Agilent Technologies

2001 Wireless Technology Seminar

Bluetooth™ Basics

presented by:

Peter Cain

The cabling and configuration required to let today's digital devices talk to each other can get complicated, and inconvenient if you want to change your configuration or have them talk to devices in both home and office (moving cables, installing software etc.)

Enter Bluetooth. Add a small unobtrusive and (soon to be) inexpensive module & antenna to each host device, and you have an instant connection to all other Bluetooth devices (that you choose to be connected with) within the radio's range.

We'll start this presentation with an overview of the market and discuss the factors that are driving the acceptance of this technology and the growth of its market.

Current and potential applications will be presented and described.

The major elements of the Bluetooth Standard reviewed along with the qualification process.

The implementation of the technology is given and we finish with a comparison of competing technologies

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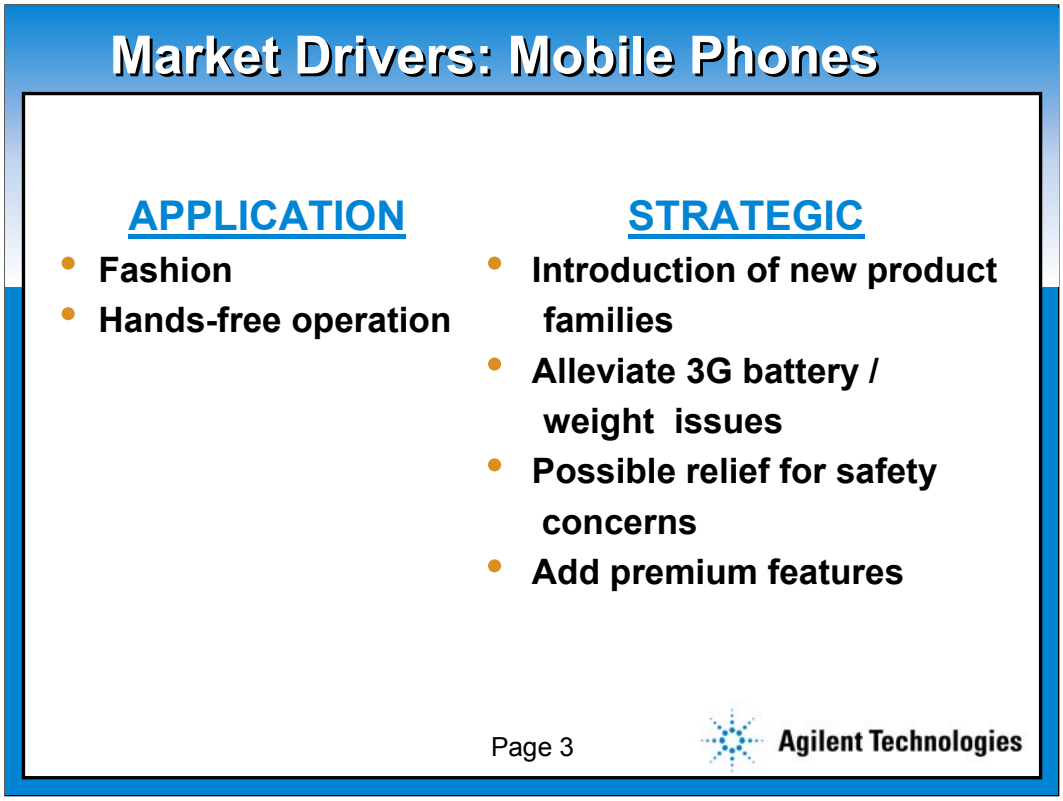
Note:

This Agenda is shown only at this point in the presentation. There is no delineation between topics within the presentation. The Technology Implementation section has its own sub-agenda.



Applications likely to benefit from the integration of Bluetooth are Cell phones, PDA's, digital cordless phones, digital cameras, adapters, PC Cards, dongles, headsets, PCs, printers and faxes, and so on. It is predicted that up to 1.5 Billion Bluetooth-enabled devices will be in use by 2005!

We use a combination of handheld/mobile devices that each need to be able to connect to at least one other device in order to utilize their full functionality.

One of the first applications developed are Bluetooth headsets for use with, among other things, mobile phones.

Ericsson, Motorola and Nokia are leading proponents of integrating Bluetooth technology into their mobile phone products. Nearly all of the world's mobile phone manufacturers are Bluetooth adopters. This technology is a significant and perhaps essential element of their 3G development and marketing plans.

Bluetooth will allow completely new combinations of innovative products and allow new premium features to be added to mobile phones.

Market Drivers: PCs, Laptops & Peripherals

APPLICATION

- Talk to portable devices
- Convenient low / medium rate data transfer, RS232, USB, Ethernet?
- Data synchronizing
- Cell phone links for laptops / palmtops

STRATEGIC

- New products for the market
- *IR* function that is user friendly
- Don't assume Bluetooth will be the only Wireless interface for LAN
- Cost effective product differentiation, leading to a customer expectation

Page 4

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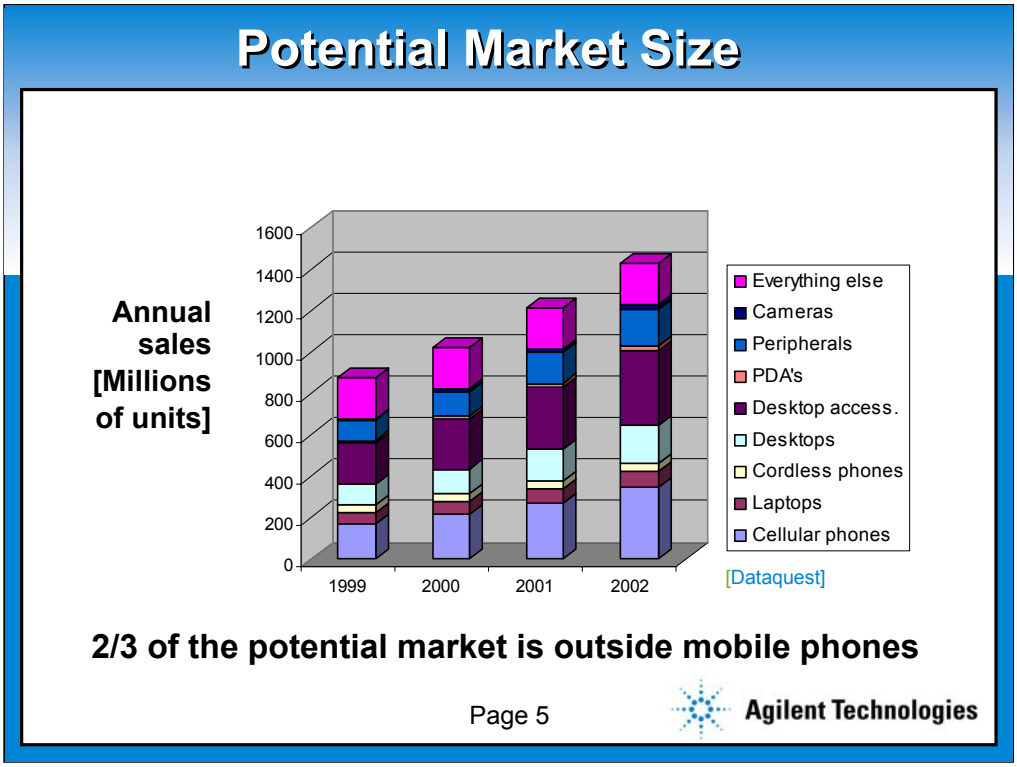
Bluetooth is really suited to portable devices, but even desktop PCs will benefit from being able to "talk" to peripheral devices such as a digital camera, printer, mouse, or modem.

A notebook PC can synchronize appointments with the PDA, back up its files on a shared zip drive.

A phone would be able to automatically dial phone numbers stored on either the PDA or Notebook.

The infrared organization is working with the Bluetooth S.I.G., so that Bluetooth learns some lessons, but also IR will benefit from improvements in Software support / ease of use.



