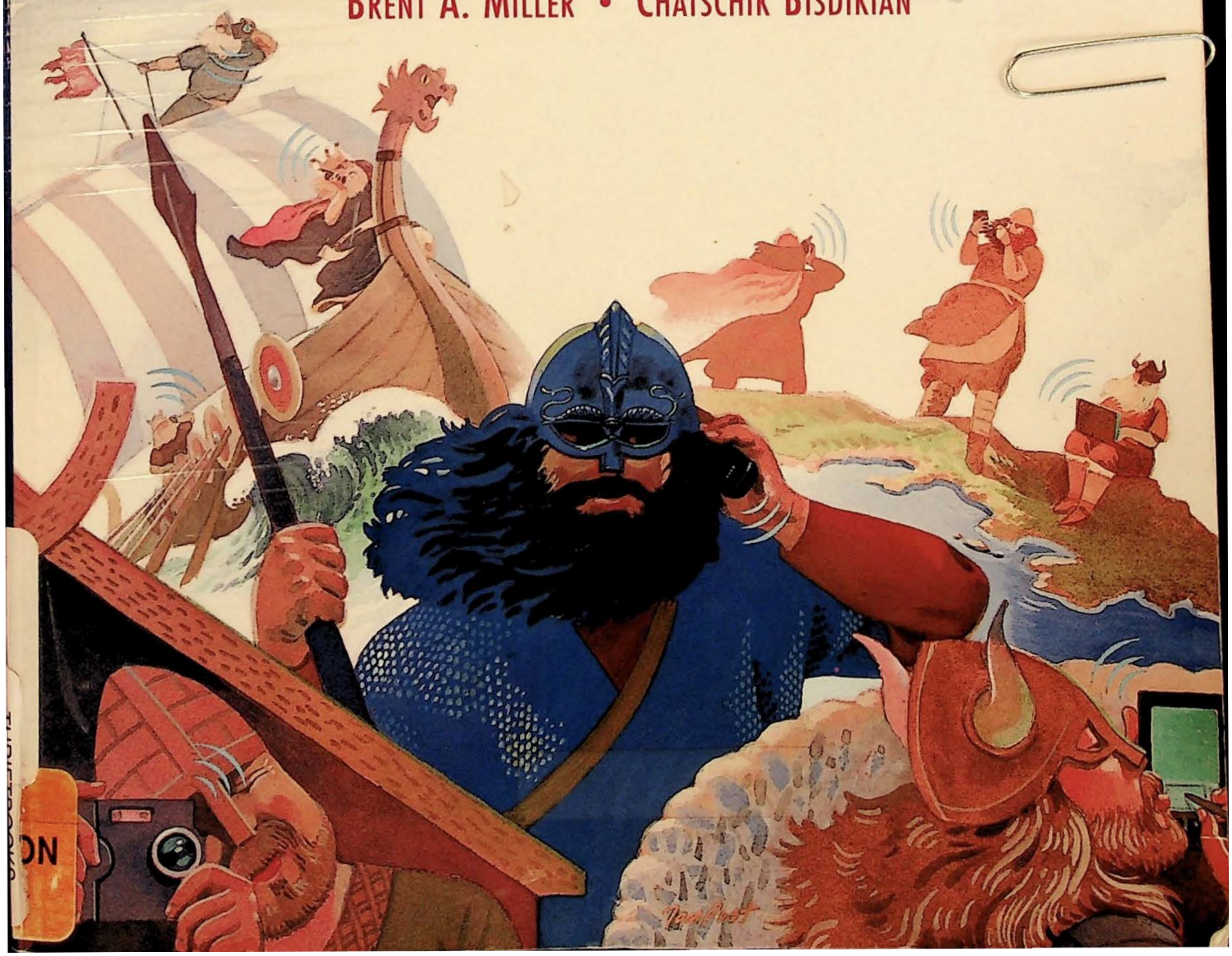
BLUETOOTH REVEALED

THE INSIDER'S GUIDE TO AN OPEN SPECIFICATION FOR GLOBAL WIRELESS COMMUNICATIONS

BRENT A. MILLER • CHATSCHIK BISDIKIAN



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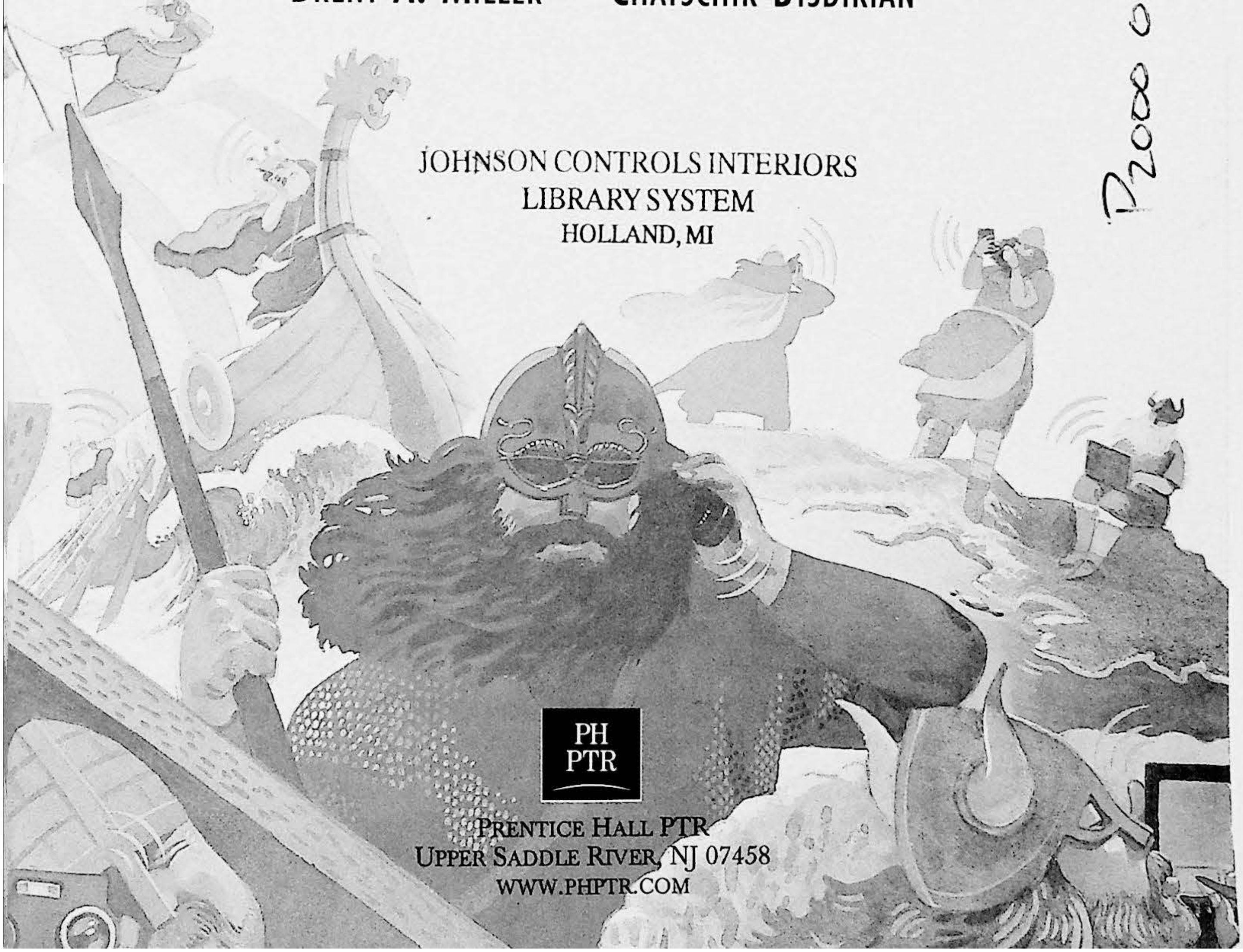

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To Laurie, Benjamin and Andrew;
Teresa, Eugene and Theodore;
and King Harald Bluetooth

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THE BLUETOOTH PROFILES EXAMINED 201

Foreword

My work with the Bluetooth wireless technology, which began long before it became *Bluetooth*, has been a privilege and an extremely rewarding experience. In 1997, when a few major players in the telecommunications and portable computing industries engaged in some initial discussions, no one could even dream of the unprecedented success the program was to enjoy a few years down the road. We all knew that there was a great need for a low-power, low-cost, short-range cable replacement, but from there to the overwhelmingly favorable industry and media response was a quantum leap.

The Bluetooth SIG managed from the beginning to focus on consumer requirements rather than just designing the technically best possible radio. A zero-cost license, good marketing (of course) and a bit of luck with the timing are always useful, too, when you want to establish a worldwide de facto standard.

Predictions from many independent sources, such as Frost & Sullivan, Cahners In-Stat, Merrill Lynch and many other research institutes, indicate that indeed the Bluetooth wireless technology will become a smashing success, with as many as 1.5 billion or more devices being equipped with Bluetooth wireless technology in the year 2005.

With tens of thousands of engineers around the world working on implementations and perhaps even hundreds of thousands of other people such as students and professionals becoming interested in this technology, it is easy to understand the need for the publication you have in your hands.

Written by people involved from the beginning in key roles to develop the Bluetooth specification, you will find the book to be most authoritative. Perhaps even more importantly, it is written in an easy-to-understand way, explaining a lot of the thinking behind the development of many chapters in the specification.

In short, *Bluetooth Revealed: The Insider's Guide to an Open Specification for Global Wireless Communications* provides an important source of easy-to-access information about this new and exciting technology.

I look forward to seeing you in my "piconet" soon!

Anders Edlund
Marketing Director, Bluetooth Product Unit
Ericsson Mobile Communication

Preface

The convergence of computing and communications has been predicted for many years. Today's explosion of a myriad of new types of personal computing and communications devices–notebook computers, personal digital assistants, "smart" phones, two-way pagers, digital cameras and so on–has resulted in new ways for people to communicate and gain access to data. The advent of this pervasive computing, especially via wireless communications, enables these devices to be used in new settings: not only can people make voice calls from their automobile using a mobile phone, but also they can access the World Wide Web from a wireless notebook or handheld computer while at the airport or a shopping mall. We are rapidly moving toward a world where computing and communications become ubiquitous–not only at work but also in the home, in public places and in personal surroundings.

Until recently, enabling all of these devices to communicate with each other has been cumbersome, often involving the use of special cables to connect the devices together along with device-specific software that might use proprietary protocols. To exchange information among all of her personal devices, a person might need to carry as many cables as devices and still lack assurance that all the devices could interconnect. The inability to share information among devices or the difficulty in doing so limits their usefulness.

The *Bluetooth*™ technology enables devices to communicate seamlessly without wires. While Bluetooth wireless communication is first and foremost a means for cable replacement, it also enables many new applications–the use of a single mobile telephone as a cellular phone, cordless phone or intercom and the use of a notebook computer as a speakerphone, just to name two. The Bluetooth Special Interest Group (SIG) was formed in early 1998 by Ericsson®, Intel®, IBM®, Nokia® and Toshiba® to develop an open specification for globally available short-range wireless radio frequency communications. The SIG has published a specification for the Bluetooth radio and baseband along with a set of communication protocols comprising a software stack used with the Bluetooth radio hardware. The Bluetooth radio module design is optimized for very low power consumption, low cost, small footprint and use anywhere in the world. In addition to the core specification, the SIG has also published Bluetooth profiles that describe how to use the software protocols such that interoperability among all kinds of devices can be achieved, regardless of who manufactures these devices. Version 1.0 of the specification was published in July 1999. Today the Bluetooth Special Interest Group consists of nine promoter companies (joining the five founding companies noted above in the SIG's core group are 3Com®, Lucent®, Microsoft® and Motorola®) and well over 1,800 adopter companies from around the world, representing a diverse set of industries.

