the other hand, promises to be robust yet inexpensive. So, even though cable replacement may not represent a fundamental new capability, the convenience of Bluetooth may nonetheless succeed in revolutionizing the way we use personal electronic devices.

Unfortunately, Bluetooth stops short of providing full networking capability. This will limit its application domain to some extent. For instance, it does not support user-transparent peer-to-peer communication with other PCs. But the reward for this limitation is low cost and low power consumption, which themselves enable new applications.

Bluetooth Uses Microwave-Oven Frequency

The first problem was finding spectrum for a new radio link. Bluetooth engineers found a clever solution in the unlicensed ISM (industry, scientific, and medical) "free band" at 2.45 GHz—the same frequency used in microwave ovens, among other products. This band is globally available for communications and is regulated in the U.S. by the Federal Communications Commission (FCC) to control interference. The band has 89 MHz of available spectrum. Bluetooth transmitters will broadcast less power than is allowed as leakage from a microwave oven and less than FCC Class B EMI limits. This would allow it to be used anywhere, including on aircraft, which is critical for its success. This has not yet been thoroughly tested or FCC certified, however, so it is too early to know for sure.

Although Bluetooth will operate in the vicinity of microwave ovens, some degradation of the signal-to-noise ratio is expected, with a consequent loss of up to 40% in bandwidth or range. Again, not enough testing has been done to quantify this accurately.

Ericsson initially developed the Bluetooth radio technology, with help from Nokia. The link uses a packet-switching protocol based on a hybrid fast-frequency-hopping direct-sequenced (FFH/DS) spread-spectrum radio that hops 1,600 times per second across 79 frequency bands, each 1 MHz wide (similar to IEEE 802.11). This technique minimizes susceptibility to interference, allowing the transmitters to operate at exceptionally low power levels. Short data packets further improve performance in the presence of interference.

A Bluetooth link is quite secure. Spread-spectrum technology provides some natural immunity to eavesdropping. An added link-layer security protocol and 40-bit encryption make it nearly bulletproof.

The radio link forms a personal network bubble around the PC to a range of 10 meters. Connections do not require line-of-sight, but the signal is attenuated by intervening objects. Communicating with devices in pockets or briefcases at short range is not an issue, but communicating through walls to more distant devices in a home or office might be. If necessary, an optional power amplifier fixes this problem.

Ten independent full-data-rate "piconets" can be operational within a bubble. Bandwidth degradation is graceful when more than 10 piconets are in operation. Eight devices are addressable on each piconet. This means, for example, that 10 people in a conference room, each with eight personal devices, would all receive full bandwidth.

The available data bandwidth of each piconet is 432 kbps full-duplex, 721/56 kbps asymmetric half-duplex, or 384 kbps TMS2000 (a third-generation GSM standard). A piconet can also support three 64-kbps CVSD (continuous variable slope delta modulation) full-duplex voice channels, or a combination of voice and data channels. The available bandwidth is divided among the active devices on a piconet.

The RF transmitter uses the 2FSK (frequency shift keying) modulation technique. This could later be enhanced to 4FSK, doubling the data rate. The higher-speed version would still be backward compatible, but there appears to be no well-defined plan or schedule for deploying this upgrade.

Protocol Cuts Cost and Power

To minimize cost and power consumption, Bluetooth was limited to a point-to-point link, as opposed to a full-fledged multidrop local area network. This decision avoided the complexity of such techniques as collision detection, which would have been needed for a full network protocol. Instead, the Bluetooth protocol is kept simple. All devices on a piconet are synchronized. A master-slave arrangement controls transmission to prevent devices from talking at the same time on the same frequency. The master is dynamically established, and any Bluetooth node can be a master. Each transceiver is identified by a unique 48-bit address derived from the IEEE 802 standard.

A Bluetooth network is not self-configuring. The policies that will be used to manage the network are not yet worked out, but it is likely that users will have to manually configure a device into the network the first time, usually when it is purchased. Once a device is configured, any time it comes into the bubble, the network will automatically sense its presence and begin communicating with it.

There is no automatic method, however, for dealing with a foreign device. Presumably there will be some sort of manual software interface that allows a user to temporarily connect to a foreign device so, for example, a file can be transferred to someone else's PC. But as currently envisioned, this will require user intervention (e.g., a software dialog box) each time. Thus, device configuration may be less daunting than assigning IRQs in a PC, but not quite as simple as plugging into a LAN.

To minimize power consumption and reduce interference between piconets, the power level of the RF transmitter is programmable. Using a technique similar to that used in cellular phones, the signal level coming from a remote transmitter is measured and fed back to automatically adjust the transmitter's power to the minimum level necessary to maintain a reliable link.