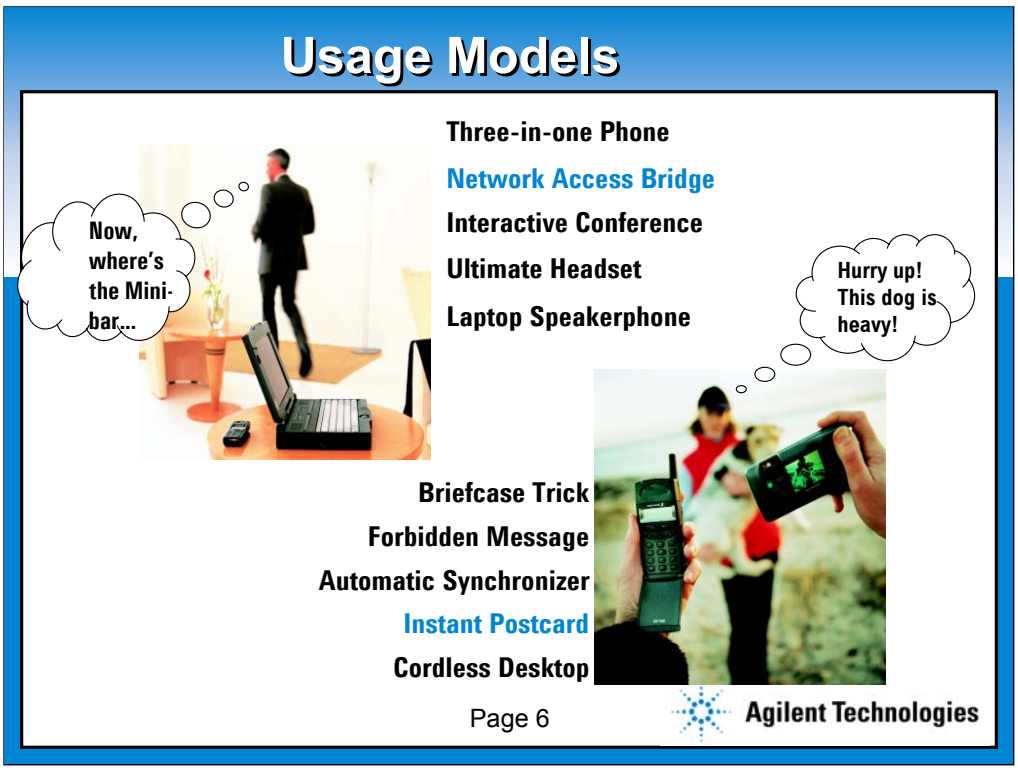
This shows the number of units that COULD use Bluetooth as an interface. You may need to study a printed slide to see all the detail.

Bluetooth technology is not necessarily a good fit for Wireless LAN, because it has limited bandwidth & is basically not meant for situations with multiple "masters" calling some other device.

It doesn't have to be Bluetooth OR some other wireless data technology. If price is right, may well get more than one. Of course, there will still be several ways to solve connection problems. Cables, infrared and memory sticks aren't going away overnight.

As noted in a previous slide, the utility of a desktop PC will be enhanced with the addition of Bluetooth. This will either be as an interface to portable devices, or as a convenience to reduce wiring to peripherals.

We expect two-thirds of the Bluetooth market to be outside the mobile phone. Either this is for things the phone talks to, or simply other devices making use of a low cost cordless link.



THE THREE-IN-ONE PHONE. Use the same phone wherever you are.

When you're at the office, your phone functions as an intercom (no telephony charge). At home, it functions as a portable phone (fixed line charge). And when you're on the move, the phone functions as a mobile phone (cellular charge).

THE INTERNET BRIDGE. Surf the Internet regardless of the connection.

Use your laptop to surf the Internet wherever your are, and regardless if you're cordlessly connected through a mobile phone (cellular) or through a wire-bound connection (PSTN, ISDN, LAN, xDSL).

THE INTERACTIVE CONFERENCE. Connect all participants for instant data exchange.

In meetings and conferences, you can share information instantly with all participant, and without any cord connections. You can also cordlessly run and control, for instance, a projector.

THE ULTIMATE HEADSET. A cordlessly connected headset keeps your hands free at all times.

Connect your headset to your mobile or any wire-bound connection to keep your hands free for more important tasks when you're at the office or in your car.

THE LAPTOP SPEAKERPHONE. Use your laptop as a speaker phone wherever you are.

Connect cordless headsets to your laptop and use the lap top as a speaker phone regardless of whether you're in your office, in your car or at home.

THE BRIEFCASE TRICK. Use e-mail while your laptop is still in the briefcase.

When your laptop receives an e-mail, you'll get an alert on your mobile phone. You can also browse all incoming e-mails and read those you select in the mobile phone's window.

THE FORBIDDEN MESSAGE. Write e-mails on your laptop while you're on an airplane.

As soon as you've landed and switched on your mobile phone, all messages are immediately sent.

THE AUTOMATIC SYNCHRONIZER. Automatic background synchronization keeps you up-to-date.

Automatic synchronization of you desktop, laptop, notebook (PC-PDA and PC-HPC) and your mobile phone. For instance, as soon as you enter your office the address list and calendar in your notebook will automatically be updated to agree with the one in your desktop, or vice versa.

THE INSTANT POSTCARD. Send instant photos and video clips from any location.

Cordlessly connect your camera to your mobile phone or any wire-bound connection. Add comments with your mobile phone, a notebook or your laptop and send them instantly to a receiver anywhere in the world. Suitable for professional as well as personal use.

THE CORDLESS DESKTOP. Connect all peripheral tools to your PC or to the LAN.

Cordless connection of your desktop or laptop to printers, scanners and to the LAN. Increase your sense of freedom in everyday work by cordless connection of your mouse and keyboard to your PC.

Example Bluetooth Module

[CSR September 2000]

Page 7

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This is a picture of the Cambridge Silicon Radio (CSR) solution. Little extra is required to turn it into a wireless headset or some other target application.

Further integrated solutions are in work and will shortly allow the entire radio to reside on a single chip [except for perhaps the crystal and the battery!].

Acronyms

Bps	Bits per second
BGA	Ball Grid Array
BQRB	Bluetooth Qualification Review Board
BQA	BT Administrator
BQTF	BTQ Test Facility
BQB	BTQ Board
BTAB	BT Advisory Board
FHSS	Frequency Hopping Spread Spectrum
GFSK	Gaussian Frequency Shift keying
ISM	Industrial, Scientific & Medical
LTCC	Low Temperature Coefficient Ceramic Carrier
SIG	Special Interest Group
TF1	Task Force 1
TF2	Task Force 2
TF3	Task Force 3
TCP/IP	Transmission Control Protocol / Internet Protocol
HID	Human Interface Driver
L2CAP	Logical Link Control and Adaptation Protocol
LMP	Link Manager Protocol
NF	Noise Figure

Page 8

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This list of acronyms is provided for your reference.

Promoters, Associates & Adopters

Promoters are a group of large companies driving the technology into the market :

Ericsson	Nokia	Toshiba
Intel	IBM	3Com
Lucent	Motorola	Microsoft

- Bluetooth Special Interest Group (SIG)
- Over 2000 companies have become adopters of the technology
- Associate membership

Page 9 Agilent Technologies

A Special Interest Group [SIG] has been formed to advance the acceptance of Bluetooth. It is commercially backed [not government, like ETSI]; largely by the companies above that are referred to as the Promoters of Bluetooth. They are in charge of the development of specifications, as well as their own products.

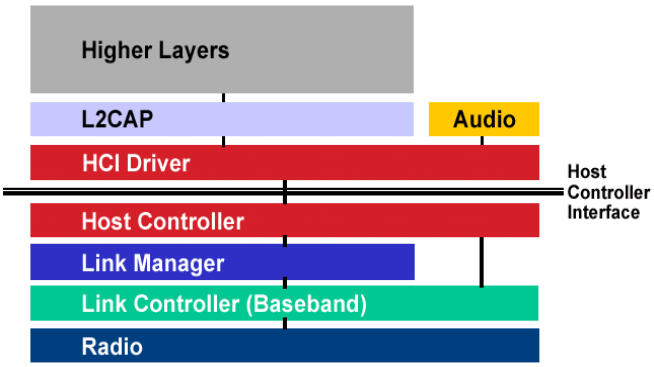
As well as promoters there are companies called the adopters. Currently there are over 2000 companies that bear no financial responsibility but have pledged to adhere to the standard when developing Bluetooth products.

Another category of membership that lies between the previous two is that of Associate. Associates bear a portion of the financial support required by the SIG, in turn they participate in the development of the standard and the associated profiles.

The wide range of interests these companies have, means there are some conflicting priorities. An example is the proposal before the US FCC for a 1 watt specification as part of 802.11. The Bluetooth SIG are finding it difficult to give a united response, because some members will find this useful. This is despite the fact Bluetooth itself will suffer more interference.