The specification and profiles continue to evolve as the SIG develops new ways to use the Bluetooth technology. The first products with Bluetooth wireless communications arrived in 2000 led by development tools, mobile telephones, audio headsets, notebook computers, handheld computers and network access points.

A great deal of interest, talent and energy has marshaled around this exciting new technology. Until now most of the information available about Bluetooth wireless communications has been from the SIG's official web site (http://www.bluetooth.com) or from brief press articles or newsletters. This book aims to be at once authoritative and accessible. Besides discussing background, history and potential future developments, *Bluetooth Revealed: The Insider's Guide to an Open Specification for Global Wireless Communications* delivers practical explanations of the specification by people who helped to develop it. It is a broad discussion of the topic, containing information that should be of value to industry practitioners, professionals, students and any others who are interested in this topic. No matter what your particular interest is, *Bluetooth Revealed* is intended to give you the information you need to become a "Bluetooth Insider."

ACKNOWLEDGEMENTS

We already knew that developing the Bluetooth technology was a tremendous undertaking, and we now have discovered that writing a book is a lot of work. The fun part is being able to include a short list of people who supported, encouraged or otherwise aided in the development of this book or of the Bluetooth technology that makes this book relevant.

At the risk of omitting those who deserve mention, both authors acknowledge all of the members of the Bluetooth SIG who worked passionately and tirelessly as a team to make the technology possible, especially our Air and Software Working Group colleagues who made a major difference: Jon Inouye of Intel; Thomas Muller, Stephane Bouet and Riku Mettälä of Nokia; Johannes Elg, Jaap Haartsen and Tobias Melin of Ericsson; Dale Farnsworth of Motorola; Shaun Astarabadi of Toshiba; Paul Moran and Ned Plasson of 3Com; and most of all our IBM colleagues around the globe who worked to advance the Bluetooth technology, most notably our teammates Peter Lee, Mahmoud Naghshineh, Nathan Lee, Parviz Kermani, Brian Gaucher and Toru Aihara and former IBM colleague Pravin Bhagwat. We are also indebted to Bouet, Elg and Aihara-san, along with Gabriel Montenegro of Sun Microsystems, for their exemplary and valuable technical review of the book. We also acknowledge Mary Franz and her team at Prentice Hall PTR, whose support, expertise and responsiveness made it possible to carry out this project.

Brent Miller thanks Sandeep Singhal for his experienced author advice; his co-author Chatschik Bisdikian, who wrote all the hard parts; his wife Laurie and sons Benjamin and Andrew for their encouragement and support; and God who makes this and all things possible.

Dr. Chatschik Bisdikian thanks co-author Brent for inviting him to contribute to this project and patiently rewriting in plain English what he wrote; his manager Mahmoud Naghshineh for encouraging him (rather strongly and persistently) to get involved with the Bluetooth wireless technology from the outset; and last but not least his wife Teresa and sons Eugene and Theodore for their unconditional encouragement and support through long nights and weekends of working on this project.

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Part 1

INTRODUCTION TO BLUETOOTH WIRELESS COMMUNICATION

This book begins with background information about Bluetooth wireless communication. The technology is described at the highest level and its origins and history are explored, including the story of how this technology came to be named Bluetooth. The Bluetooth Special Interest Group is described from the authors' own perspective as participating members. Chapter 1 contains a reader's guide for the remainder of the book. In Chapter 2 the basics of wireless communications are covered, including spread spectrum radio frequency communications in the 2.4 gigahertz spectrum and infrared communications, both of which influence the Bluetooth specification. The fundamental principles of Bluetooth communication, including master and slave roles, baseband modes and communication topology are presented. Chapter 3 describes most of the well-known usage models in which Bluetooth wireless communication can be employed. In these usage scenarios the end user's viewpoint and derived benefits are emphasized. Finally Chapter 4 provides an introduction to the Bluetooth core specification and profiles that are explored in detail in Parts 2 and 3 of the book, respectively.

Part 1 is designed to aid readers who are not already familiar with Bluetooth wireless communication in understanding the fundamentals of the technology and how that technology came to be. At the same time, readers already familiar with Bluetooth wireless communication may discover new information or perspectives that will further their understanding of this important new technology.

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Part 1

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1

What Is *Bluetooth?*

The term *Bluetooth*™ [1] refers to an open specification for a technology to enable short-range wireless voice and data communications anywhere in the world. This simple and straightforward description of the Bluetooth technology[2] includes several points that are key to its understanding:

Open specification: The Bluetooth Special Interest Group (SIG) has produced a specification for Bluetooth wireless communication that is publicly available and royalty free. To help foster widespread acceptance of the technology, a truly open specification has been a fundamental objective of the SIG since its formation.

Short-range wireless: There are many instances of short-range digital communication among computing and communications devices; today much of that communication takes place over cables. These cables connect to a multitude of devices using a wide variety of connectors with many combinations of shapes, sizes and number of pins; this plethora of cables can become quite burdensome to users. With Bluetooth technology, these devices can communicate without wires over a single *air-interface*, using radio waves to transmit and receive data. Bluetooth wireless technology is specifically designed for short-range (nominally 10 meters) communications; one result of

1. Bluetooth is a trademark owned by Telefonaktiebolaget L M Ericsson, Sweden and licensed to promoters and adopters of the Bluetooth Special Interest Group.
2. *The Bluetooth Brand Book* contains guidelines for the use of the term *Bluetooth*. To be consistent with those guidelines, we will henceforth use the term as an adjective, not as a standalone noun.

this design is very low power consumption, making the technology well suited for use with small, portable personal devices that typically are powered by batteries.

Voice and data: Traditional lines between computing and communications environments are continually becoming less distinct. Voice is now commonly transmitted and stored in digital formats. Voice appliances such as mobile telephones are also used for data applications such as information access or browsing. Through voice recognition, computers can be controlled by voice, and through voice synthesis, computers can produce audio output in addition to visual output. Some wireless communication technologies are designed to carry only voice while others handle only data traffic. Bluetooth wireless communication makes provisions for both voice and data, and thus it is an ideal technology for unifying these worlds by enabling all sorts of devices to communicate using either or both of these content types.

Anywhere in the world: The telecommunications industry is highly regulated in many parts of the world. Telephone systems, for example, must comply with many governmental restrictions, and telephony standards vary by country. Many forms of wireless communications are also regulated; radio frequency spectrum usage often requires a license with strict transmission power obligations. However, some portions of the available radio frequency spectrum may be used without license, and Bluetooth wireless communications operate within a chosen frequency spectrum that is unlicensed throughout the world (with certain limitations and restrictions that are discussed later in the book). Thus devices that employ Bluetooth wireless communication can be used unmodified, no matter where a person might be.

The Bluetooth short-range wireless technology is ideally suited for replacing the many cables that are associated with today's pervasive devices. The Bluetooth specification ([BTSIG99], hereafter referred to as the specification) explicitly defines a means for wireless transports to replace serial cables, such as those used with modems, digital cameras and personal digital assistants; the technology could also be used to replace other cables, such as those associated with computer peripherals (including printers, scanners, keyboards, mice and others). Moreover, wireless connectivity among a plethora of fixed and mobile devices can enable many other new and exciting usage scenarios beyond simple cable replacement. In this book we explore various applications of the technology.

Important characteristics and applications of Bluetooth wireless communications are examined in detail in this book. The Bluetooth specification is explained in easy-to-understand terms with the benefit of the authors' experiences gained while participating in its development. If Bluetooth wireless technology succeeds in the marketplace to the extent predicted by many analysts, it has the potential to change people's lives and the way that people think about and interact with computing and communication devices. Understanding this emerging technology can benefit not only industry professionals but also consumers who can use and obtain value from it.

The Bluetooth Special Interest Group

As described above, Bluetooth wireless communication is embodied as a technology specification. This specification is a result of the cooperation of many companies within an organization called the *Bluetooth Special Interest Group*, or *SIG*. There is no "Bluetooth headquarters" nor is there any "Bluetooth corporation" nor any sort of legally incorporated entity. The SIG is governed by legal agreements among the member parties but it is not a company unto itself. The SIG should not be construed as a formal standards body; rather it is an organization chartered to define and promote the technology. In fulfilling this charter the SIG is dependent upon the contributions and participation of its member companies. Clearly a major task of the SIG has been to develop the specification, but other SIG activities include joint work with other consortia and standards and regulatory bodies, educational and promotional events such as developers conferences and the definition of a testing and certification process.

Technology and SIG Origins

Bluetooth wireless technology was conceived by engineers at Swedish telecommunications manufacturer Telefonaktiebolaget LM Ericsson (hereafter, Ericsson) who realized the potential of global short-range wireless communications. In 1994 Ericsson had begun a project to study the feasibility of a low-power and low-cost radio interface to eliminate cables between mobile phones and their accessories.

In today's computing and communications industries, proprietary new technologies rarely succeed; customers clearly prefer to purchase and deploy technologies based upon industry standards. By creating a level playing field, standards give customers greater freedom to choose from among competing platforms and solutions, to protect their investments as technologies evolve and to leverage (and in some cases, also influence) multicompany skills and organizations devoted to developing the standards.

In this industry environment, the Ericsson inventors understood that the technology was more likely to be widely accepted, and thus could be more powerful, if it was adopted and refined by an industry group that could produce an open, common specification. In early 1998, leading companies in the computing and telecommunication industries formed the Bluetooth SIG to focus on developing exactly such an open specification. The founding companies of the SIG are Ericsson, Intel Corporation, International Business Machines Corporation (IBM), Nokia Corporation and Toshiba Corporation. These companies formed the original core group (known as *promoter* companies) of the SIG. The SIG was publicly announced in May 1998 with a charter to produce an open specification for hardware and software that would promote interoperable, cross-platform implementations for all kinds of devices.

While open standards can be quite advantageous, one potential disadvantage of standards bodies, consortia, special interest groups and similar organizations is that they tend toward inherent inefficiencies as compared to single-company efforts. Within a single company there is often one overriding objective for developing new technology; in a multi-company effort each participant may have different, perhaps even competing goals. Even with modern ways to exchange information, such as electronic mail, group interactions are still likely to be more efficient within a single organization than throughout a group composed of many organizations (especially when those organizations are geographically diverse, as is the case for the members of the SIG–telephone calls, for example, have to take into account the fact that the people involved reside in time zones with little or no overlap of typical working [or even waking] hours). To overcome some of these potential drawbacks, the SIG intentionally was created with a small number of companies committed to the rapid development of the specification who were willing to expend the resources necessary to accomplish this.

