Bluetooth vendors bite the bullet

The original idea for Bluetooth was simple: Embed low-cost, short-range RF transceivers into computing devices to eliminate the rat’s nests of interconnecting cables. With a Bluetooth RF link, users need only bring the devices within range, and the devices will automatically link up and exchange information. But in practice, designers have uncovered significant operational issues, such as multiple transceivers within range, interference from non-Bluetooth devices, and incompatibilities with other vendors’ products. Today, with a broader specification and a renewed concentration on interoperability, manufacturers are ready to forge ahead and take Bluetooth products to the marketplace.

Embedded designers are incorporating Bluetooth wireless technology into a range of new products to meet the surging demand for connected information appliances. With industry analysts predicting that the market for Bluetooth will exceed 100 million devices within the next three years, manufacturers are preparing for an explosion in Bluetooth interest. Cellular phones, PDAs (personal digital assistants), portable office equipment, digital cameras, medical equipment, and industrial-automation products are just a few applications that will benefit from such interest. Designers have also extended the original cable-replacement applications to include network access, wireless games, toys, and even digital jewelry.

Designers at Ericsson conceived Bluetooth in 1994 to replace interconnecting cables in the company’s portable consumer devices. One of the company’s first concept products was a wireless headset that links to a Bluetooth-enabled cellular phone that the user holds in his or her pocket. Ericsson derived Bluetooth’s catchy and memorable name from Scandinavian history. Bluetooth was a Viking king who lived around 950 and was credited with ending hostilities between Denmark and Norway. Developers formed a Bluetooth SIG (Special Interest Group) in 1998 to monitor the technology’s development and to create an open, global standard. The group released its first specification in 1999, and today the Bluetooth SIG boasts more than 2000 mem-
bers. In addition to promoting the technology and maintaining the specification, the SIG defines product-interoperability requirements and resolves global-frequency-band conflicts.

Bluetooth manufacturers are competing with other wireless technologies, such as infrared, IEEE 802.11, HomeRF, and possibly Ultrawideband. Infrared, as defined by the IrDA (Infrared Data Association), enables low-cost, line-of-sight communications over a distance of less than 1m. Although IEEE 802.11 operates in the same ISM (industrial, scientific, and medical) band as Bluetooth, has a data rate of 11 Mbps, and operates over 100m, transceiver complexity and high node cost limit its application. HomeRF is similar to IEEE 802.11 but has a 50m range, 1- to 2-Mbps data rate, and a somewhat lower per-node cost. Not yet approved by the FCC, Ultrawideband technology promises high-data-rate, short-range, 1- to 2-Mbps data rate, and a maximum data rate of 11 Mbps, and operates over 100m, transceiver complexity and high node cost limit its application. HomeRF is similar to IEEE 802.11 but has a 50m range, 1- to 2-Mbps data rate, and a somewhat lower per-node cost. Not yet approved by the FCC.

The current version of the Bluetooth specification demonstrates the complexity of a system intended to simply replace a cable with a short-range radio link. The core specification exceeds 1000 pages and covers the radio link, baseband processing, protocol requirements, basic interoperability, and compliance testing. An additional 400-page document covers usage profiles that define interoperability scenarios for various Bluetooth applications, such as cordless telephones, headsets, networking, synchronization, and others. You can download both documents from the SIG’s Web site (www.bluetooth.com) free of charge.

In normal operation, Bluetooth-enabled devices search for other units and configure themselves into small networks on an impromptu or ad-hoc basis. Two to eight Bluetooth units sharing the same channel form a piconet with one unit acting as the master. Individual units may participate in multiple piconets on a time-division-multiplex basis. When you link together two or more piconets, the resulting network is called a scatternet. The specification defines a normal 10m range with a 1-mW RF output signal and an optional 100m range capability if you boost the signal to 100 mW.

The transmitter sends channel data in packets that include a 72-bit access code, a 54-bit header, and a 0- to 2745-bit data payload (Figure 1). Bluetooth packets follow the little-endian format, in which the least significant bit is the first bit that the transmitter sends over the RF link. The receiver uses the access code for identification and synchronization. A sliding correlator in the receiver looks for expected access codes and generates a trigger when it finds a match. The Bluetooth baseband layer defines 13 packet types. Higher layers use these packets to compose more complex messages.

