Understanding Bluetooth

Bluetooth is a wireless technology standard originally designed by Ericsson for small, hand-held devices such as mobile phones, but can actually be used for connecting any two devices that would otherwise have required a cable connection.

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Bluetooth is designed to be a low-power, short-range wireless technology to allow devices to communicate without needing a wired connection. Although in theory it can be used for any type of device, it's aimed primarily at portable equipment such as mobile telephones and PDAs.

Bluetooth promises to rid our home and working environments of many of the complexities of existing wired technologies - for instance, a Bluetooth-enabled PDA could synchronise its content with a PC without requiring a physical connection. More imaginative scenarios are also made possible with Bluetooth. A PDA user could print a document merely by moving within range of a public printer kiosk and entering the appropriate security code. A single headset could service a mobile telephone, a landline telephone, PC audio and hi-fi audio. It would certainly be possible to do that today with a wired headset, but the wiring would be impossibly complicated and unwieldy, and the project would in any case founder on impedance incompatibilities.

Bluetooth will allow people to connect any device to any other, at any time, with the minimum of effort - no physical connection, no installation of device drivers, and no configuration apart from possibly entering security information to establish a connection. The possibilities for Bluetooth really are boundless. Indeed, it is difficult today to conceive of any electronic device to which you would certainly never want to connect anything else - be it to transfer corporate data, rich media such as audio and video, or sensor and control information. Sony plans to put Bluetooth into virtually every device it produces, and over one billion Bluetooth-driven devices will be in use by 2005, according to Cahners In-Stat Group.

Within the corporate environment, Bluetooth can deliver what other technologies such as wireless networking and infrared have promised - the ability to walk into the office with a laptop or PDA and be immediately connected to the network or a PC without any further ado. For the mobile user, Bluetooth will make it much easier to interconnect the notebook computer, PDA and mobile telephone.

Bluetooth Technology

Although most of the obvious applications for Bluetooth require a one-to-one connection, the technology can also be applied to point-to-multipoint connections, such as a wireless network where several PCs or other devices are connected to a single base station. Bluetooth has its own vocabulary, and a network comprising two or more units is known as a piconet. A piconet can host up to eight active units at any one time. However, unlike conventional wired networks, setting up a piconet (whether between two devices or several) doesn't require any user action other than physically bringing the devices within range. The distance between devices is nominally 100mm to 10m, but designers can choose to extend this to more than 100m by increasing the transmitter power. It's also possible for several piconets to exist in the same room. This is necessary if there are more than eight units, or where devices are communicating in private and have no need to be part of a larger piconet - available bandwidth would be reduced if they were all part of the same net. For example, if one user is synchronising his or her PDA with a PC, neither of those devices will need to be in communication with the office Bluetooth-enabled printer that three laptop users are currently printing to. Where you have two or more piconets in the same area, this is known as a scatternet.

Scatternets

One piconet has a fixed amount of bandwidth, regardless of the number of devices in the piconet, so sometimes it may make more sense to establish new piconets

rather than join existing ones - which isn't as difficult as it sounds, since nodes can be members of two piconets at once. Additional piconets in the same room do detract from the total bandwidth available, but not by much - simulations suggest that performance within a scatternet consisting of 10 piconets is degraded by only 10%. However, it can take as many as 15 seconds to establish a Bluetooth connection. Thus, if there are several devices within the same area that may need to communicate at some point, it might be better for them to all become part of the same piconet, and suffer the degraded bandwidth, rather than require the user to wait 15 seconds before the telephone can be answered. Although only eight nodes can be active within a piconet, many more can stay in synchronisation with the net, ready to participate without suffering the usual connection delay.

Some wireless LAN basestation designs make use of the scatternet technique to improve on the overall bandwidth obtainable from Bluetooth. By including several Bluetooth transceivers, they're able to communicate with several PCs at the same time on separate piconets - or to one PC, similarly equipped, at higher speeds.

Masters And Slaves

Each piconet requires one master node, to define the sequence and phase of the piconet. All other units within the piconet are slaves, following the frequency-hopping pattern of the master. A device cannot be the master of two piconets, because they would then be in the same phase, and operate on the same frequencies, thus defeating the object of having multiple piconets. Furthermore, it's against the rules of the ISM band for different piconets to run in synchronisation.

Layers

The Bluetooth standard involves far more than the technology required to transmit and receive packets. All Bluetooth nodes will of course include a radio unit to modulate, and a microwave signal with the baseband data to transmit it, and will perform the reverse operation for reception. Other layers include a link controller. This hardware layer deals with the baseband protocols involved with frequency hopping and packet handling. Finally, a link manager is responsible for establishing and releasing membership of piconets. But it is a central tenet of the Bluetooth philosophy that life is made easy for the user. Therefore, while software will have to provide networking protocols such as TCP/IP, the most important part of the Bluetooth connection will be the application software, which will be responsible for performing useful tasks such as synchronising PDAs, or printing documents.