SIG Progression

As the specification evolved and awareness of the technology and the SIG increased, many other companies joined the SIG as adopters; *adopters* are entitled to a royalty-free license to produce products with Bluetooth wireless communication based upon the specification and can receive and comment upon early versions of SIG publications. Today there are over 1,800 adopter members of the SIG, representing academia and industries such as consumer electronics, automotive, silicon manufacturing, consulting, telecommunications and many others. The original SIG's objective was to develop, as rapidly as possible, an open specification that was sufficiently complete to enable implementations. By carefully organizing the SIG and making use of frequent in-person meetings supplemented by even more frequent conference calls and e-mail exchanges, the SIG produced a thorough specification (together, the volume 1 core specification and volume 2 profiles number over 1,500 pages) in about one and one-half years (version 1.0 of the specification, including profiles, was published in July 1999).

The SIG organized itself into several working groups, each with a focus on a specific part of the technology or on some supporting service. These working groups included:

- the air interface working group, which focused on the radio and baseband layers;
- the software working group, which developed the specification for the protocol stack;
- the interoperability working group, which focused on profiles;
- the compliance working group, which defined the testing, compliance and certification process;
- the legal working group, which managed the legal affairs of the SIG such as membership and intellectual property agreements; and
- the marketing working group, which promoted the technology and helped to generate the marketing requirements that the specification was to address.

Some of the larger working groups, such as the software working group, were further divided into task forces focusing on a particular layer of the Bluetooth protocol stack. Coordinating all of these working groups and governing the overall SIG was a program management committee composed of voting representatives from each of the promoter companies.

During the one and one-half years that the SIG was developing the specification, working groups and task forces met and conducted their business both together and separately. Full working group (and sometimes complete SIG) meetings were held every few weeks, often hosted by promoter companies in locations where many of their involved personnel worked–these included Ericsson's Lund, Sweden facility; Intel's Chandler, Arizona software laboratory; IBM's sites in Research Triangle Park, North Carolina and Hawthorne, New York; and Nokia's Tampere, Finland location. Most working groups and task forces also held weekly conference calls. In addition, e-mail distribution lists were used liberally and in fact were a primary method for conducting working group business. Because of the geographic diversity of the people involved, it was difficult to find mutually convenient times for frequent voice conversations;[3] thus electronic mail quickly became a convenient and heavily used means of communication (in many respects it allowed specification development around the clock). Indeed, the official ratification of the final versions of the specification, profiles and errata was conducted using the e-mail reflectors.

In December 1999, four new promoter companies (3Com Corporation, Lucent Technologies Inc., Microsoft Corporation and Motorola, Inc., some of whom had made contributions to the original specification as adopter companies) joined the SIG. The group remains very active today in maintaining the existing documentation and in creating enhancements to the specification, along with new profiles. This work is discussed in further detail in Part 4 of this book.

It easily can be seen that it took an enormous effort to develop over 1,500 pages of complex and detailed information in just over a year's time. For many in the SIG this became their full-time job or at least a primary responsibility. Issues, both technical and non-technical, inevitably arose and were handled through discussion and voting when necessary, but in general the development and refinement of specifications and profiles progressed in an exemplary manner. A spirit of cooperation, fostered by the common objective of producing an open specification for this important new technology, usually carried the day (at least in the authors' experience in the software and interoperability working groups).

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3. When it was 9:00 a.m. on the west coast of the United States, where many involved parties worked and lived, it often (depending upon daylight-saving time observance) was 7:00 p.m. in Finland and 2:00 a.m. the following morning in Japan.

The Bluetooth Name and History

Bluetooth is notable in the high-technology industry in several respects, but in particular its name garners much attention. Most new industry initiatives are known by a name which describes their associated technology or its application and often they quickly become known by an acronym describing the full name. Why wasn't the technology called, for example, "Short-Range Wireless Radio," or SRWR, or some other descriptive name? The answer lies in the heritage (and perhaps the whimsy) of the original inventors. There are numerous histories and accounts of the Bluetooth namesake and how that name came to be chosen; the generally accepted story and facts are cited here.

Harald Blåtand was King of Denmark from approximately A.D. 940 to 985. During his reign King Harald is reported to have united Denmark and Norway and to have brought Christianity to Scandinavia. Apparently "Blåtand" translates, at least loosely, to "Blue Tooth." The origins of this name are uncertain, although it was relatively common during this time for kings to have a distinguishing name (some histories say that the name is attributed to Harald's dark complexion; some accounts even indicate that King Harald was known for teeth of a bluish hue resulting from his fondness for blueberries, although this is probably folklore). For a technology with its origins in Scandinavia, it seemed appropriate to the SIG founders to name the organization that was intended to unify multinational companies after a Scandinavian king who united countries. Thus was born the Bluetooth name, which initially was an unofficial code name for the project but today has become the trademark name (see footnote 1 on page 3) of the technology and the special interest group. Figure 1.1 shows the Bluetooth logo, inspired by the initials "H B" for Harald Bluetooth.

TM

Figure 1.1
The *Bluetooth* logo, a trademark owned by Telefonaktiebolaget L M Ericsson, Sweden and licensed to promoters and adopters of the Bluetooth Special Interest Group.

Bluetooth wireless communication has engendered tremendous interest since the SIG's formation was announced. Articles in many leading computer-industry trade press publications and in quite a few of the mainstream media have appeared with some frequency. Many analysts such as the Cahners In-Stat Group and the Gartner Group DataQuest now include Bluetooth wireless communications in their studies and forecasts. Between November 1998 and June 2000 at least nine major Bluetooth developers conferences were held in cities including Atlanta, Tokyo, London, Amsterdam, Geneva, Los Angeles and Monte Carlo. The SIG-sponsored conference in December 1999 in Los Angeles attracted over 2,000 developers from diverse geographies and industries.

Reader's Guide to This Book

This chapter has introduced the Bluetooth Special Interest Group, the technology, its chief characteristics and the history of its development. The remaining chapters of Part 1 provide additional background intended to aid in understanding the technology and what it can do.

Chapter 2 discusses wireless communication technologies in general and the Bluetooth radio frequency wireless solution in particular, including requirements and design choices for use of the 2.4-gigahertz spectrum, radio power consumption, "master/slave" radio relationship, adaptive audio range, "piconet" and "scatternet" topologies and global radio use.

Chapter 3 describes the significance of developing usage models for Bluetooth wireless communication and how these usage models relate to Bluetooth profiles. Each of the usage models is described, focusing on the benefits and value for a product's end user. Distinctions are drawn between those usage models enabled with version 1.0 of the specification and those intended for future use.

Chapter 4 briefly explains the purpose, scope, structure and relationships of the Bluetooth specification and profiles, serving as an introduction to Parts 2 and 3 where these topics are covered in detail.

"Part 2: The Bluetooth Specification Examined" introduces the Bluetooth protocol stack in Chapter 5, partitioning the stack into transport, middleware and application protocol groups. In **Chapter 5** the relationships among the various layers of the stack are examined, and each of the remaining chapters in Part 2 then covers one or more of these layers in detail. The intent is not just to reiterate information already available in the specification but rather to provide information that supplements the specification and aids in its understanding. Wherever possible we include information about the history, rationale and justification of the technical contents of the specification based upon our participation in its development.

Chapter 6 describes the radio hardware, link controller, baseband, and link manager layers of the protocol stack. Together these layers comprise the lower layers of the transport group of the protocol stack. Topics covered include the motivation and design tradeoffs behind the radio and baseband specifications, including the choice of the 2.4 gigahertz ISM frequency band; the reasons behind some of the radio and baseband parameters; the choice of the master/slave baseband model; the basis for the piconet and scatternet topologies; and the motivation and design tradeoffs for security features such as pairing and encryption.

Chapter 7 describes the logical link control and adaptation protocol (L2CAP) and host controller interface (HCI) layers of the protocol stack. We call these the upper layers of the transport group of the protocol stack, and they form the basis for the remainder of the software stack, including any new protocols that may be introduced in the future. Topics covered include the motivation and design tradeoffs leading to the development of the HCI and the situations in which this layer is relevant; issues with flow control and its architectural placement within the stack; and how higher-layer elements of the stack can use and benefit from L2CAP.

Chapter 8 presents the RFCOMM and service discovery protocol (SDP) layers of the protocol stack. These are middleware layers that provide abstractions in the form of logical interfaces and message transactions that can be used by application layers. Topics covered include the motivation and design tradeoffs for specifying a logical serial interface and its resulting benefits; how legacy applications could use Bluetooth wireless communication via RFCOMM; the motivation and design tradeoffs for specifying a new discovery protocol; and how SDP maps to other discovery protocols.

Chapter 9 describes the IrDA® Interoperability layers of the protocol stack. These are layers of the protocol stack that incorporate protocols and object formats specified by the Infrared Data Association (IrDA) into the Bluetooth specification. Topics covered include the motivation and design tradeoffs for reusing existing IrDA protocols and object formats; how existing IrDA applications could use Bluetooth wireless communications; and similarities and differences between IrDA and Bluetooth wireless communications.

Chapter 10 discusses the telephony control specification (TCS) layer of the protocol stack and also describes how voice and audio communications are managed. Together audio and TCS provide full telephony support for both voice and data calls. Topics covered include the motivation and design tradeoffs for specifying separate voice and data channels; reasons for the selection of voice encoding techniques, including tradeoffs of quality and efficiency; and alternative forms of telephony control protocols and why TCS was chosen.

In **"Part 3. The Bluetooth Profiles Examined"** we look into volume 2 of the Bluetooth specification, commonly known as the Bluetooth profiles, in the same manner in which we covered the core specification in Part 2. **Chapter 11** examines the motivation for, development of and relationships among the various profiles, which define how to use the protocol stack to achieve interoperable solutions. Each of the remaining chapters in Part 3 then covers one or more of these profiles in detail. Just as in Part 2, the intent of these chapters is not simply to reiterate information already available in the profile specification but rather to provide information to supplement the specification and aid in its understanding.

Chapter 12 describes the generic access profile (GAP) and the service discovery application profile (SDAP). These profiles define fundamental principles used to establish connections among devices with Bluetooth wireless communication capability and provide a basis upon which the remaining profiles are built. Topics covered include the motivation and design tradeoffs for security features such as pairing and encryption; the various possibilities for devices to be discovered; and how applications could access and make use of the service discovery protocol for service location and browsing.

Chapter 13 discusses the telephony class of profiles, including cordless telephony, intercom and headset. These profiles define various ways to use voice communication and call control for telephony applications. Topics covered include the motivation and design tradeoffs for selection of the version 1.0 telephony profiles; 10-meter versus 100-meter radio range with respect to the intercom profile; and current and future applications for voice headsets developed according to the headset profile.

Chapter 14 presents the serial port-based class of profiles, including generic object exchange, object push, file transfer and synchronization in addition to the common serial port profile itself. These profiles all define ways to use the RFCOMM virtual serial port to exchange and synchronize data between two peer devices. Topics covered include the serial port profile "family tree"; configuration of the serial port profile and the relevance of typical serial parameters in Bluetooth wireless communications; why the distinction between object exchange, object push and file transfer is important; and current and future possibilities for data synchronization.

Chapter 15 describes the networking class of profiles that includes dial-up networking, LAN access and fax. These profiles all deal with some variation on data networking between two or more peer devices. Topics covered include limitations of Bluetooth wireless communications relative to some fax requirements; the relevance and value of audio feedback for dial-up networking; and the many possibilities for networking with Bluetooth wireless communications and why LAN Access using PPP was chosen for version 1.0.