The Standard

- Has two parts:
  - **Core**
  - **Profiles**
- Currently at Version 1.1.
- Version 1.1 corrects errata - not backwards compatible with 1.0b.
- Main effort now in profiles.



GLOSSARY

L2CAP - Logical Link Control and Adaptation Protocol

LMP - Link Manager Protocol

Page 10

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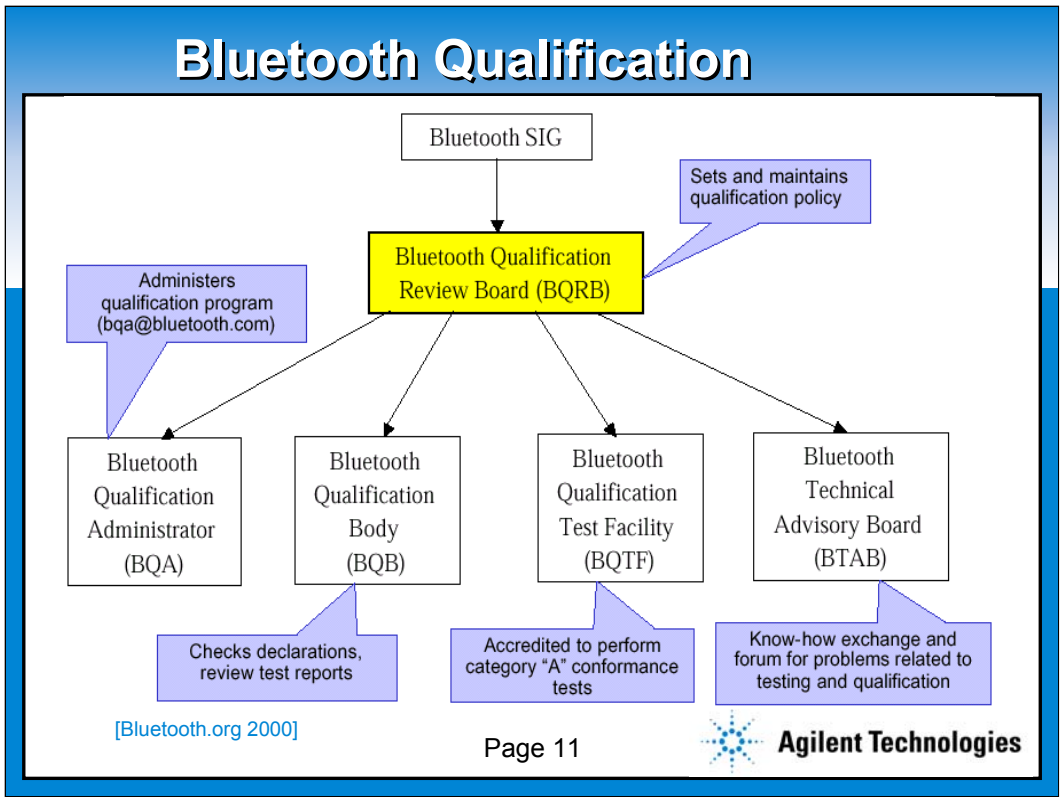
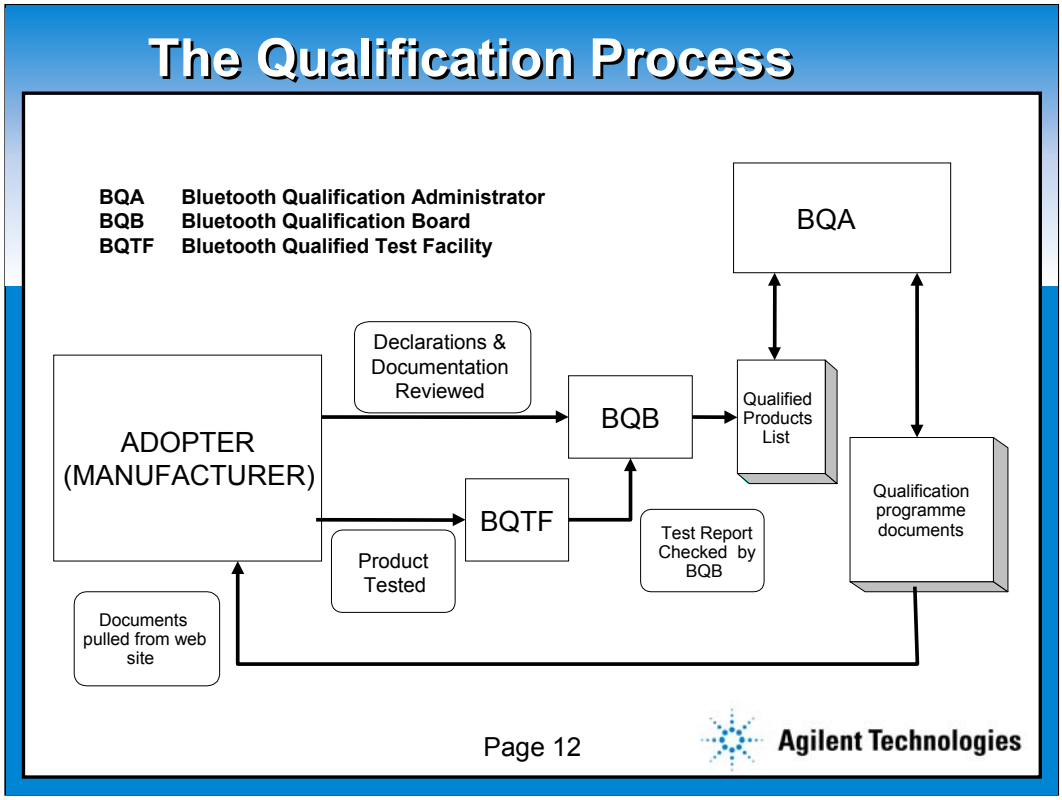
A the time of this writing, the current released version of the Standard is version 1.1. Some use is still being made of 1.0b, but it is expected this will decrease over time.



The Bluetooth SIG Qualification hierarchy.



The Bluetooth SIG hold the rights to use the Bluetooth name & logo. They will not allow other organizations to use it unless equipment has been through this qualification process.

"Interoperability", devices working together properly, is what will make Bluetooth really succeed. This involved process is one way the SIG is trying to build interoperability into the system.

Adherence to the qualification process will be about half the battle to get Bluetooth widely accepted. The rest will be down to market acceptance that in turn will drive the engineering investment. This is similar to the way the computer software market works.

Alongside the formal process shown here, the SIG are organizing "unplugfests". Companies with devices to test can go to these large technical meetings and find out how well their product works with everyone else's products.

Question and Answer Session

Wireless Technology Seminar:

