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# BLUETOOTH

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## 1. ABSTRACT

During the past two decades, the progress in microelectronics and VLSI technology has driven the cost of many consumer electronic products down to an acceptable level for average people. Only in the 1st quarter of 2001, 32.5 million PCs were sold. The number of cellular phones is predicted to reach 1 billion in 2005. With the increase in the number of these devices, so does the need of connecting them together. Today numerous kinds of special cables are used for interconnection. These are cumbersome, not interchangeable and expensive. Bluetooth is devised to replace these cables. Bluetooth is a low cost, low power, radio frequency technology for short-range communications. It can be used to replace the cables connecting portable/fixed electronic devices, build ad-hoc networks or provide data/voice access points. Bluetooth is an open standard specification for a radio frequency (RF)-based, short-range connectivity technology that promises to change the face of computing and wireless communication. It is designed to be an inexpensive, wireless networking system for all classes of portable devices, such as laptops, PDAs (personal digital assistants), and mobile phones. It will also enable wireless connections for desktop computers, making connections between monitors, printers, keyboards, and the CPU cable-free. The idea of a cable-free, or wireless, technology was initially conceived by Ericsson in 1994, when the company began a study to investigate the feasibility of a low-power, low-cost radio interface between mobile phones and their accessories. As the idea grew, a special interest group (SIG) was formed to create a standard for this technology. The original SIG, formed in 1998, consisted of five companies:

- Ericsson
- IBM
- Intel
- Nokia
- Toshiba

Four other major companies (Microsoft, 3Com, Lucent, and Motorola) later joined this founding group to form the Bluetooth Promoter Group. Many more companies have since become part of the Bluetooth revolution, expanding on the original vision, and helping drive the development of this new technology.

**Keywords:** Bluetooth Profiles, Bluetooth Stack, Service Discovery, Scatter Net, Piconet, Radio Frequency Communication (RFCOMM), Logical Link and Adaptation Protocol (L2CAP), Service Discovery Protocol (SDP), Host Controller Interface (HCI), Link Manager, Link Controller.

## 2. BLUETOOTH COMPONENTS

A complete Bluetooth system will require these elements:

- An RF portion for receiving and transmitting data
- A module with a baseband microprocessor
- Memory
- An interface to the host device (such as a mobile phone)

This basic system will vary, however, depending on whether the Bluetooth module is independent of the host or embedded. First, consider the module scenario. The RF portion can be implemented as a module or as a single chip. Ericsson has a module available that includes a short-range radio transceiver, an external antenna, and a clock reference (required for synchronization). It can be used independently or with a baseband module, which Ericsson also offers. Other transceivers also are available for Bluetooth applications, and those transceivers also can be used with another company's baseband solution or with a packaged baseband processor. In this type of arrangement, the lower-layer Bluetooth protocols are supported in the baseband module, and the host processor must support the upper-layer protocols (for example, file transfer). In other words, the RF/baseband solution provides the means to communicate with the host, but you need to implement a connection interface, as well as any upper-layer protocols, to use applications supported by the final product. The upper layers of the technology support what are known as the *Bluetooth profiles* — in other words, a set of protocols. A set of protocols is optimized for a class of applications — for example, dial-up networking or file transfer. This feature is important, because it enables interoperability among devices. Requiring a specific profile for devices that provide comparable applications ensures interoperability

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across a spectrum of devices. Another option for manufacturers is to embed a fully integrated RF/baseband Bluetooth chip. In this scenario, the upper-layer protocols reside within the single chip, freeing the host processor from the protocol processing. The cost of the chip necessarily will be higher, but the fully integrated final design can be less complex, use less power, and reduce production cost. In this scenario, the Bluetooth unit can connect to the host device through a serial interface such as a universal serial bus (USB).

## 3. BLUETOOTH TERMINOLOGY

The Bluetooth specification, while innovative, does not define a totally new technology. In fact, Bluetooth draws heavily on existing radio communications and networking technologies, which enables it to be operationally compatible with the existing devices that also use these technologies. Many of the various terms and concepts used in Bluetooth are borrowed from other areas and included in the specification of Bluetooth's elements, such as baseband, RF communications, and many of the upper- and lower-layer protocols. What makes Bluetooth unique is how it applies its proprietary components and the existing technologies to define its central core operations and its application profiles. Regardless of their source, the terms that are integral to Bluetooth are worth examining a little more closely.

