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Cover: Bluetooth technology substitutes a universal short-range radio link for the many proprietary cables that are presently used for connecting devices. But more than this, Bluetooth radio technology provides a universal bridge to existing data networks, a peripheral interface, and a mechanism for forming small *ad hoc* groupings of connected devices away from fixed network infrastructures.

Contents

Bluetooth—The universal radio interface for *ad hoc*, wireless connectivity

Jaap Haartsen

Bluetooth is a universal radio interface in the 2.45 GHz frequency band that enables portable electronic devices to connect and communicate wirelessly via short-range, *ad hoc* networks. Each unit can simultaneously communicate with up to seven other units per piconet. Moreover, each unit can simultaneously belong to several piconets.

Bluetooth technology—which apart from Ericsson, has gained the support of Nokia, IBM, Toshiba, Intel and many other manufacturers—eliminates the need for wires, cables and connectors for and between cordless or mobile phones, modems, headsets, PDAs, computers, printers, projectors, local area networks, and so on, and paves the way for new and completely different devices and applications.

Before guiding us through frequency-hopping technology and the channel, packet and physical-link definitions that characterize the Bluetooth air interface, the author briefly describes the conditions that led up to the development of Bluetooth. He then acquaints us with the networking aspects of Bluetooth technology, describing piconets and scatternets, connection procedures, and inter-piconet communication.

Imagine a cheap, power-efficient radio chip that is small enough to fit inside any electronic device or machine, that provides local connectivity, and that creates a (worldwide) micro-scale web. What applications might you use it in?

In 1994, Ericsson Mobile Communications AB in Lund, Sweden, initiated a study to investigate the feasibility of a low-power, low-cost radio interface between mobile phones and their accessories. The intention was to eliminate cables between phones and PC cards, wireless headsets, and so forth. The study was part of a larger project that investigated multi-communicators connected to the cellular network via cellular telephones. The last link in the connection between a communicator and the cellular network was a short-range radio link to the phone—thus, the link was called the multi-communicator link or MC link. As the MC link project progressed, it became clear that there was no limit to the kinds of application that could use a short-range radio link. Cheap, short-range radios would make wireless communication between portable devices economically feasible.

Current portable devices use infrared links (IrDA) to communicate with each other. Although infrared transceivers are inexpensive, they

- have limited range (typically one to two meters);
- are sensitive to direction and require direct line-of-sight;
- can in principle only be used between two devices.

By contrast, radios have much greater range, can propagate around objects and through various materials, and connect to many devices simultaneously. What is more, radio interfaces do not require user interaction.