Bluetooth Basics

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Page 13

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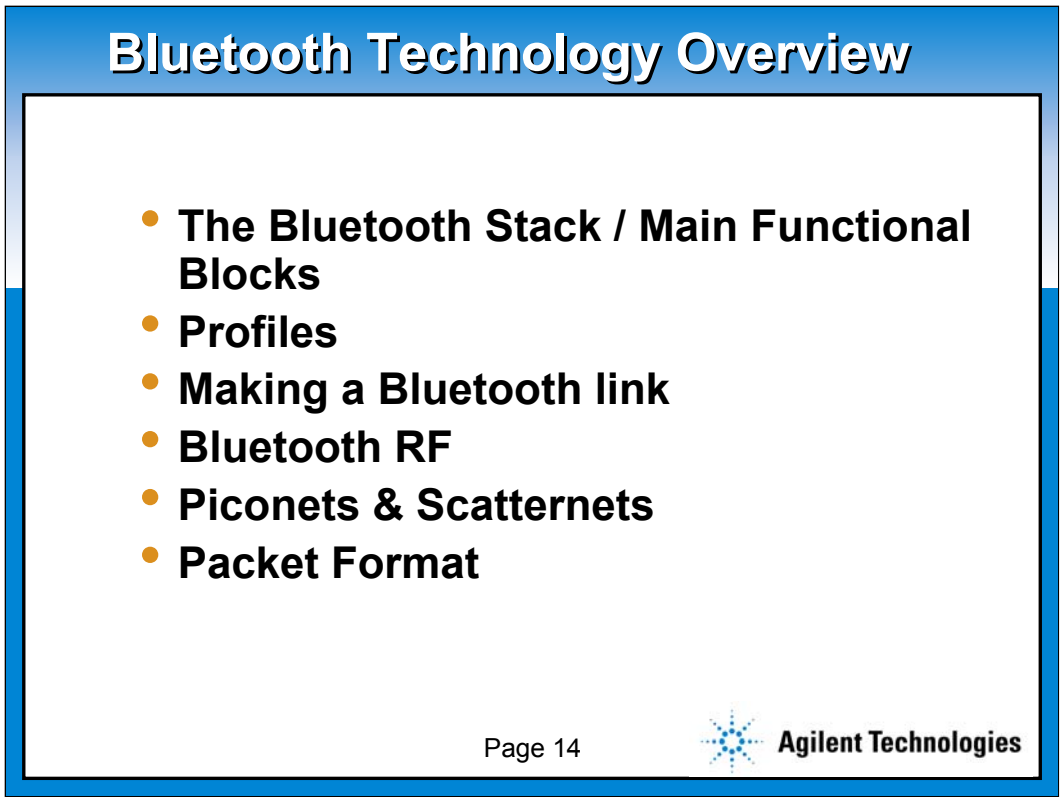
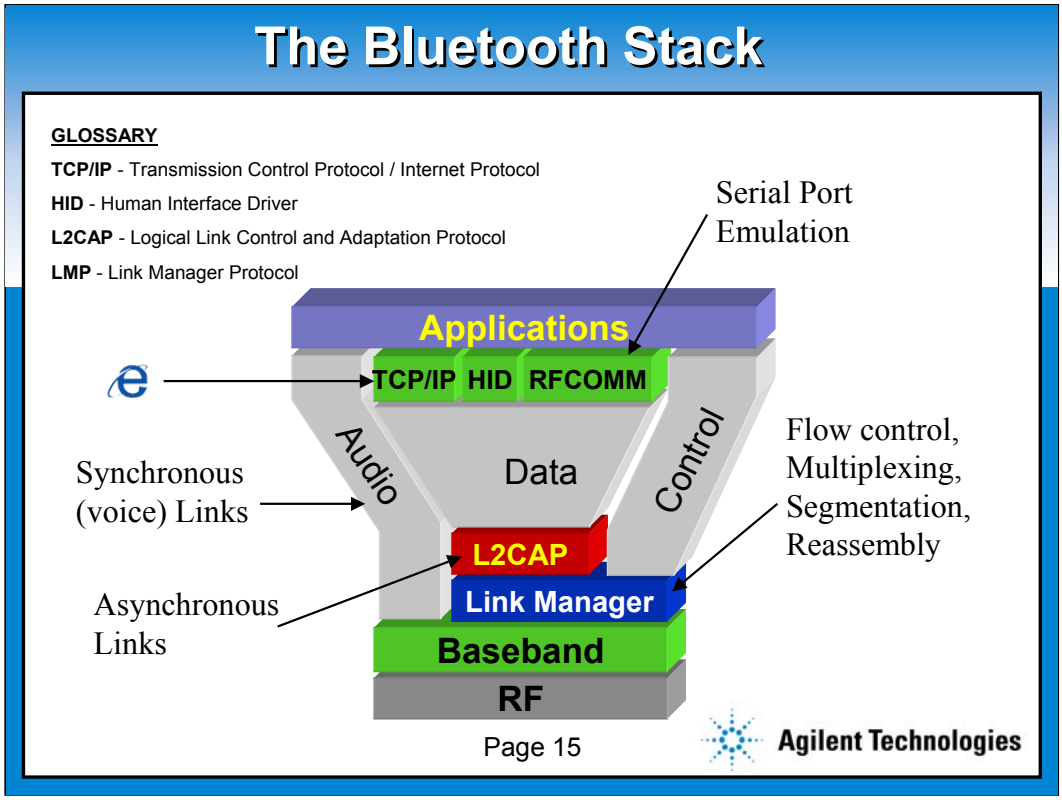


Technology overview agenda.



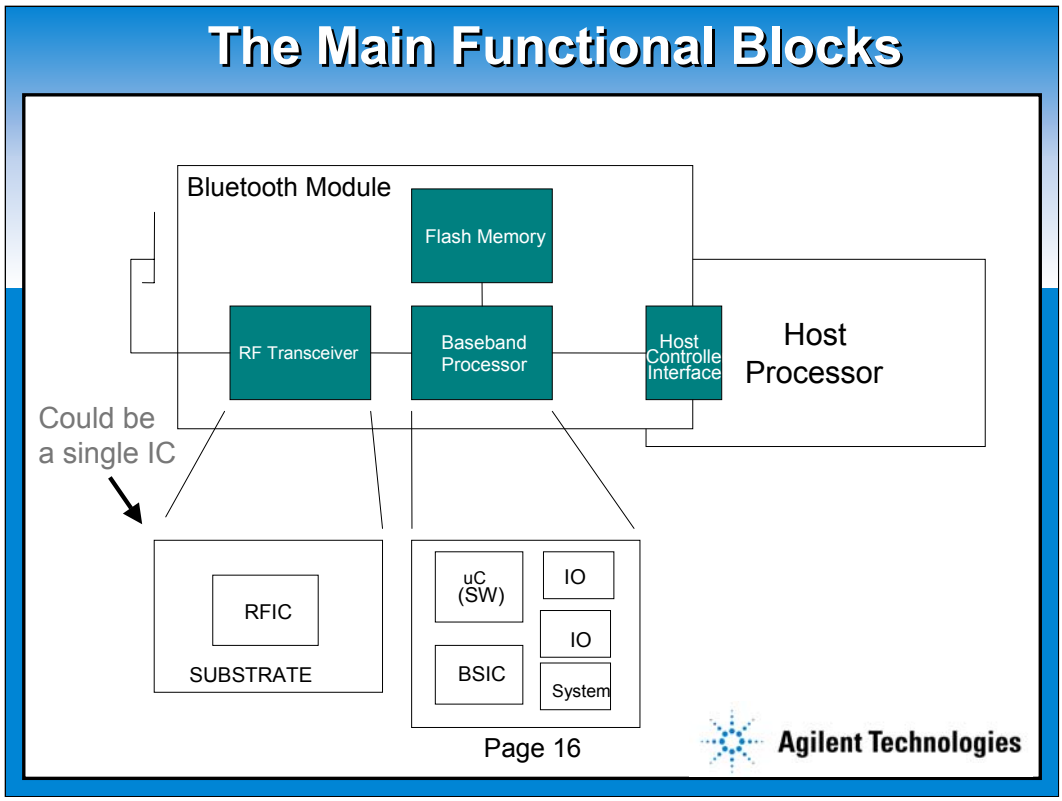
Here we have an overview of the complete Bluetooth protocol stack. Two distinct types of connection between devices are supported: synchronously using the audio layer, and asynchronously going through the data layer. Bluetooth actually supports data and voice simultaneously.

The application layer has access to TCP/IP for web browsing/ftp etc. The obvious use here is surfing the internet from your PDA or Notebook. The RFCOMM layer, for serial port emulation, would be used to connect devices not equipped with Bluetooth, but have a serial connection.

A synchronous link connected directly to the baseband processing layer is used for voice transmission.

Data are transmitted on asynchronous links and are managed though the L2CAP (Logical Link Control and Adaptation Protocol). The link manager protocol (LMP) applies flow control, packet assembly and multiplexing services.

