IEEE 802.15 (WPAN)

(Bluetooth)

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Figure Credits: some figures have been taken form slides found on the web by the following authors (in alfabethical order):

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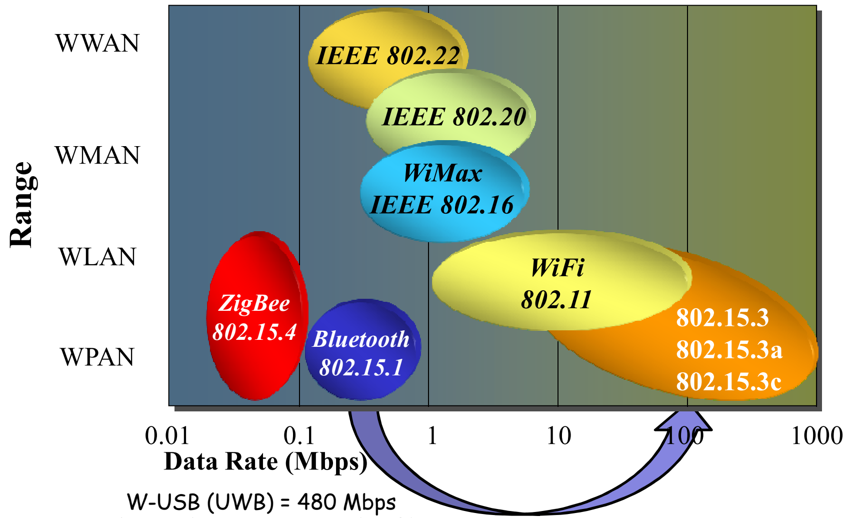
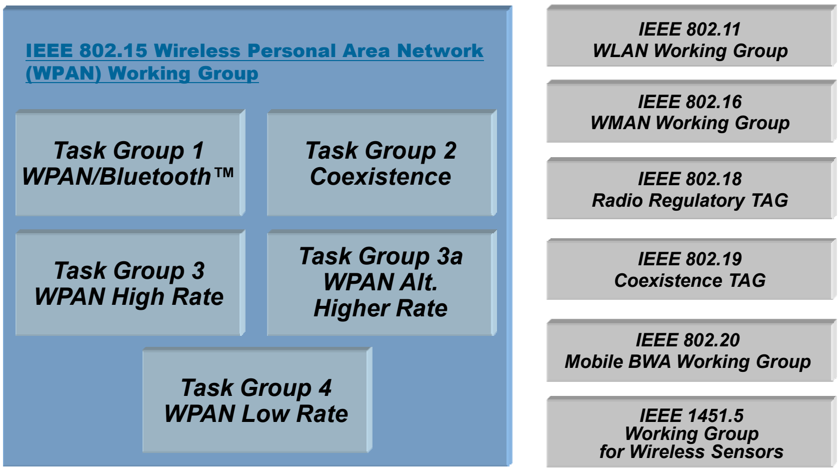
IEEE 802.xy Wireless Standards



W-USB (UWB) = 480 Mbps
Bluetooth 3.0 = 24 Mbps (wi-fi)

Working Group 802.15 and the Other IEEE Wireless Standards Areas



IEEE 802.15 Wireless Personal Area Network (WPAN) Working Group

Task Group 1
WPAN/Bluetooth™

Task Group 2
Coexistence

Task Group 3
WPAN High Rate

Task Group 3a
WPAN Alt.
Higher Rate

Task Group 4
WPAN Low Rate

IEEE 802.11
WLAN Working Group

IEEE 802.16
WMAN Working Group

IEEE 802.18
Radio Regulatory TAG

IEEE 802.19
Coexistence TAG

IEEE 802.20
Mobile BWA Working Group

IEEE 1451.5
Working Group
for Wireless Sensors

Working Group 15:
Wireless Personal Area Networks

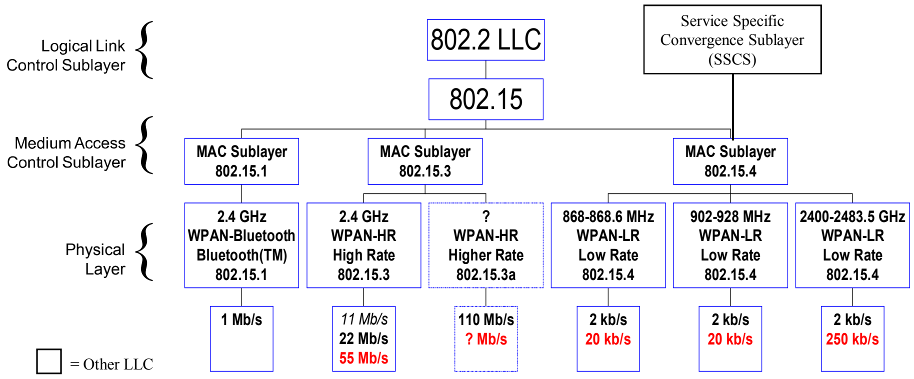
Synopsis:

802.15 focuses on the development of consensus standards for Personal Area Networks or short distance wireless networks. These WPANs address wireless networking of portable and mobile computing devices such as PCs, PDAs, peripherals, cell phones and consumer electronics. The goal is to publish standards, recommended practices, or guides that have broad market applicability and deal effectively with the issues of coexistence and interoperability with other wired and wireless networking solutions.

802.15 is part of the 802 Local and Metropolitan Area Network Standards Committee of the IEEE Computer Society. The IEEE-SA is an international membership organization serving today's industries with a complete portfolio of standards programs.

The latest status of 802.15 and other IEEE802 activities is available at http://standards.ieee.org/802news/.

802.15 WG is developing 3 MACs and 5 PHYs, TG3a is the 6th PHY



Logical Link Control Sublayer

Medium Access Control Sublayer

Physical Layer

802.2 LLC

Service Specific Convergence Sublayer (SSCS)

802.15

MAC Sublayer 802.15.1

MAC Sublayer 802.15.3

MAC Sublayer 802.15.4

2.4 GHz WPAN-Bluetooth Bluetooth(TM) 802.15.1

2.4 GHz WPAN-HR High Rate 802.15.3

? WPAN-HR Higher Rate 802.15.3a

868-868.6 MHz WPAN-LR Low Rate 802.15.4

902-928 MHz WPAN-LR Low Rate 802.15.4

2400-2483.5 GHz WPAN-LR Low Rate 802.15.4

1 Mb/s

11 Mb/s 22 Mb/s 55 Mb/s

110 Mb/s ? Mb/s

2 kb/s 20 kb/s

2 kb/s 20 kb/s

2 kb/s 250 kb/s

□ = Other LLC

□ = Draft in process or complete

⬚ = Draft not defined e.g., CFP, etc.