### 3.1 BLUETOOTH STACK

As already noted, the baseband, or radio module, is the hardware that enables wireless communication between devices. The building block of this technology is the *Bluetooth stack*, which includes the hardware and software portions of the system. Essentially, the stack contains a physical-level protocol (baseband) and a link level protocol (Link Manager Protocol, or LMP) with an adaptation layer (Logical Link Control and Adaptation Layer Protocol, or L2CAP), enabling upper-layer protocols to interact with the lower layer. The Bluetooth stack has the following components:

- RF portion for reception and transmission
- Baseband portion with microcontroller
- Link control unit
- Link manager to support lower-layer protocols
- Interface to the host device

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- Host processor to support upper-layer protocols
- L2CAP to support upper-layer protocols

The *radio frequency* (RF) portion provides the digital signal processing component of the system, and the baseband processes these signals. The *link controller* handles all the baseband functions and supports the link manager. It sends and receives data, identifies the sending device, performs authentication, and determines the type of frame to use for sending transmissions. The link controller also directs how devices listen for transmissions from other devices and can move devices into power-saving modes. The *link manager*, located on top of the link controller, controls setup, authentication, link configuration, and other low-level protocols. Together, the baseband and the link manager establish connections for the network. The *host controller interface* (HCI) communicates the lower-layer protocols to the host device (mobile computer or mobile phone, for example). The host contains a processor, the *L2CAP*, which supports the upper-layer protocols and communicates between upper and lower layers. The upper-layer protocols consist of service-specific applications that must be integrated into the host application. Another element in the Bluetooth stack that relates to radio communications is the *RFCOMM protocol,* which allows for the emulation of serial ports over the L2CAP. The *Service Discovery Protocol* (SDP) provides the means for Bluetooth applications to discover the services and the characteristics of the available services that are unique to Bluetooth.

## 3.2 LINKS AND CHANNELS

Links and channels are used to transmit data between Bluetooth units. First, the links are established. Bluetooth technology supports two link types: synchronous connection-oriented (SCO) and asynchronous connectionless (ACL) links. The SCO links are used primarily for voice communications. The ACL links are used for packet data. Bluetooth devices can use either link type and can change link types during transmissions, although an ACL link must be established before an SCO link can be used. After the link has been established, Bluetooth uses five logical channels to transfer different types of information between devices:

- Link control (LC) manages the flow of packets over the link interface.
- Link manager (LM) transports link management information between participating stations.

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- User asynchronous (UA) carries user data.
- User isochronous (UI) carries user data.
- User synchronous (US) carries synchronous (SCO) data.

## 3.3 PROTOCOLS

Bluetooth protocols are sets of conventions that govern the transmission of data in upper and lower layers of the system. The lower-layer protocols pertain to establishing connections, and the upper layers correspond to specific types of applications. Some of the protocols used are:

### 3.3.1 LINK CONTROL PROTOCOL

The link control protocol is responsible for delivery of the basic data elements. All packet information is transmitted in a specific time-slot format (a single time slot in the Bluetooth system lasts 625 μs), and specific links are designed to transport a range of data types. The Bluetooth link control protocol can be used to manage the associations and delivery of information between the various units within a Bluetooth network. This format is used for both synchronous (voice) and asynchronous (data) modes of operation, with specific formats specified for voice transport.

### 3.3.2 LINK MANAGER PROTOCOL

The link manager protocol (LMP) is a command-response system for transmitting data. It transports packets through the Bluetooth baseband link protocol, which is a time-slot-oriented mechanism. LMP packets are limited in size to ensure that they fit into a single time slot. The format of the protocol data unit (PDU) is simple. Two fields are used:

- The OpCode identifies the type and sequence of the packet.
- The content field contains application-specific information.

