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An overview of Wireless LAN standards
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Gibraltar
'top of the rock'
en route to
Tangier


Gibraltar (from plane)
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Merging of Computing and Communications Technologies has led to revolutionary changes in our working and personal lives.
Most evident is the proliferation of mobile telephones and laptop and pocket computers.
Concept: everyone and everything should be capable of being linked by a communications channel at all times !
The main obstacle to achieving this vision is the need for connecting cables.


Photos of real installations !
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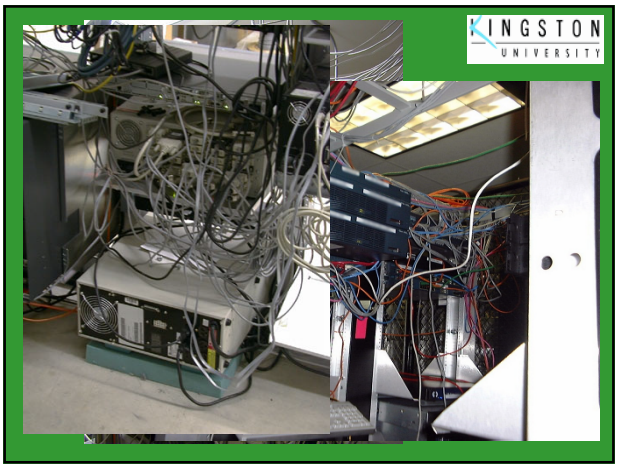


Typical (?) domestic scene

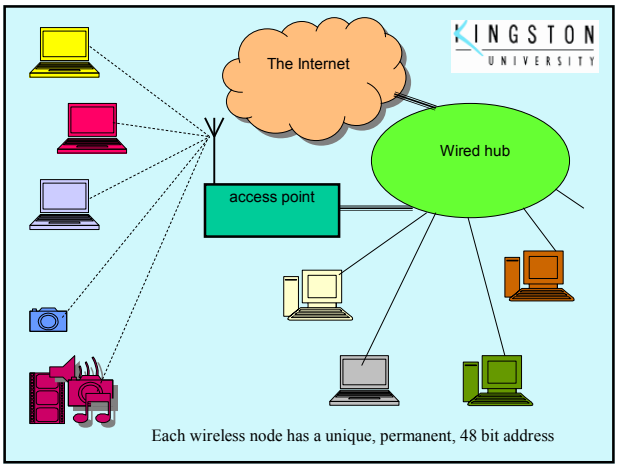
Low-cost Wireless Local Area Networks (WLANs) provide an escape from the need for physical connections

WLANs are being deployed in the office, the home, in shopping malls, in factories, etc. This deployment is crucially dependent upon Standards, to ensure proper interoperability between the components of the WLANs and to prevent interference.

The 'ideal': no connecting wires!

Image is property of Bluetooth SIG: http://www.bluetooth.com/news/dwnlds.asp

BT's publicity (Stansted airport)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The Internet
Wired hub
access point
Each wireless node has a unique, permanent, 48 bit address


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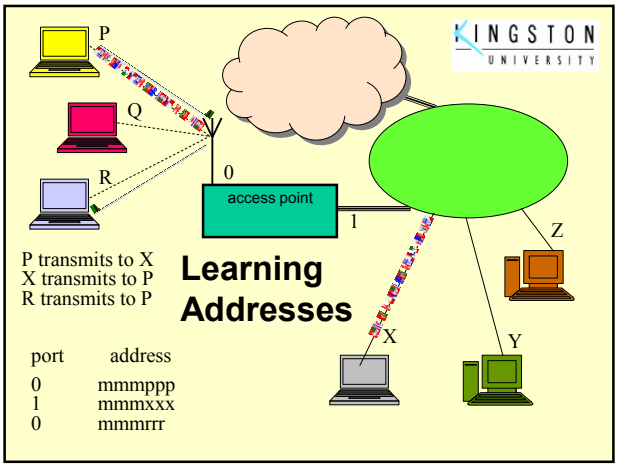
Real Products
Wireless ADSL routers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P
Q
R
0
access point
1
Z
X
Y
P transmits to X
X transmits to P
R transmits to P
Learning Addresses
port address
0 mmmppp
1 mmmxxx
0 mmmrrr


GET IEEE 802 IEEE Standards
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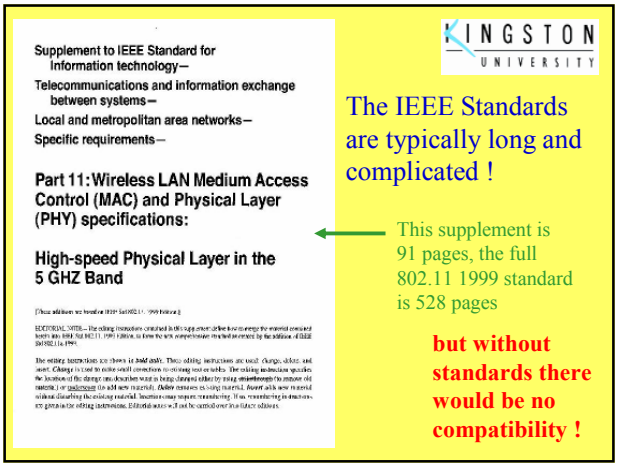
Many Standards have been developed, and the IEEE '802.11' working groups and ETSI have made a tremendous contribution.
This large number of standards can be quite confusing !
ETSI
IEEE 802 Wireless World