Task Group 1: WPAN/Bluetooth™

Synopsis:

Bluetooth is an industry specification for short-range RF-based connectivity for portable personal devices. The WPAN/Bluetooth™ Task Group (TG1) has reviewed and provided a standard adaptation of the Bluetooth Specification v1.1 Foundation MAC and PHY (L2CAP, LMP, Baseband, and radio). Also specified are: a clause on SAPs which includes a LLC/MAC interface for the ISO/IEC 8802-2 LLC; a normative annex which provides a Protocol Implementation Conformance Statement (PICS) proforma; and a informative annex high level behavioral ITU-T Z.100 Specification and Description Language (SDL) model for an integrated Bluetooth MAC Sublayer.

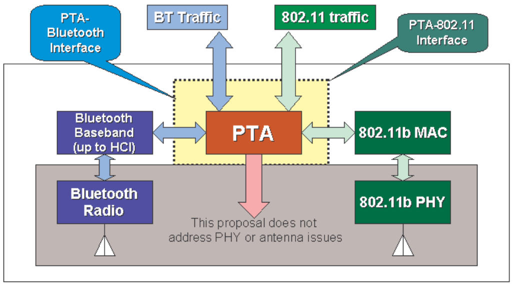
More info is available at http://ieee802.org/15/pub/TG1.html.

Task Group 2: Coexistence

Synopsis:

The Coexistence Task Group (TG2) is developing Recommended Practices to facilitate coexistence of Wireless Personal Area Networks (802.15) and Wireless Local Area Networks (802.11). The group is developing a Coexistence Model to quantify the mutual interference of a WLAN and a WPAN. They are also developing a set of Coexistence Mechanisms to facilitate coexistence of WLAN and WPAN devices.

More info is available at http://ieee802.org/15/pub/TG2.html.



Task Group 3: WPAN High Rate

Synopsis:

The WPAN High Rate Task Group (TG3) for Wireless Personal Area Networks (WPANs™) is chartered to draft and publish a new standard for high-rate (20Mbps or greater) WPANs. Besides a high data rate, the new standard will provide for low power, low cost solutions addressing the needs of portable consumer digital imaging and multimedia applications.

More info is available at http://ieee802.org/15/pub/TG3.html.

Task Group 3a:
WPAN Alternate Higher Rate

Synopsis:

The WPAN Higher Rate Alternate PHY Task Group (TG3a) is chartered to draft and publish a new standard which will provide a higher speed (110 Mbps or greater) PHY amendment to the draft P802.15.3 standard. This will address streaming video and other multimedia applications. The new PHY will use the P802.15.3 MAC with limited modification.

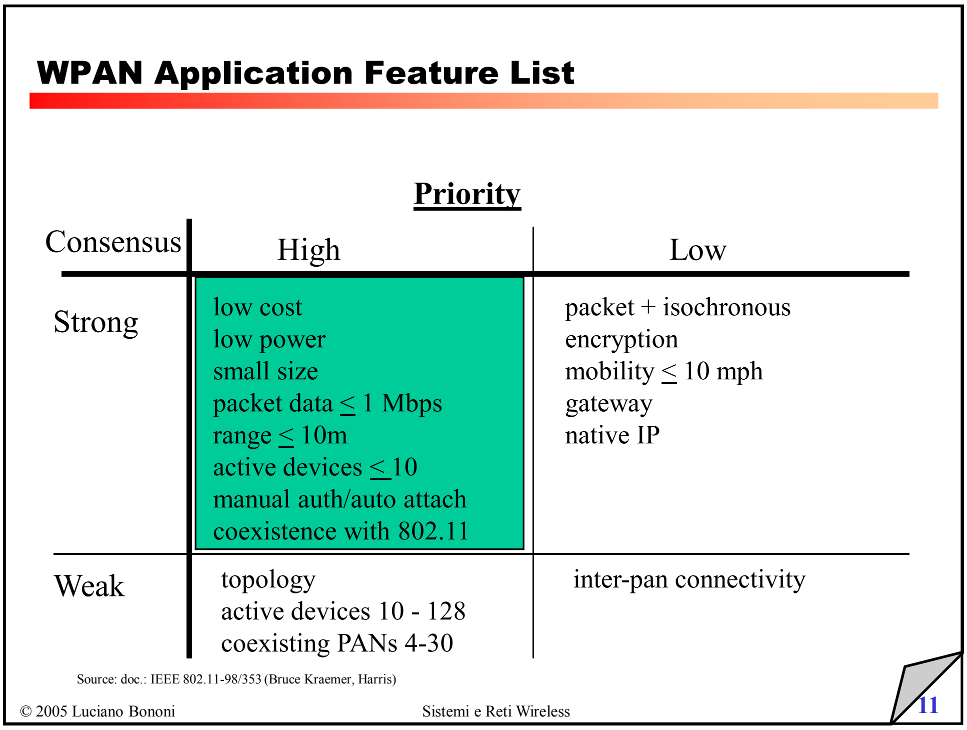
More info is available at http://ieee802.org/15/pub/SG3a.html.
And http://grouper.ieee.org/groups/802/15/arc/802-wpanlist/msg00735.html

Task Group 4: WPAN Low Rate

Synopsis:

The WPAN Low Rate Task Group (TG4) is chartered to investigate a low data rate solution with multi-month to multi-year battery life and very low complexity. This standard specifies two physical layers: an 868 MHz/915 MHz direct sequence spread spectrum PHY and a 2.4 GHz direct sequence spread spectrum PHY. The 2.4 GHz PHY supports an over air data rate of 250 kb/s and the 868 MHz/915 MHz PHY supports over the air data rates of 20 kb/s and 40 kb/s. The physical layer chosen depends on local regulations and user preference. Potential applications are sensors, interactive toys, smart badges, remote controls, and home automation.

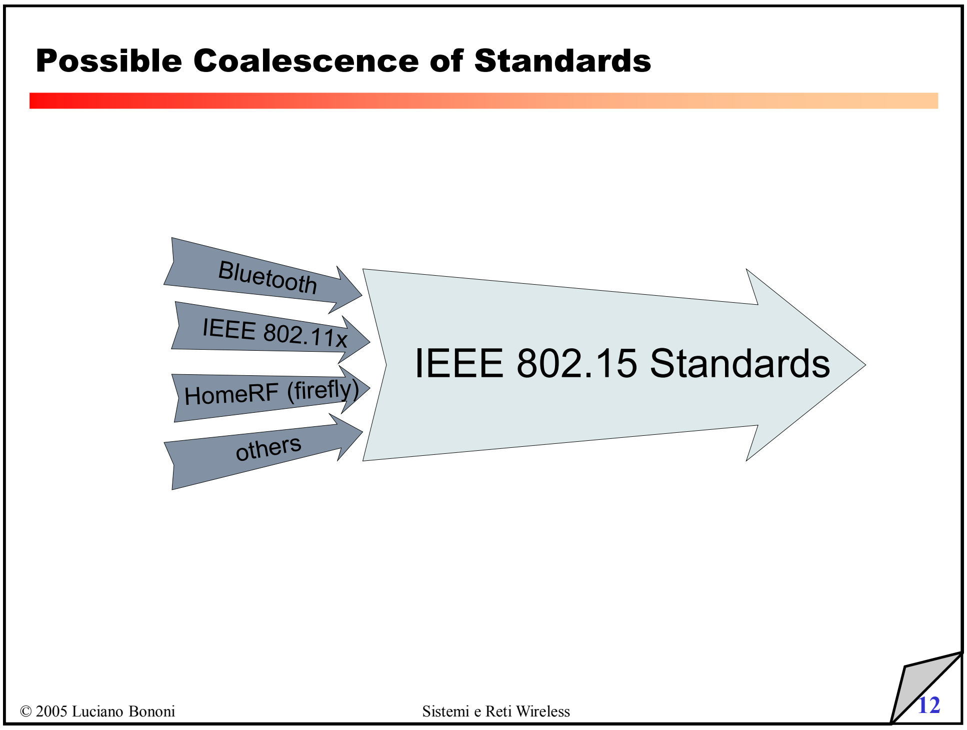
More info is available at http://ieee802.org/15/pub/TG4.html.



