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From IEEE standards, to HomeRf to personal-area networks like Bluetooth, users will be untethered like never before.

IMAGE PHOTOGRAPH

Since the FCC opened up the spectrum in the 2.4-GHz band for unlicensed use, companies such as Proxim, Lucent, and Symbol Technologies have led the charge of proprietary wireless connectivity solutions into vertical markets. These include warehousing/manufacturing, government, and educational institutions. Only recently have solutions started to leak into the enterprise and consumer markets. From all indications, however, the trickle is about to become a flood as companies rally around wireless local-area-network (WLAN) standards such as 802.11b and HomeRF, and personal-area networks (PANs) like Bluetooth.

Devices based on each of these standards are in various stages of rollout. Each has its own demons to overcome in terms of cost, performance, interoperability, security, and overall implementation. In addition, as these devices proliferate, there's much concern over their ability to coexist peacefully. This concern is only heightened by proposals to widen the instantaneous bandwidth of frequency-hopping (FH) systems to allow for higher data rates. It could be argued that widening the FH bandwidth is a good thing. The sooner the 2.4-GHz band gets overcrowded, then the sooner the jump will be made to the much-anticipated 5-GHz band, which still remains tantalizingly at bay.

Though the various WLANs face many complicated problems, the possible solutions are a welcoming match of variety and elegance. All of these solutions are designed to improve the performance, lower the cost, and shrink the size of upcoming designs, while making the devices more user-friendly.

At the forefront of chip development for 802.11b is Intersil. With its Prism II chip set, the company has been one of the leading suppliers of chip solutions to OEMs such as Symbol Technologies. Symbol has incorporated the Prism II into its Spec2rum24 11-Mbit/s line (see opening photo).

IMAGE PHOTOGRAPH

1. Originally introduced as a five-chip set, the Prism II chip set jumps to Prism 2.5 through the integration of the baseband processor (BBP) and the media-access controller (MAC), bringing the total chip count to four,

Originally introduced as a five-chip set, the Prism II takes advantage of higher integration and Intersil's own UHF2 biCMOS process to integrate into one chip the baseband processor and the media-access controller (MAC) (Fig. 1). Dubbed the Prism 2.5, the solution brings the chip count for a complete solution down to four. Available this summer, the Prism 2.5 weighs in with a bill-of-materials (BOM) cost of roughly \$50 for a reference design.

Why DSSS?

Both Intersil and Symbol have myriad reasons for focusing on the directsequence, spread-spectrum (DSSS)based standard of 802.11b. But both agree that the high data-rate capability of DS, plus the fact that it's an approved, ratified standard at this point, is a really strong selling point. At this stage, no high-rate standard exists for frequency-hopping spread-spectrum (FHSS), which remains at the original 802.11 specification of 1 to 2 Mbits/s. That goes along with FCC regulations specifying that an FH radio has to hop 79 channels and have an instantaneous bandwidth of 1 MHz.

This has been a thorn in the side of FH developers. The laws of physics and communications theory limits the possible maximum data throughput with encoding to the neighborhood of around 2 Mbits/s. While it's possible to encode more bits per symbol, the energy per bit increases, thereby violating the FCC's output-power limitation. Spread spectrum is limited to an output power of 1 W, though most radios use lower-power outputs, in the 100-mW range.

The DS modulation scheme specifies three, non-overlapping channels, with a 22-MHz bandwidth. This wide bandwidth per channel allows up to 8 bits per symbol, to give an aggregate throughput of up to 11 Mbits/s. But in reality, much like IOBase-T Ethernet, this may only reach 4 to 7 Mbits/s.

DS itself refers to taking a pseudorandom-noise (PN) code, and using it to directly spread the waveform. The 802.11 standard specifies Barker, or 11bit, codes for 1 and 2 Mbits. For higher data rates, complementary code keying (CCK) is used-six bits in the code, then two more bits by rotating the waveform 90, using quadrature phase-shift keying (QPSK).

Now that DS has reached data rates comparable to that of Ethernet, MIS departments are taking a closer look at WLANs as a viable augmentation to their networks. According to

John Hughes, director of product management for wireless products at Symbol, this raises the interesting question, "Which users will drive the WLAN market-those who buy the LAN for home and bring it to work, or those who use it at work and bring it home?"