Bluetooth devices operate in the unlicensed 2400- to 2483.5-MHz ISM band using a frequency-hopping signal to spread the spectrum and, therefore, reduce fading and interference. The transmitted signal hops in a pseudorandom sequence among 79 RF channels spaced 1 MHz apart. The device address of the master determines the hopping sequence. The transmitter must hold at each frequency for a time slot of 625 μsec to send one packet of data. You can extend the dwelling time to as many as five time slots to accommodate longer packets (Figure 2). Bluetooth devices use a time-division-duplex scheme to exchange data. The master starts transmissions only in even numbered time slots, and the slave responds only in odd time slots. The master must poll slaves before slaves can transmit data (Figure 3).

Although the binary-frequency-shift-keying modulation technique that Bluetooth transceivers use operates at 1 Mbps, the protocol overhead results in a maximum data rate of approximately 720 kbps per channel. A positive frequency deviation from the hop frequen-
cy represents a binary one, and a negative deviation represents a binary zero. Bluetooth adopts Gaussian modulation filtering with a BT (bandwidth-time) product (bandwidth per bit) of 0.5.

Bluetooth can support a data channel, as many as three simultaneous voice channels, or a combination voice-and-data channels. Voice channels are synchronous and reserve time slots to support real-time 64-kbps data in each direction. Asynchronous data channels can support a symmetric 433.9-kbps data rate or an asymmetric maximum rate of 723.2 kbps with 57.6 kbps in the return direction. Without reserved time slots, the asynchronous data channels may suffer from latency or delays depending on traffic.

**ANY CORRECTIONS?**

The Bluetooth specification defines three error-correction techniques to recover data that becomes corrupt in the transmission media. Two FEC (forward-error-correction) codes add redundant information to transmitted data, and an automatic repeat scheme retransmits packets until the receiver acknowledges them. FEC use is optional, because it creates unnecessary overhead that reduces throughput in an error-free environment. A 3-bit repetition FEC always protects the packet header, because it contains critical link information.

The hardware of a Bluetooth transceiver includes a 2.4-GHz analog-radio section, an optional power amplifier, a link-controller section, and a link manager (Figure 4). The power amplifier is necessary to increase the range from 10 to 100 m; however, most portable devices omit the amplifier to reduce battery drain. The link controller performs the low-level digital-signal processing to establish connections, assemble or disassemble packets, control frequency hopping, correct errors, and encrypt data. The link manager is a software function that uses the services of the link controller to perform link setup, authentication, link configuration, and other protocols. Depending on the implementation, the link-controller and link-manager functions may not reside in the same processor.

To ensure that products are interoperable and conform to the Bluetooth specification, manufacturers must become qualified to apply the Bluetooth trademark to their products. Qualification requires product testing by the manufacturer and a Bluetooth Qualification Test Facility and review of test reports, product documents, and manufacturer declarations by a Bluetooth Qualification Body. OEMs can use prequalified components and bypass the qualification tests for the functions that the component covers. Qualification does not replace the type-approval requirements that the FCC or an equivalent agency in your target region impose.

Interoperability has been one of the toughest hurdles for the Bluetooth community. So many possible combinations of Bluetooth products exist, that manufacturers cannot account for each one in their application software. For example, what happens when a Bluetooth-enabled mouse detects a passing PDA? The SIG has defined a series of profiles to help
guarantee interoperability between products from different manufacturers. Currently, about a dozen profiles exist, such as general access, service discovery, intercom, serial port, LAN access, and file transfer. Manufacturers must test each product against one or more profiles during the qualification process.

IF THREE’S A CROWD...

Another big concern of potential Bluetooth users is interference or performance degradation in a frequency band crowded with unlicensed transmitters. Bluetooth competes for bandwidth with devices, such as microwave ovens, cordless phones, wireless video, and IEEE 802.11b LANs. As the number of competing devices grows, Bluetooth connection time increases, and throughput and message reliability decrease. Several efforts are underway to coordinate transmissions with other devices. The IEEE has initiated an 802.15 personal-area-network working group to coordinate wireless standards (www.manta.ieee.org/groups/802/15/). Other researchers have proposed adding Bluetooth capability to microwave ovens to manage RF interference (Reference 2). Bluetooth performance will also suffer when a large number of compatible devices operate in the same local area. Collisions and retransmissions will slow the effective data rate. Depending on the usage within each piconet, simulations show that voice quality degrades when as few as six Bluetooth devices are within range.

Bluetooth architecture raises an interesting problem for travelers. Current airline regulations require passengers to turn off in-flight transmitters to avoid interference with navigation equipment. Bluetooth transceivers can easily power up and operate even when the devices are turned off. To deal with this problem, the SIG has changed the Bluetooth specification to give users a way to disable Bluetooth modules. This change will also allow users to operate some Bluetooth-enabled equipment, such as laptops, while in flight. If Bluetooth is to become ubiquitous, an exemption to the airline regulations would be necessary.