WPAN Application Feature List

	Priority	
Consensus	High	Low
Strong	low cost low power small size packet data ≤ 1 Mbps range ≤ 10m active devices ≤ 10 manual auth/auto attach coexistence with 802.11	packet + isochronous encryption mobility ≤ 10 mph gateway native IP
Weak	topology active devices 10 - 128 coexisting PANs 4-30	inter-pan connectivity

Source: doc.: IEEE 802.11-98/353 (Bruce Kraemer, Harris)



Possible Coalescence of Standards

WPAN usage model in existing Solutions

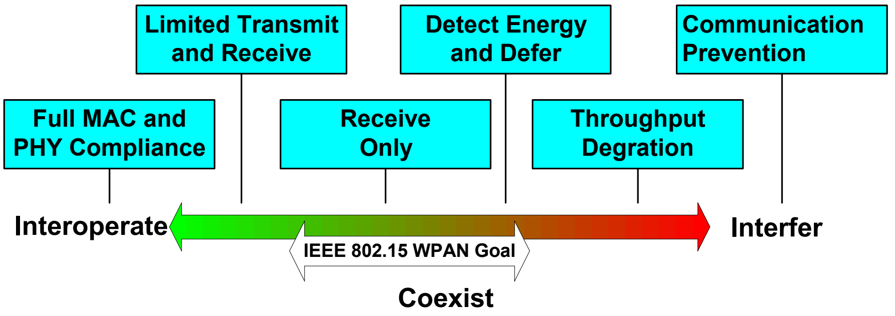
Bluetooth

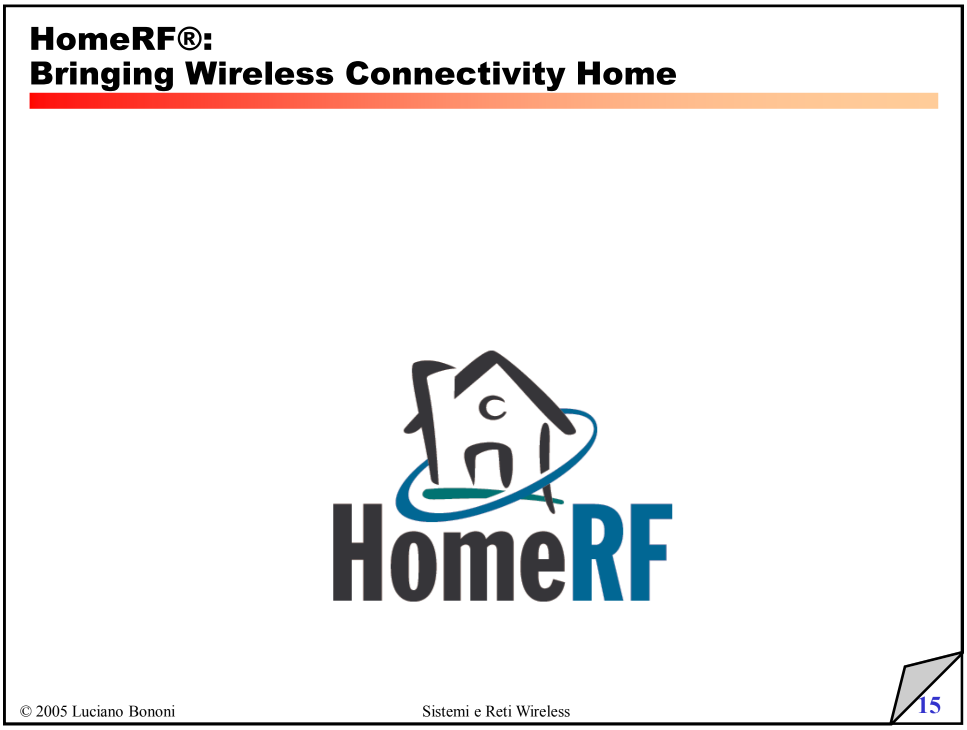
- Three-In-One Phone
- Interactive Conference
- Briefcase Trick
- Forbidden Message
- Automatic Synchronizer
- Instant Postcard
- Portable PC Speaker Phone
- Cordless Desktop
- Videos
- Ultimate Headset
- Internet Bridge

HomeRF

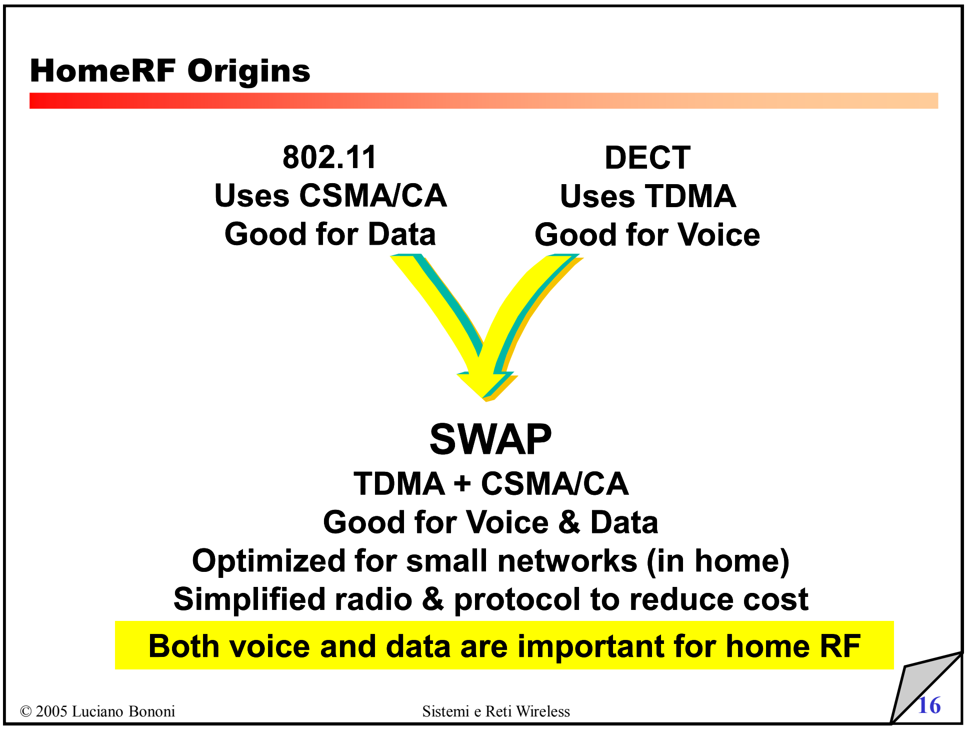
- wireless home network to share voice and data between PC's, peripherals, PC-enhanced cordless phones, and new portable display pads
- Access the Internet and share ISP connection
- Share files/modems/printers in multi-PC homes
- Intelligently forward and review incoming telephone call, FAX, e-mail messages to multiple cordless handsets, FAX machines and voice mailboxes
- Activate other home electronic systems by simply speaking a command into a PC-enhanced cordless handset
- Multi-player games

