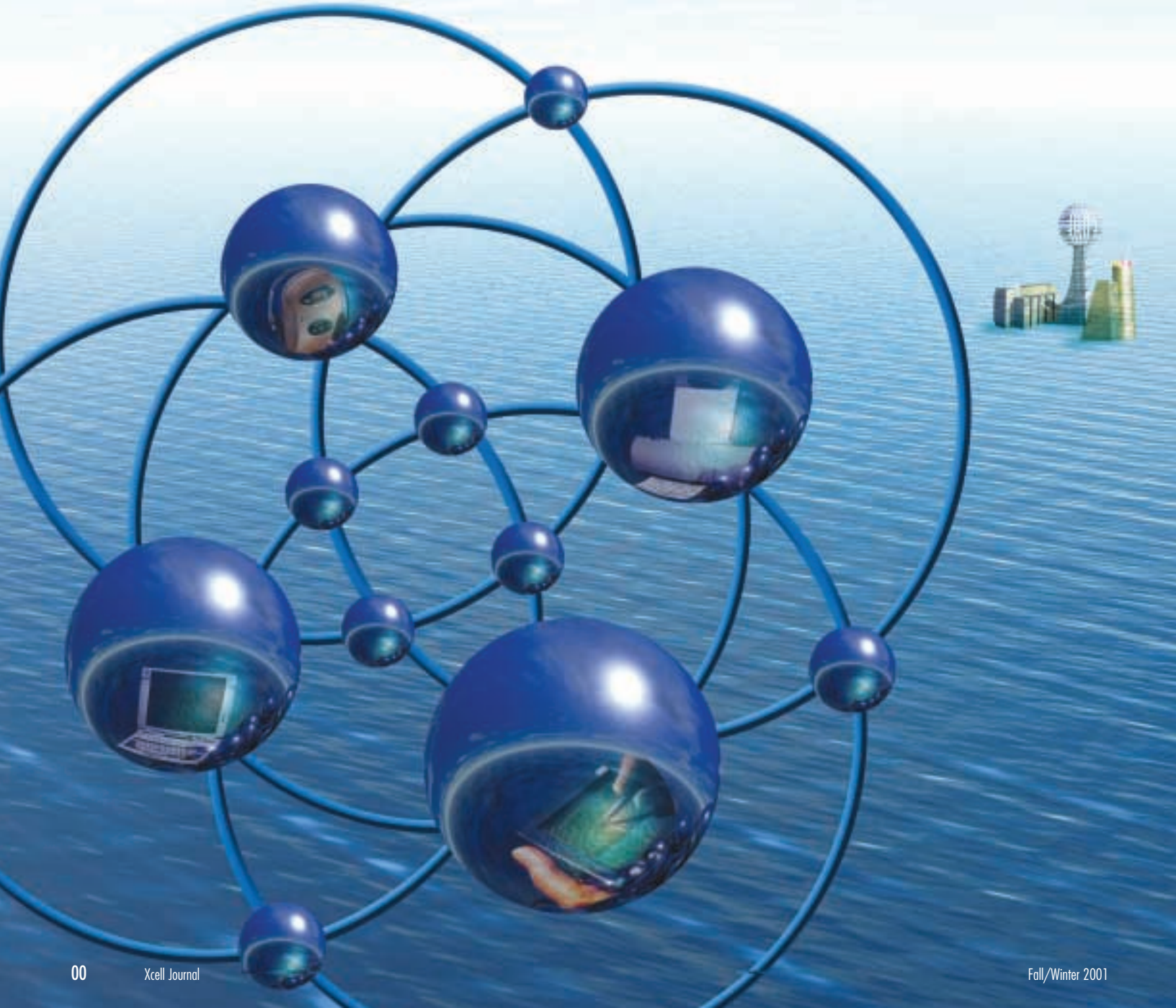
Bluetooth Wireless Technology and Personal Area Networking – In Your Home and on the Road

Bluetooth wireless technology and personal area networking promise to radically change the way we live and work.



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Are you ready to cut the cords? Is wireless networking the way you want to go – but with as many as a half dozen competing wireless technologies, which is right for you?