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regulations may be necessary. Many vendors envision travelers of the future loaded with Bluetooth devices that can communicate with each other or join nearby piconets without intervention. The concept of Bluetooth-enabled jewelry or clothing may fail if regulations force manufacturers to add an on-off switch to each item. Luckily, airline testing to date has failed to detect interference with any flight instrumentation. But more obstacles are on the horizon for Bluetooth and other wireless technologies. Gasoline stations are posting warnings to turn off all electronics devices, including cell phones.

QUALIFIED PRODUCTS

Although they have hesitated somewhat over the past year, manufacturers are beginning to unveil their Bluetooth products and fight for their share of the market. At press time, the SIG Web site (www.bluetooth.com) lists more than 100 qualified products, and the list is growing daily. Although many of the early products were components, add-on dongles, software stacks, and product-development kits, the list now shows higher level products, such as laptop computers, PC cards, and LAN-access-point hardware.

Component-level parts include baseband DSP, analog-radio functions, and host-controller processing. The ultimate goal is to provide as many functions as possible on one chip. Cambridge Silicon Radio has qualified its BlueCore01 chip, which integrates a CMOS-based radio transceiver, baseband processor, and microcontroller with a Bluetooth software stack and support for a USB connection (Figure 5). The Bluecore01 eliminates most of the external components that radio systems normally require. The chip operates with an external flash memory to provide for Bluetooth-specification changes. CSR expects BlueCore01 quantity prices to reach the magical $5 level later this year.

IBM offers a qualified Bluetooth mod-

The CrossNet node from Crossbow Technology collects data from multiple sensors and transmits the data via Bluetooth to a central controller.
ule based on the PCMCIA (Personal Computer Memory Card International Association) type-II PC-card specification. This type of plug-in card gives add-on Bluetooth capabilities to laptop computers and PDAs. IBM sells the Bluetooth PC card on its Web site for $189 each.

Bluetooth is also finding its way into industrial applications to combat the high cost of network wiring. Crossbow Technology offers the CrossNet node, a wireless interface to replace wiring between analog sensors and a central controller. The system contains four sensor ports, a multiplexer, a 16-bit ADC, an ARM µP, a radio module, and an optional power amplifier to increase the range from 10 to 100m (Figure 6). The CrossNet system costs $1495 and is available immediately.

The easiest way to get started with Bluetooth technology is to purchase a development kit. Ericsson Microelectronics offers a typical unit based on its ROK 101 007 Bluetooth Module (Figure 7). The prototype board provides access to all signals around the baseband processor and the radio transceiver. The kit supports development in host-based (two-CPU) and stand-alone (one-CPU) applications. Interfaces include three RS-232 ports, USB, PCM, I²C, and a JTAG-debugging port. Ericsson provides one development license for its host software, test routines, and sample programs and a wizard for application development.

WHAT’S COMING?

Although the list of off-the-shelf qualified parts is still sparse, plenty of new applications are in the works. For example, most major automotive manufacturers are planning to offer Bluetooth options in upcoming models. The built-in electronics will communicate with cell phones in your pocket or purse so that you can make hands-free, voice-activated calls while driving without fumbling around with handsets.

Because portable devices benefit most from Bluetooth, many new applications are destined for PDAs. LAN-access-point servers that will enable users to temporarily connect to the Internet are expected in airports and other public places. Game vendors are also incorporating Bluetooth into PDA platforms to enable multiplayer interaction. By plugging a Bluetooth network card into the CompactFlash slot of a PocketPC, users can compete with similarly equipped players within a 10m range. Another PDA example is the wireless translation of foreign signs to travelers’ native languages.

Bluetooth technology is not expected to remain static. Just as the first round of qualified products hit the market, the Bluetooth SIG already has specification extensions in the works. For example, many users want a higher data rate to handle streaming video. The SIG has commissioned a Radio2 working group to look at a higher speed transmission scheme that would give 10-Mbps data rates at the 10m range. Radio2 would remain compatible with Bluetooth devices.

As the Bluetooth era develops, manufacturers are searching for the right product mix. There are plenty of cable-replacement applications, but only a few that users will buy. For example a wireless headset for a phone in your pocket may not be a viable product. By the time you add electronics and a battery to the headset, it may be too big and too expensive to satisfy you. Other applications, such as LAN access and digital-camera downloading, promise to become immediately popular. Bluetooth will be a big part of our wireless future and possibly your next embedded design. □

References