WPAN standard: Levels of Compatibility





HomeRF®: Bringing Wireless Connectivity Home



HomeRF Origins

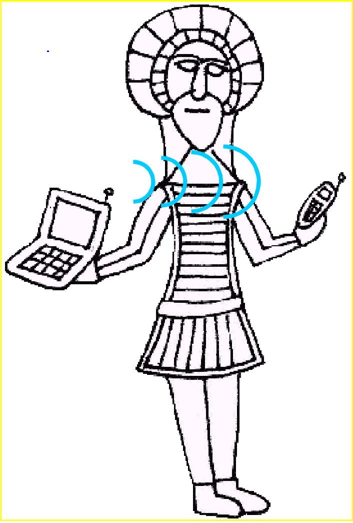
802.11
Uses CSMA/CA
Good for Data

DECT
Uses TDMA
Good for Voice

SWAP
TDMA + CSMA/CA
Good for Voice & Data
Optimized for small networks (in home)
Simplified radio & protocol to reduce cost

Both voice and data are important for home RF

Bluetooth ™

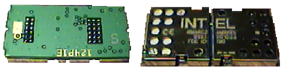


Harald Blaatand “Bluetooth” II
King of Denmark 940-981

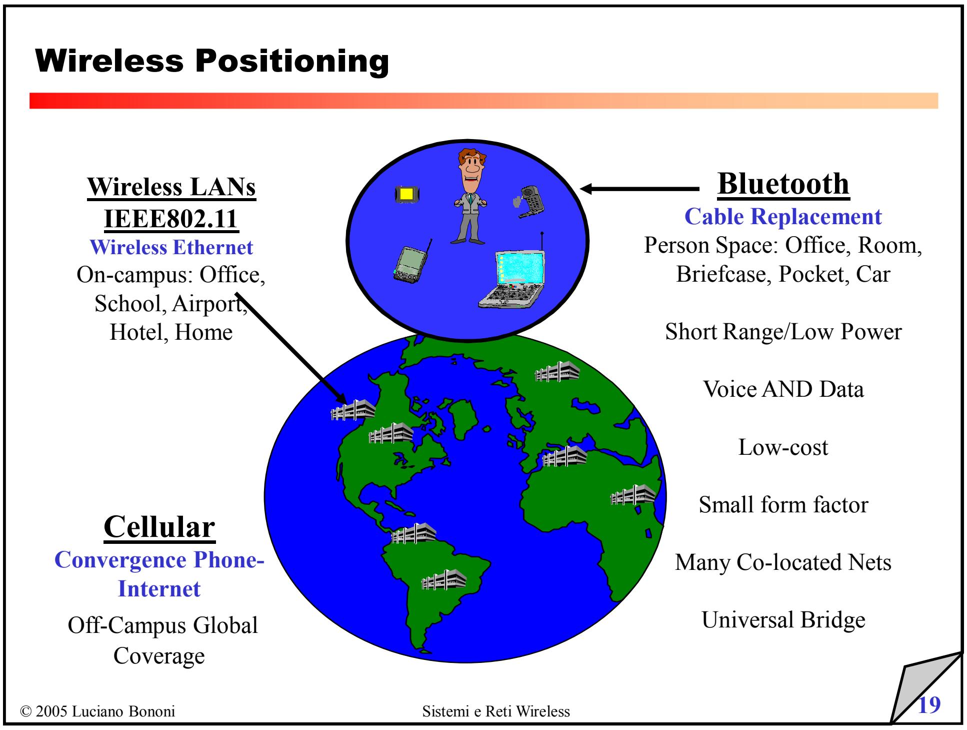
- Harald christianized the Danes
- Harald controlled Denmark and Norway

Bluetooth

- Cable Replacement, low cost, low power, low range



Topology	Supports up to 7 simultaneous links	Each link requires another cable
Flexibility	Goes through walls, bodies, cloths...	Line of sight or modified environment
Data rate	1 MSPS, 720 Kbps	Varies with use and cost
Power	0.1 watts active power	0.05 watts active power or higher
Size/Weight	25 mm x 13 mm x 2 mm, several grams	Size is equal to range. Typically 1-2 meters. Weight varies with length (ounces to pounds)
Cost	Long-term $5 per endpoint	~ $3-$100/meter (end user cost)
Range	10 meters or less Up to 100 meters with PA	Range equal to size. Typically 1-2 meters
Universal	Intended to work anywhere in the world	Cables vary with local customs
Security	Very, link layer security, SS radio	Secure (its a cable)



Wireless Positioning

Wireless LANs
IEEE802.11
Wireless Ethernet
On-campus: Office, School, Airport, Hotel, Home