We don't know what is right for you, but we do know that Bluetooth™ wireless technology is the leading networking technology for enabling connectivity across a wide range of information appliances. Although the performance capabilities of Bluetooth wireless technology are somewhat modest (in comparison to the other technologies – see Table 1), they are acceptable for almost every networking application you need except high-quality video. At 720 Kbps over a range of 10 meters, the quality of voice and data transmission are equivalent to hard-wired networks. Furthermore, the unique functional capabilities, low cost, and support of Bluetooth wireless technology by more than 2,490 companies worldwide make this wireless networking system one of the highest volume home-networking applications available today.

The three main objectives of the Bluetooth wireless technology are:

- To eliminate the connecting wires associated with most consumer electronics and computer equipment
- To allow a collection of products to function as an intelligent whole
- To make personal area networking (PAN) seamless.

Personal area networking is a new connectivity paradigm supported by Bluetooth brand products. Bluetooth wireless technology and PANs will change the future of computing and consumer electronics. Using Bluetooth wireless technology, you can create dynamic, ad hoc PANs at home, at work, on the road, and almost anywhere else you choose.

How Bluetooth Wireless Technology Works

Instead of having devices connected by a plethora of cables and wires, each Bluetooth-enabled component has a small radio transceiver, similar to the one shown in Figure 1. These transceiver modules use protocols developed by the Bluetooth Special Interest Group *(www.bluetooth.com)*, of which Xilinx® is a member.

Figure 1 - Ericsson Bluetooth transceiver module

Bluetooth Architecture Protocol Stack

The Bluetooth architecture protocol stack allows devices to discover, network, and exchange information with each other

	Technology					
	Bluetooth	HomeRF	802.11b	HiperLAN	802.11a	HiperLAN2
Frequency Band	2.4GHz	2.4GHz	2.4GHz	2.4GHz	5GHz	5GHz
Technology	Frequency Hopping Spread Spectrum	Frequency Hopping Spread Spectrum	Direct Sequence Spread Spectrum	Guassian Minimum Shift Keying	Orthogonal Freq. Division Multiplexing	Orthogonal Freq. Division Multiplexing
Performance	720Kbps	1.6Mbps	11Mbps	23Mbps	~50Mbps	~50Mbps
Range	<10 meters	50 meters	150 meters	150 meters	50 meters	50 meters
Power	Very Low	Medium	Medium	Medium	Medium High?	Medium High?
Relative Cost	Low/ Very Low	Medium/Low	Medium	Medium	High	High
Target Applications	Cable Replacement Wireless Data Wireless Voice Personal Networks	Wireless Data Wireless Voice	Wireless Data	Wireless Data	Wireless Data	Wireless Data
Fixed N/W Support	PPP, Ethernet"	DECT, Ethernet	Ethernet	Ethernet	Ethernet PPP, 1394, UMTS	Ethernet, IP, ATM,
Key Features	Very Low Power Voice and Data Roaming Low Cost Good noise immunity	Voice and Data Moderate Cost	Good Performance	Good Performance	High Performance	High Performance
Promoters	2000+	<50	~100	<50	~100	<50
Regional Support	Worldwide	US	US/Asia	Europe	US	Europe
Shipping	Now	Now	Now	Now	2001	2001

Table 1 - Bluetooth specifications compared to competing wireless local area network technologies

seamlessly. It is a layering of functional modules as shown in Figure 2.

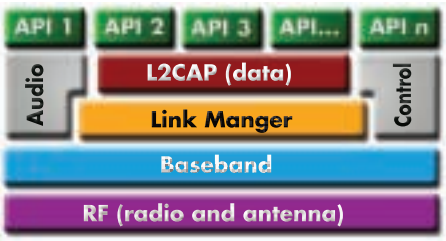

Figure 2 - Bluetooth architecture protocol stack

Application Program Interface Libraries

Software modules called API libraries connect the host application program to the Bluetooth communications system. They reside and execute on the same processing resource as the host system application.

Logical Link Control and Adaptation Protocol

The L2CAP provides the overall control of a Bluetooth system. It manages the high level aspects of each connection (such as determining who is connected to whom, whether to use encryption or not, what level of performance is required, and so on). In addition, L2CAP converts the format of data, as necessary, between the APIs and the lower level Bluetooth protocols. The L2CAP is implemented in software and can execute on either the host system processor or on a local processor in the Bluetooth system.