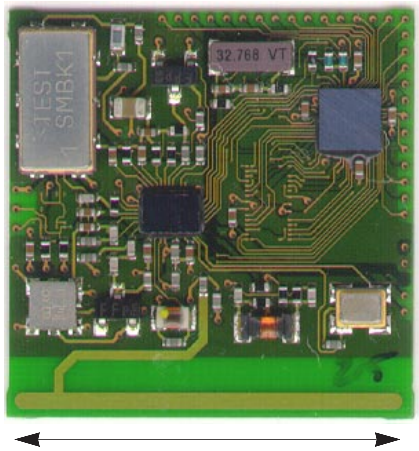

Figure 2. Everything necessary to implement a Bluetooth node is contained on a single module. This prototype module is 1" x 1", but the production module will be 1" x 0.5"

The transmitter operates at 0 dBm (1 mW) nominal output power, and the receiver sensitivity is –70 dBm. The chips operate at 2.7 volts (in 0.25-micron CMOS) and consume 8–30 mA while actively transmitting (depending on packet types, traffic patterns, and distance).

There are three progressively deeper power-saving modes that trade power for wake-up latency. In standby mode, a device continues actively listening, consuming on average approximately 300 µA. In hold mode, a device stops listening but continues frequency hopping and remains synchronized. The wake-up latency from hold mode is around 4 milliseconds, but the device requires only 60 µA of current. In sleep mode, the transmitter shuts down and draws a scant 30 µA, including the power necessary to occasionally power-up and listen, so the device can be woken remotely.

Radio Delivered As a Module

The Bluetooth radio will be available on a standard 1" by 0.5" module. The module can be used in any device including a notebook PC, although integration into smaller devices will often be in the form of discrete components, to save space. The module includes everything necessary for a Bluetooth node: host interfaces, baseband controller, flash ROM for the software stack, RF circuitry, and the antenna. Figure 2 shows a 1" by 1" prototype module. Intel said it expects the module will initially be sold to OEMs for around $20 in quantities, coming down over time to $5. How quickly that happens will depend on market acceptance and volume.

The modules will be available with either serial or USB host interfaces. Intel expects the modules to be integrated directly into notebook computers but not onto the motherboard of desktop PCs. Instead, it envisions USB dongles as the primary desktop deployment method.

One reason for not integrating the module on the motherboard is that the antenna for the RF signal is on the module itself. This implies that the module must be physically located outside the enclosure's EMI shields. In a notebook PC, the module could be located on the top edge of the display, outside the shields. Radios with off-module antennas could eliminate this constraint. The radiation pattern of the simple PCB-trace antenna shown in Figure 2 would be too directional, so the production module will employ an omnidirectional switched (between transmit and receive) antenna that will eliminate orientation problems.

Bluetooth has been designed so it can be implemented on a single chip in pure CMOS technology, even though initial production modules use two chips. Exotic gallium-arsenide technology or bipolar circuits were avoided for obvious cost reasons. Bluetooth can be implemented in 0.25-micron technology but probably only with some special process tweaks. A standard 0.18-micron process, however, should do the trick.

Creating an Open Standard

Intel wants Bluetooth to become an open standard to promote rapid adoption. To this end, it helped form an industry-based special interest group (SIG) with control over the specification. Ericsson, IBM, Intel, Nokia, and Toshiba make up the initial core SIG. Another dozen companies have signed to join the SIG, including PC manufacturers Compaq and Dell; communications giants Lucent, Motorola, and Qualcomm; semiconductor manufacturer VLSI; and 3Com, whose Palm Computing division will integrate the technology into a future Palm Pilot. In addition, HP said it will be integrating Bluetooth into its mobile products.

Intellectual-property ownership is controlled by contracts with the SIG. The IP model is similar to that used in other industry standards projects, such as PCI. Members of the Bluetooth SIG will get royalty-free licenses to all the technology and intellectual property developed therein. The SIG will control certification of Bluetooth devices.

The SIG intends to have the Bluetooth specification ready for broad industry review by the end of this year. At that time, additional adopters of the technology will also be announced. Revision 1.0 of the specification will be finalized by 1H99, and initial products are expected to be announced and available in the market during 2H99.

A Few Barriers Remain

To become truly compelling, Bluetooth must be deployed ubiquitously. But there are a few potential obstacles.

The first is cost. High-end notebooks have margin structures that can absorb a $20 cost adder; low-end notebooks, PDAs, and cell-phones don't. Customers for these high-volume products will be reluctant to buy more expensive models just to get Bluetooth. Bluetooth PC Cards will show up for notebooks, but it's less obvious how add-on or add-in options work for devices like cell-phones. Unfortunately, Bluetooth manufacturing costs will come down only with high volumes. This implies a gradual process of higher volume leading to lower cost, which leads to higher volume, until costs become low enough for ubiquitous deployment. Ericsson said it believes costs will come down rapidly.