Bluetooth
Cable Replacement
Person Space: Office, Room, Briefcase, Pocket, Car

Short Range/Low Power

Voice AND Data

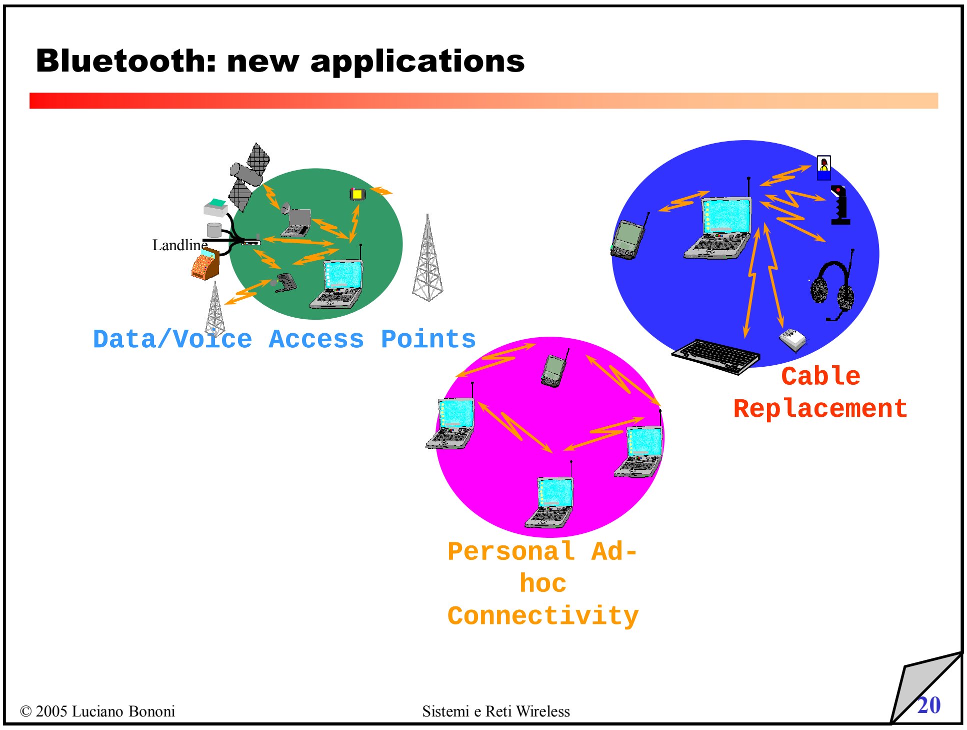
Low-cost

Small form factor

Many Co-located Nets

Universal Bridge

Cellular
Convergence Phone-Internet
Off-Campus Global Coverage



Bluetooth: new applications

Data/Voice Access Points

Cable Replacement

Personal Ad-hoc Connectivity

Characteristics

•Operates in the **2.4 GHz** band at a data rate of **720Kb/s**
(1 Mbps v1.2, 3 Mbps v2.0, 24 Mbps v3.0, 54-480 Mbps UWB)

•Uses **Frequency Hopping (FH) spread spectrum**, which divides the frequency band into a number of channels (2.402 - 2.480 GHz yielding 79 channels).

•Radio transceivers **hop** from one channel to another in a **pseudo-random fashion, determined by the master**.

•Supports up to **8 devices in a piconet** (1 master and 7 slaves).

•**Piconets** can combine to form **scatternets.**

Characteristics

Bluetooth 1.0 and 1.0B
•many interoperability problems, and anonymity impossible at the protocol level
Bluetooth 1.1
•Ratified as IEEE Standard 802.15.1-2002.
•1.0B errors fixed.
•Added support for non-encrypted channels.
•Received Signal Strength Indicator
Bluetooth 1.2
•Ratified as IEEE Standard 802.15.1-2005.
•backward compatible with 1.1
•Faster Connection and Discovery
•*Adaptive frequency-hopping spread spectrum (AFH)*
•Higher transmission speeds up to 720 kbit/s
•Extended Synchronous Connections (eSCO), improve voice quality via retransmissions of corrupted packets

Characteristics

Bluetooth 2.0

•November 10, 2004. Backward compatible with version 1.2.
•introduction of an Enhanced Data Rate (EDR) 3 megabits per second (2.1)
•Gaussian Frequency Shift Keying (GFSK) + EDR = a combination of GFSK and Phase Shift Keying modulation (PSK) with two variants, π/4-DQPSK and 8DPSK.
•Lower power consumption through a reduced duty cycle.

Bluetooth 2.1

backward compatible with 1.2, July 26, 2007.

Extended inquiry response: better filtering of devices before connection.

Sniff subrating: reduces the power consumption when devices are in the sniff low-power mode.

Encryption Pause Resume: refresh of encryption key enabled

Secure Simple Pairing: radically improves the pairing experience

Characteristics

Bluetooth 3.0

The 3.0 specification was adopted April 21st, 2009. Its main new feature is AMP (Alternate MAC/PHY), the addition of Wi-Fi as a high speed transport. Two technologies had been anticipated for AMP: Wi-Fi and UWB, but UWB is missing from the specification.

Alternate MAC PHY: enables the use of alternative MAC and PHY's for transporting Bluetooth profile data. The Bluetooth Radio is still used for device discovery, initial connection and profile configuration. The high speed alternate MAC PHY (802.11, Wi-Fi) will be used to transport the data.

Unicast Connectionless Data: permits service data to be sent without establishing an explicit L2CAP channel. It is intended for use by applications that require low latency between user action and reconnection/transmission of data. This is only appropriate for small amounts of data.

Characteristics

Power classes

Class	Max power (mW, dBm)	Approx. Range (m)
Class 1	100 mW (20 dBm)	100 m
Class 2	2.5 mW (4 dBm)	10 m
Class 3	1 mW (0 dBm)	1 m

What is a Piconet?

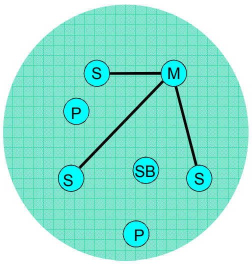
•A **collection** of devices connected in an **ad hoc** fashion.

•One unit will act as a **master** and the others as **slave**s for the duration of the piconet connection.

•**Master** sets the **clock** and **hopping** pattern.

•Each piconet has a u**nique hopping pattern/ID**

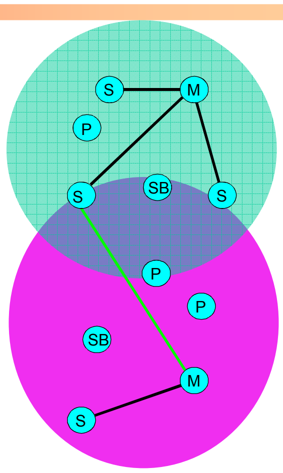
•Each **master** can connect to **7 simultaneous** or **200+ inactive (parked) slaves** per piconet



M=Master P=Parked
S=Slave SB=Standby

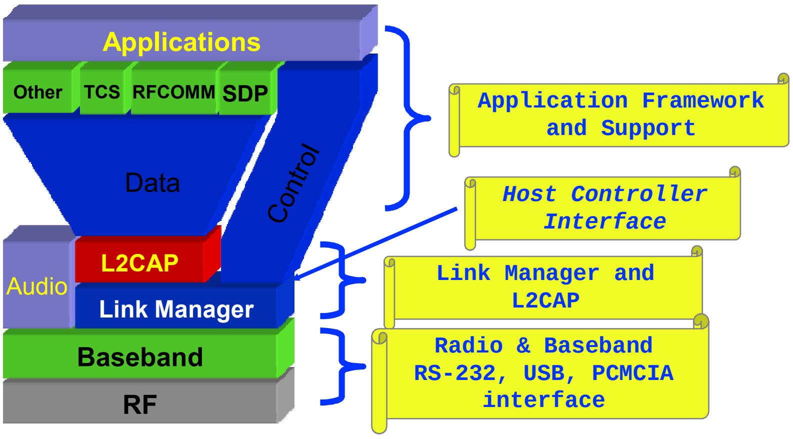
What is a Scatternet?