Supplement to IEEE Standard for Information technology—
Telecommunications and information exchange between systems—
Local and metropolitan area networks—
Specific requirements—
Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications:
High-speed Physical Layer in the 5 GHZ Band
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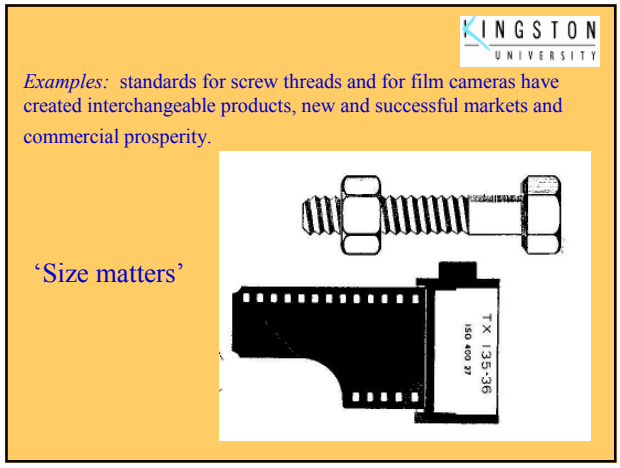
The IEEE Standards are typically long and complicated !
This supplement is 91 pages, the full 802.11 1999 standard is 528 pages
but without standards there would be no compatibility !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Examples: standards for screw threads and for film cameras have created interchangeable products, new and successful markets and commercial prosperity.
'Size matters'

Most Standards specify operation in the unlicensed **ISM** *(Industrial Scientific, Medical)* frequency bands.

With some variations, these bands are available worldwide; however, sharing with other unlicensed services has to be allowed for.

The unlicensed bands:

ISM bands: 915 MHz, 2.4GHz, 5 GHz

U-NII band (in USA) – 'unlicensed national information infrastructure':
300 MHz bandwidth allocated in the 5 GHz band

'spectrum etiquette' rules [*] had to be developed for **co-existence** in the un-licensed bands
"CDMA/CA" – not "CDMA/CD"

* 1. 'listen before talk' protocols
2. Low transmitter power
3. Restricted transmit durations

Új Némzeti Szinhaz (New National Theatre) Budapest

Új Némzeti Szinhaz, Budapest

Transmission Methods:

Three principal alternatives have been chosen:

Direct Sequence Spread Spectrum (DSSS)
Frequency Hopping Spread Spectrum (FHSS)
Orthogonal Frequency Division Multiplex (OFDM)

OFDM relies for success upon the use of digital processing, especially the use of FFT.

More about spread-spectrum communications:

TDM: fixed channel time-slots, sequenced in time
FDM: fixed channel frequency-slots, sequenced in frequency
Spread-spectrum (also includes Code division multiple access – CDMA):
Channel slots move in a complex (pseudorandom) way around the time-frequency plane

Principal Classical Spread-spectrum methods and applications
1. Direct sequence – for signal hiding, covert sharing with other users
2. Frequency hopping – improved multi-channel spectral utilisation, agile 'difficult to track/intercept transmissions'

Frequency-hoppers:

Two main classes:

many bits per hop *or* **many hops per bit.**

Bluetooth and similar schemes use the first class.

example (SWAN hopper [*]):

79 frequencies F[j] per sequence, **22** different sequences per family, chosen as:

F[j] = {fj[0], fj(1], fj[2],……..fj[79]}

fj(i) = (i × j) mod 79

i = 0, 1, 2, 3, ……. 79 i = sequence-step

j = 7, 10, 13, 16, 19, ……. 67, 70 j = sequence in family for 'Family ONE'.

F[7] = 0, 7, 14, 21, 28, 35, 42, 49, 56, 63, 70, 77, 5, 12, 19, 27, 34, 41, 48, …

F[10] = 0, 10, 20, 30, 40, 50, 60, 70, 1, 11, 21, 31, 41, 51, 61, 71, 2, 12, 22, ….

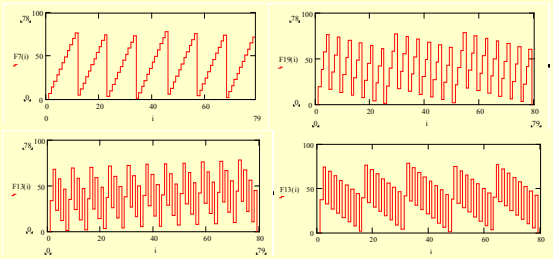
F[13] = 0, 13, 26, 39, 52, 65, 78, 12, 25, 38, 51, 64, 77, 11, 24, 37, 50, 63, ….

etc.

* see: Chandrahasa and Broderson, J. of VLSI Signal Processing Systems, 1996 (date ?)