"Part 4. The Future of Bluetooth Wireless Communications" looks at where the technology is headed. **Chapter 16** discusses future possibilities for the technology, including those that the SIG is currently developing: automotive, imaging, printing, extended service discovery, association with the IEEE 802.15 standards organization and others. This chapter discusses how new usage cases might be realized using Bluetooth wireless communication and how industry innovators might go about developing new Bluetooth wireless communication solutions. In addition, the product landscape for Bluetooth wireless technology is explored, including the current and projected marketplace. **Chapter 17** summarizes the book and offers concluding remarks about the future of Bluetooth wireless communication, including a short discussion of interoperability and the opportunities that the technology presents.

2

Technology Basics

Communication can take many forms–audio, visual, written, electronic and so on. In the realm of electronics, analog and digital communications are so pervasive in modern society that they are largely taken for granted. The exchange of data using these forms of communication has led to the use of terms such as "the information industry" and "the information age." From telephones to computers to televisions, communication in many respects "makes the world go around." Bluetooth wireless technology is one form of electronic communication, and in this chapter we examine some of its fundamental and specific characteristics, including relationships to other forms of communication. We begin with a brief general discussion of wireless communications and then progress through more specific forms relevant to the Bluetooth technology. There are many other types of wireless communication; our intent here is to touch upon those that provide background for the Bluetooth technology rather than to provide a primer on wireless technologies in general.

Wired and Wireless Communications

A great deal of data is carried over wired networks–many telephones, coaxial cable systems, local area networks and parts of the Internet communicate via wires and cables. Many televisions are connected to cable systems, most networked computers are connected to telephone lines or wired networks such as Ethernet networks, and even cordless and mobile telephones rely on wired "landline" telephone systems to carry and route calls between endpoints.

Communicating without wires is not a new concept. Broadcast radio and television are two common examples of wireless communications; others include satellites, cordless and cellular telephones and remotely controlled televisions, garage door openers and automobile door locks. While most of these examples employ communication via radio waves, the use of infrared, a nonvisible spectrum of light, is also relatively common. Bluetooth wireless communication employs *radio frequency* (or RF) technology, using radio waves to communicate through the air in a manner fundamentally similar to broadcast radio or television.

Radio Frequency Wireless Communications

RF technologies employ transmitters and receivers tuned to produce and consume, respectively, radio waves of a given frequency range. The transmitter's power and the receiver's sensitivity help to determine the distance over which they can communicate. High transmission power output is used for long-range communications such as broadcast television while short-range communications generally require much less power; thus technologies that are designed to communicate across only a few meters could be employed in small, mobile battery powered devices. Another characteristic that is relevant for communication applications is the ability of radio waves to penetrate many objects. Obstacles reflect light waves used in technologies such as infrared, but radio waves used in RF technologies in general can (with certain limitations) penetrate many obstacles (although in some cases radio waves can diffract or go around objects too). Thus RF technologies can permeate many obstacles such as clothing, bodies, walls, doors and the like. This means that there is no requirement for a "line of sight" between the transmitter and the receiver.

RF technologies use frequency modulation to generate radio waves within a certain frequency spectrum, which encode information and can be intercepted by receivers tuned to the corresponding frequency. FM radio broadcasts, for example, operate in the 88 megahertz (MHz) to 108 MHz frequency spectrum; some cordless telephones operate in the 900 MHz frequency spectrum; Bluetooth wireless communications and other technologies operate in the 2.4 gigahertz (or GHz; one gigahertz equals one billion cycles per second) spectrum.

Because the usable radio frequency space is finite, most governments regulate its use, partitioning frequency ranges and granting licenses to transmit at those frequencies at specified power levels. In the United States, for example, a federal license is required to transmit in the FM radio frequency spectrum except at extremely low power levels that limit the range to no more than about 30 meters. Some frequencies are reserved for use without a license under certain conditions. For example, in the United States unlicensed operation is permitted, with some restrictions, in the 900 MHz and 2.4 GHz frequency ranges (the latter being where Bluetooth wireless communication operates). In fact, through multinational agreement, the 2.4 GHz spectrum requires no license for its use anywhere in the world.[1] The SIG together with other organizations such as the IEEE 802.11 standards body is working with regulatory authorities in some countries to pursue harmonization of the frequency assignments for unlicensed use within the 2.4 GHz spectrum and of the approval process for wireless communications. In general the chosen frequency spectrum can be used globally without license so long as the rules for operating within this spectrum are followed.

RF Communications in the 2.4 GHz Frequency Spectrum

While the 2.4 GHz spectrum is globally unlicensed, there are regulatory requirements and other considerations for its use. These include:

- The spectrum is divided into 79 channels (although in some countries, notably Spain and France, only 23 channels were available for use in the year 2000. Japan began using all 79 channels in 2000).
- Bandwidth is limited to 1 MHz per channel.
- Frequency hopping spread spectrum communications (described below) must be employed.
- Interference must be anticipated and appropriately handled.

Other RF communications technologies also use this spectrum; notable among them are HomeRF™ (an open industry specification for RF communications in home environments; see http://www.homerf.org) and the Institute of Electrical and Electronics Engineers (IEEE) 802.11 specification for wireless local area networks (see http://www.ieee.org). Microwave ovens also operate within this frequency range. Because this

1. In some countries there are restrictions and only part of this spectrum is available for unlicensed use; these restrictions are discussed elsewhere in the book, notably in Chapter 6.

spectrum is unlicensed, new uses for it are to be expected (for example, a new generation of cordless telephones also uses the 2.4 GHz frequency) and as the spectrum becomes more widely used, radio interference is more likely. Thus the requirement to anticipate and address interference in the 2.4 GHz range is important for all technologies that operate in it.

Each technology using this spectrum has made design choices within the spectrum's constraints that optimize that technology for particular applications or domains. Bluetooth wireless communication is designed to take maximum advantage of the available channel bandwidth and to minimize RF interference and its effects while operating at very low power.

Spread Spectrum RF Communications

Within RF communications, *spread spectrum* refers to dividing the available spectrum based upon frequency, time, a coding scheme or some other method. Messages to be sent are then divided into various parts (packets) that are transmitted across the divided spectrum. Frequency division spread spectrum (or *frequency hopping*), which is the method employed with Bluetooth wireless communication, divides the spectrum into different frequencies, or channels.[2] A single message packet is transmitted on a selected channel, then the radio selects a new channel (a process called *hopping* to a new frequency) to transmit the next packet, and the process repeats, thereby spreading the message across the available frequency spectrum. Each technology specifies its own method for establishing the frequency hopping pattern. Obviously the receiver(s) of the message must know the hopping pattern to tune to the correct channels in succession to receive each packet and assemble the complete message. This process is called *frequency hopping spread spectrum,* or FHSS.

FHSS introduces additional complexity as compared to using a single statically selected frequency, yet it also supplies some benefits. First, RF interference can be reduced since all radios hop (often randomly or at least pseudorandomly, and often rapidly) from one frequency to another. When all of the participants in the spectrum employ FHSS, interference caused by colliding transmissions on the same frequency is less likely than it would be if each radio used a single channel

2. Contrast frequency hopping spread spectrum with direct sequence spread spectrum, which is not examined here. Direct sequence is another form of spread spectrum RF communication employed in other technologies such as wireless LANs and is outside the scope of this book.

for a long duration. In addition, when collisions do occur, their effects are lessened, since only a single packet is lost and that packet could be retransmitted at a new frequency, where again it is less likely to encounter interference. Second, FHSS can provide a degree of security for communications in that only a receiver that knows the frequency hopping pattern can receive and assemble all the packets of a message. Because the hopping pattern for a given spectrum could be constructed in a number of ways, it could be difficult to deduce and follow an unknown hopping pattern, especially when the spectrum is heavily utilized with many radios. Thus FHSS can be employed to hinder eavesdropping. In fact, this latter characteristic led to the invention of FHSS, usually attributed to George Antheil and Hedy Lamarr (the latter is more famous as an American actress). Their 1942 patent of the frequency hopping concept was motivated by an attempt to find a "secret communication system" using radio waves to control torpedoes during World War II.[3]

As previously noted, the use of spread spectrum is required in the 2.4 GHz range, largely to minimize interference problems because the spectrum is unlicensed. The design for Bluetooth wireless communication employs relatively rapid frequency hopping (nominally 1,600 times per second) and is described more fully below and in Chapter 6.

Infrared Wireless Communication

RF is not the only form of wireless communication. Infrared technology is used with devices such as notebook computers, personal digital assistants and electronic remote controls. Infrared wireless communication makes use of the invisible spectrum of light just beyond red in the visible spectrum.

In particular, one standard method for infrared communication is specified by the Infrared Data Association (IrDA; see http://www.irda.org); this method is commonly used with mobile phones and notebook and handheld computers. IrDA technology is relevant when discussing Bluetooth technology because IrDA is also designed for short-range, low-power unlicensed communications. IrDA also defines

3. The complete story of this invention is fascinating but is outside the scope of this book. Interested readers are referred to, for example, [IAL99] or other accounts easily found via World Wide Web search engines. Furthermore, any rationale or implications of the choice of naming the Bluetooth technology after a Danish king rather than an American actress are not explored here.

a physical layer and a software protocol stack designed to promote interoperable communications, as does the Bluetooth specification.

Despite the differences between IrDA and Bluetooth wireless communications, such as data transmission speeds and signal paths (infrared largely requires line-of-sight paths while RF can penetrate many objects), the similarities are such that the SIG worked with the IrDA in developing the specification. Because there is overlap in the application spaces of IrDA and Bluetooth wireless communications, the specification includes an IrDA interoperability layer in which some protocols defined by IrDA are incorporated. This helps to promote interoperability among wireless applications no matter which communications transport is being used. IrDA interoperability in the Bluetooth specification is further detailed in Chapter 9.

The Bluetooth RF Communications Solution

The preceding discussion forms the basis for understanding the Bluetooth design, which:

- in the lower layers centers around wireless RF communications in the 2.4 GHz spectrum;
- is optimized for short-range communication, low power consumption and low cost; and
- in the higher layers reuses transport and application protocols already developed for similar domains such as those used with infrared wireless communication.

The result is a wireless communication technology that is especially appropriate for cable replacement and for use with portable devices in pervasive computing applications. Some of the fundamental principles for Bluetooth RF communication are described here; details of the radio and baseband operation are given in Chapter 6.

Master and Slave Roles

At the baseband level, when two devices establish a Bluetooth link, one acts in the role of *master* and the other in the role of *slave*. The specification permits any Bluetooth radio to assume either role, and a device may act as a master for one communication link and as a slave for another link.[4] The role of master does not imply special privileges or authority; instead it governs the synchronization of the FHSS communications between the devices. The master device determines the frequency hopping pattern (based upon its Bluetooth device address) and the phase for the hopping sequence (based upon its clock). All slaves communicating with a given master hop together in unison with the master. The master role generally is assumed by the device that initiates the communication.[5] Part 2 of this book provides more details about establishing communications links.

A given master may communicate with multiple slaves–up to 7 *active* slaves and up to 255 *parked* slaves[6] (active and parked slaves are described more fully below); all slaves communicating with a single master form what the specification calls a *piconet* (also described more fully below). There can be only one master in a single piconet.