Profiles

It clearly wouldn't make much sense for a set of headphones to communicate with a printer. Bluetooth therefore specifies "application profiles" that define the type of operation a Bluetooth-enabled device is capable of handling. Some examples of these interoperability definitions are:

- Service discovery application profile.
- Serial port profile.
- Headset profile.
- Dial-up networking profile.
- Fax profile.
- Operating System.

Figure 1 - The Bluetooth protocol stack.

Current versions of Windows don't include Bluetooth support, but both Intel and Microsoft have announced a roadmap to provide native support within the next few months. The companies are also working on a standard method for PC platforms to interface with the Bluetooth technology that the PC industry can implement in their products. The initial development work is being undertaken by Intel, so early adopters can bring out products reasonably quickly, before Windows support is ready to ship. Microsoft has promised to provide a true plug-and-play user experience in the first half of 2001 by implementing an architecture based on the Winsock programming model.

The interim Intel software suite will provide all the components necessary to implement Bluetooth technology on a PC, including driver software, control

software, and support for application interfaces. For example, using the software suite, today's synchronisation software applications will operate wirelessly without modification. Intel is also developing an integrated hardware and software solution for mobile PC platforms with the Bluetooth wireless capability. This meets the Bluetooth 1.0 specification - the current version - and is compatible with Windows 98 and Windows 2000. It was first publicly demonstrated on 7th December 2000. Microsoft's initial native Windows solution will support the initial Bluetooth usage scenarios mentioned above, in addition to providing a more flexible architecture for the future.

Product Availability

Availability of software support for Bluetooth is slow, and so too is availability of products. Although many vendors are currently working on products - over 1000 are seeking to qualify for the Bluetooth seal - the first commercially available headset to receive Bluetooth certification was actually the GN Netcom GN9015-BT, available in December of 2000, which was intended for use with a Bluetooth mobile phone or PC. The Ericsson Bluetooth headset was available worldwide in the same month.

For the consumer, several vendors have announced Bluetooth basestations which use Bluetooth to connect to various devices in your house, including your cordless phone, cellphone, laptop computer or PDA. The Ericsson version - the Bluetooth Home Base - gives mobile phones the attributes of a cordless phone by automatically connecting a Bluetooth-enabled mobile phone to the fixed telephone line. Wireless Modem Stations from Fujitsu and Toshiba are also designed for home use. They provide Internet access using standard modem technology over analogue telephone lines, with connection to the PC or PCs being via Bluetooth rather than cables. Of course, since Bluetooth was originally developed with the mobile telephone in mind, Ericsson and many other mobile telephone manufacturers plan to build Bluetooth technology into mobile phone handsets. The Timeport 270C is a Motorola CDMA telephone with Bluetooth capabilities.

Many of the other products available today are evaluation systems and development kits targeted at developers and hardware vendors, to allow them to test their own designs. There are also large numbers of PC Cards and USB adapters, to enable developers and experimenters to connect Bluetooth devices to PCs. For an up-to-date list of Bluetooth products look on the Web at **qualweb.opengroup.org** and select Qualified Products. Bluetooth currently adds around US$20-$30 to the cost of a device, a price that's expected to fall to nearer US$5 as volumes increase.

Motorola PC Card

The Motorola product is a good example of a Bluetooth PC Card. It includes all the hardware, drivers and software applications to allow a PCMCIA-enabled Windows platform to perform *ad hoc* networking, peer-to-peer file transfers, data synchronisation and other applications. The product actually contains three main modules: the Digianswer Bluetooth software suite, the Digianswer Bluetooth baseband stack, and the Digianswer Bluetooth radio. *Ad hoc* networking to other Bluetooth technology devices using TCP/IP is supported, and simple peer-to-peer networking between two computers using NDIS. Devices like this can also be used to establish a piconet - more usually known as a Personal Area Network, or PAN - for data exchange between TCP/IP-enabled Bluetooth devices.

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The installation process doesn't require any configuration to achieve ready-to-run Personal Area Networking using the network manager. The network manager also provides a one-click-only switch between different network settings on the PC - for example, between the Bluetooth adapter settings and a regular LAN setting. Motorola PC Card and USB solutions are being built into IBM and Toshiba notebook computers.