Frequency-hoppers:

example (the SWAN hopper):



4 typical hopping sequences from the 22 in Family ONE

All are mutually weakly-orthogonal

Travelling to Scuol, Switzerland for NDES'03 workshop

Alexander Nevsky Cathedral, Sofia, Bulgaria

Bluetooth Wireless Technology

A short range (up to 10m) wireless networking method for personal, office and industrial environments

80 MHz bandwidth frequency-hopper, operating in licence-free 2.4 GHz ISM band *(Industrial, Scientific, Medical band)*

Origins:

- 1998: Bluetooth *Special Interest Group* (SIG) formed.
  - Founders: IBM, Intel, Nokia, Toshiba
- Aimed for a global standard.
- Initially adopted by 70 SIG members, increased to 3000 SIG members by end of 2001

Concepts:

- Intended to be a LOW COST solution, for avoiding connecting-cables, etc.
- Target price for market-penetration:
  $5 or less for the hardware (chip) costs

Intention initially was to achieve 100% domination of the world market by having a universal royalty-free standard.

Name:

- Originated from Danish king, Harald Blåtand, considered to have united the Scandinavians in 10th century AD.
- Bluetooth Standard supposed to 'unite' personal-computing devices.
- Was to be a temporary name but became permanent.
- Bluetooth is a trademark of the SIG

Market penetration:

- Ericsson and Nokia guarantee 100% use in their mobile phones.
- Microsoft decided against including Bluetooth support in Windows XP
- 560 million Bluetooth devices by 2006 (prediction by industry-analyst Ovum)
- (slower growth than initially predicted)

What the 'user' gets:

Competing standards?

'**Wi-Fi**' = IEEE 802.11b (and 'a' and 'g')

- This is 'wireless ethernet' – a replacement for wired networks of many computing devices
- **It is *claimed* that Wi-Fi and Bluetooth do not compete**

European hiperLAN (an ETSI standard)
uses licence-exempt 5 GHz band,
24 Mb/s data rate
Same application area as Wi-Fi

Competing standards?

European hiperLAN

Intended to be equivalent in performance to standard **Ethernet**, with some support for isochronous services (e.g.audio, video) with seamless roaming.

50 metre range, 5.150 to 5.300 GHz, five channels available, each 23 MHz wide
17.1-17.2 GHz band may be used in future
modulation: GMSK (for high rate, 23.5 Mb/s)
FSK (for low rate, 1.47 Mb/s)
BCH error correcting code, CRC for error detection

Competing standards?

An enhanced standard, European hiperLAN2 is now available – but commercial future seems doubtful.

In Japan, **HiSWANa** is a similar standard
There is an intention to 'harmonise' 802.11a and hiperLAN2 and HiSWANa

hiperLAN slogan: ***World without wire***

No doubt belongs with the ***Paperless Office***

The IEEE 802 LAN standards:

802.11 is for **Wireless** Local Area Networks, and developed from an 802.4L (wireless) category (~ 1977) of **802.3,** the well-known **Ethernet** (CSMA/CD) LAN standard for wired (copper or fibre) networks.

The original 802.11 was for rates up to 2 Mb/s, allowing Direct Sequence or Frequency-Hopping Spread-Spectrum in the unlicensed 2.4 GHz ISM band, or use of the infrared band (850-950 nm).
(Direct Sequence standard allows only 11-bit spreading code)

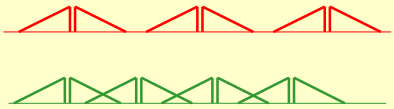
Many versions of 802.11 arose, particularly for higher data rates (up to ~ 55 Mb/s)

The IEEE 802 LAN standards:

802.11b is a 'high-rate' version for up to 11 Mb/s.
- DS SS uses 26 MHz bandwidth and 52 carriers in a 20 MHz bandwidth, each carrier ~ 300 kHz wide. Each carrier capable of up to 1.5 Mb/s

802.11g – for up to 22 Mb/s

802.11a is more recent, using Orthogonal FDM ('OFDM') in the 5 GHz band, capable of up to 54 Mb/s.

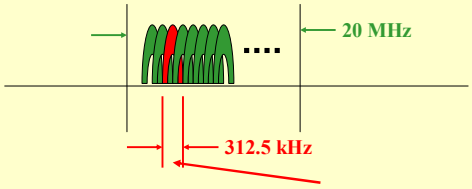


Normal FDM required 'guard bands' to separate the channels

OFDM uses partially orthogonal carriers, allowing some overlap

802.11a - the fastest 'Wi-Fi' so far

Each channel of OFDM in the 5 GHz band is 20 MHz wide, each has 52 carriers, 312.5 kHz wide (48 for data, 4 for pilot signals)



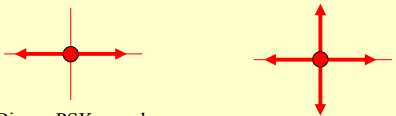
Raw data per carrier: 125kb/s – 1.125Mb/s

BPSK, QPSK, 16-QAM, 64-QAM

6Mb/s to 54Mb/s total in a 20MHz Channel.

Getting more '*bits per baud*'

Binary ASK, FSK, PSK *carry one bit per transmitted symbol.*
The key to getting more bits in a given bandwidth is to send more bits per symbol – but immunity to interference is worse



Binary PSK – each vector is one bit

0, 1

Quad PSK – each vector is two bits, Gray-coded

00, 01, 11, 10

Bit rate for QPSK is thus **double** that of BPSK for the same symbol rate.