In the beginning of 1997, when designers had already begun work on an MC link

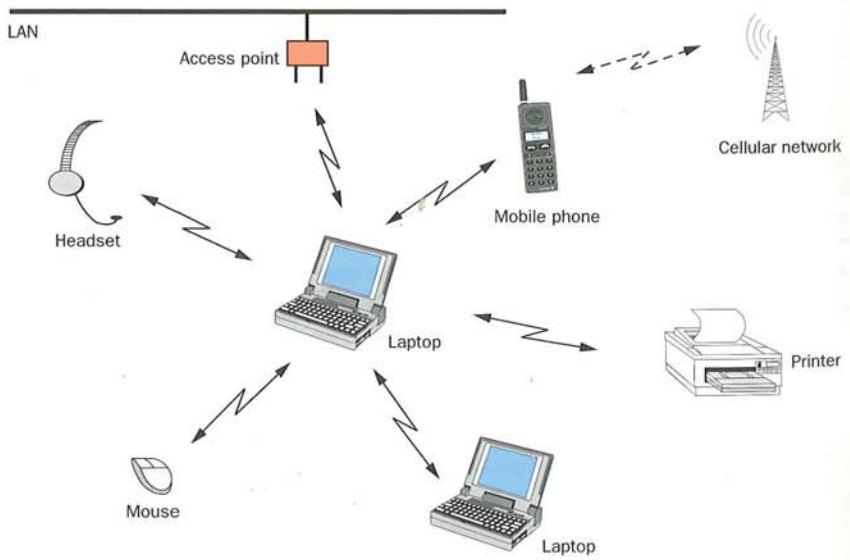

Figure 1
User model with local wireless connectivity

transceiver chip, Ericsson approached other manufacturers of portable devices to raise interest in the technology—for the system to succeed, a critical mass of portable devices must use the short-range radio. In February 1998, five promoters—Ericsson, Nokia, IBM, Toshiba and Intel—formed a special interest group (SIG). The idea was to achieve a proper mix of business areas: two market leaders in mobile telephony, two market leaders in laptop computing, and a market leader in core, digital-signal-processor (DSP) technology. On May 20 and 21, 1998, the Bluetooth consortium announced itself to the general public from London, England; San Jose, California; and Tokyo, Japan. Since then, several companies have joined as adopters of the technology (Box B).

The purpose of the consortium is to establish a *de facto* standard for the air interface and the software that controls it, thereby ensuring interoperability between devices of different manufacturers. The first products to use MC link technology will emerge at the end of 1999 in mobile phones, notebook computers and accessories (Figure 1).

Box A
Abbreviations

ACL	Asynchronous connectionless
ARQ	Automatic retransmission query
CVSD	Continuous variable slope delta
DSP	Digital signal processor
FEC	Forward error correction
FH	Frequency hop
FSK	Frequency shift keying
HEC	Header error correction
HPC	Handheld personal computer
IrDA	Infrared Data Association
ISM	Industrial Scientific Medical
MAC	Media access control
MC	Multicommunicator
PC	Personal computer
PDA	Personal digital assistant
RF	Radio frequency
SCO	Synchronous connection-oriented
SIG	Special interest group
TDD	Time division duplex
TDM	Time division multiplex

Box B
The Bluetooth consortium—promoters and adopters

The promoters of the Bluetooth* consortium formed a special interest group (SIG) at Ericsson Inc., Research Triangle Park, North Carolina, on February 4, 1998.
The consortium was announced to the public on May 20 and 21, 1998. Many companies have since joined the consortium as adopters of the technology (status as of July 11, 1998):

Ericsson	Promoter	Plantronics
Intel	Promoter	Psion
IBM	Promoter	Puma Technologies
Nokia	Promoter	Quadriga
Toshiba	Promoter	Qualcomm, Inc.
3Com		Samsung Electronics Ltd.
Axis		Siemens Forsvarsystem A/S
BreezeCOM		Symbian
Casio		Symbionics Ltd.
Cambridge consultantsLtd.		T-Span System
CETECOM GmbH		Temic Semiconductor
Cirrus Logic		TDK
Compaq Computer Corp.		TTP Communications Ltd.
Convergence Corporation		Universal Empowering Technologies
Dell Computer Corp.		VLSI Technology, Inc.
InnoLabs Corporation		Xircom
Jeeves Telecom Ltd.		
Lucent Technologies UK Ltd.		
Metricom		
Motorola		

* The name, Bluetooth, was taken from Harald Blåtand, a Danish Viking king from the early Middle Ages.

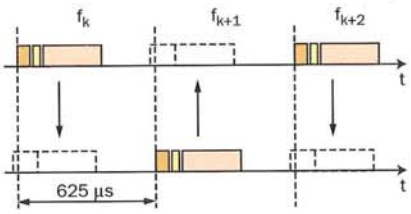

Figure 2
Frequency-hop/time-division-duplex channel.

The Bluetooth air interface

The focus of user scenarios envisioned for first-generation products is typically on traveling business people. Portable devices that contain Bluetooth radios would enable them to leave cables and connectors at home (Box C). Before the air interface for Bluetooth could be designed, however, certain requirements had to be settled:

- The system must operate worldwide.
- The connection must support voice and data—for instance, for multimedia applications.
- The radio transceiver must be small and operate at low power. That is, the radio must fit into small, portable devices, such as mobile phones, headsets and personal digital assistants (PDA).