The issue revolves around the enterprise buying large amounts of 802.11b high-rate products. The circle will then begin whereby prices will fall and volumes will go up. "So, while there's a hodgepodge in the home now, you still want something easy and standard to implement-that someone in the office knows how to work so you can call them, " says Hughes. "I believe 802.11b will win at home. The products are all interoperable."

Interoperability is a major issue with any WLAN, and 802.11b is no different. Because of this, devices developed under 802.11b are submitted to tests at the University of New Hampshire's Interoperability Lab. According to Michael Froning of the wireless lab, the devices are very close to full interoperability. But they tend to fall down in the areas of the Wired Equivalent Privacy (WEP) protocol and power save. WEP refers to how the data frames are encrypted and offers a security option. To date, failures have been restricted to select pairs, with the problem residing in the MAC.

"Another issue," says Froning, "and one that's not defined in the standard, is the handling of roaming, in terms of how an access point (AP) notifies another AP as a cell roams." There isn't a way within the 802.11 standard to define how the AP actually does that, so each vendor has their own solution. As a result, it behooves MIS departments to avoid mixing and matching APs in a network until the issue is resolved. Security and roaming will be enhanced through firmware upgrades.

Rld the 802.11b Wave

Though some outstanding issues remain, the momentum behind 802.11b right now ensures that any difficulties will be overcome in short order. Only in the past few weeks, Lucent, 3Com, and Zoom Telephonics, have each announced. 11b products-Orinoco, AirConnect, and ZoomAir, respectively.

Along with Symbol, Zoom uses the Prism II chip set as well. But according to Zoom's president, Dana Whitney, implementing an 802.11b device requires more than just sticking a standard chip set on a pc board. "We've found that good control of the manufacturing process is essential," says Whitney. "The carrier frequency is at 2.4 GHz, so controlling impedances is important." Other items, such as component specifying, need to be monitored closely. If this isn't done, production models won't reflect the prototype in terms of range, throughput, and mobile characteristics.

While 802.11b devices dominate on the enterprise, they're far from the only game in town on the home front. As proponents of 802.11b take the tack that wireless home networking will trickle down from the office, groups like HomeRF have taken a bottom-up approach.

HomeRF uses FHSS modulation, with a maximum throughput of 1.6 Mbits/s. The

HomeRF Working Group opted for this radio to minimize cost, as the 1-MHz bandwidth places minimal requirements on the radio amplifier. Highly linear and, hence, expensive amplifiers are required by the 22-MHz bandwidth of DS implementations.

Another reason the group selected FH is because it possesses the ability to operate in high-density situations. With DS, it's possible to have up to three basestations operating in a given space on different channels. If a fourth station is introduced, though, it will pick one of the channels currently in use by one of the other three stations. As a result, DS has to be located carefully to minimize interference. Good vendors of DS solutions will provide placement software for office and home spaces for the basestations.

SWAP For

To get up and running quickly, the HomeRF Working Group chose Proxim's Shared Wireless Access Protocol (SWAP). To date, devices based on HomeRF technology have been confined to Proxim's Symphony line, raising questions regarding the standard's potential for success. Cayman Systems and Intel recently laid those fears to rest by announcing their respective introductions into the home market.

Cayman offers the 3220HW, an ADSL gateway that's fully integrated with Proxim's Symphony HomeRF solution. The 3220HW is designed to help service providers rapidly accelerate the deployment of integrated wireless solutions in small offices and homes. There, portable, high-speed Internet access is a burgeoning market. The inclusion of a four-port Ethernet hub adds extra value by linking mobile wireless devices with existing stationary PCs, printers, and other network resources. The gateway is available now for \$998. Intel's offering is the AnyPoint Wireless Home Network PC Card or USB connection.

Key to the HomeRF standard is the provision for both data connections and high-quality voice connections. This provision was enhanced by Siemens, working closely within the group to integrate 802.11 data into its DECT voice expertise, with the former being a packet-based protocol and the latter based on time-division multiple access (TDMA). Voice is a weakness for DS systems. The currently used digitized voice-over Internet Protocol (VoIP) packets can suffer from latency problems and a plethora of other issues as a result of not having built-in telephony support.

According to Ben Manny, chair of the HomeRF Working Group, "these early [HomeRF] products will be asynchronous nodes." Manny explains, "The specification calls out three different types of devices you can build. One is just an asynchronous data node, for peer-to-peer networking and native TCP/IP wireless communication. Another type is an isochronous node (I-node), like a cordless phone. The third device is a basestation, or control point."