Much more complex, multi-level, multi-phase schemes are used for higher data rates in the recently developed Wireless LANs

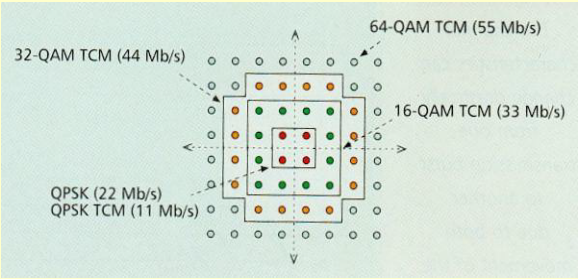
Getting more '*bits per baud*'

64-QAM

is used for the highest rates in the current WLAN standards

25dB SNR required to get a 10^{-5} error probability

Getting more '*bits per baud*'



TCM = trellis-coded modulation

Diagram from: Karaoguz, J. in IEEE Communications Magazine, p99, Dec 2001

Heroes Square (Hösök tér), Budapest

Bluetooth communications method:

Frequency-hopping spread-spectrum used with *1600* hops/sec at *79* frequencies:

at $(2402 + k)$ MHz, $k = 0,1,2,....78$

e.g. *2402, 2403, 2404, 2405, 2406,…… 2480*

The frequency-sequence is selected in a pseudorandom manner.

All Bluetooth devices share the same frequency space, and the band may be used concurrently by other ISM devices

*Frequency-hoppers may use **many hops per bit** or **many bits per hop*** – Bluetooth uses the latter

Bluetooth communications method:

Maximum data rate:

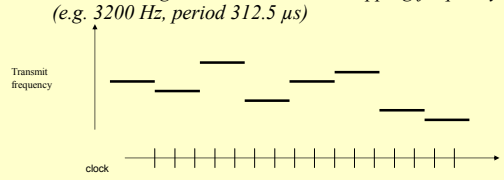
1 Mbit/sec, Gaussian binary frequency shift keying

Each device has:

a unique 48 bit hard-wired device-address for identity

$2^{48} = 281474976710656 \approx 2.815 \times 10^{14}$ *(e.g. lots of devices possible!)*

a 28 bit clock running at twice the nominal hopping-frequency (e.g. 3200 Hz, period 312.5 µs)



Bluetooth communications method:

The Bluetooth Standard has been updated to version 1.2

This version uses an adaptive frequency hopping method, intended to provide better interference-immunity.

A priority-scheme for voice channels is included.

Slightly higher data-rates expected.

Bluetooth 2 provides for data rates up to 3 Mb/s – the main objective is to maintain data rates when there is congestion. Products available ~ summer 2005

DQPSK instead of GFSK is used for the packet payload.

"8DPSK" (45°) can be selected, giving 3 bits per symbol, hence 3 Mb/s

Competing standards?

Bluetooth is accepted as a candidate standard **IEEE 802.15.1**

The IEEE 802.15 standards working group covers the development of a family of communications standards for ***Wireless Personal Area Networks*** (WPANs), for up to 55 Mb/s

Bluetooth versus Wi-Fi:

'Wi-Fi' (IEEE 802.11b)

- indoor range 45m, outdoor range 300m
- **direct-sequence spread-spectrum**
- **also** in 2.4 GHz ISM band
- Wi-fi data-rate is up to 22 Mb/s
- *even 22 Mb/s not enough for some consumer applications! For faster needs, IEEE 802.11g provides ≈ 55 Mb/s*

Wi-Fi is a higher-cost, higher-power scheme
Chip costs probably > 3 times **Bluetooth** chip-cost
ARM had all of 802.11 on 'half a chip' by 2003

Competing technologies?

Infra-red vs. Bluetooth

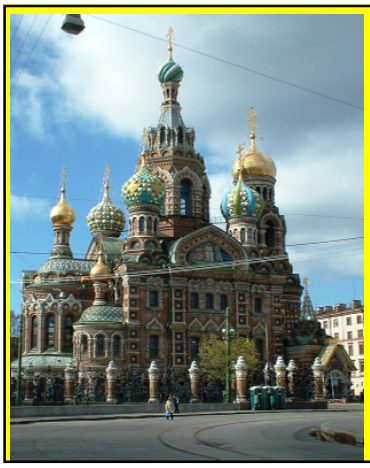
infra-red is 'line of sight', Bluetooth is not

IEEE 1394 'Firewire'

Copper or fibre link replacing many separate cables.
Much faster, up to 400 Mb/s
Hot-plugging support, asynchronous and isochronous data transfers
Popular and Important, but not a LAN standard

PLC (power line carrier)
Uses existing mains power wiring in a building
(noisy time-variant transmission medium)

HomePNA (Home Phone-line Networking Alliance)
Uses existing phone extension wiring in a building



St Petersburg, Russia

'Church on Spilled Blood'

'Bluetooth everywhere' concept:

The development of **Bluetooth** was based on the concept that in future many more devices will be linked – however, the standard limits the applications in several ways:

1. The need for rechargeable batteries (or a mains power connection).
2. The set-up time for joining a WLAN – it may be too long
3. The limited number of nodes in a **Bluetooth** Network (Piconet).
4. Cost too high for some applications

'Bluetooth everywhere' concept – typical example:

Lighting and heating control:

1. uses sensors to turn off lights and heat in unoccupied rooms
2. detects movements of occupants and adjusts conditions to match their needs.
3. pre-heats rooms in advance of owner's return by detecting approach of owner's car or mobile phone.