Bluetooth Bandwidth

The peak raw data rate provided by Bluetooth is just 1 Mbit/sec, which is slow compared to LAN speeds today. In any case, the maximum data rate is a lot lower than the raw rate, because the Bluetooth protocol involves a significant amount of additional data for communication between the master and slaves, and for error

correction. The maximum that an asynchronous data channel running asymmetrically can achieve is 721 Kbits/sec with 57.6 Kbits/sec in the return direction, and just 432.6 Kbits/sec synchronously. These are maximum theoretical rates, since the presence of interference from other ISM devices or other Bluetooth piconets will have an impact on this figure. And they only apply where just two devices are communicating. Remember that all devices within one piconet share the total bandwidth.

Bluetooth packets are separated by a short time interval, to give nodes the chance to switch between transmission and reception. To increase the data rate, nodes can transmit three or five packets together, thereby increasing the overall bandwidth by removing the gaps and also getting rid of the need for three or five sets of header information. The higher throughput of 721 Kbits/sec is achieved by also removing the error correction information, although a simple CRC code is retained. Any retries that result from dropped or corrupted packets caused by interference will impact the overall data rate.

Voice And Data

With applications such as mobile telephones and headsets in mind, the Bluetooth specification allows for voice as well as data transmission, with voice channels delivering up to 64 Kbits/sec in each direction. A link that's been set up between two nodes can operate in one of three ways - a data channel, three simultaneous voice channels, or both voice and data on the same channel. The specification allows the application to choose the desired compromise between high bandwidth and high quality. Three different types of voice packet are defined, each using a different amount of error correction.

Error correction is very bandwidth-hungry, so with the highest degree of correction there is only space for 1.25 ms of speech within each of the 1,600 packets transmitted in a second. 1,600 packets of 1.25 ms each gives us 2000 ms of speech transmitted within a second (1000 ms), and thus just enough to support a bi-directional voice link (one second of speech in each direction), leaving no bandwidth for any other applications. By opting for no error correction at all, each packet slot can carry 3.75 ms of speech, which is three times as much, and gives

Battery Saving

Unfortunately the ISM band is not the most practical choice from a power consumption point of view. Since the original aim of Bluetooth was to facilitate communication between portable devices, battery life is extremely important. Hence the Bluetooth specification includes a number of techniques to help conserve batteries.

Normally, the transmitter power is just 1 milliwatt. Higher power ratings of up to 100 milliwatts are permitted, but only if the transmitter implements power control. With power control, when it's the turn of the receiving node to transmit, it sends back a command to the transmitter to increase or decrease the power, until the transmitter is running at the minimum power compatible with maintaining a reliable link. It's also permitted for devices running at the standard rating of 1 milliwatt to use power control to reduce their transmission power further, all the way down to 1 microwatt.

Clearly, a Bluetooth node will use even less power when it's not transmitting at all, and therefore a device won't transmit unless it has any data to send. But the receiver also consumes significant amounts of power, so there are three power-saving modes to cut down on receiver time.

While a slave device is in sniff mode, it doesn't listen to the master device in every time slot, but at longer intervals. In park mode, the slave relinquishes active participation in the piconet altogether, but does stay synchronised to the master clock by waking up from time to time and listening in. In hold mode, a slave is freed to do something else entirely, such as participate in a second piconet. The master and slave negotiate how long hold mode is going to last, and at the end of that period the slave re-awakens and listens to the master for further instruction.

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us six seconds of speech in every second (1,600 x 3.75 ms) - so only one slot in three is required to maintain that bi-directional telephone call. Because they're carrying real-time information, voice packets aren't re-sent in the event of an error - the resultant speech would sound distorted - and so the error correction will be important in situations of high interference.

Wireless LANs

Using Bluetooth to implement a wireless LAN will not be significantly different from using other technologies based on IEEE 802.11. A Bluetooth access point will be connected to the existing LAN cabling; because the bandwidth is not particularly high there will be no need to employ any techniques such as a dedicated 100 Mbits / sec Ethernet card in the server. As far as the user is concerned, the difference is that Bluetooth access points, currently being developed by Tadlys, 3Com and others, won't be restricted to private offices, but will be available in hotels, airports and even shopping malls to give users access to the Internet, printers, faxes and other communications media. And, in the hotel, your Bluetooth mobile phone can also check you in automatically as you pass the reception desk, and when you arrive at the room whose number appears on the screen the electronic door lock will automatically open.

The WA1001 Bluetooth access point from F=ma (*sic*) Networks has a built-in patch antenna and supports both 10 and 100 Mbits / sec Ethernet connections. It features a console port for local configuration, but also supports HTML for Web-based management across the network. 3Com's Wireless Bluetooth Access Point 1000 provides Ethernet LAN access for Bluetooth devices, with up to seven simultaneous wireless connections, and is intended to be available in summer of 2001.