The second issue is size. Although a Bluetooth module is incredibly small, it is still too large to fit easily into a Motorola StarTAC cell-phone, for example. There, a different form factor, perhaps direct integration onto the phone's circuit board, would be required. But there is limited space in such devices, and the additional Bluetooth circuitry will carry some lost-opportunity cost. This size issue may impede Bluetooth's deployment in the very devices that could support its initially high $20 cost.

The third concern is competition. The infrared IrDA link, already deployed in most notebooks and the newest Palm Pilot, also offers a wireless alternative to serial cables. IrDA has about four times the bandwidth of Bluetooth and is dirt cheap. Bluetooth, on the other hand, uses RF transmission. This eliminates the line-of-sight-communication restrictions that make IrDA useless for connecting to a cell-phone in your shirt pocket. Bluetooth also allows connection to more than one device at a time. These advantages seem overwhelming, so we expect IrDA will at worst slow the adoption of Bluetooth.

A fourth potential barrier is the U.S. Federal Aviation Administration. The FAA and other international regulatory agencies have not yet evaluated the technology or ruled on its safety in airplanes. A negative ruling could be devastating. Even if Bluetooth itself were found to be safe, its potential to facilitate covert use of hidden cell-phones could attract the FAA's attention and perhaps even strengthen the move to ban PCs on aircraft entirely.

And finally, Bluetooth does not have full network functionality or dynamic network-configuration capability. While simple cable replacement is certainly a valuable function, it is too limited to address applications needing peer-to-peer interaction or transparent connection to hidden computers, such as the one in a rental car's navigation system. This is not a killer defect, but it does expose Bluetooth to being derailed by a future competitor with networking capability before it reaches critical mass. Ericsson said a full networking protocol could be implemented in a future version simply by changing the firmware.

What's in This for Intel?

At this point, Intel is positioning itself strictly in the role of industry enabler. Intel has not announced any product plans for Bluetooth, nor has it said whether it intends to manufacture silicon or modules. It is likely that Intel will not try to profit from Bluetooth itself. Intel would probably prefer to commit its wafers to higher-margin devices, although it might build chips or modules if it felt the need to jumpstart the industry. Instead, Intel is more likely to see Bluetooth as an opportunity to increase microprocessor sales.

Bluetooth is definitely not the traditional microprocessor-related technology you expect to see Intel promoting. It is, however, a fascinating example of just how far afield Intel will go to make PCs more attractive and generate demand for its microprocessors.

How much impact Bluetooth will ultimately have on sales of Intel's processors is unclear. While Bluetooth may make notebook PCs easier to use and more attractive, it's hard to see how that alone would significantly increase market size. The largest effect may simply be to shift more users off desktop machines onto notebooks. This may increase Intel's processor volumes, but only to the extent it enjoys a disproportionately large share of the notebook market.

There is nothing obvious about Bluetooth that would increase demand for the high-performance microprocessors that only Intel can deliver. In fact, the technology looks most attractive for connecting PDAs to cell-phones—markets that Intel doesn't serve at all today (although it could with StrongArm). So it's unlikely that Bluetooth's impact on Intel's processor sales will be anything more than incremental. But with Intel's volumes, even a small increase in market size could mean hundreds of millions of dollars.

It is also possible that Bluetooth could prompt some unforeseen killer application that would drive new demand. Fortunately for Intel, it is in the enviable position of having the wherewithal to drill a few random dry holes on the outside chance of striking oil. This potential alone, regardless of how improbable, justifies the investment for Intel.

Bluetooth Looks Promising

Bluetooth looks like a technology with a bright future. Eliminating cumbersome cables and line-of-sight restrictions has obvious market appeal, especially for road warriors. The technology looks sound, and the partners are quite competent. The open standard route is the way to go for rapid adoption. Broad industry backing is already in place, and it looks like more is on the way. There are a few hurdles in the way, but none too high for this impressive cast of supporters.

For users, Bluetooth improves notebook connectivity and makes sharing data among personal electronic devices much more convenient. For Intel, some increase in the market for its processors is possible, and it may even get a small market-share bump. There's also the potential upside of a new killer application. Notebook PC makers should see more unit sales, higher ASPs, and possibly even better margins. The benefits to cell-phone and PDA vendors will be similar, although they will be under heavier cost pressure. The biggest winner of all may be cellular service providers, which should get a sizable boost in airtime billings from cellular data traffic. All in all, it looks like everyone stands to win, although the magnitude of the win remains to be seen. M

For More Information

For more information on Bluetooth, access the Web at *www.bluetooth.com.*