'Bluetooth everywhere' concept – typical example:

Personal possessions control:

Valuable or portable items permanently transmit their location, so can be tracked and recovered if lost or stolen

This could include children, elderly relatives, pet animals etc.

This might have a big impact on insurance premiums

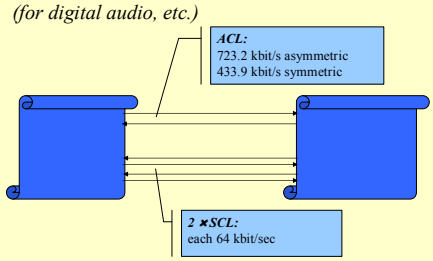
Dubai, UAE

Bluetooth information links:

Each device supports:

One *Asynchronous Connectionless Communications link (for file and data transfers)*

Two *Synchronous Connection-oriented Communications links (for digital audio, etc.)*



Bluetooth information links:

Error-handling:

ACL: packet-sequence numbers are transmitted, and the receiver can request a re-transmission.
Uses flow-control, and a 16 bit CRC

SCL: No re-transmission, have to accept 'as-is' – can use forward error-correcting-codes

The links are NOT fast enough for some Consumer applications !

Downloads from Digital cameras, Photo Imaging, etc.

High-definition DVD requires 9.8 Mb/s .

19.2 Mb/s for MPEG2 video data stream to High-definition TV Display.

Real-time 1024×768 60Hz computer graphics requires 38 Mb/s

Game-consoles linked to virtual-reality 3D viewing goggles

Statue of St. Stephen, Budapest.

Statue of St. Stephen, Budapest (modern version !)

'Bluetooth everywhere' concept ??????

For some of the **suggested** applications the power consumption and cost of Bluetooth is likely to be too great.

This led to the development of ideas for even cheaper and lower cost WLANs – and to the Zigbee Alliance

Zigbee is now associated with standard 802.15.4

ZigBee Alliance

Name: :

Supposed to have some connection with the 'dance' of a honey bee when returning to the hive. The bee signals by a zig-zag dance the direction and type of food available.

Zigbee

Promoting Companies:
Honeywell, Invensys, Mitsubishi, Motorola, Philips

Zigbee aims for a device cost of $1 and static networks of many nodes each with infrequent use, low data rate and quick 'start-up' (30 ms)

Compare **Bluetooth**, which can take several seconds to synchronise when 'starting-up' nodes.

Zigbee Alliance.

ZigBee supports 255 active nodes per *'network coordinator'*.

Multiple *'network coordinators'* can be linked to form extremely large networks of over 4,000 unique nodes in a single network with high system reliability.

Compare with **Bluetooth** provision for 8 active nodes per Piconet.

Zigbee

ZigBee nodes typically in 'hibernate' mode for most of the time, using a only a few microamps.

Called the **'wireless dormouse'**

Compare with **Bluetooth** node:
about 100 microamps when ' sleeping'.

Zigbee

Applications examples (from Zigbee web-site):

- Wireless home security
- Remote thermostats for air conditioners
- Remote lighting control, curtain controller
- Call button for elderly and disabled people
- Universal remote controller to TV and radio
- Wireless keyboard, mouse and game pads
- Wireless smoke and Carbon Monoxide detectors
- Industrial and building automation and control (lighting, etc.)
- Electronic toys

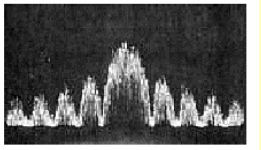
ZigBee

- DS-SS
- 11 chips / symbol
- 62.5 K symbols / s
- 4 Bits/ symbol
- Peak Information Rate: ~128 Kbit/s

Bluetooth

- FH-SS
- 1 M Symbol / s
- Peak Information Rate: ~720 Kbit / s

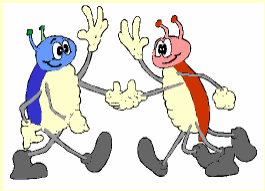
Zigbee DS-SS spectrum



Bluetooth FH-SS spectrum

From: **Venkat Bahl** (ZigBee Alliance)

'Comparison of Bluetooth and ZigBee protocols'



Bluetooth *and* Zigbee

(from ' ZigBee and Bluetooth – Competitive or Complementary?' Sep. 2002,
Venkat Bahl, ZigBee Alliance)

Zigbee

uses **2.45GHz ISM** band, **250kb/s** data-rate,
Direct Sequence Spread Spectrum, with a matched filter receiver.

- Zigbee has to co-exist with the Frequency Hopping **Bluetooth** in the same frequency band – but it is claimed that the low duty cycle of Zigbee will cause little interference. Range up to 30m.
- Devices should operate for several years on two 'AA' batteries (**Bluetooth** devices normally require a re-chargeable battery or access to power supply).