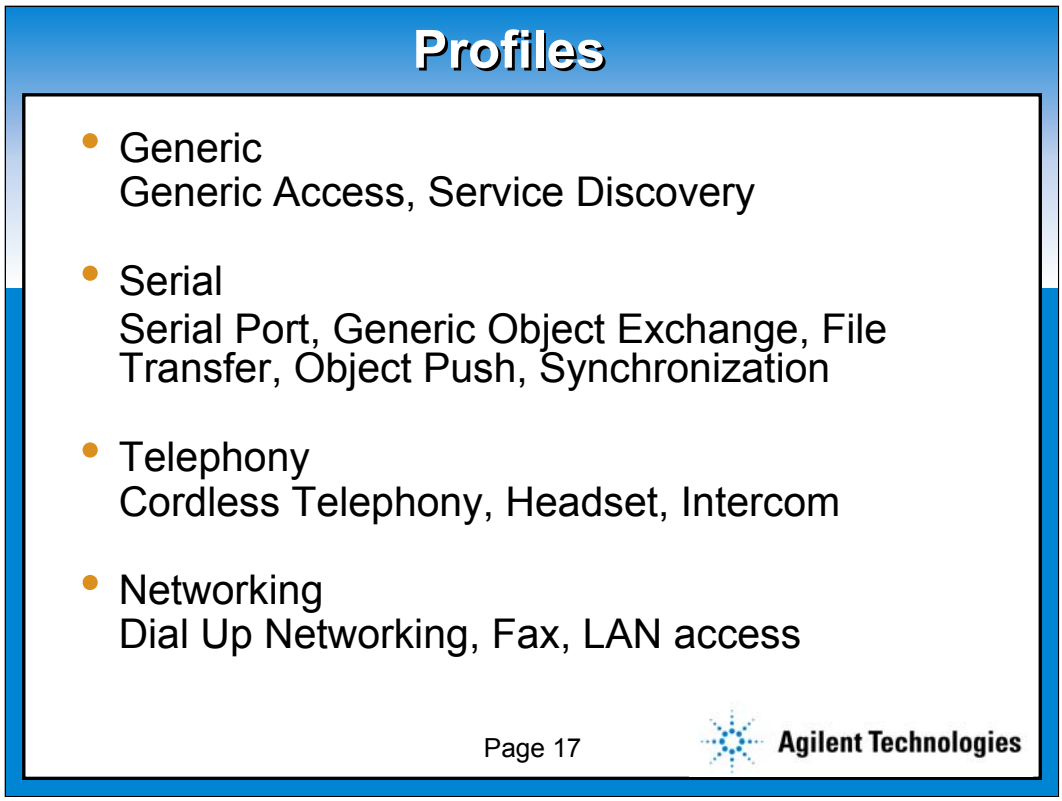
At the lower levels, the baseband layer forms the basic modulating signal and the RF layer provides the physical transport mechanism for the modulated signal.



A Bluetooth system requires these basic blocks, but there are many different ways to implement it. Application Software lies beyond the the Host processor, depending on the Profile(s) supported.

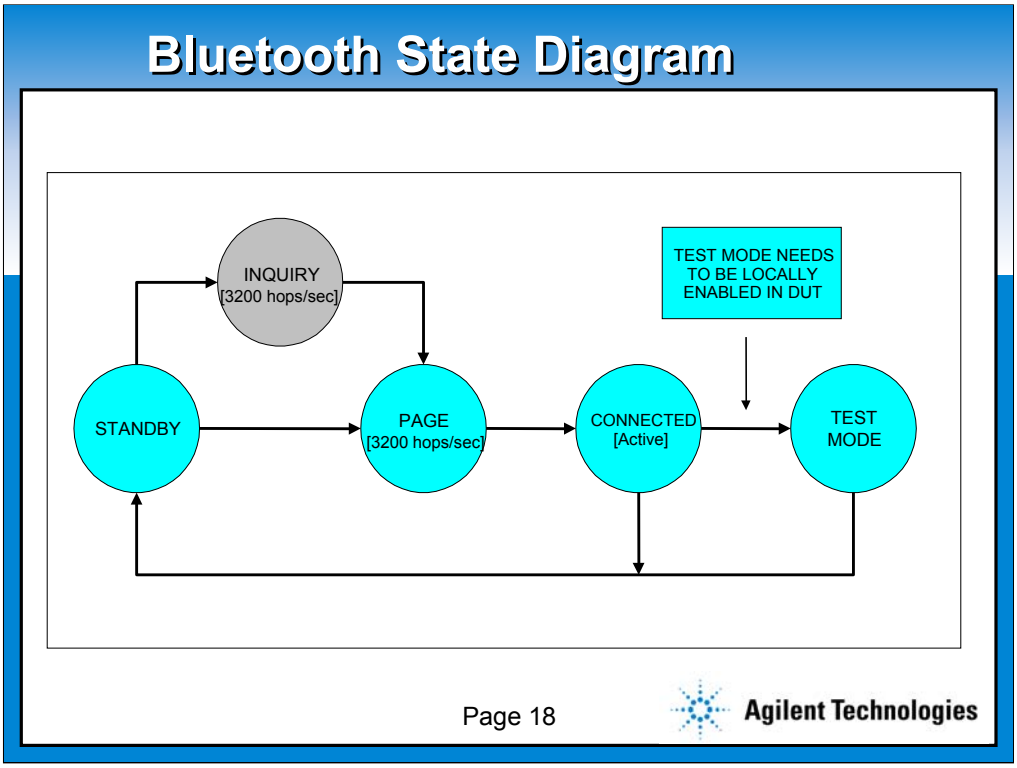
Both CMOS and SiGe are being used for the radio itself. Performance, power and die size being the variables that get traded.

The Baseband is typically being quoted as taking 70,000 gates.



A profile defines what is needed at the Host level to support particular applications. Profiles have their own part of the specification, that runs to more than 400 pages.

GAP (generic access) and SDAP (Service Discovery) are common parts to many if not all of the other profiles. It turns out that these were defined later than some of the others after the SIG working groups realized there were common elements within the application profiles.



The Bluetooth address is a unique 48bit address assigned to each device

Standby - Waiting to be told to join a piconet

Inquire - Ask about radios to connect to. Inquirer transmits two short [68us] packets twice in one 625us period. The listener, listens every 1.28 seconds

Page - Connect to a specific radio. Similar to Inquiry, but paged device's address is sent, which reduces the time to connect, to around 2.5 seconds.

Connected - Actively on a piconet (master or slave)

[Bluetooth defines four Connected modes: Active, Sniff, Hold and Park. These allow dynamically settable alternatives in responsiveness to the Master and power consumption. Park is the lowest power.]

Park/Hold - Low Power connected states

Bluetooth also defines a Test Mode that allows the Test Set to control the DUT. [e.g. turn off frequency hopping]

Radio Parameter Overview

- Operating Frequency: ISM band 2.402 - 2.480 GHz
- Number of carriers: 79 carriers at 1 MHz spacing
- Frequency Hopping: nominally 1600 hops/s
- Modulation: 0.5 BT GFSK modulation
- Raw Symbol rate: 1 Mb/s
- 3 Power Classes:Nominally < 0dBm, 0dBm, +20dBm
- Reference sensitivity: -70dBm, but some designs claiming -90dBm

Page 19

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Bluetooth devices operate in the ISM (Industrial, Scientific & Medical) band, on 79 channels from 2.402GHz to 2.480GHz. They communicate with each other using a digital frequency modulation method known as 0.5 GFSK. This means that a carrier is shifted up nominally 157kHz to represent a '1' or down to represent a '0', at a rate of 1 million symbols (or bits) per second. The '0.5' (Bandwidth Time) sets the -3dB bandwidth of the data filter to 500kHz. This is used to limit the RF spectrum occupied.

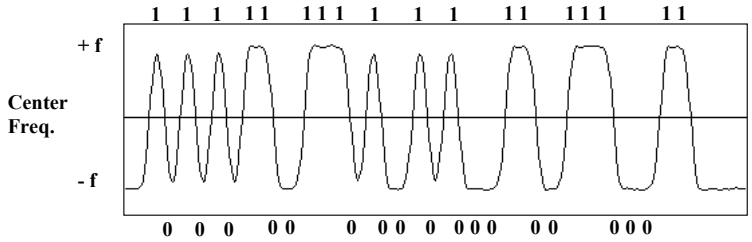
The peak data rate (including protocol overhead) is 721 kbps/sec

Communication between two devices is Time Division Duplexed, meaning that the transmitter and receiver alternate their transmissions in separate timeslots, one after the other. In addition, a very fast frequency hopping scheme (up to 1600 hops/sec) is employed to aid the reliability of the link in what is likely to be a crowded band. Recent U.S. FCC rulings indicate the band use is only going to increase.