The master-slave relationship is necessary in Bluetooth low level communications but in general devices operate as peers. When one device establishes a point-to-point link with another device, the role that each device assumes (master or slave) is often unimportant and is irrelevant to higher-level protocols and to the user of the device. In some usage scenarios it may be advantageous or even necessary for a given device to assume a particular role, but in many cases it is not critical to establish a single specific role for each device; some scenarios work equally well with device roles reversed. It is important to understand the master-slave relationship for low-level communications while at the same time understanding that in general devices operate as peers to each other. Figure 2.1 shows the master and slave roles in a simple piconet.

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4. Some devices might be configured to act in only one role, but most Bluetooth devices are expected to include radios that can assume either role, depending upon the usage case being performed.
5. The device initiating communication assumes the master role at the outset, although the master and slave roles can be switched, as detailed in Chapter 6.
6. Actually more than 255 parked slaves are possible. The Bluetooth specification defines "direct" addressing for up to 255 parked slaves via a *parked slave address* but also permits "indirect" addressing of parked slaves by their specific *Bluetooth device* address, thus effectively allowing any number of parked slaves, although from a practical perspective it would be unusual to have more than 256 devices in a single piconet. This topic is explored more fully in Chapter 6.

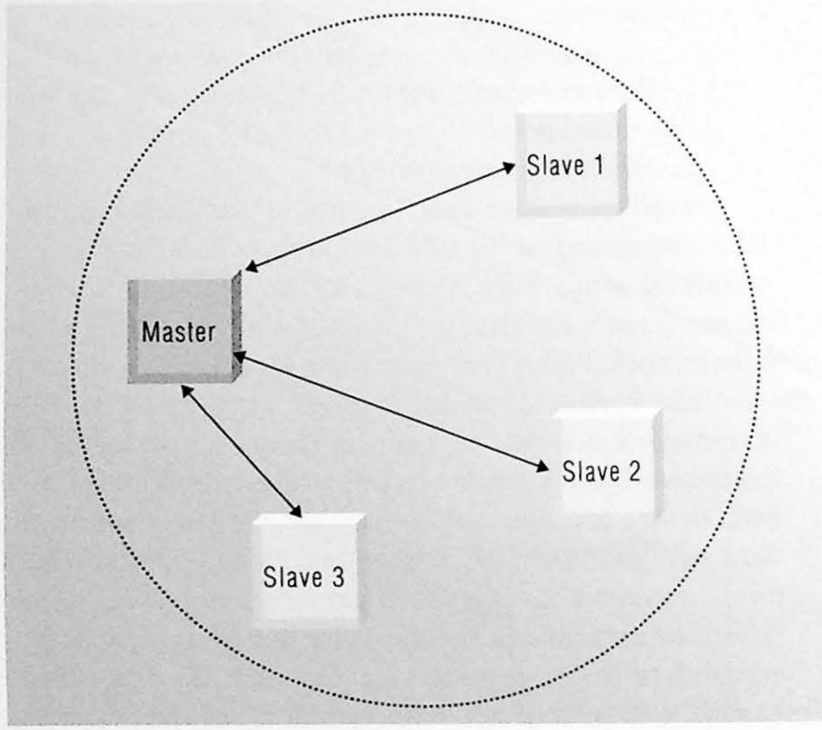

Figure 2.1
Master and slave roles in a simple piconet.

Baseband Modes and Energy-Conserving Features

As noted above, a piconet can include up to seven active slaves and many more *parked* slaves. The specification includes a definition for this parked baseband mode, as well as for other modes called *sniff* and *hold*. The various baseband modes facilitate energy conservation by allowing the radios to enter low-power states. These low-power modes are really just three different methods for entering and exiting a low-power state, and the mode applies to a given Bluetooth connection (rather than to the device as a whole). These baseband modes also permit a greater number of devices to be co-located in the same proximity sphere, since not all devices need to have active communication links at the same time. All four of these baseband modes (active, sniff, hold and park) apply when the baseband is in a connection state; when not connected, the baseband is in a *standby* state, which should not be confused with any of the connected state modes. That is, the baseband states are connected and standby; within the connected state there are four modes (active, sniff, hold and parked). These states and modes are described in more detail in Chapter 6.

In active mode a slave essentially always listens for transmissions from the master. Active slaves receive packets that enable them to remain synchronized with the master and that inform them when they can transmit packets back to the master. An active slave must listen for all packets coming from the master, although one optimization is permitted in which active slaves need not listen for entire packets (rather, just the packet headers) coming from the master when it is known that some other active slave is communicating with the master during that time. The active state typically provides the fastest response time but also typically consumes the most power, since it is always receiving packets and is always prepared to transmit packets.

Sniff mode is one method for reducing power consumption. In sniff mode a slave essentially becomes active periodically. The master agrees to transmit packets destined for a particular slave only at certain regular intervals (although it may not transmit packets at every interval). The slave then needs to listen for packets from the master only at the start of each interval (subject to some timing tolerances). If the slave receives packets at the start of the interval it continues to listen and receive packets; otherwise it can "sleep" until the next interval. Sniff mode could permit reduced power consumption by reducing the average duty cycle of the radio but is likely to be less responsive than active mode. The power consumption and responsiveness in sniff mode depend upon the length of the sniff interval.

In hold mode a slave may stop listening for packets entirely for a specified time interval.[7] The master and slave agree upon a hold time, and the communication link is quiesced for that amount of time. During the hold time the slave need not listen for packets from the master and could be doing other things such as establishing links to other devices, or the slave could just sleep during the hold time. At the end of the hold period the slave resumes listening for packets from the master. Hold mode may be less responsive than sniff mode and could permit greater power savings than sniff mode, although this depends upon the hold time duration and upon what the slave does during the hold time (sleeps versus communicates on other links).

7. Or at least certain types of packets. Since packet types have not yet been introduced, this section describes the fundamental concept of hold mode. A more complete description can be found in Chapter 6.

In parked mode a slave maintains synchronization with the master but is no longer considered active (slaves in active, sniff and hold modes are considered active). Since there can be only seven active slaves in a piconet at one time, the use of parked mode allows the master to orchestrate communications within a piconet of more than seven devices by exchanging active and parked slaves to maintain up to seven active connections while the remaining slaves in the piconet are parked. A parked slave still needs to maintain synchronization with the master and does so by listening to the master periodically, using a *beaconing* scheme described in Chapter 6. Parked mode is typically the least responsive of the connected modes, since the slave must make the transition to become an active member of the piconet before resuming general communications, but parked mode may permit greater power conservation.

Figure 2.2 shows a typical relationship of the connected state modes in terms of their relative responsiveness versus power consumption. However, both power consumption and responsiveness in these modes is highly dependent upon factors such as the amount of communications traffic and the hold and sniff periods, which can affect the duty cycle of the radios. As a general rule, active slaves will consume the most power but will be the most responsive, while parked slaves will typically be the least responsive. The figure illustrates the general trend, although these relationships may vary in specific cases.

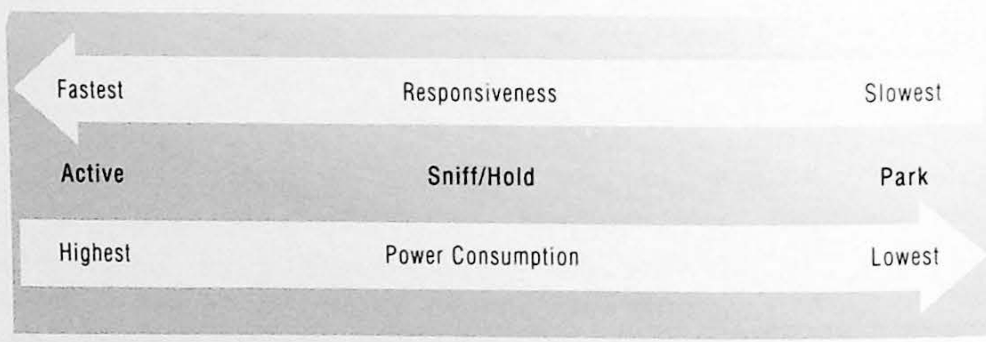

Figure 2.2
Typical relative responsiveness versus power consumption for connected state baseband modes (generalized; may not apply in all cases).

In addition to the baseband modes which permit energy conservation, another power-saving feature is *adaptive transmission power.* This feature allows slaves to inform the master when the master's transmission power is not appropriate, so that the master can adjust its transmission power. This is accomplished through the use of a *received signal strength indicator* (RSSI). When the RSSI value is outside some determined boundaries, the slave can ask the master to adjust the power. This is especially useful when two devices are in close proximity and maximum transmission power is not required (analogous to two people standing next to each other, with one person shouting and the second person asking the shouter to speak more quietly). Of course the converse is also true: transmission power increases also could be requested when the RSSI value indicates too weak a signal but the primary motivation for adaptive transmission power is to reduce power consumption when a lower transmission power is sufficient. The master maintains transmission power settings for each slave so that a change in transmission power for one slave does not affect other slaves in the piconet. Like other energy-conservation features, adaptive transmission power could also allow a greater number of devices to be co-located in the same proximity sphere, since it could further reduce the possibility of RF interference with other devices.

Communications Topology

The Bluetooth network model is one of peer-to-peer communications based upon proximity networking. When two devices come within range of each other,[8] they could automatically establish a communications link. Devices will not necessarily begin to communicate spontaneously when they encounter each other, as the baseband could be configured to accept only certain connections, or even none at all. The process of initiating communications links is explored in detail in Chapters 6 and 7.

Proximity networking without wires enables the formation of *personal area networks*, or federations of personal devices such as mobile telephones, pagers, notebook computers and personal digital assistants. When these devices can communicate seamlessly, their overall utility is enhanced. Another application for proximity networking is the interaction of mobile devices with fixed devices such as kiosks, printers, network access points and vending machines–a person could establish communication between his personal device and a fixed device just by

8. Nominal range for the standard 0 dBm Bluetooth radio is approximately 10 meters; power-amplified 20 dBm radios with a range of about 100 meters are also possible. The Bluetooth version 1.0 specification focuses primarily on the standard radio and thus deals mostly with communication within a 10-meter range.

approaching it. This topology enables other usage models, too; these are explored more fully in Chapter 3.

Piconet topology, introduced earlier, can now be further explored given the foregoing discussion of master and slave roles and baseband modes. A piconet consists of a single master and all slaves in proximity that are connected to (in communication with) that master. The slaves may be in active, sniff, hold or park modes at any given time. All of the devices in the piconet are synchronized, all hopping together. There may be other devices in proximity that are not connected to (not in communication with) the master and thus are not part of the piconet, including devices in standby state. Figure 2.3 shows this more general view of a piconet; note that there could be up to seven active slaves and any number of parked slaves and standby devices (although most typical piconets, especially those that are formed to support the version 1.0 profiles, are expected to have only a few devices).