License-free band

To operate worldwide, the required frequency band must be available globally. Further, it must be license-free and open to any radio system. The only frequency band that satisfies these requirements is at 2.45 GHz—the Industrial-Scientific-Medical (ISM) band, which ranges from 2,400 to 2,483.5 MHz in the US and Europe (only parts of this band are available in France and Spain), and from 2,471 to 2,497 MHz in Japan. Consequently, the system can be used worldwide, given that the radio transceivers cover the frequency band between 2,400 and 2,500 MHz and that they can select the proper segment in this band.

Frequency hopping

Since the ISM band is open to anyone, radio systems operating in this band must cope with several unpredictable sources of interference, such as baby monitors, garage door openers, cordless phones and microwave ovens (the strongest source of interference). Interference can be avoided using an adaptive scheme that finds an unused part of the spectrum, or it can be suppressed by means of spectrum spreading. In the US, radios operating in the 2.45 GHz ISM band are required to apply spectrum-spreading techniques if their transmitted power levels exceed 0 dBm.

Bluetooth radios use frequency-hop (FH) spread spectrum, since this technology better supports low-cost, low-power radio implementations. Frequency-hop systems divide the frequency band into several hop channels. During a connection, radio transceivers hop from one channel to another in a pseudo-random fashion. The instantaneous (hop) bandwidth is small in frequency-hop radios, but spreading is usually obtained over the entire frequency band. This results in low-cost, narrowband transceivers with maximum immunity to interference. Occasionally, interference jams a hop channel, causing faulty reception. When this occurs, error-correction schemes in the link restore bit errors.

Channel definition

Bluetooth channels use a frequency-hop/time-division-duplex (FH/TDD) scheme (Figure 2). The channel is divided into 625 µs intervals—called slots—where a different hop frequency is used for each slot. This gives a nominal hop rate of 1,600 hops

Box C User scenarios

Three-in-one phone—use the same phone everywhere
When you are at the office, your phone functions as an intercom (no telephony charge). At home, it functions as a cordless phone (fixed-line charge). When you are on the move, it functions as a mobile phone (cellular charge).

Internet bridge—surf the Internet regardless of the connection
Use your portable PC to surf the Internet anywhere, regardless of whether you are connected wirelessly through a mobile phone (cellular) or through a wired connection (PSTN, ISDN, LAN, xDSL).

Interactive conference—connect every participant for instant data exchange
In meetings and at conferences, you can share information instantly with other participants. You can also operate a projector remotely without wire connectors.

The ultimate headset—a cordless headset keeps your hands free
Connect a headset to your mobile PC or to any wired connection and free your hands for more important tasks at the office or in your car.

Portable PC speakerphone
Connect cordless headsets to your portable PC and use it as a speakerphone regardless of whether you are in the office, your car, or at home.

Briefcase trick (hidden computing 1)
Access e-mail while your portable PC is still in the briefcase. When your portable PC receives an e-mail message, you will be notified by your mobile phone. You can also use the phone to browse incoming e-mail and read messages.

Forbidden message (hidden computing 2)
Compose e-mail on your PC while you are on an airplane. When you land and are allowed to switch on your mobile phone, the messages are sent immediately.

Automatic synchronization (hidden computing 3)
Automatically synchronize your desktop computer, portable PC, notebook (PDA or HPC) and mobile phone. As soon as you enter the office, the address list and calendar in your notebook automatically updates the files on your desktop computer or vice versa.

Instant postcard—send photos and video clips instantly from any location
Connect a camera cordlessly to your mobile phone or to any wire-bound connection. Add comments from your mobile phone, a notebook, or portable PC and send them instantly to a recipient anywhere in the world. Suitable for professional and personal use.

Cordless desktop—connect all peripheral tools to your PC or the LAN
Connect your desktop/laptop computer cordlessly to printers, scanners and the LAN. Increase your sense of freedom through cordless mouse and keyboard connections to your PC.

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