Did you know: Microwave Ovens operate in this frequency band, but only use one half of the the line cycle

Several suppliers looking to offer 20dB better Rx sensitivity for non-interference limited applications

Waveform Characteristics



- Peak deviation +/- 157.5 kHz (nominal)
- 1 Million bits/sec
- Modulation index = 0.28 - 0.35
- '1010' deviation approx. 88% of max due to 0.5 BT Filter
- 500 kHz rate of modulation (2 bits per cycle)

Page 20

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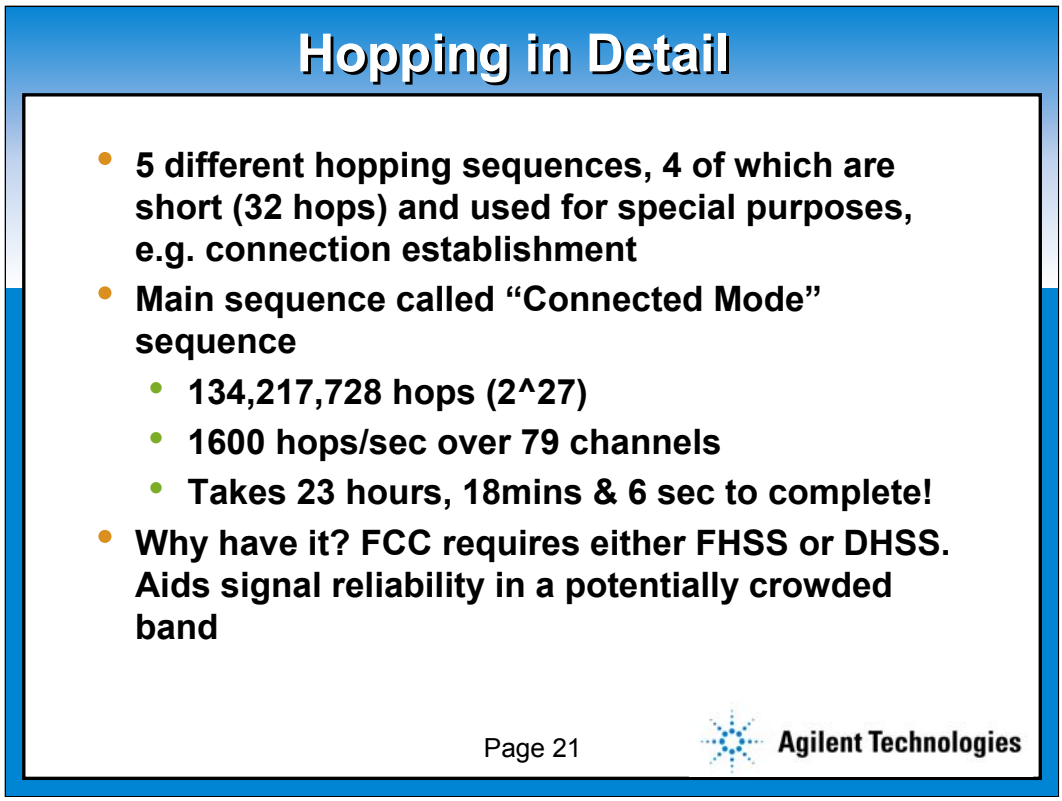
The Carrier Wave (CW) is modulated by shifting it up 157.5 kHz to represent a '1' or down 157.5 kHz to represent a '0', all at a rate of 1million bits per second.

The 0.5 BT Gaussian filter is used to limit spectral spread, thus allowing a 1 MHz channel spacing. The effect of this is that higher frequency bit patterns I.e. '1010' experience less deviation than long trains of 1's or 0's.

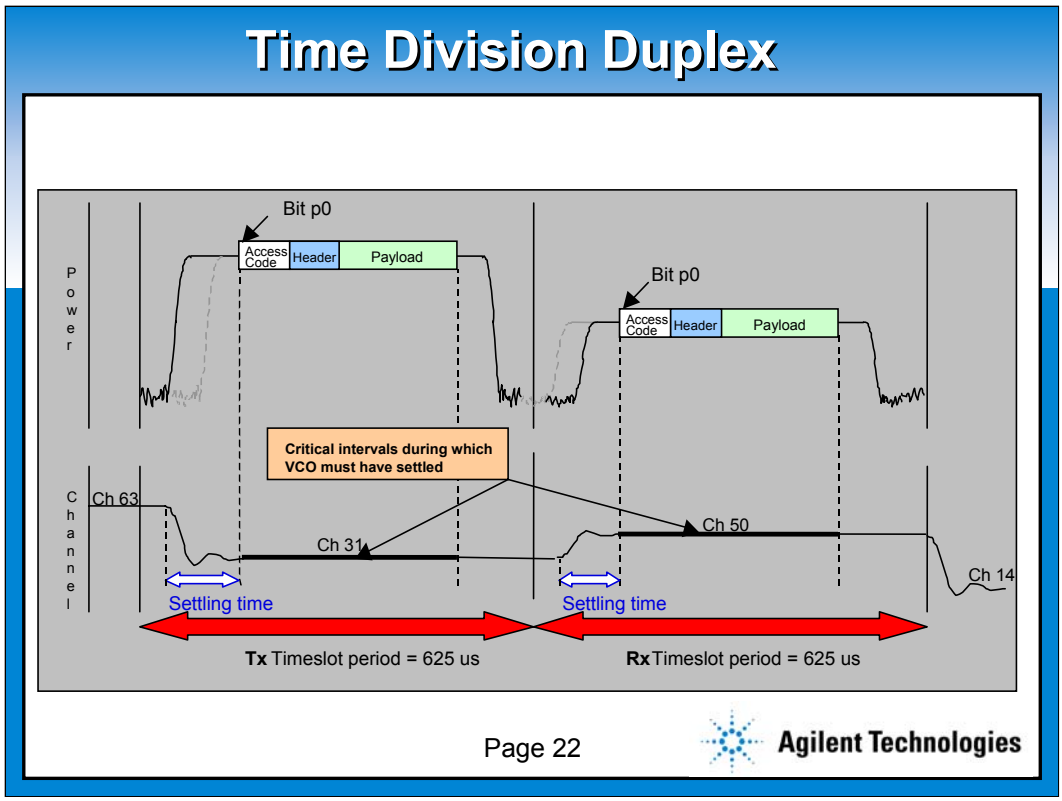
Note that although we get 1 million bits/sec, the fundamental rate of modulation is actually only 500 kHz because we get 2 bits per cycle.



There are 5 different hopping sequences, although 4 of them are used for special purposes such as paging & inquiry and utilize only 32 different frequencies. These show repetitive patterns over a short interval to allow quick synchronization between devices.

The main hopping sequence, known as the ‘Connected Mode’ sequence has a very long period length 134,217,728 and distributes the hop frequencies equally over the 79 channels. Therefore at a rate of 1600 hops/second, you would expect to see about 20 visits per second to each channel.

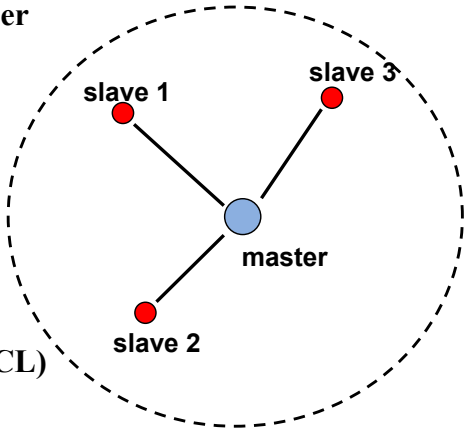
Frequency hopping helps combat any static interference present within the band and reduces the susceptibility to errors due to multi-path.



This illustrates possible timings for sending and receiving a 366us DH1 packet relative to the 625 us timeslots. The graph beneath the bursts shows the intervals (labeled "Settling Time") when the device must hop to the next channel frequency and how the VCO must have settled in time for transmitting or receiving the packet data. Note the start of the packet is not directly related to the rising edge of the RF burst as shown by the dotted lines representing possible alternative rising edges. The rising edge of the burst is not related to the beginning of the timeslot either. After transmission of all the packet data, the designer may choose to ramp down the power straight away, or wait until near the end of the timeslot.

Piconet

- All devices equal - configure as either master or slave
- A master can have up to 7 slaves in one piconet
- Hopping sequence determined by master
- Slaves gather information from master in order to follow hopping sequence
- Asynchronous Connection-Less (ACL)
- Synchronous Connection Oriented (SCO)



[Ericsson 2000]

Page 23

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At the basic link level, all devices are the same - you don't buy master devices and slave devices. Any device can take on the role of a master or a slave.