- A **Scatternet** is the **linking** of multiple **co-located piconets** through the sharing of common master or slave devices.
- A device can be both a **master** and a **slave.**
- Radios are **symmetric** (same radio can be master or slave)
- **High capacity system**, each piconet has maximum capacity (720 Kbps)



M=Master P=Parked
S=Slave SB=Standby

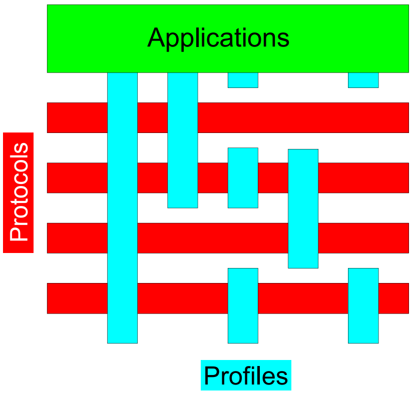
The Bluetooth protocols: specifications


Applications
Other
TCS
RFCOMM
SDP
Data
Control
Audio
L2CAP
Link Manager
Baseband
RF
Application Framework and Support
Host Controller Interface
Link Manager and L2CAP
Radio & Baseband RS-232, USB, PCMCIA interface

- A hardware/software protocol description
- An application framework

Interoperability & Profiles

- Represents default solution for a usage model
- Vertical slice through the protocol stack
- Basis for interoperability and logo requirements
- Each Bluetooth device supports one or more profiles

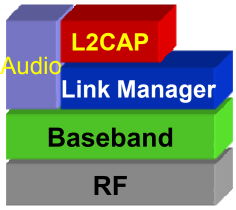


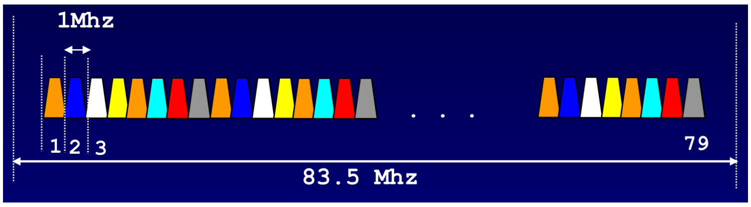
Profiles (spec v.1)

- *Generic Access Profile (GAP)*
  - Service Discovery Application Profile (SDAP)
    - -> (alternate MAC/PHY) basis for Bluetooth 3.0
  - Serial Port Profile (SPP)
    - Dial-up Networking Profile (DUNP)
    - Fax Profile
    - Headset Profile (HSP)
    - LAN Access Profile (using PPP) (LAP)
    - Generic Object Exchange Profile (GOEP)
      - File Transfer Profile (FTP)
      - Object Push Profile (OPP)
      - Synchronization Profile (SP)
  - *TCS_BIN-based profiles*
    - Cordless Telephony Profile (CTP)
    - Intercom Profile (IP)

The Radio Frequency (PHY RF) layer

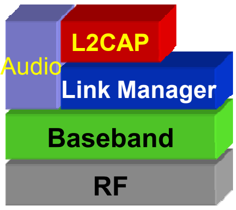
- **Radio (RF)**
  - The Bluetooth radio front-end: ISM band; 1Mbps
    - Frequency hopping spread spectrum
    - CH = 2.402 GHz + k MHz, k=0..78
    - 1,600hops/sec
    - GFSK modulation: 1Mb/s symbol rate
      - CH-115khz (binary 0), CH+115khz (binary 1)
    - PTx: 0dBm (1mW) radio (up to 20dBm)

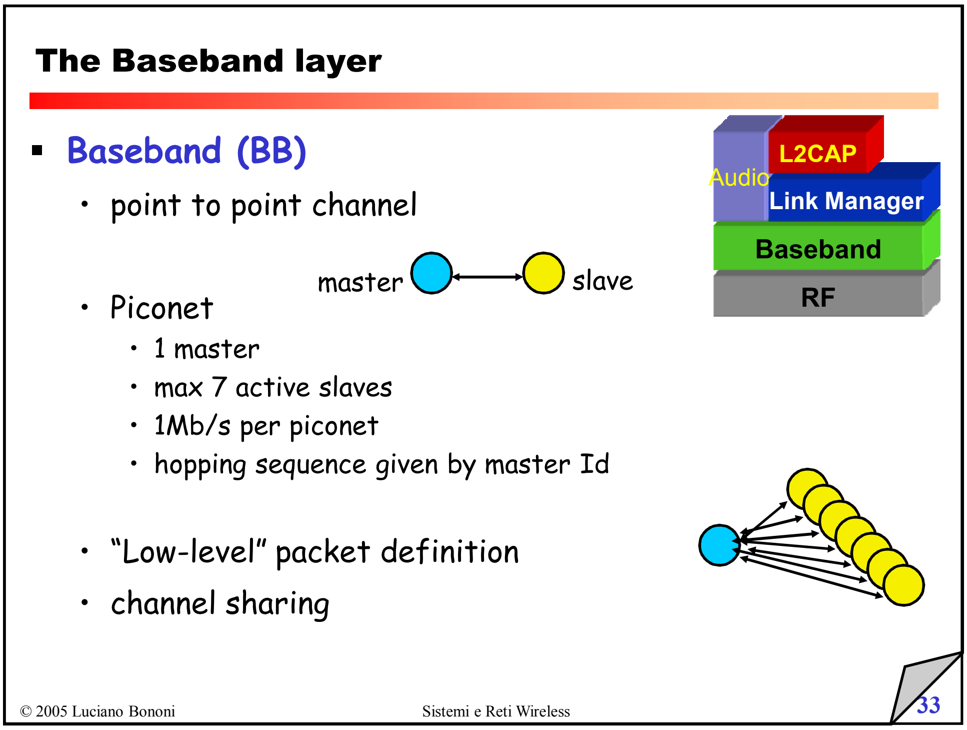




The Baseband layer

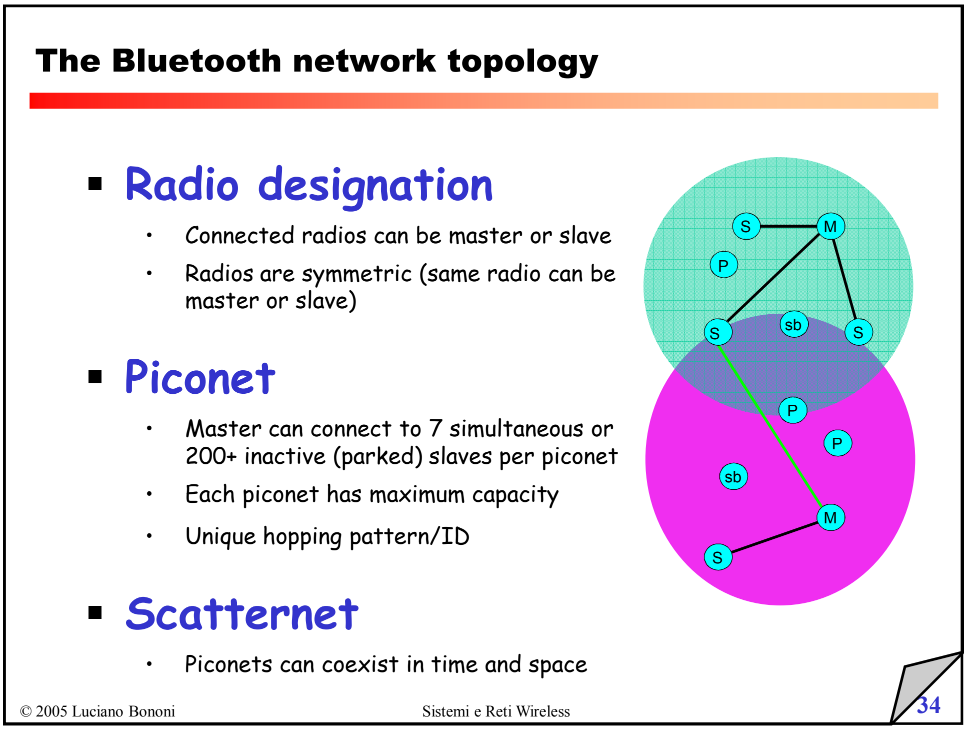
- **Baseband (BB)**
  - TDD, frequency hopping physical layer
  - Device Inquiry and Paging
  - Two type of links: SCO and ACL
  - multiple packet types
    - multiple data rates, with/without FEC