Future developments

UWB (**ultrawideband**) now being explored because of congestion in the ISM bands (802.15.3a working group)

Very short pulses (0.2 to 1.5 ns), 2 to 14 GHz spectrum, up to 500 Mb/s data rate possible.

Power density so low that other users will not notice the UWB transmissions

But [1] ……such transmissions are currently illegal in many parts of the world.

UWB (**ultrawideband**)

But [2] …… FCC imposed unexpected restrictions on UWB (defined as any transmission of more than 500MHz) and on 'carrierless' transmissions.

Now allowed only in 3.1-10.6 GHz range

Supposed to be due to 'FCC concerns about interference'

Two competing technologies:

Multiband OFDM Alliance (OFDM) – including Intel as advocate

XtremeSpectrum Group – including Motorola as advocate

No agreement in the 802.15.3a working group so far ?

Future developments

802.16a 'Fixed Wireless'

74 Mb/s using OFDM

No handovers, users must stay within range of their base-station

50 km wide networks could be built

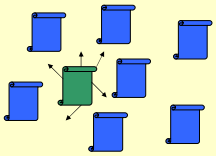
Toronto Waterfront

Red sandstone, Nevada

Bluetooth networking:

Bluetooth devices form 'Piconets' in order to communicate.

A piconet comprises up to 8 devices, in which one device takes the role of '*master*' while the others (up to 7) are '*slaves*'

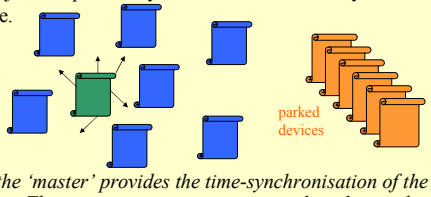


The 'master' transmits 'enquiry messages' at 1.28 second intervals in order to locate bluetooth devices which are in range. This is followed by the transmission of invitations to join the piconet, addressed to specific devices.

Bluetooth networking:

Bluetooth 'Piconets'

Additional devices (exceeding the maximum of 8 active ones) may be registered with the master and 'parked' in an inactive mode – until invited to join the piconet by the master. Others may be in 'standby' mode.



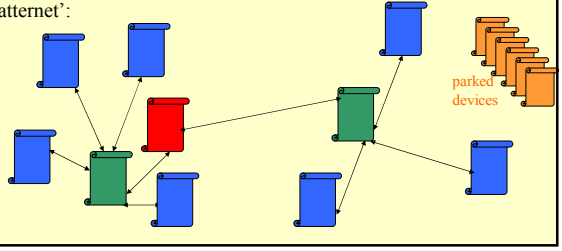
The clock of the 'master' provides the time-synchronisation of the whole piconet. The master transmits in even-numbered time-slots and the slaves all transmit in odd-numbered time-slots (timing based on 2nd lsb *of master clock – since* clock = 2 × hop-rate

Bluetooth networking:

Bluetooth 'Piconets'

The master allocates a member-address to the active slaves and controls their transmissions.
A master and slave may agree to reverse their roles.

A device may belong concurrently to several piconets and so form a 'scatternet':



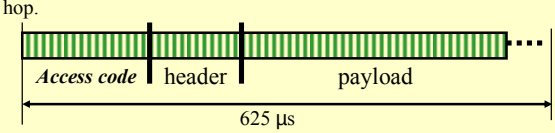
Teotihuacan, Mexico

Aspendos Amphitheatre (near Antalya), Turkey

Bluetooth networking:

Bluetooth 'Piconets'

The devices transmit message packets within one 625 µs frequency hop.



The master determines the frequency-hop sequence.

multi-slot packets are allowed: for these, the frequency-hopping is temporarily stopped so as to provide a constant transmission-frequency for the duration of the message.

Bluetooth Packets:

17 basic packet types! The standard packet has a 72 bit Access Code, a 54-bit header, and a payload of 0 to 2745 bits.

A standard blueooth packet

ACCESS CODE [72]	HEADER [54]	PAYLOAD [0-2745]

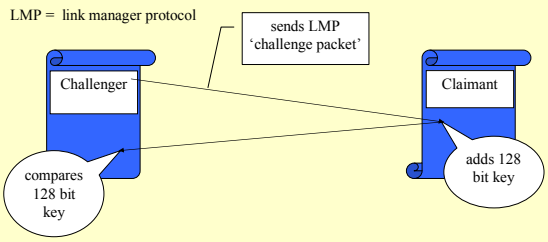
* size in bits

ACCESS CODE	Access code is used for synchronization, DC offset compensation and identification.
HEADER	Header contains link control (LC) information.
PAYLOAD	Payload carries voice and data fields of upper layers.

Bluetooth Security:

NOT public-key cryptography – uses a shared secret key,

Authentication uses a 128 bit key



if the keys are the same, this verifies claimant-identity to challenger

Bluetooth Security:

following successful authentication, link encryption may follow

Encryption uses a key of ≤ 128 bits

[upper limit controlled by Government Regulations – to allow interception by security agencies such as GCHQ, NSA.etc.]