The LMP also specifies a collection of mandatory and optional PDUs. Transmission and reception of mandatory PDUs must be supported. Optional PDUs don't need to be implemented, but can be used as necessary. The protocol sequences are similar to client-server architectures, with the exchange of information following a similar request-response pattern. In

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general, a single response PDU is sent upon receipt of the original request. Because Bluetooth is an RF broadcast technology, a set of request messages can be broadcast to all participants on a network. In this case, one request can elicit several responses.

### 3.3.3 L2CAP

Logical link and adaptation protocol (L2CAP) enables transmission of data between upper and lower layers of the stack. It also enables support for many third-party upper-layer protocols such as TCP/IP. In addition, L2CAP provides group management by mapping upper-layer protocol groups to Bluetooth networks. It is also a factor in ensuring interoperability among Bluetooth units by providing application-specific protocols. Other protocols interfacing to the L2CAP include service discovery protocol (SDP), radio frequency communication (RFCOMM), telephony control protocol specification (TCS), and IrDA Object Exchange Protocol (IrOBEX):

- SDP provides service discovery specific to Bluetooth. That is, one device can determine the services available in another connected device by implementing the SDP.
- RFCOMM is a transport protocol that provides serial data transfer. In other words, it enables legacy software applications to operate on a Bluetooth device.
- TCS is for voice and data call control. It provides group management capabilities and allows for signaling unrelated to an ongoing call.
- OBEX is a session protocol, and for Bluetooth devices, only connection-oriented OBEX is supported. Three application profiles have been developed using OBEX: synchronization (for phonebooks, calendars, messaging, and so on), file transfer between connected devices, and object push for business card support

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## 4. BLUETOOTH NETWORKING

The Bluetooth technology provides both a point-to-point connection and a point-to-multipoint connection. In point-to-multipoint connections, the channel is shared among several Bluetooth units. In point-to-point connections, only two units share the connection. Bluetooth protocols assume that a small number of units will participate in communications at any given time. These small groups are called piconets, and they consist of one master unit and up to seven active slave units. The master is the unit that initiates transmissions, and the slaves are the responding units. This type of Bluetooth network can have only one master unit. If several piconets overlap a physical area, and members of the various piconets communicate with each other, this new, larger network is known as a scatternet. Any unit in one piconet can communicate in a second piconet as long as it serves as master for only one piconet at a time.

## 5. BLUETOOTH BASICS – HOW IT WORKS

### 5.1 NETWORK TOPOLOGY

Any Bluetooth device can be a *master* or a *slave*, depending on the application scenario. Bluetooth employs frequency hopping spread spectrum (FHSS) to communicate. So in order for multiple Bluetooth devices to communicate, they must all synchronize to the same hopping sequence. The master sets the hopping sequence, and the slaves synchronize to the Master.

A *piconet* is formed by a master and up to seven active slaves. The slaves in a piconet only communicate with the master.

A *scatter net* can be formed by linking two or more piconets. When a device is present in more than one piconet, it must time-share and synchronize to the master of the piconet with which it is currently communicating.

While the topology and hierarchical structure of WLAN networks are relatively simple, Bluetooth networks are far more diverse and dynamic. They are constantly being formed, modified, and dissolved, as Bluetooth devices move in and out of range of one another. And because different Bluetooth devices can represent many different usage profiles, there are many different ways in which Bluetooth devices can interact.

### 5.2 SERVICE DISCOVERY

The concept of *service discovery* is utilized to determine what kind of Bluetooth devices are present and what services they desire or offer. When a Bluetooth device requires a service, it begins a discovery process by sending out a query for other Bluetooth devices and the information needed to establish a connection with them. Once other Bluetooth devices are

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found and communication is established, the Service Discovery Protocol (SDP) is utilized to determine what services are supported and what kinds of connections should be made.

In order for the above to happen, devices willing to connect must be located. Some devices may be set up so that they are invisible. In this case, they can scan for other Bluetooth devices, but will not respond if they are likewise queried. Applications determine whether a device is connectable or discoverable, and thus applications determine the topologies of networks and their internal hierarchies.

Once a connection has been established between two devices an Asynchronous Connection-Less (ACL) link is formed between them. An ACL link provides packet-switched communication and is the most common link used to handle data traffic. A master has the option to change an ACL link to a Synchronous Connection Oriented (SCO) link. An SCO link provides a QoS feature by reserving time slots for transmission of time-critical information such as voice. A piconet can have up to three full-duplex voice links.