The Baseband layer

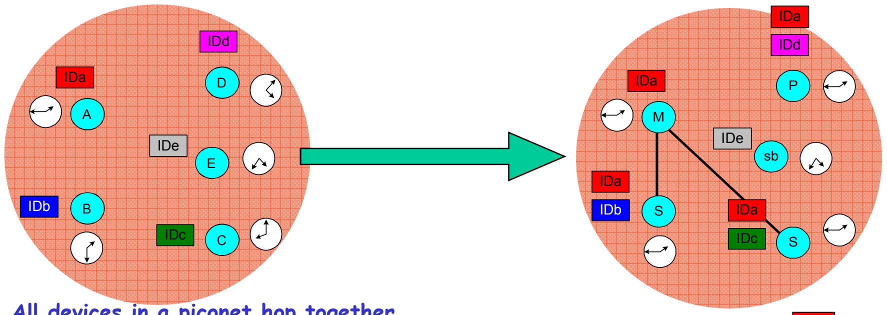
- **Baseband (BB)**
  - point to point channel
  - Piconet
    - 1 master
    - max 7 active slaves
    - 1Mb/s per piconet
    - hopping sequence given by master Id
  - "Low-level" packet definition
  - channel sharing



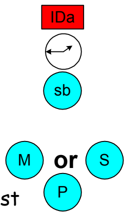
The Bluetooth network topology

- **Radio designation**
  - Connected radios can be master or slave
  - Radios are symmetric (same radio can be master or slave)
- **Piconet**
  - Master can connect to 7 simultaneous or 200+ inactive (parked) slaves per piconet
  - Each piconet has maximum capacity
  - Unique hopping pattern/ID
- **Scatternet**
  - Piconets can coexist in time and space

The piconet

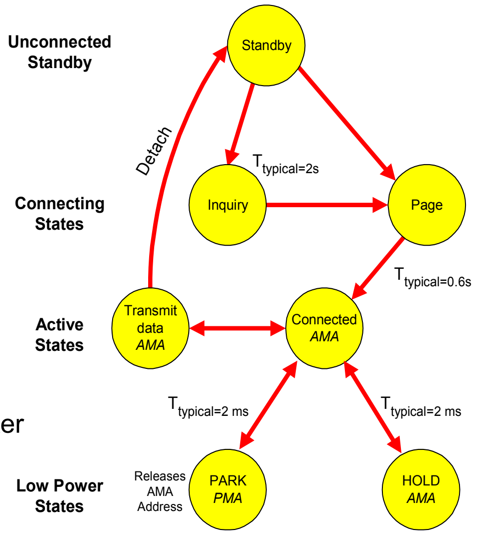


- **All devices in a piconet hop together**
  - To form a piconet: master gives slaves its *clock* and *device ID*
    - Hopping pattern determined by *device ID* (48-bit)
    - Phase in hopping pattern determined by *Clock*
- **Piconet Addressing**
  - Bluetooth device address (BD_ADDR):48 bit IEEE MAC Address
  - Active Member Address (AM_ADDR): 3-bits active slave, all-zero broadcast
  - Parked Member Address (PM_Addr): 8-bits parked slave

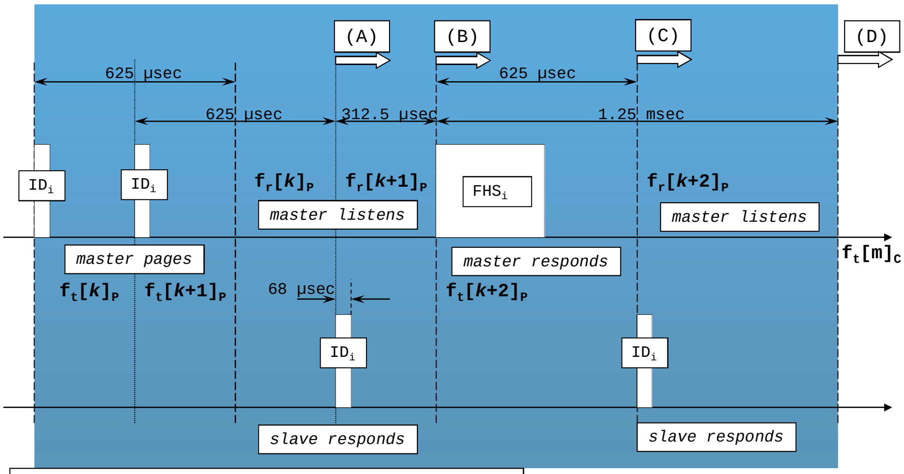


The baseband states: piconet formation

- **Standby**
  - Waiting to join a piconet
- **Inquire**
  - looking about radios to connect to
- **Page**
  - Connect to a specific inquired radio
- **Connected**
  - Actively on a piconet (master or slave)
- **Park/Hold**
  - Low Power connected states

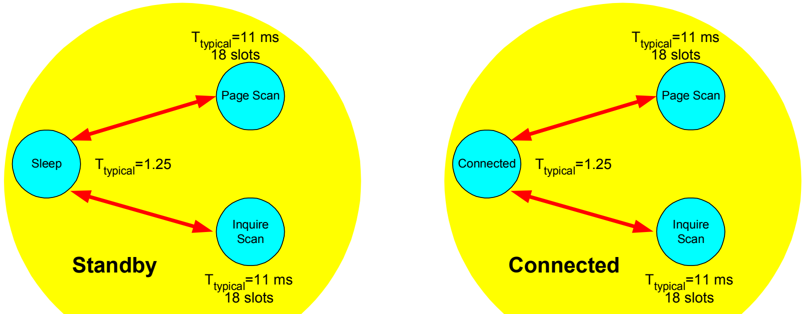


Paging sequence



```
A: slave acquires half-slot synchronization
B: slave acquires full-slot synchronization
C: slave capable to join master's piconet
D: piconet communications start with master Tx slot
```