The encryption key changes with each packet transmitted.

If encryption is used, the whole connection is encrypted, e.g. the asynchronous and synchronous links are all encrypted. Called 'Wired-Equivalent Privacy (WEP) was claimed to be 'adequate for financial transactions' but this is no longer accepted as true

WLAN Security:

There are increasing concerns about the security of WLAN transmissions, and the 802.11i working group is addressing this issue.

General issues:

'AAA': Authentication, Authorisation, Accounting + Encryption

Bluetooth higher level protocols:

RFCOMM protocol
Emulation of RS-232 nine-wire serial connection

Telephony protocol (TCS-AT)
Uses the RFCOMM protocol to transmit AT commands

and more ……..

Bluetooth transmissions:

Transmit power classes: 1mW, 2.5mW, 100mW

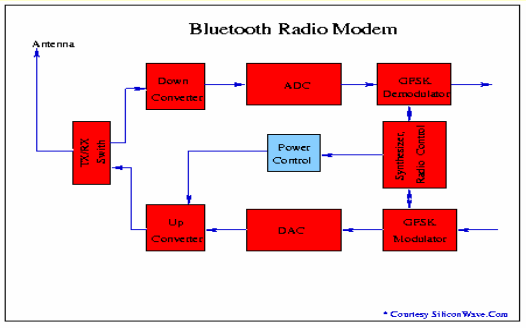
Most devices expected to be in 1mW or 2.5mW class, with 10cm to 10m range

Transmitter Power Control is required – the Bluetooth device must be able to adjust the transmitted power in accordance with the needs of the receiver.

Keleti palyaudvar (Eastern rail terminus), Budapest

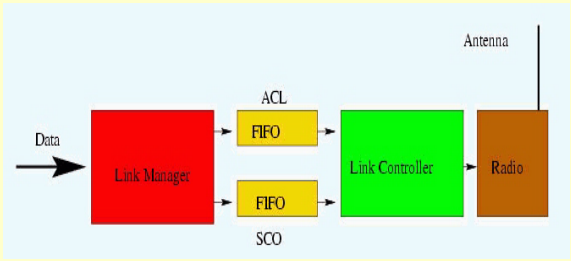
Bluetooth Promotional Movie

Block Diagrams



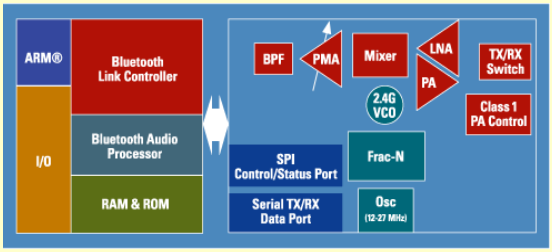
from *Palowireless* web site

Implementation



from Palowireless web site

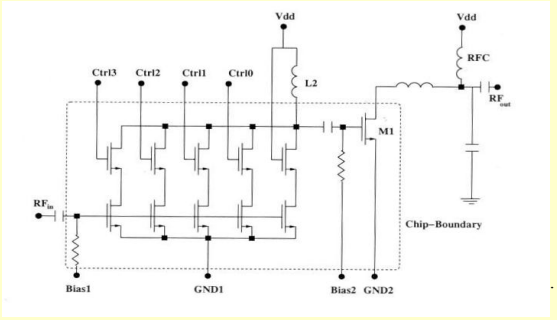
Implementation



Motorola's 'Bluetooth Platform' - a 'complete silicon solution', with software stack, reference designs, and development kits.

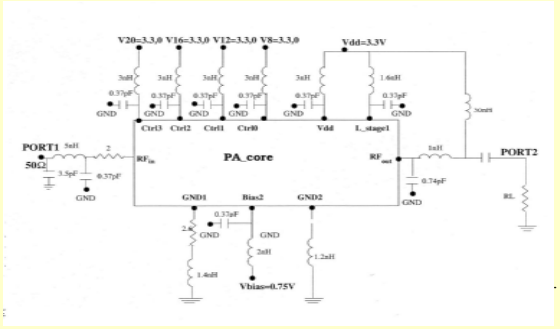
from Motorola web-site

CMOS Power Amplifier Implementation



from *Hella and Ismail*, RF CMOS Power Amplifiers

CMOS Power Amplifier Implementation



from *Hella and Ismail*, RF CMOS Power Amplifiers

Bluetooth hardware:

Design goals and results (from **Cambridge Silicon Radio**)

requirements:

Integrated circuit dies to cost less than $2 each (in 2001)
Manufacture 10^9 units per year
End-product test time ≤ 3 secs.

implications:

Pure CMOS, no production trimming, 90% yield
Single chip with radio-frequency and baseband and DSP and microcontroller and memory.
Preferably no r.f. components off-chip

design problems:

Low Q of on-chip inductors
Receiver is 5cm from +33dBm mobile phone transmitter
Transmission to 100m required, so how to keep r.f. from going all over the integrated circuit chip?