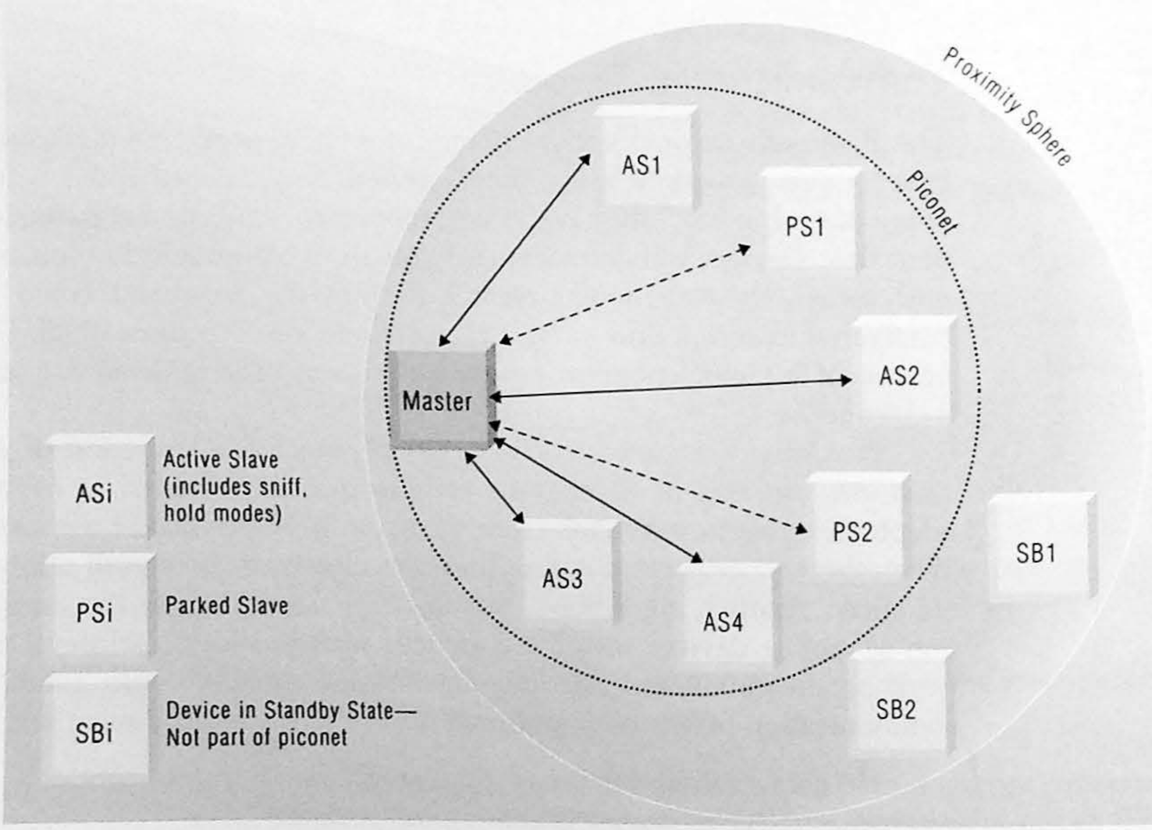

Figure 2.3
General Bluetooth piconet including active and parked slaves. Standby devices which are in proximity but are not part of the piconet are also illustrated.

As described and illustrated above, a device may be an active or parked participant in a piconet or it may not be part of any piconet. In addition, it is possible for a device to take part in more than one piconet. When two or more piconets at least partially overlap in time and space a *scatternet* is formed. All of the same principles of piconets also apply for scatternets; each piconet has a single master and a set of slaves which may be active or parked. Each piconet has its own hopping pattern determined by its master. A slave could participate in multiple piconets by in turn establishing connections with and synchronizing to different masters in proximity. In fact, a single device might act as a slave in one piconet but assume the master role in another piconet. The scatternet topology provides a flexible method by which devices could maintain multiple connections. This could be especially useful for mobile devices which frequently move into and out of proximity to other devices. Figure 2.4 shows one example of a scatternet using the same representations as in Figure 2.3; other examples of scatternets are possible. In this example slave A2/B3 is a member of both piconet A and piconet B as an active slave.

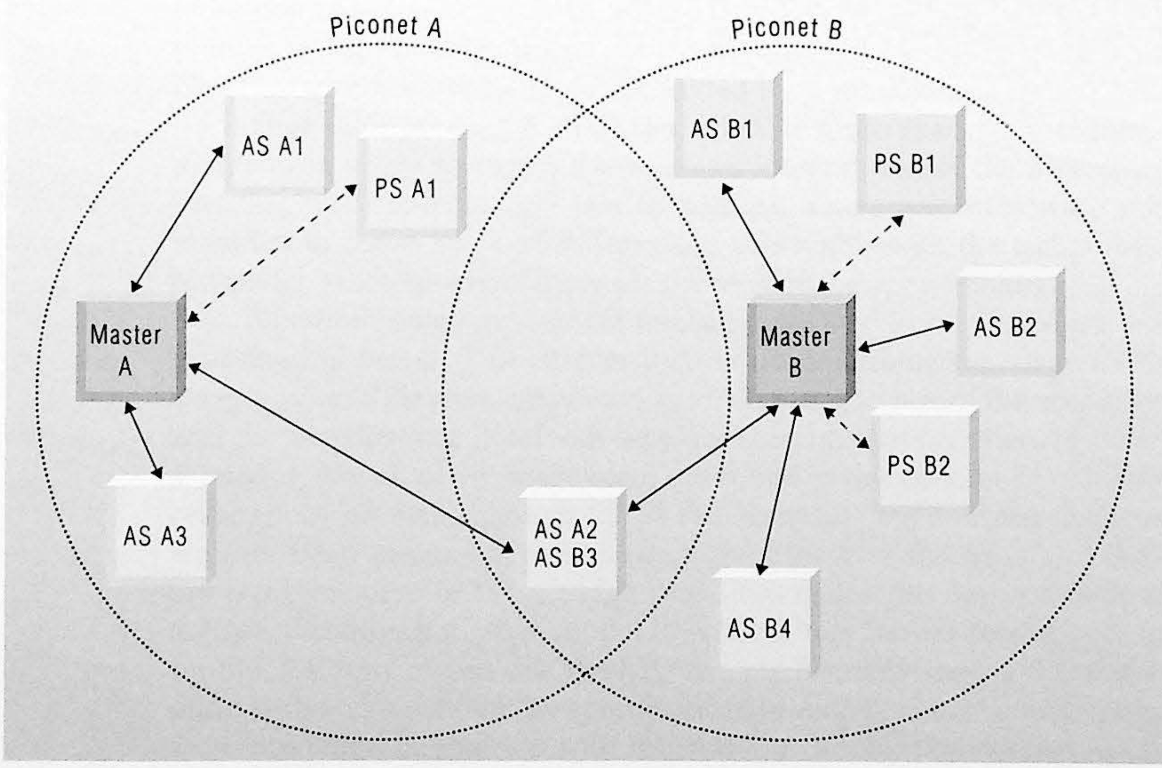

Figure 2.4
Scatternet example. Slave A2/B3 participates as an active slave in both piconet A and piconet B.

3

Bluetooth Usage Models

While much of the focus of Bluetooth wireless communication is on the specification of the technology–which is explored in depth in Part 2 of this book–the specification is actually rooted in a set of usage models (sometimes also called usage scenarios or usage cases). Long before there was a specification, the official Bluetooth web site included descriptions of several of these usage models that the technology makes possible. The specification itself was preceded by a marketing requirements document (internal to the SIG); included in those marketing requirements were usage scenarios that were an integral part of the objectives that the initial specification was to address. These scenarios were not intended to cover all possible functions achievable with the technology but rather to set the initial focus for the version 1.0 specification.

Bluetooth usage models are formally specified in *profiles*, which are examined in Part 3. This chapter focuses on describing the usage models in a general fashion, emphasizing an end user's view of the scenarios and the benefits that Bluetooth wireless communication offers in those scenarios. Not all of the usage cases described in this chapter have a corresponding profile, although all of the scenarios have at one time or another been discussed, presented or published by the SIG, and they are representative of those usage cases that drove the development of the specification. If a usage model described here has no corresponding profile, it simply means that the SIG has not formally specified that scenario with version 1.0 of the specification. In many instances such usage scenarios could be realized with Bluetooth technology as defined in the current specification, but the SIG has not (yet) formalized an interoperable definition for doing so.

The usage models described here are just an initial set of scenarios that could be accomplished with Bluetooth wireless communication.[1] New applications of the technology will undoubtedly continue to be invented, and it is expected that new scenarios and new profiles will emerge from the SIG over time (Part 4 discusses some future possibilities).

The Cordless Computer

At its heart, Bluetooth wireless communication is all about replacing cables. One place where many cables exist, and where these cables are sometimes unwieldy, is the typical desktop computer. The cordless computer usage model is not specifically addressed in version 1.0 of the specification, but it is expected that this scenario could be realized in a straightforward manner in the future. As depicted in Figure 3.1, many of the cables associated with computer peripherals could be replaced by wireless links. Keyboards, mice, joysticks, speakers, printers, scanners and the like might all employ Bluetooth wireless communications. While not shown in the figure, other computer-related wires such as personal digital assistant cradles, digital camera cables and network connection cables could also be replaced by wireless connections (these three examples are discussed below in "The Automatic Synchronizer," "The Instant Postcard" and "The Internet Bridge" usage models, respectively).

1. Some scenarios could also be accomplished with other technologies, and the usage models are not necessarily unique to Bluetooth wireless communication.

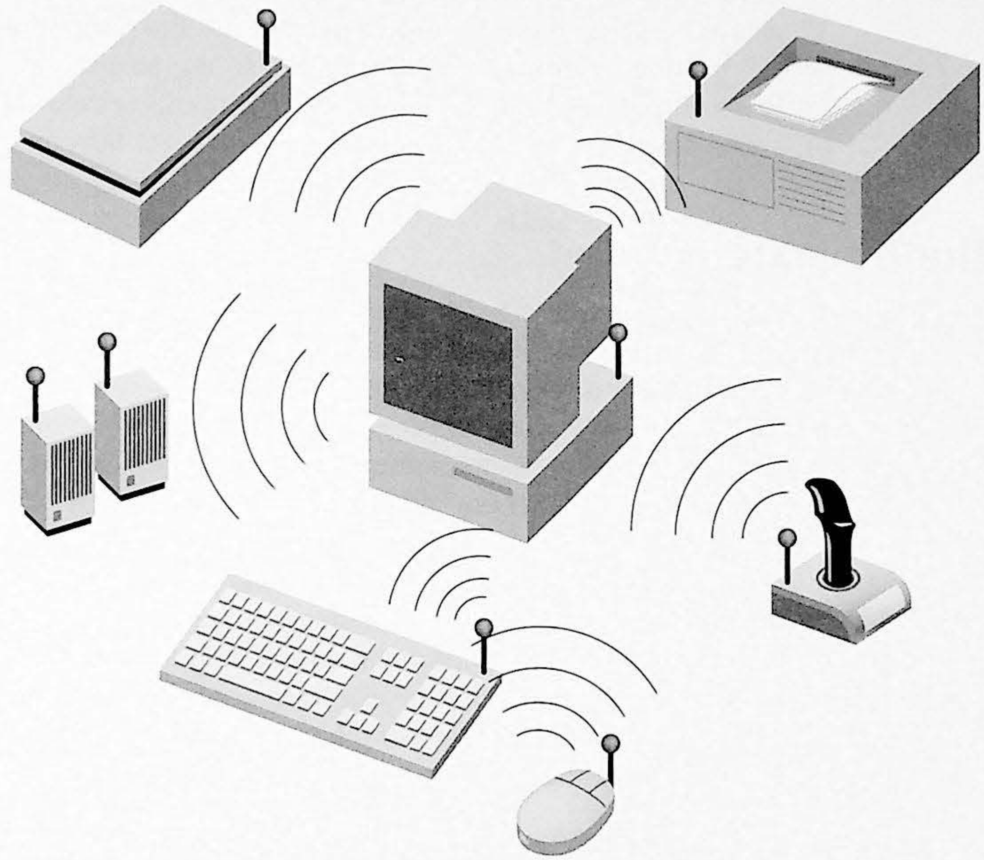

Figure 3.1
The Bluetooth cordless computer usage model.