Link Manager

The Link Manager handles the physical details for Bluetooth connections. It creates the links, monitors their health, and terminates them gracefully upon command or failure. The Link Manager is implemented in a mix of hardware and software.

Baseband

The Baseband is the digital engine of a Bluetooth system. It constructs and decodes packets, encodes and manages error correction, encrypts and decrypts data for secure communications, calculates radio transmission frequency patterns, maintains synchronization, controls the radio, and takes care of all the other low-level details necessary to realize Bluetooth communications.

Radio

The Bluetooth radio converts the digital baseband data to and from a 2.4 GHz analog signal.

How Bluetooth Networking Works

Bluetooth devices connect into piconets – small networks comprised of a master device connected to anywhere from one to seven active slave devices.

When multiple piconets are interconnected, they create wireless networks called scatternets. Figure 3 illustrates a piconet made of nodes A, K, L, M, and G interacting with yet another piconet comprised of nodes H, E, C, K, and L. These two piconets share nodes K and L, and collectively, form a scatternet.

Bluetooth devices have four basic states. They can be any of the following:

- **Master** – In control of a piconet (nodes A and H in Figure 3)
- **Active slave** – Connected and actively monitoring/participating on a piconet
- **Passive slave** – Still logically part of a piconet but in a low power mode; occasionally monitoring, and still synchronized in an inactive state
- **Standby** – Not connected to a piconet, occasionally monitoring for inquiries from other devices, but not synchronized with any other devices (nodes B, J, I, and F).

Standby Mode

Initially, all Bluetooth devices are not synchronized or coordinated in any way. They are all listening at different times and on different frequencies. Bluetooth devices know only about themselves, and in this state, they are in standby mode. Standby is a passive mode where a Bluetooth device listens on an occasional basis, performing what are called inquiry and page scans (for 10 milliseconds out of every 1.28 seconds) to see if any other Bluetooth devices are looking to communicate. Passive behavior is inherent to half of Bluetooth states (standby and passive slave), and is a key mechanism for achieving very low power consumption. In standby mode, the Bluetooth device's occasional scans reduce power consumption by more than 98%.

Paging

Paging is how a Bluetooth device learns about other devices that are within its range. Node A in Figure 3 executes a page command and receives replies from devices within range. Through these replies, device A learns the explicit identity of these other devices (such as their unique Bluetooth device ID).

Piconets

In its general form, a page command establishes a formal device-to-device link between a master (the originator) and a slave. Master/slave connections in Bluetooth are referred to as a piconet. To create the piconet, Device A broadcasts the page command with the explicit device ID of the target slave (Device D in Figure 3). All Bluetooth devices except Device D will ignore this command, because it is not addressed to them. When the Device D replies, Device A will assign it an Active Member Address in the piconet. As an active slave, Device D will begin continuously monitoring for further commands from Device A, in synchronization with Device A's hopping pattern and clock offset. Furthermore, standard piconet activity continuously updates the clock-offset data, keeping the synchronization extremely accurate. Through successive page commands, a Bluetooth master can attach up to seven active slaves.

Scatternets

Each Bluetooth node is capable of maintaining multiple states simultaneously. This allows multiple piconets to combine into a structure called a scatternet. In Figure 3, two piconets combine into a scatternet through the common slaves K and L. Scatternets can evolve into extremely complex structures. Note that a node can potentially be a master, an active slave, and a "parked" slave on three different piconets, all at the same time.

The only hard limitation on scatternet configurations is that each Bluetooth node can only be the master of one piconet at any given time.

A critical feature making such configurations practicable is the support for Quality of Service (QoS) in the L2CAP. Through this mechanism in the L2CAP, Bluetooth devices are able to determine that the connections they are establishing are feasible and sustainable. Thus, a node would not agree to an additional connection if it would require bandwidth that it is unable to support. It may, however, negotiate to establish another connection, but at a more modest data rate that it can support.