The number and variety of different Bluetooth usage models mean that Bluetooth devices must call from a large collection of different protocols and functions to implement a specific usage model. In order to ensure that all usage models will work among devices from many different manufacturers, this collection of protocols and functions must be standardized. Bluetooth profiles are standardized definitions of protocols and functions required for specific kinds of tasks. The current Bluetooth Standard 1.1 contains 13 profiles, with more being continually added. One or more of these profiles are utilized when implementing various usage models. Some profiles are dependent upon others. Some of the most basic are:

- *General Access Profile (GAP)* - This profile is required by all usage models and defines how Bluetooth devices discover and connect to one another, as well as defines security protocols. All Bluetooth devices must conform to at least the GAP to ensure basic interoperability between devices.
- *Service Discovery Application Profile (SDAP)* - The SDAP uses parts of the GAP to define the discovery of services for Bluetooth devices.
- *Serial Port Profile* - This profile defines how to set up and connect virtual serial ports between two devices. This serial cable emulation can then be used for tasks such as data transfer and printing.

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- *Generic Object Exchange Profile (GOEP)* - GOEP is dependent on the Serial Port Profile and is used by applications to handle object exchanges. This capability is then used, in turn, by other profiles to perform such functions as Object Push, File Transfer, and Synchronization.
- *Objects Push* - This profile is used for the exchange of small objects, such as electronic calling cards.
- *File Transfer* - This profile is used to transfer files between two Bluetooth devices.
- *Synchronization* - This profile is used to synchronize calendars and address information between devices.

New profiles not yet part of the standard include the following:

- *Basic Printing Profile* to facilitate printing of text emails, short messages, and formatted documents.
- *Hands Free Profile* to enable a mobile phone to be used with a hands-free device in a car.
- *Basic Imaging Profile* enabling Bluetooth devices to negotiate the size and encoding of exchanged images.
- *Hardcopy Cable Replacement Profile* used by devices such as laptops and desktop computers that utilize printer drivers.

## 5.3 POWER LEVELS AND RANGE

Most Bluetooth devices, dependent on batteries for power, are designated as class 3 devices and are designed to operate at a power level of 0 dBm (1 mW), which provides a range of up to 10 m. Class 2 devices can utilize as much as 4 dBm (2.5 mW) output power, and class 1 devices can utilize up to 20 dBm (100 mW) of output power. Class 1 devices can have a range up to 100 m.

Bluetooth class 2 and 3 devices can optionally implement adaptive power control. Required for class 1 devices, this mechanism allows a Bluetooth radio to reduce power to the minimum level required to maintain its link, thus saving power and reducing the potential for interfering with other nearby networks.

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## 6. BLUETOOTH SECURITY

Bluetooth security, when compared with WLAN security, is both more complex and simpler. It is more complex in the sense that there are many different options for security based on different application scenarios. It is simpler in the sense that, for the most part, they are transparent to the user.

With WLANs it is up to the network administrator to add security at higher levels. With Bluetooth higher-level security features are already built into the devices when appropriate.

Bluetooth security includes both authentication and confidentiality, and is based around the SAFER+ encryption algorithm. SAFER+ is a block cipher, but in this application it is implemented as a stream cipher. SAFER+ has been thoroughly analyzed and tested. Although some versions were found to have very minor weaknesses, the 128-bit version as used in Bluetooth is considered very strong.

### 6.1 LINK LAYER SECURITY – KEYS AND MORE KEYS

The Bluetooth Baseband (link layer) specification defines methods for both authentication and encryption that are subsequently utilized by higher layers.

These methods utilize a number of keys generated by a process that begins with three basic device entities: a public 48-bit device address, a random number generator, and a secret PIN which is either built into the unit by the manufacturer or programmed by the user. A typical PIN may consist of just four decimal digits. However, for applications requiring more security a PIN code up to 128-bits long can be entered.

The first of many keys is created the first time the Bluetooth device is installed on the host and is typically never changed. This is referred to as the *unit key*.