In addition to the directly evident benefits of not having to deal with cables during installation and operation of the computer, wireless devices offer more freedom in placement and use. Speakers, printers and scanners, for example, could be placed in the most appropriate location for the environment, unrestricted by connectors and cable length. User interface devices such as keyboards, mice and joysticks could be used wherever it is convenient to do so and could move with the user rather than being fixed in a certain location where they would be constrained by a cable.

Device sharing is much easier in this configuration than in a cabled environment. A joystick, for example, need not be used exclusively with the computer but might also be used with a video game. Even more important for many people, though, is the capability to share peripherals such as printers or scanners. Today sharing these devices often requires a networked environment where the computer that hosts the peripheral acts as a server; if other devices need to use the peripheral they do so via the hosting computer which is cabled to the peripheral. With the cordless computer, other devices using Bluetooth wireless communication could directly access peripherals in peer-to-peer fashion.

The Ultimate Headset

Support for voice in Bluetooth wireless communication fosters this usage model. Telephone headsets are increasingly common for use with both fixed and mobile telephones. In environments such as call centers (help desks, centralized reservations offices, and so on) headsets might be used with standard telephones to keep a person's hands free to use a computer. Headsets are also available for use with many mobile telephones, also for hands-free operation for situations such as driving or walking while carrying items. Bluetooth wireless communication removes the cable between the headset and the telephone. A call could be placed using the telephone keypad, with the audio portion of the call being carried through the headset's microphone and speaker. Figure 3.2 illustrates various instances of the ultimate headset usage model, including the use of the headset with nontelephony devices, described more fully below.

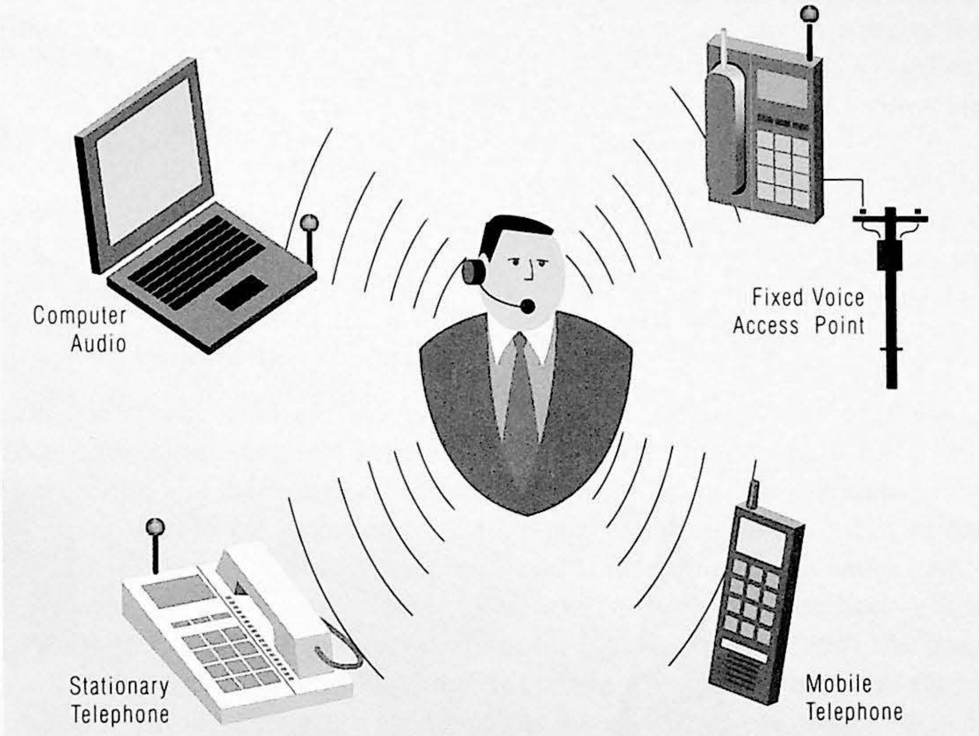

Figure 3.2
The Bluetooth ultimate headset usage model.

One advantage of the ultimate headset is that it supports mobility. The user of the headset is not physically tied to the audio device and thus is free to roam about the area while keeping the connection intact. Another advantage is the ability to use the same headset with multiple devices. Because the specification offers a standard interface, the same headset used with a telephone might also be used with a fixed *voice access point*, such as a cordless telephone base station, and could also be used for audio interaction with computers. In the future it also may be possible to use such a headset with stereos, portable CD players and recording devices. As with the cordless computer, the ultimate headset allows devices to be placed wherever it may be convenient, which for mobile devices might be in a pocket or briefcase. With appropriate speech technologies it indeed may be possible, through the use of voice recognition, to place telephone calls using only the headset as the user interface.

The Three-in-One Phone

Today many people use multiple telephones: a phone in the office, one or more telephones at home (some wired, some cordless), a mobile (cellular) telephone, public telephones, and so on. A single phone using Bluetooth wireless communication could be used in place of many of these other telephones. The three-in-one phone usage model allows a mobile telephone to be used as a cellular phone in the standard manner, as a cordless phone connecting to a voice access point (cordless phone base station), and as an intercom or "walkie-talkie" for direct phone-to-phone communications with another device in proximity. Figure 3.3 shows all three uses of the three-in-one phone.

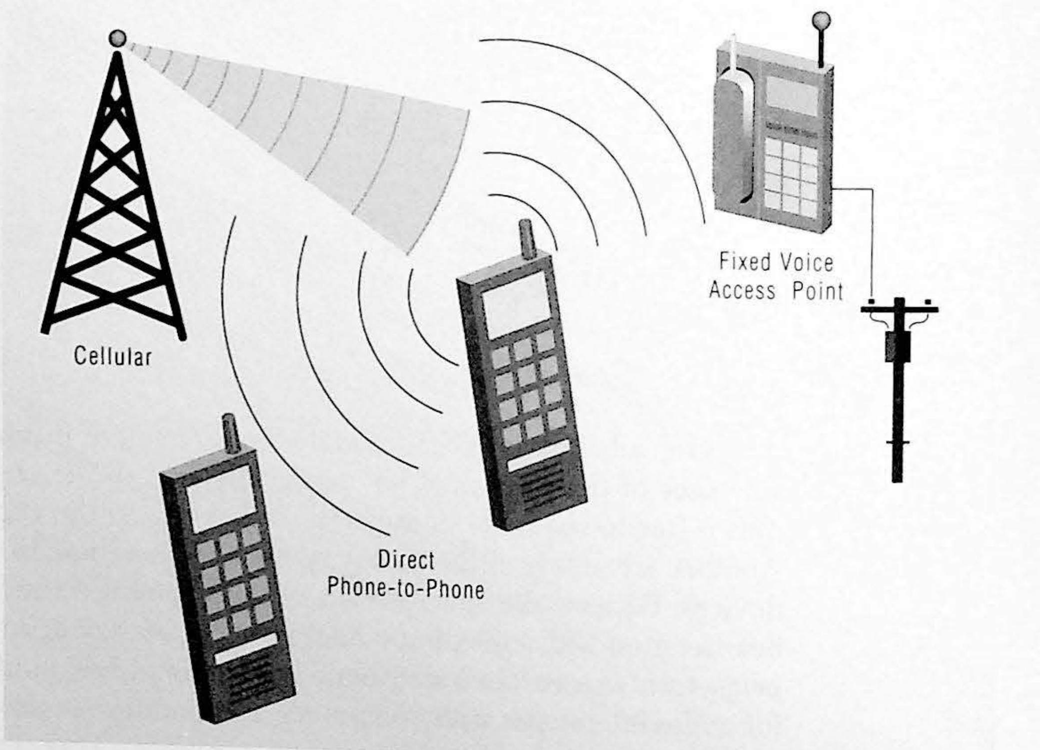

Figure 3.3
The Bluetooth three-in-one phone usage model.

A key benefit of the three-in-one phone is that a single telephone could become the only one that a person needs. If multiple voice access points using Bluetooth wireless communication become available in environments such as the home, office and public areas, a single personal telephone that is usable almost anywhere becomes realistic. The need for separate telephones and separate telephone numbers in the office, at home and while traveling could be reduced. Another benefit that derives from the use of such voice access points is the possibility for reduced cellular airtime charges. When the handset is used as a cordless phone, communicating with a standard "landline" telephone service via an access point, no cellular airtime charges need be incurred.

The direct telephone-to-telephone, or "walkie-talkie" function of the three-in-one phone usage model is most useful with the 20 dBm power amplified radio, with its range of 100 meters. When two parties are within range of each other using standard Bluetooth radios (10 meters), it is likely that they could shout at each other rather than use telephone radio communication (aside from situations where a physical obstacle might separate the parties). Because a direct phone-to-phone communication scenario across only a 10-meter range might have limited utility, the SIG indeed debated whether or not this walkie-talkie function should be included in the usage model, since the focus of the version 1.0 specification is on a standard 0 dBm Bluetooth radio (there was some discussion of removing this use of the telephone and calling this usage model the two-in-one phone). However, even with the standard radio with its 10-meter range there are situations where the direct phone-to-phone communication might be useful. These might include cases such as people communicating across different floors of a building, from within confined spaces or when nonintrusive communication is desired even when both parties might be able to see each other (for example, video and sound control workers in a crowded auditorium).

The Interactive Conference (File Transfer)

One of the most fundamental and useful applications for any type of data networking, including simple point-to-point links (like those of Bluetooth wireless communication), is to exchange files and other data objects. File transfer using floppy disks or cables is common; wireless communication removes the need for cables, making it much easier to form temporary links between devices to quickly exchange files and other data objects. For example, as infrared data ports become more widely used with notebook computers, mobile telephones and personal digital assistants, it is not uncommon for users to establish a temporary infrared link to exchange electronic business cards and other data. This same sort of file and object transfer is possible with Bluetooth wireless communication. In an interactive conference room scenario, business cards and files could be exchanged among the participants of the meeting. Figure 3.4 illustrates the Bluetooth file transfer usage case; as shown, not only could files be transferred between two computers but objects also could be transferred between any two devices using Bluetooth wireless communications. Chapter 14 discusses the details of the various modes and types of file and object transfer.