There are two basestation classes: data-only and a voice/data control point. The basestation is a data node with the ability to cache messages. So, it's a centralized controller for the home network. This allows a couple of a-nodes to talk to each other, while the other goes

to sleep. The centralized controller will cache for that device. A power-management scheme allows them to go to sleep and still participate in the network by having this control point manage the network.

On behalf of the Working Group, the most recent act was the approval of a certification test. Two types of testing are required. The first, parametric or self testing, is a list of basic measurements on the radio to make sure it conforms with the specification. The second is a series of defined interoperability tests done by a third party, in this case PlugLabs and Purdue University (the same group that does the tests for HomePNA).

FCC To Rule On FH Bandwidth

While these tests take place, the debate rages on concerning the proposal before the FCC to widen the instantaneous bandwidth of FH systems to 3 and 5 MHz. The proposal will allow increased data throughput up to 10 Mbits/s, thereby allowing HomeRF devices to compete fairly with DS systems. Kevin Negus, director of business development at Proxim, says, "We want a convergence of the FH regulations on a global basis. Today we can build 10Mbit/s FH products in Europe and Japan." Negus continues, "But in the U.S., the way the rules were written artificially constricts the bandwidth on FH in a way different than elsewhere. The FCC is simply in the process of making a role to allow FH devices to use bandwidth in a flexible manner, like DS."

Not everyone, though, views it as simply as Negus. The proponents of both DS and Bluetooth claim that widening the bandwidth would create insurmountable interference issues. In addition, "they won't get the performance they think, because they want to reduce the dwell time, and increase the frequency and overlap channels," remarks Dana Whitney of Zoom. "If you look at this closely, it won't yield them 10 Mbits/s. It will be dramatically lower-4 or 5 Mbits/s." The interference stems from the fact that as the band is widened, the signals occupy bigger slots.

IMAGE CHART

2, The PH2401 Bluetooth radio from Philips Semiconductor features an ultra-low-power consumption of under 20 mA at 1.8 V. It's designed for Class 2 and Class 3 operation.

Cost Comparison

Echoing this feeling is Bob Pearson, wireless marketing manager at Intersil. He also tackled the cost angle, which remains a rallying point for HomeRF. Pearson says, "We have done extensive analysis, and DS radios are pretty much on cost parity with FH radios, so the FH approach won't have any cost benefit. The other thing is that, as you go up in data rate, the receiver complexity goes up in order to demodulate the waveform."

He goes on to point out, "Our analysis has shown that any benefit from going to higher data rates using FH will be offset by the higher cost of an increased complexity receiver." Of course, any cost analysis has to be taken with a pinch of salt, as it's extremely dependent on quantities and the OEM's relationship with the supplier.

One could argue, however, that the proponents of FH have largely ignored the higher-data-rate waveform complications of demodulation. "They're on a learning curve there, as it's necessary to add an equalizer on the baseband processor to demodulate the waveform because it's so much more susceptible to multipath interference," says Pearson. "DS is much farther down the learning curve."

While HomeRF might counter that DS radios are capable of transmitting at up to 1 W in the 2.4-GHz band to overcome interference issues, most 11-Mbit radios transmit at about 40 mW to conserve power. Overall, many believe the ruling will decimate the band, and the arguments continue.

Despite the objections of DS proponents, it appears, at this juncture anyway, that the FCC is well on its way to allowing the ruling. If it goes ahead, Ben Manny predicts that the next thing to happen after this first launch of products will be a line of products that take advantage of the ruling. Those will allow for things such as multiple MP3 streams. Although SWAP can perform MP3 streams right now, it can handle only two streams with its payload of 500 kbits/s. MP3 is about 150 kbits/s. Manny envisions, "It would be nice if everyone in the house could have their own private MP3 streams." Other plans exist for full AC-3, bridges to HomePNA, improved voice support, and an increased number of supported handsets.

None of these modifications overshadow the basic affinity HomeRF has for telephony, and that shall remain a strong selling point. As broadband enters the home, the battle for dial-tone dollars escalates. AT&T wants to go around the local-exchange carrier (LEC). The LEC wishes to sell multiple dialtones without having to lay more copper and, therefore, would like to prepare its DSL lines for VoDSL.