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Spread Spectrum

Bluetooth communicates using the unlicensed microwave ISM (Industrial, Scientific and Medical) band at 2.4 GHz. Being an unlicensed band, it's not surprising that there are other uses for it - cordless phones, baby alarms, garage door openers and, last but certainly not least, microwave ovens. With all these sources of interference, it's obvious that Bluetooth has had to be designed to be extremely robust. In any case, in the USA there is a requirement for ISM band radio equipment to use a technique known as spread spectrum if transmitter power exceeds 1 milliwatt.

Originally created as a security measure, spread spectrum techniques involve hopping between different carrier frequencies. Thus fixed-frequency interference from other devices will only disrupt the occasional packet that is sent on that frequency. Unfortunately, the ISM band is also used for the wireless networking standard IEEE 802.11b. Bluetooth uses shorter packets and faster hopping, so in the event that both technologies are present within range of each other, Bluetooth is the one likely to win out.

The bandwidth available to devices using the ISM band varies around the world. Although it's 84.5 MHz wide throughout most of the world, Spain, France and Japan restrict it currently to between 27 and 38 MHz. While Bluetooth therefore can operate on 79 channels in most of the world, taking into account guard bands, it's restricted to just 23 in those three countries for the time being. Although hopping between these 79 channels means Bluetooth is reasonably immune to interference, there will still be data loss in the event that other transmissions are taking place within range. Hence, the bandwidth available to Bluetooth will be reduced, and there must be an error correction scheme in place to restore lost packets.

So that devices within a piconet know which frequency to hop to next, the hopping sequence and phase is defined by the master device and communicated to the slaves when the piconet is first established. Which device becomes the master is not hardwired, but negotiated. There are about 1,600 Bluetooth packets per second. Note that Bluetooth is a unidirectional technology - if there are two devices in a piconet that wish to communicate, they must transmit in alternate slots.

Bluetooth Security

The ability to walk into an office with a Bluetooth device and potentially connect to the network, PCs, telephones and other devices clearly raises important security concerns. The Bluetooth specification therefore provides for both authentication (to control who can connect to devices) and encryption (to ensure data transmitted remains private). Authentication requires the devices in communication to share a secret key. Within each Bluetooth node is a unique key, known as a unit key. This isn't fixed and is stored in non-volatile RAM, although there's normally no need for it to ever change.

The first problem is that, in order to establish a link, each device needs to know the other's unit key. A device cannot simply pass its unit key to any other device, since that would defeat the entire object of the authentication process. Therefore, there must first be a successful authentication process using an initialisation key, which is derived from a PIN code that the user enters at each end of the link. Some devices and applications may require much more sophisticated user authentication, such as biometric devices and smartcards. A PIN code may not be appropriate for every device, such as a set of headphones. These devices will come with a PIN code fixed within the device, but there must also be some means of changing it in case it falls into the wrong hands.

After the PIN exchange has succeeded, a new key is generated for subsequent authentication and then encryption of data in transit. Encryption can use a key of up to 128 bits but, initially, devices will probably restrict themselves to 64 bits.

IEEE 802.11b

Problems occur where IEEE 802.11b is already in use for wireless networking, and an organisation wishes to introduce Bluetooth for such tasks as synchronisation of PDAs with notebook computers. Although both systems may co-exist in the same area without serious performance degradation, both systems cannot be used in the same device at the same time. According to Charles Dittmer, Director of Communication Technologies, Portable PC Division at Compaq, even with two devices less than three feet apart the two networks interfere with each other. This could mean that a user will have to disconnect from an office LAN using IEEE 802.11b before synchronising a PDA with a PC.

Conclusion

Bluetooth is designed to be as easy to use as possible, and the network manager will have little to worry about as far as implementing Bluetooth for PDA-to-PC access is concerned. The important decisions will be strategic - whether to use Bluetooth or IEEE 802.11b for wireless networking, and whether to provide Bluetooth LAN Access Points for general usage or to restrict Bluetooth usage to personal connections to individual PCs. It's early days for Bluetooth, and it's difficult to predict at this stage exactly which Bluetooth devices will prove popular, and to know what users will want to do with them. It's quite clear that synchronisation between devices holding personal information (mobile telephones and PDAs) and desktop PCs will be important, as will use of headsets to support a range of audio communication devices. It also seems likely that facilities like Internet access and printing will be required by users, and delivered via LAN access points. But beyond that, it's too soon to tell.

Further Information

www.bluetooth.com
www.10meters.com
www.palowireless.com

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