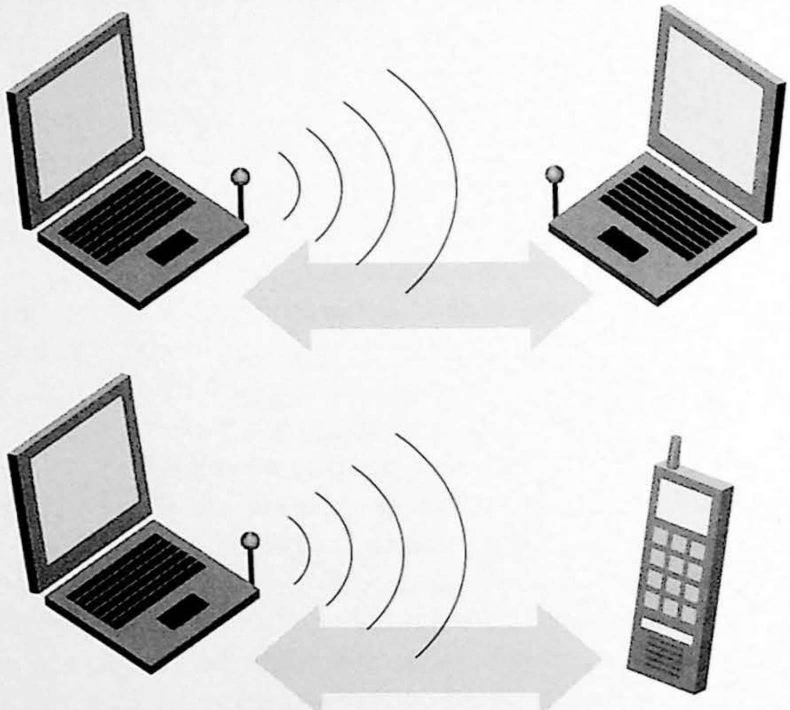

Figure 3.4
The Bluetooth interactive conference (file and object transfer) usage case.

A primary benefit of wireless file transfer is the convenience that it offers. Data could be exchanged easily between two or more devices without the use of cables (which, as pointed out in the introduction, are likely to be cumbersome, proprietary and incompatible between two given devices) and without the need to set up and configure a full-blown network among the devices. Files and other objects could be exchanged immediately in a conference room setting, rather than deferring the transmission of the files until after a meeting is over when a computer or other device can be connected to a network.

The Internet Bridge

There are two similar yet different methods for using Bluetooth communication as a wireless "bridge"[2] to established networks like the Internet or campus or corporate intranets. The first method is dial-up networking using a telephone as a wireless data modem; the second is direct local area network (LAN) access using a data access point.

Dial-Up Networking

This form of the Internet bridge is no different from the method many people use to access the Internet today. A conventional arrangement involves connecting a computer to the Internet using a telephone to dial an Internet service provider through a modem. What Bluetooth communication adds to this scenario is the ability to accomplish this usage model entirely without wires. Today's usage models for dial-up networking typically require a cable between the computer and the telephone; even when a mobile telephone is used, a cable between the computer and the mobile telephone is usually required. With a computer and a telephone that both support the dial-up networking profile, the end-to-end connection to the Internet (or other network) could be wireless, as illustrated in Figure 3.5.

2. The term bridge is used here since it is consistent with the nomenclature used by the SIG. The function described here is similar to a traditional network bridge, which is distinct from a router. While no Bluetooth "Internet router" usage case exists in version 1.0, such a function is not beyond the realm of possibility.

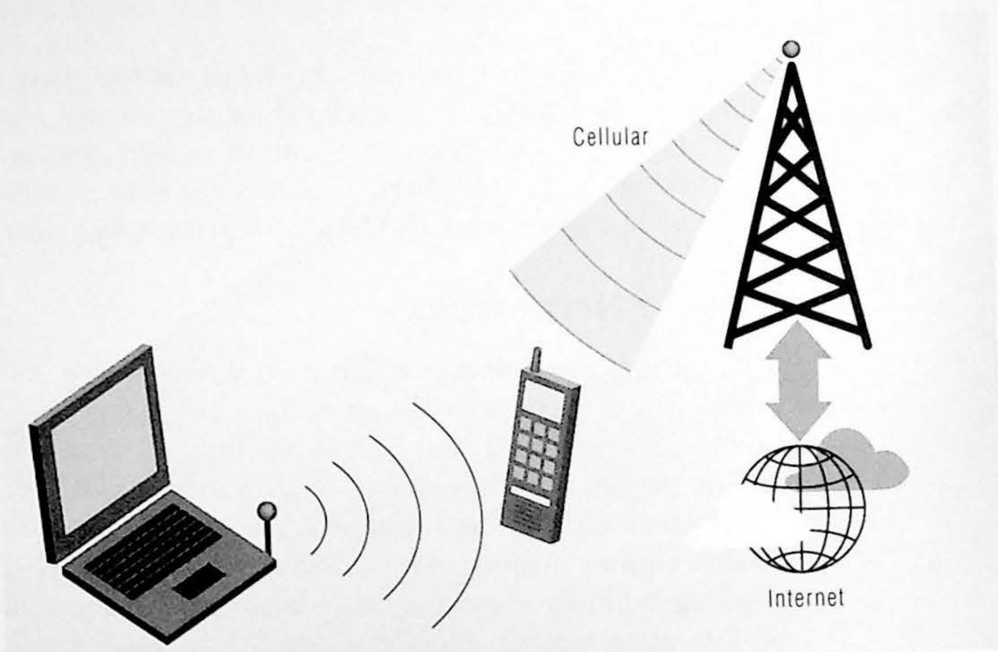

Figure 3.5
The internet bridge usage case 1: wireless dial-up networking.

Direct Network Access

While dial-up networking is a popular way to access the Internet, especially from homes or other environments where telephone lines (or in some cases, cable or high-speed data connections) are the primary communications bridge, direct access to LANs is common in enterprises, on campuses, and in other similar environments. The directly accessed local area network often provides a gateway to the Internet, enabling the Internet to be accessed from the LAN without a dial-up connection.

Direct network access via Bluetooth wireless communication is possible using *data access points.* A data access point allows devices to connect to it wirelessly; the data access point in turn connects to the local area network. Once again this is not functionally different from the same sort of connection in a wired environment, such as a traditional Ethernet network where computers connect to network access points using cables. A data access point with Bluetooth wireless communication simply provides a "wireless plug" to connect to the network as illustrated in Figure 3.6.

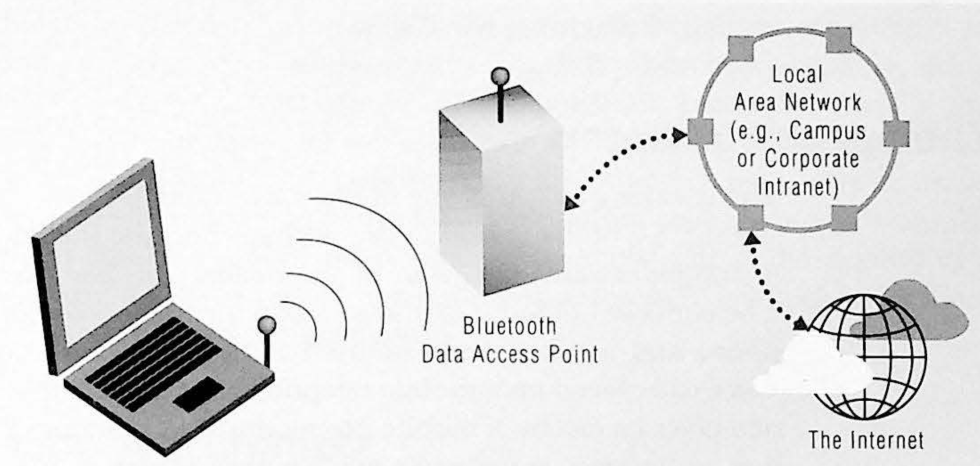

Figure 3.6
The Bluetooth internet bridge usage case 2: direct local area network access through a data access point.

The Internet bridge is one case where Bluetooth wireless communication can be used to replace cables, making a common task easier and more convenient. Dial-up networking, for example, is common today with wired modems and telephones. Many business travelers have experienced searching a hotel room for the telephone jack so as to plug in their notebook computer's modem for dial-up networking. With Bluetooth wireless communication, no cable connection is required; a hotel room telephone or a person's own mobile phone could be used as a wireless data modem. The use of a mobile telephone as a wireless data modem is not uncommon today, but in most cases the mobile phone still needs to be cabled to the notebook computer; Bluetooth wireless communications could further improve upon this scenario by removing the cable between the computer and the phone.

Direct network access using Bluetooth wireless communication offers advantages over the equivalent wired scenario. In addition to obviating the need to provide an in-building wired infrastructure with endpoint connections at every access point, a wireless data access point also offers the possibility for devices to share the access point. Multiple devices in proximity of a single data access point could access the network wirelessly rather than requiring each device to have a separate cabled connection to its own access point. Moreover, data access points could be designed such that they could plug into existing network wiring infrastructure and thus allow "the last hop" to be wireless, with its associated conveniences, while making use of and protecting the investment in the existing wired network.

The Speaking Laptop

The speaking laptop is one of the usage models that is not advertised in version 1.0 of the specification, perhaps because it could be considered a straightforward extension of the headset profile already described.[3] The concept behind it is that a laptop (or notebook) computer's microphone and speaker could be used as the audio input and output for a voice call placed on a mobile telephone. As an example, suppose someone places a call on a mobile phone during a meeting. As the conversation progresses, it becomes evident that others in the meeting would benefit from taking part in the call. Bluetooth wireless communication could be used to route the voice traffic to a notebook computer in the conference room, allowing the computer to be used as a speakerphone. The call is still being carried over the mobile phone's wide area voice network but the audio source and sink are now at the notebook computer. Figure 3.7 illustrates the speaking laptop scenario.

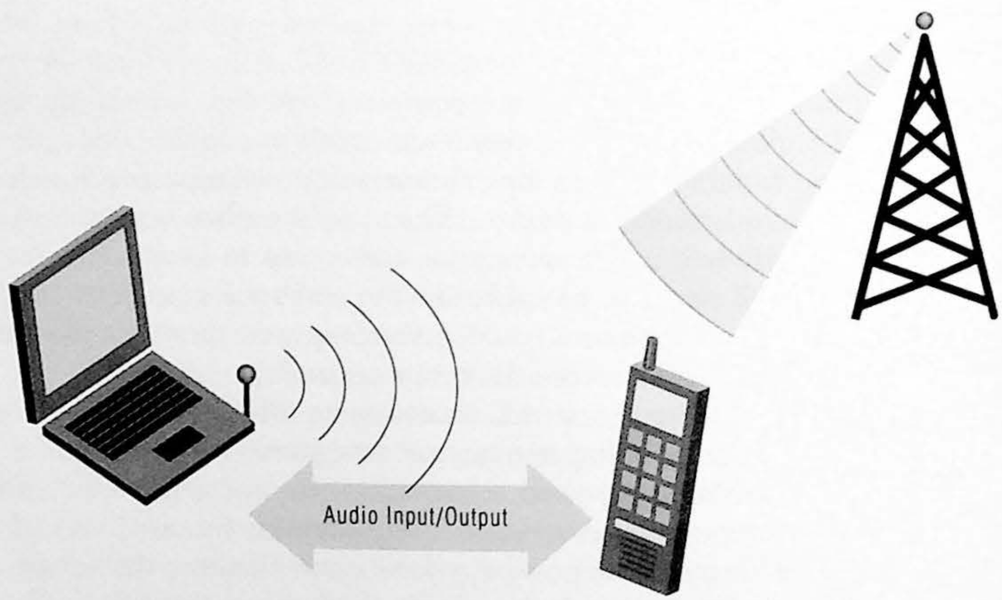

Figure 3.7
The Bluetooth speaking laptop usage model.

3. The technical underpinnings of routing voice traffic between a telephone and another device are similar, although the speaking laptop has some distinct end-user considerations that merit its independent discussion here.