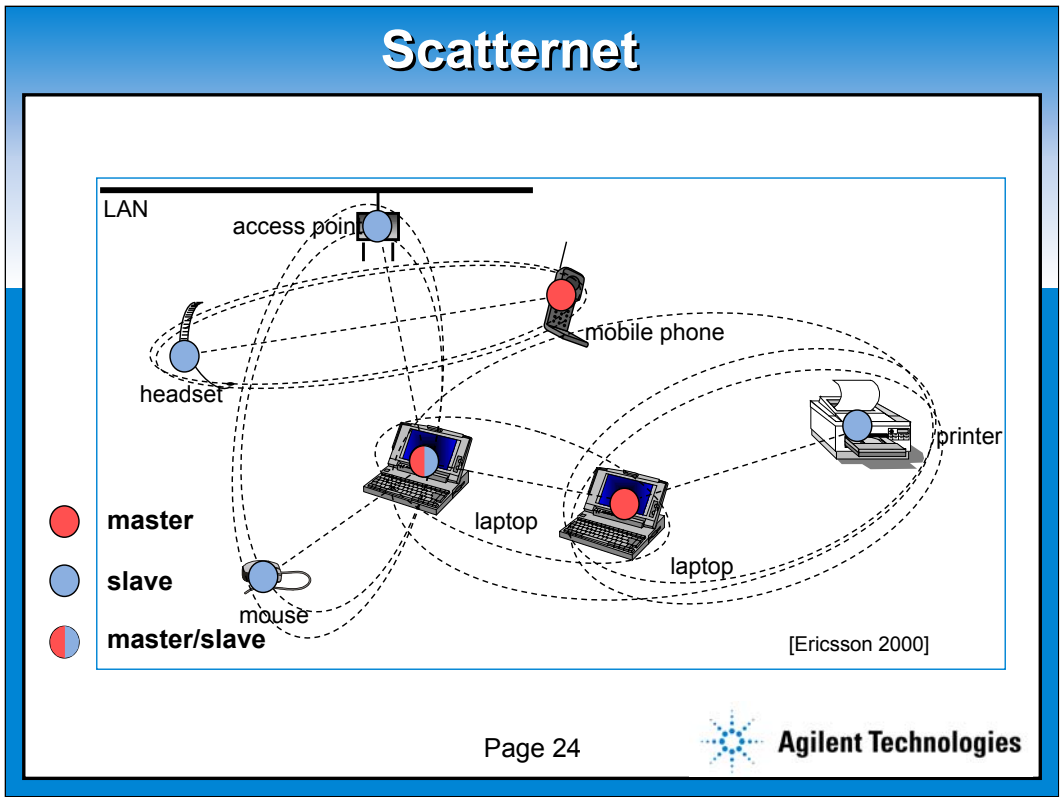
Once a master is established, it can have up to 7 slaves in one piconet - each slave being assigned a 3-bit AM_ADDR.

The master is also responsible for determining the pseudo-random hopping sequence to be followed. This is derived from the master's address (BD_ADDR) and the state of its free-running clock. Slave devices acquire the relevant information from the master during connection establishment so they can follow the hopping sequence of the master and thus participate in the Piconet.

The nature of the sequence is such that the hops should be evenly distributed over all 79 channels. That is, any channel should see roughly the same number of visits per second.

Once a connection has been established, devices can communicate either in a SCO (voice traffic) or ACL (data traffic) fashion.

A maximum of 3 SCO links can be established in one Piconet

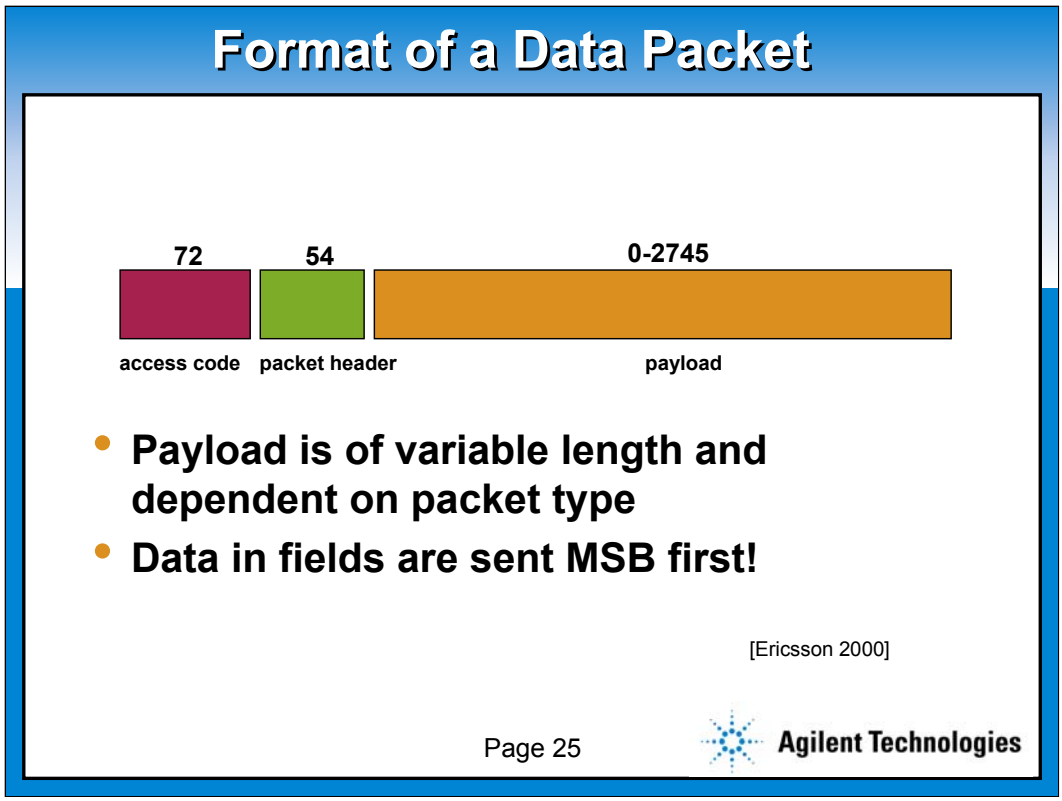


Here we have 3 piconets, each one containing a master and one or more slaves.

A master in one piconet can also act as a slave in another piconet thus forming what is called a 'scatternet'. Remember that slaves in a piconet cannot communicate with each other directly. The devices must reconfigure themselves such that one acts as a master.

Slaves can be active or parked - in a parked state they cannot communicate although remain synchronized to the master. This is also a power-saving mode.

Slaves can participate in more than one piconet, but only on a time division multiplex basis.

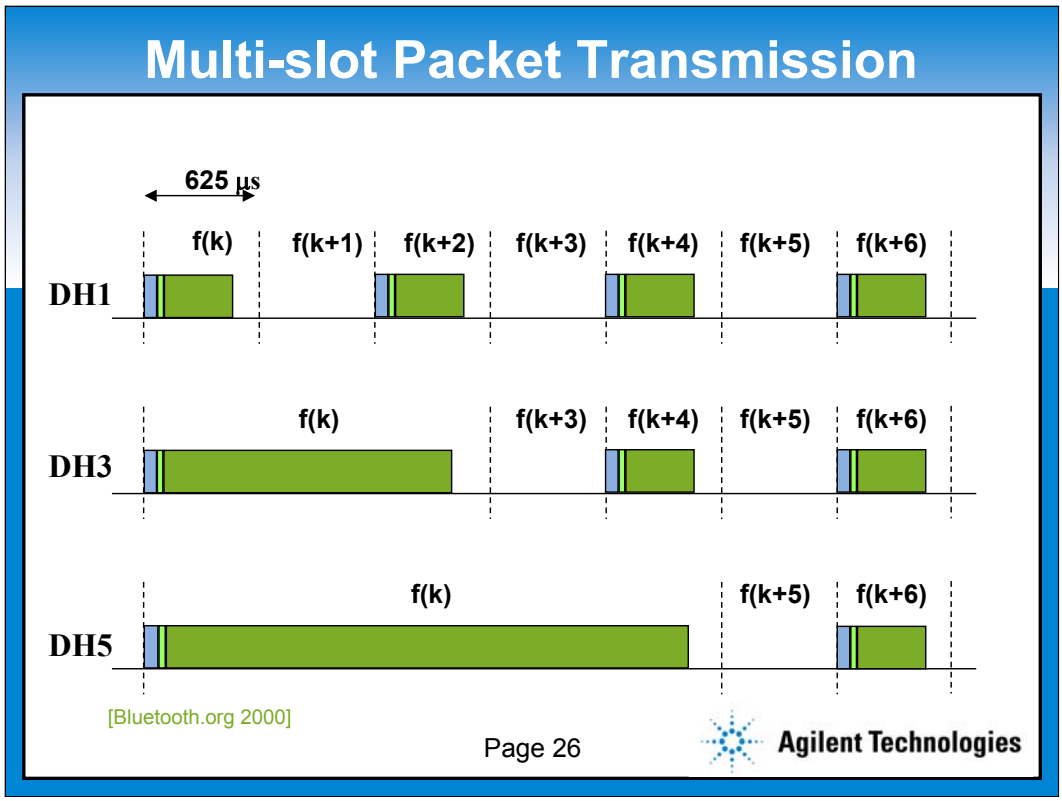


The above packet structure applies to DH1, DH3 and DH5 packets. The only difference among them is the length of the payload. Each of these packet types has a maximum length restriction on the payload, but each type can have a 0-length payload.