### 6.2 AUTHENTICATION

When a Bluetooth *session* (defined as the time interval for which the device is part of a piconet) is initiated, a series of additional keys is generated. One of these keys, referred to as the *link key* or *authentication key,* is a one-time 128-bit secret key that is used only during that session.

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The process of authentication employs the encryption of a random number by each device to verify that each is sharing the same secret link key.

## 6.3 ENCRYPTION

If encryption is required by the application, an encryption key is further derived from the link key, a ciphering offset number, and a random number. While the authentication key is always 128-bits, the encryption key may be shorter to accommodate government restrictions on encryption, which vary from country to country. A new encryption key is generated each time the device enters encryption mode. The authentication key, however, is used during the entire session. The Bluetooth General Access Profile defines three security modes:

- *Mode 1* is non-secure. Authentication is optional.
- *Mode 2* gives service-level enforced security. The service provided by the application decides whether or not authentication or encryption is required. The Bluetooth SIG has published the Bluetooth Security Architecture white paper that defines a suitable architecture for implementing service-level enforced security on Bluetooth devices. The white paper splits devices into different categories and trust levels, as well as suggesting three security levels for services. The utilization of a database is suggested for enabling the user to authorize devices to utilize only particular services. Because the implementation of security at this level does not affect interoperability, this white paper is advisory only, and is not part of the Bluetooth specification.
- *Mode 3* is link-level enforced security. Both devices must implement security procedures in order for a connection to be established.

In addition to the above modes, a device can be configured to not respond to paging, so that other devices cannot connect to it. Or it can be configured so that only devices that already know its address can connect to it. Such numerous and complex levels of security are necessary to accommodate the large variety of different usage scenarios. It falls on the designers of Bluetooth products to ensure that the complexity of Bluetooth is hidden from the user, while still providing the user with necessary security options.

## 7. BLUETOOTH CONCEPTS

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Bluetooth is an emerging standard for wireless connectivity. It specifies a system — not just a radio — that encompasses the hardware, software framework, and interoperability requirements. And, the radio system is optimized for mobility. In other words, Bluetooth primarily specifies a cable-replacement technology that targets mobile users in the global marketplace.

## 7.1 BLUETOOTH CONNECTIONS

The major difference between Bluetooth wireless connectivity and the cellular radio architecture is that Bluetooth enables ad hoc networking. Rather than depending on a broadband system, which relies on terminals and base stations for maintaining connections to the network via radio links, Bluetooth implements peer-to-peer connectivity — no base stations or terminals are involved. Using peer-to-peer connectivity, Bluetooth technology simplifies personal area wireless connections, enabling all digital devices to communicate spontaneously. Early applications are expected to include cable replacement for laptops, PDAs, mobile phones, and digital cameras. Because Bluetooth supports voice transmissions, headsets also are in line to become wireless. The Bluetooth technology offers the following advantages:

- Voice/data access points will allow, for example, mobile phone/Internet connections.
- Cable is replaced by a Bluetooth chip that transmits information at a special radio frequency to a receiver Bluetooth chip.
- Ad hoc networking enables personal devices to automatically exchange information and synchronize with each other. For example, appointments made on a PDA calendar automatically appear on a desktop calendar as well.

## 7.2 RELIABLE AND SECURE TRANSMISSIONS

Bluetooth technology also provides fast, secure voice and data transmissions. The range for connectivity is up to 10 meters, and line of sight is not required. The Bluetooth radio unit

- Functions even in noisy radio environments, ensuring audible voice transmissions in severe conditions.
- Protects data by using error-correction methods.
- Provides a high transmission rate.
- Encrypts and authenticates for privacy.

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As with any wireless interface, Bluetooth must address issues involving reliable delivery of information. Noise and interference from other ISM (Industrial, Scientific, and Medical) band transmissions, for example, are factors that come into play. To help deliver accurate information, Bluetooth provides two error-correction mechanisms: forward error correction (FEC) and automatic repeat request (ARQ). Typically, FEC is applied to voice traffic for which the timeliness of the delivery takes precedence over the accuracy — late voice traffic being unacceptable. ARQ mechanisms are used for data applications. Because Bluetooth operates in the unlicensed ISM frequency band, it competes with signals from other devices, such as garage door openers and microwave ovens. In order for Bluetooth devices to operate reliably, each Bluetooth network is synchronized to a specific frequency pattern. The Bluetooth unit moves through 1,600 different frequencies per second, and the pattern is unique to each network. Bluetooth also implements various security measures, including authentication and encryption. Authentication is used to verify the identity of the device sending information, and encryption is used to ensure the integrity of the data.