Explaining the situation, Manny points out, "That's great, but how do you get these multiple dialtones to the handsets in your house? Consumers like the flexibility of cordless phones. So, do you bring these to a box and buy four different cordless phones and four different basestations, or do you use HRF DECT which allows you to have distinct handsets and allows you to deliver four separate dial tones to each handset?" Manny continues, "That same radio also can connect to your PC or Web tablet, and deliver the Internet connection wirelessly." The argument is only validated by the move to next-generation, 2.4-GHz cordless phones as the 900-MHz band gets crowded out.

Bluetooth Stumbles

While 802.11b and HomeRF duke it out, Bluetooth has hit a stumbling block of its own. Now hailed as complementary to WLANs, it stands to form the basis of the IEEE's 802.15 standards work on personal-area networks (PANs). Bluetooth, however, is proving to be long on promise, but short on delivery. With limited silicon availability, no one even nearly ready for production, and no fully qualified devices at all, projections for a Bluetooth solution with a BOM of under \$5 may have to be pushed out until at least the year 2003. Some think it might even have to wait until 2005.

Right now though, a slew of companies are conducting "show and tell." One of the many is Philsar, with its very-low-power solution, the PH2401 (Fig. 2). In fact, its ultra-low-current draw at 1.8 V of under 20 mA was one of the main reasons Conexant chose to snap up Philsar recently. The move will give Conexant a leg up in the potentially explosive Bluetooth market

IMAGE CHART

3. In one step, ParkerVision directly converts 2.4 GHz to baseband analog by using its proprietary D2D technology. The all CMOS technology is a major advance on the path to full radio-baseband integration.

IMAGE ILLUSTRATION

4. Using thin-film-on-glass technology, Intarsia raises the possible level of passive component integration in RF designs. This results in a 40% reduction in footprint over competing LTCC technology

The radio is fully compliant with the Bluetooth specification in v1.0, and is designed for Class 2 and Class 3 operation of 1 to 10 meters. The transmitter, which offers programmable power output levels of between -10 and 2 dBm and an RF sensitivity of -84 dBm, comes in a BCC48++ package. Operating off 1.8 V, with the option of 1.2 V, the device is a fully integrated solution. It contains an on-chip voltage-controlled oscillator (VCO), a synthesizer, a power amplifier, a low-noise amplifier (LNA), IF filters, a signal-strength indicator, and a bit slicer.

Philsar also recently teamed up with Mitel, which is developing a Bluetooth baseband hardware and software solution for standalone low-power applications. Mitel's solution, the MT1020A, contains an on-board ARM-7 processor to reduce the amount of processing power required.

This approach will raise the gate count. Still, according to Martin Huckle, product line manager for Bluetooth at Mitel, analysis has shown that the company's power consumption is actually less, partly due to its migration to a 0.18- μ m process. Huckle claims that there's a possible savings in power of up to 50% over competing devices. Plus, the processor includes a fully functional codec as part of the baseband. Mitel is the only company that provides such a feature. "We see voice as being essential to Bluetooth, so we're offering the full data/voice solution," Huckle clarifies. While the first iterations will be done at 0.35 μ m, Mitel will move to 0.18 μ m by the third quarter of 2001.

Other companies touting product availability include Atmel, with its T2901. Developed by Temic, the T2901 includes the transceiver, synthesizer, and a VCO, too. Fully Bluetooth compliant, the device has a noise floor of 23 dB, a linearity, in terms of spurious-free dynamic range (SFDR), of 50 dB, an inband image of 20 dBc/Hz, and a VCO phase noise of -89 dBc/Hz at 500 kHz. Atmel's chip features a closed-loop modulation scheme to eliminate frequency drift and render it insensitive to component tolerance and noise effects.

While the above reflects increasing levels of integration, the ultimate goal is to bring everything on board. Alcatel is far along on the road to this with its latest Bluetooth

offering. Introduced at CeBIT 2000, the company is offering the device as the world's most integrated solution, and they might be right.

Into a 15- by 15-mm package, the company managed to include the complete radio; baseband controller; an ARM7 processor; the Bluetooth 1.0 software stack on flash ROM with optional application-layer software; the baseband interfaces of SPI-bus, UART, and PCM, with USB optional; and the antenna. All external components, such as the RF input filter and decoupling components, are embedded in the BGA package.