The payload starts with either an 8 (single-slot packets) or 16 (multi-slot packets) bit 'payload header' which indicates the number of bytes to follow. A 16 bit CRC is also included within the payload at the end.

Data is transmitted MSB first, so for a data field of '11110000', looking at the signal you will see '0000111'.

The access code identifies all packets exchanged on a single channel: all packets sent in the same piconet are preceded by the same channel access code. Therefore, a master receiving a packet can quickly assess which slave sent it by decoding this section of the packet.



Here we see the packet timings for links using DH1, DH3 and DH5 packets over a period of 7 625us timeslots. The first example shows a symmetric link because the transmit and receive packets are of the same length. A device transmits on even-numbered timeslots and receives on odd-numbered timeslots.

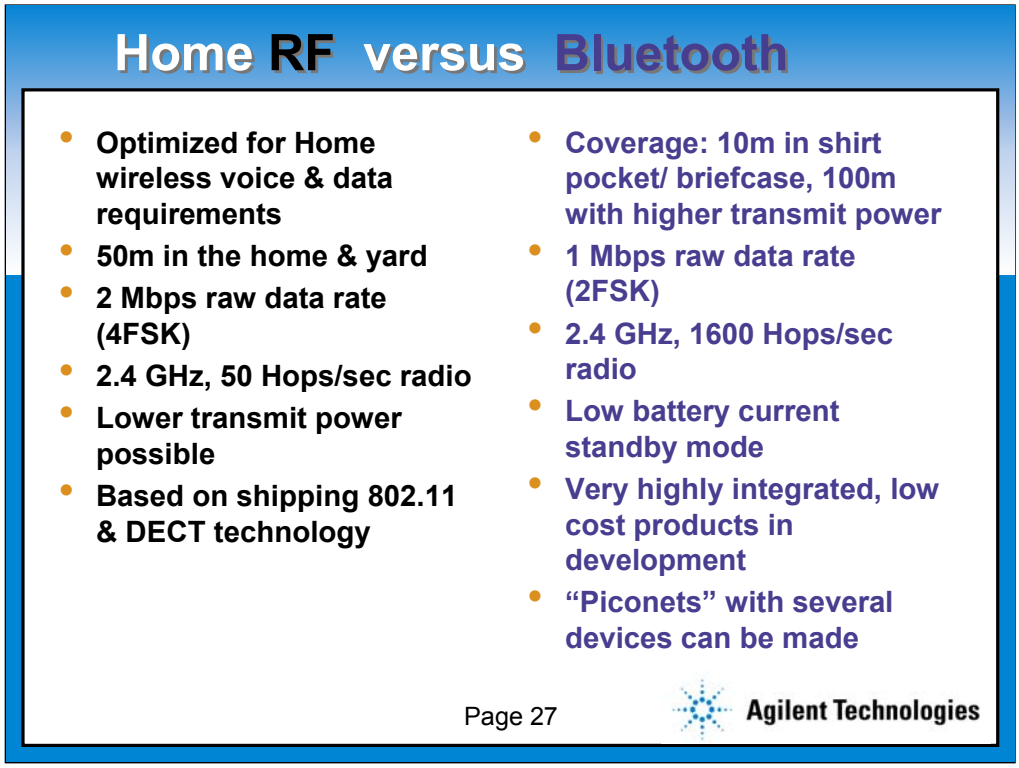
The DH3 packet uses 3 timeslots and the DH5 uses 5 timeslots.

The DH3 and DH5 examples represent asymmetric links, although the same rule applies regarding transmitting and receiving on even and odd-numbered timeslots.

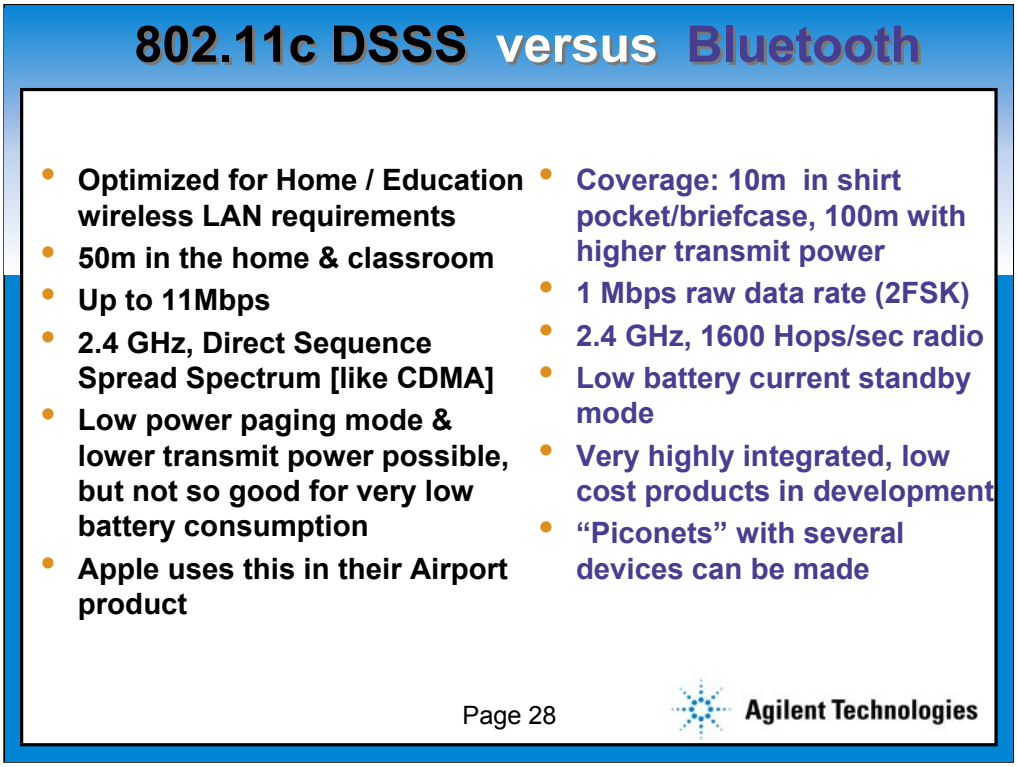
It is of course possible to have symmetric links involving DH3 and DH5 packets - the case of a symmetric DH5 link would lead to the slowest possible hopping rate of 1 hop every 5 timeslots I.e. once every 3.125 ms = 320 hops/sec

Because DH3 and DH5 packets have longer payloads they provide higher data throughput because of the fixed protocol overhead (access code + header)

Note that the above diagram shows the DH3 and DH5 packets in an asymmetric link situation, where the device transmits on the even numbered slots.



Feature review of HomeRF versus Bluetooth.



Feature review of 802.11 versus Bluetooth.

Infra Red versus Bluetooth

- Coverage: 0-1m, line of sight
- 9600 - 4Mbps now, 16Mbps in development
- Low power - good for battery applications
- Very low cost [<$2]
- Shipping in large volume
- One connection only

- Coverage: 10m in shirt pocket/briefcase, 100m with higher transmit power
- 1 Mbps raw data rate (2FSK)
- 2.4 GHz, 1600 Hops/sec radio
- Low battery current standby mode
- Very highly integrated, low cost products in development
- "Piconets" with several devices can be made

Page 29

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Feature review of Irda versus Bluetooth.

Summary

Bluetooth Technology:

- Bluetooth modulation is straightforward, but the radio band is noisy and the design must balance performance with cost & current consumption
- Cables and IR can transfer data but can't perform unconscious proximity detection

The Bluetooth Specification defines:

- An RF system that can operate in a noisy environment
- The Application Profiles that can make use of such a link

References:

- Agilent Technologies Application Note AN 1333

Page 30

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Agilent Technologies can provide equipment that meets the wide range of test needs found in the Bluetooth RF development and manufacturing environments.

Question and Answer Session

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Bluetooth Basics

Peter Cain

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Page 31

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