Bluetooth hardware:

Cambridge Silicon Radio claims to be the world's leading supplier of 'Bluetooth solutions'

1st Nov 2001, over 50% of Bluetooth products listed by Bluetooth SIG contained BlueCore™1, launched in 2000

Bluetooth single chip – BlueCore2 – meets the $5 target price 1.8V supply, <50mW (27μW in sleep mode), 0.35μ CMOS 0.18μ **BlueCore3** *announced in July 2003 for Bluetooth 1.2 std. Now* **BlueCore4** *(Bluetooth 2 and Enhanced Data Rate) and* **BlueCore5**

see www.csr.com

United Kingdom has a substantial activity in the design and licensing of processors and other silicon hardware for mobile applications.

Now . . . . .

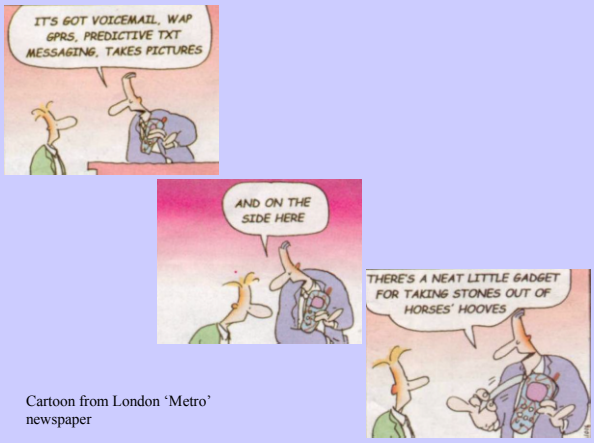
Bluetooth is becoming common in the mobile phone environment

A new activity called Bluejacking has emerged !

For Motorola V 500:

1. Go to Phone Book
2. Select New Entry
3. Insert the message you want to send in Name, email address etc.
4. Save contact
5. The contact will now be highlighted in the phone book
6. Press the Info button (one with 3 lines on)
7. Scroll to Send and select Send
8. Choose Bluetooth
9. Select Look For Devices
10. Then select the device you want to bluejack
11. That's it!

Old and New Dubai, February 2005



Cartoon from London 'Metro' newspaper

From:
http://www.firstcontactengineering.com/fce_comparison.htm

Technologies	Wi-Fi	Zigbee	Bluetooth
Standards	IEEE802.11b/g/a	IEEE802.15.4	IEEE802.15.1
Data Rate	11(b) to 54 (a,g) Mbps	10 – 115 kbps	721 kbps
RF Frequency Band	2.4 and 5 GHz bands	915 MHz, 2.4 GHz 898 Mhz in Europe	2.4 GHz
No. of Nodes	100+	65,000	8
Range	100m	10-75m	8m (classII, III) to 100m(classI)
Modulation	DSSS and OFDM	DSSS	FHSS
Topology	Star-access point	Mesh network	Peer to Peer
Current (typ.)	350 mA	30 mA	65 to 179 mA.(classI)
Battery Life	1-3 hours	Years (at low duty cycle)	4-8 hours (streaming audio)
Applications	Internet access, Computer networking, Retail inventory, Computer peripherals, Wireless networking	Wireless sensors, Industrial controls, Wireless switches, HVAC, Meter reading	Streaming audio, Cell phone, Hands-free, Computer peripheral, Printer cable, Multimedia

The Future

The Bluetooth Network Encapsulation Protocol (BNEP) provides emulation of Ethernet over Bluetooth links

This will bring **TCP/IP** and **Voice-over-IP** to the mobile end user.

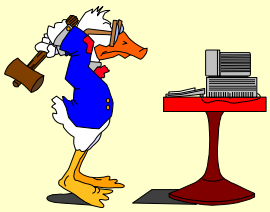
Economic viability of products will soon result in the Ethernet Medium Access Controller and the Bluetooth components, together with full real-time TCP/IP facilities, all being integrated on a **single chip**

We have come a long way since Euler invented graph theory to solve a network problem !

The Future

The end of the plain old telephone system (POTS) ?

Thank you for your attention!



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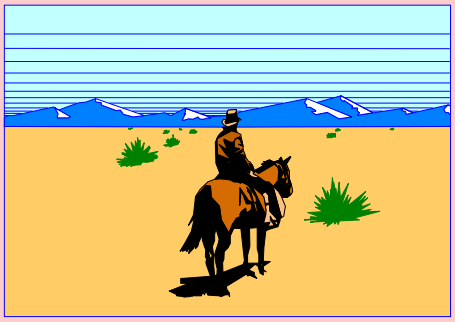
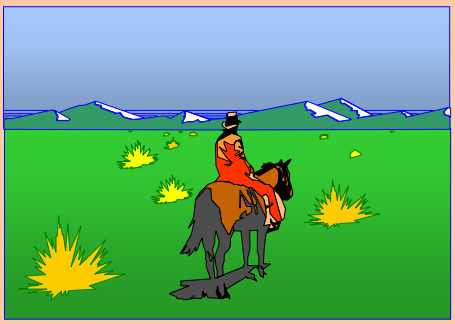
Kingston University, Surrey



Au Revoir, Auf Wiedersehen, Do widzenia, Viszontlátásra, Arrivederci, La revedere, Nashledanou, Αντίο, Tot ziens, Allahaısmarladik, До свидания, *bless bless, näkermiin ……*



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