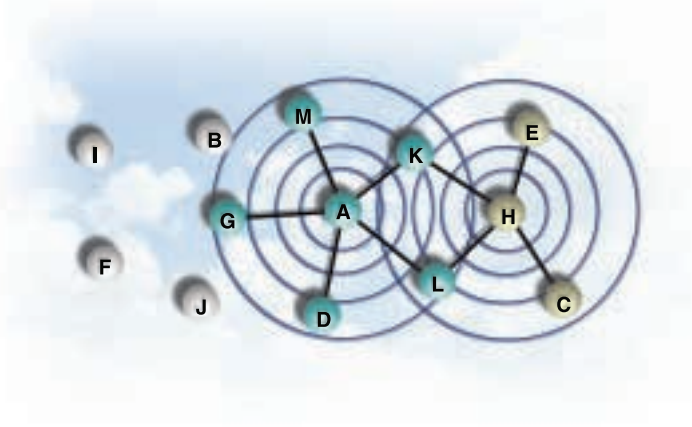

Figure 3 - Two Bluetooth piconets participating in a scatternet

Bluetooth PANs – Changing the Future of Connectivity

Bluetooth wireless technology will be widely accepted and deployed in the next few years – and Bluetooth personal area networks will revolutionize the way we interact with intelligent appliances in the future.

Bluetooth PANs will provide automatic visibility and access to Bluetooth-enabled products and services within a range of 10 meters (and up to 100 meters in high-performance systems). PANs will give you tremendous user-friendly control and flexibility. With PAN technology, you will be able to organize a collection of personal electronic products – your PDA, cell phone, laptop computer, desktop computer, MP3 player, and so on – to automatically work together. For example, the contact manager and calendar in your PDA, laptop computer, and desktop computer will all automatically synchronize whenever they are within range of each other.

Ultimately, Bluetooth technology will eliminate most cables related to consumer electronics in the home and on the road. Your PC, scanner, and printer will simply need to be within 10 meters of each other to work together. Your PDA, digital camera, and MP3 player will no longer need docking stations to transfer files or to get the latest information. And, your home stereo and other equipment will be wirelessly networked as well. What's more, your cell phone will synchronize its address book with your PC and function as a handset to your cordless phone in the house, enabling you to use the cheaper landline network.

One of the nice things about your PAN is that you can take it with you wherever you go. On the road, much of your Bluetooth PAN will go with you. Even when your laptop is in your briefcase and your cell phone is in your pocket, they will be able to collaborate to access e-mail. Moreover, next generation cell phones featuring Bluetooth and General Packet Radio Service technologies will function as wireless modems with Internet access speeds greater than 100 Kbps. With such performance, this may well be the "killer app" that ensures the widespread adoption and success of Bluetooth technology.

In your car, your cell phone will operate in a hands-free mode, allowing you to use the car audio system and an in-dash microphone while the phone itself rests comfortably in your pocket. Or you may use a wireless Bluetooth headset instead. For entertainment, your MP3 player will likely play music in eight-speaker surround sound, rip music right off an FM broadcast, or record your phone calls for later review – wirelessly.

When you're on foot, fixed landline access points, such as a pay phone in an airport or the desk phone in your hotel, will provide true broadband access. Also, look for pay phones to evolve and compete with your cell phone, because pay phone landlines – at the moment, anyway – are cheaper. In the world of deregulation and open competition, future smart phones may automatically put your calls out for bid and channel the traffic over the carrier that offers the lowest cost.

Xilinx eSP – Solutions at Your Fingertips

Earlier this year, Xilinx launched the eSP (emerging Standards and Protocols) Web portal *(www.xilinx.com/esp/)*. The first major project of the eSP portal has been to accelerate and facilitate the development of Bluetooth-based products. The site provides you with solutions ranging from the best Bluetooth-specific reference designs to the latest intellectual property resulting from our collaboration with the wide range of industry leaders participating in the Bluetooth Special Interest Group.

With the introduction of the eSP Bluetooth portal, Xilinx has taken a leading role in enabling you to achieve the successful development and deployment of products based on this fast-emerging wireless technology.

Conclusion

Although Bluetooth technology is wireless, its usage model and end-application space is quite different from wireless LANs. Bluetooth-enabled products provide a seamless interface among various information appliances and create mobile personal area networks to enrich the digital lifestyle. Bluetooth technology does not support the higher data rates of wireless LANs, but it does support both wired-quality voice and data transmissions. The voice/data capability, in combination with low prices, global acceptance, and go-anywhere PANs, bodes well for the success of Bluetooth-brand products in the marketplace.