Hardware sampling at the moment is plentiful. Still, the actual deployment of low-cost devices stands a long way down the road. While some say the Bluetooth originators set too low a goal at \$5, other factors delay the rollout.

Originally designed simply as a cable replacement for headsets, Bluetooth has fired the imagination of everyone concerned. Now it's being groomed for roles in everything from personal digital assistants (PDAs), cell phones, and printers, to voice-activated computers and control systems and mobile communications. The Special Interest Group (SIG), claiming newcomers everyday, now consists of around 1700 members. But it must be stated that membership is free and there are no obligations upon joining. Many of those members, therefore, could be developers of other, competing,, shortrange wireless technologies, just trying to keep tabs on what's happening.

Software Sills Needed

Interest has brought constant revisions to the specification. It started out at 500 pages, but has since grown to over 1500 pages. With the added profiles and dynamic nature of the specification, one requires much more than hardware finesse to achieve a successful Bluetooth. "You need somebody with extremely good software skills. The hardware isn't a problem, it's a straightforward interconnect, straightforward operation," according to Mike Bender, regional sales manager at Ericsson. -The hardest part is understanding the specification and how to use the software that exists. The 1500-page specification is like going through very heavy mud."

The other difficult part is the antenna, with its many different designs and approaches. Bender suggests buying this piece. His sentiment was echoed by Kjell Westerlund, an applications engineer at Ericsson. "The antenna is key," says Westerlund. "If that doesn't work, then the software is moot. It's important because you never know the shape and size of the device your Bluetooth solution is going into, so it's a unique design every time."

Ericsson is taking the path of providing complete, proven designs to customers. The company has kicked off its Solution Providers program, which is an attempt to enlist antenna manufacturers and software companies to do it all for a third-party customer-mostly out of Europe.

A Call For Development Tools

The dearth of available software is only exacerbated by the lack of available development tools. Someone has to write software for every device and each operating system. When Motorola got a leg up in the Bluetooth market by purchasing DigiAnswer, it arrived on the fast track to fully enabled devices. According to Buddy Broecker, operations manager for wireless emerging markets, those devices should see the light of day by the end of June. Broecker projects that by that point, they will be fully qualified and in production.

Motorola opted to make the enabling and development tools in house. "The pervasiveness of Bluetooth will be tied to the tools available to write applications," says Broecker. "Multiple layers must be laid down before it can proliferate."

For Ericsson, Motorola, or anyone in this arena, the key to proliferation is interoperability testing. With these concerns in mind, the SIG is working with Rohde & Schwarz, the Munich, Germany-based manufacturer of high-end test equipment, to install such equipment in various parts of the world in order to test upcoming Bluetooth solutions. Plus, there are many more "unplugfests" yet to come. The first one showed flaws, but by year's end they should be ironed out.

While the interoperability issue gets resolved, the Bluetooth SIG is working on service discovery. This aspect of Bluetooth keeps expanding in scope as more applications are defined. The core of an ongoing debate is the level at which the protocol stack service discovery should be implemented—down low or up high, just below the application layer.

In the opinion of Robert Pascoe, president of Salutation Consortium, it should be implemented right up at layer six or seven. "We are independent of the underlying protocol. The problem is if you're an applications provider trying to port to these [Bluetooth devices], then you need to deal not only with the lower-level protocol, but also service discovery." Pascoe adds that "We allow any device to work anywhere using a transport manager which manages the transport at the lower levels, not down at the protocol stack." Salutation is a nonprofit group providing an applications-programming-interface (API) set, thereby ensuring that the same command and data structures are passed across that API.

The Bluetooth Working Group asked the consortium, along with Microsoft (UPnP) and Sun (Jini), to come up with a service-discovery protocol for Bluetooth. According to Pascoe, that was the wrong approach. He explained that "One protocol is what we need. If you have a high-level protocol on one end, and a low-level protocol on the other, you may not be able to communicate." Further, he said that "The goal is consistency across platforms—consistency of the information to eliminate data loss."

Shrinking Size-And Cost

For any of the thousands of OEMs presently designing solutions for the 2.4-GHz market, once the technicalities of hardware design, standards compliance, and interoperability are met, the next stage is to lower the overall size and cost of the implementation. There are

many ways to do this. The two most successful paths involve architecture refinement and packaging innovation. These are the specialties of ParkerVision and Intarsia, respectively.

ParkerVision recently announced a direct-conversion technology that Companies That Contributed To This Report

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