## 7.3 LOW-POWER ARCHITECTURE

Because Bluetooth is intended for mobile devices, it implements low-power architecture in which units move into lower-power modes when not actively participating on the network. Bluetooth units also consume less power during operation. For example, the Bluetooth radio consumes less than 3 percent of the power that a mobile phone consumes.

## 7.4 GLOBAL COMPATIBILITY

Bluetooth architecture is compliant with global emissions rules, operating on a globally available frequency band (2.4 GHz ISM band) the unlicensed portion of the radio frequency spectrum. This ensures that Bluetooth devices will interact in the same way in any part of the world. Bluetooth architecture also complies with airline regulations and is safe for use on airlines. Developers of the technology work with the FAA, JAA, FCC, airplane manufacturers, and airlines to ensure compliance.

## 7.5 INTEROPERABILITY, STANDARDS, AND SPECIFICATIONS

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Another key concept in the Bluetooth environment is the idea of interoperability among Bluetooth units regardless of manufacturer. Because Bluetooth is an open specification for short range wireless communication, all Bluetooth products must conform to a standard. This ensures that wireless connections will be globally available, and Bluetooth units made anywhere in the world will be able to connect with and communicate information and services to other Bluetooth devices.

To this end, the Bluetooth SIG has developed detailed specifications for the hardware and software elements of Bluetooth units. The specifications consist of Core and Profiles documentation. The Core document discusses elements such as the radio, baseband, link manager, and interoperability with different communication protocols. The Profiles document delineates the protocols and procedures to be used for specific classes of applications. The specifications are intended to prevent discrepancies in end products due to different interpretations of the Bluetooth standard. The SIG also has implemented a qualification process. This process defines criteria for Bluetooth product qualification, ensuring the Bluetooth standards are met in any product that sports the Bluetooth name.

## 8. MARKETING AND COMPETITION

### 8.1 MARKET PROJECTION

According to the statistics of In-Stat Group, Bluetooth-enabled equipment shipments will reach 955 million units in 2005. The Bluetooth semiconductor market will rise to $4.4 billion in 2005. The potential markets include digital mobile phones, digital cordless phones, wireless headsets, data access points (hot spots), laptop, desktop and PDA, computer peripherals, digital cameras and home networking. Some “hot spots” have already appeared in some hotels, shopping malls, airports and much more are coming. It’s expected that there will be a big leap in the market next year.

Besides the market need, the vendors’ support will also play an important role. Bluetooth has great support from manufacturers. Currently, Bluetooth SIG has about 2500 members, including almost all the key players in this market. It’s estimated that in year 2000 over 60 million dollars were invested into Bluetooth R&D. The expectation from Bluetooth is huge, but so far very few commercial products are available, and they cannot interoperate very well as they are expected

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to be. One of the major reasons is the qualification program is not complete, and no official test facilities are listed so far. The number of profiles, which define guidelines for different applications, is also very limited. Bluetooth was promoted well before the technology was ready for commercial release to get enough support to become the industry standard. Now it falls short of the high expectation people have. After all, people still believe that Bluetooth will see a great market penetration by 2015.

## 9. SUMMARY

Bluetooth is a low cost, low power RF technology for short-range communications. It could be used to replace cables connecting portable devices. Compared to other similar wireless technologies, its biggest advantage is the low power and low cost, which makes it suitable for mobile applications. But its low data rate keeps it away from high-speed applications like real time video. A higher data rate version of Bluetooth is under discussion. It shares the 2.4GHz ISM band with many other products. Interference among these units is an important topic for research. There is huge market potential for Bluetooth products. The market will reach $1 billion around 2005. It has gained support from thousands of companies. There are a few commercial products available, and it’s believed many more will roll out next year.

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