Page and Inquire Scans

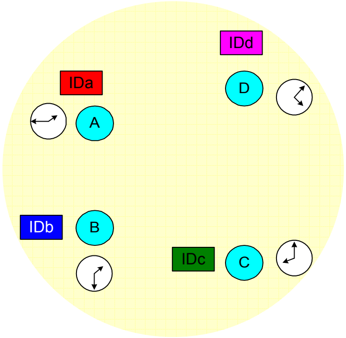


- **A radio must be enabled to accept pages or inquires**
  - Consumes 18 slots (18*0.625=11ms) every 1.25 sec. (or so) for each scan
  - Inquiry has unique device address (all BT radio use)
    - Unique set of "Inquiry" hop frequencies (32 predefined channels)
    - Any device can inquire by paging the Inquiry address
    - Correlater hit causes slave to respond with FHS packet (Device ID and Clock)

Inquire Summary

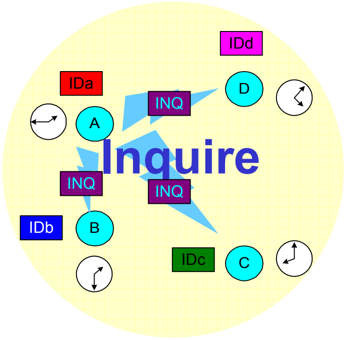
- Paging radio Issues page packet with Inquire ID
- Any radio doing an Inquire scan will respond with an FHS packet
  - FHS packet gives Inquiring radio information to page
    - ***Device ID*** IDa
    - ***Clock*** 🕒
  - If there is a collision then radios wait a random number of slots before responding to the page inquire
- After process is done, Inquiring radio has ***Device IDs*** and ***Clocks*** of all radios in range

Inquiring for Radios



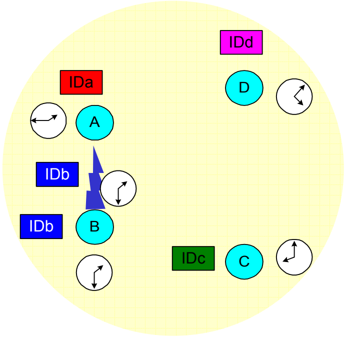
- Radio Wants to find other radios in the area

Inquiring for Radios

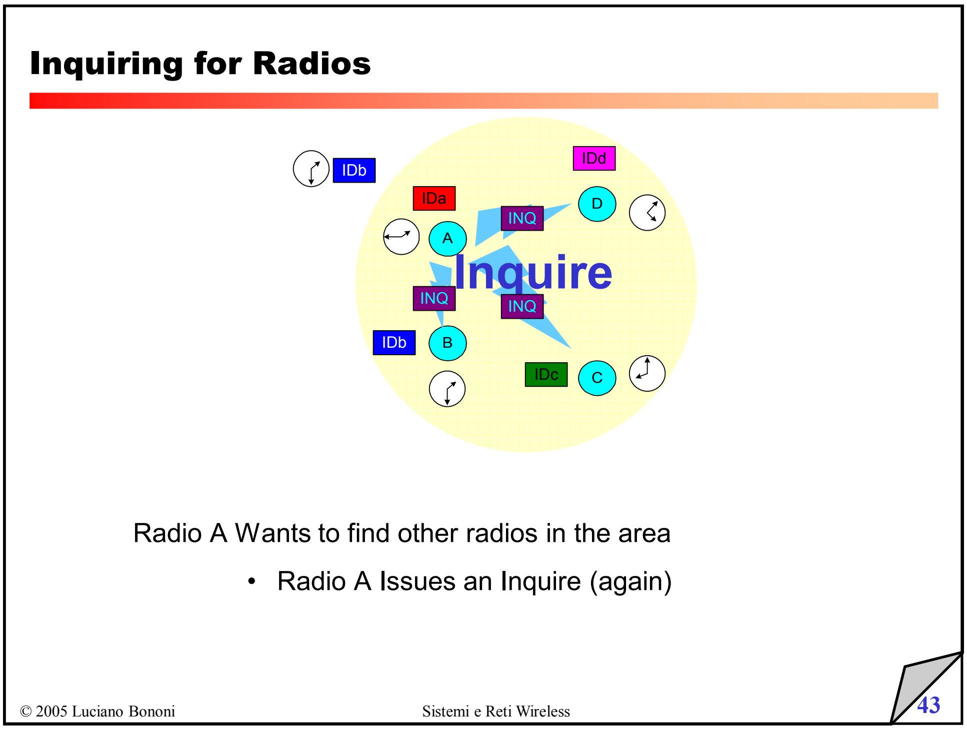


- **Radio Wants to find other radios in the area**
  - Radio A issues an Inquire (pages with the Inquire ID)
    - Radios B, C and D are doing an Inquire Scan

Inquiring for Radios



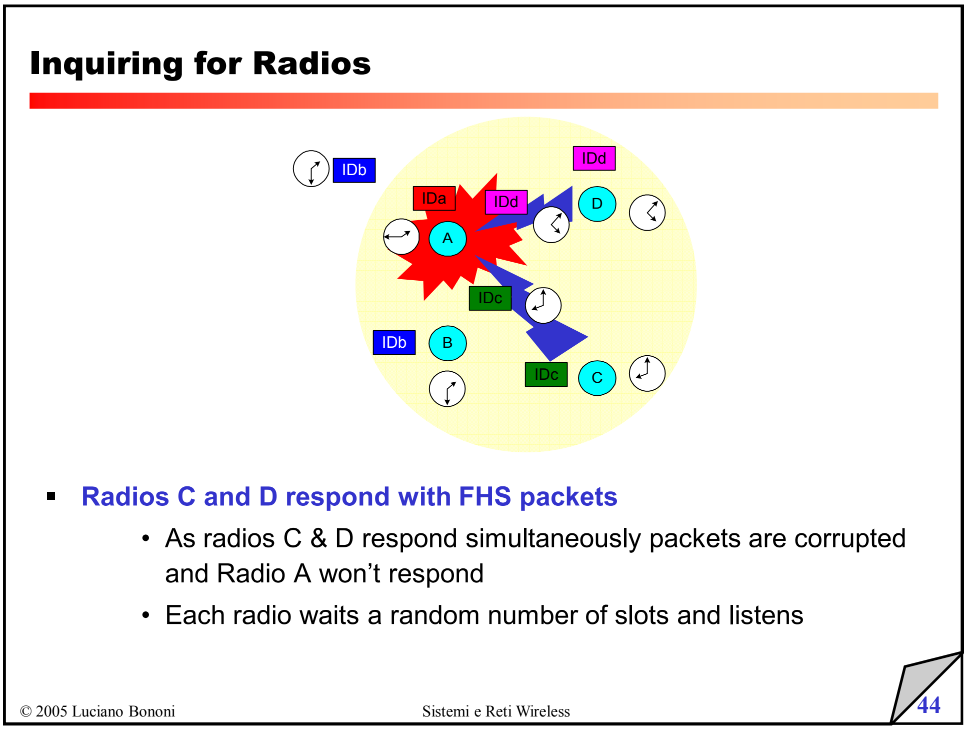
- **Radio B recognizes Inquire and responds with an FHS packet**
  - Has slave’s ***Device ID*** and ***Clock***



Inquiring for Radios

Radio A Wants to find other radios in the area

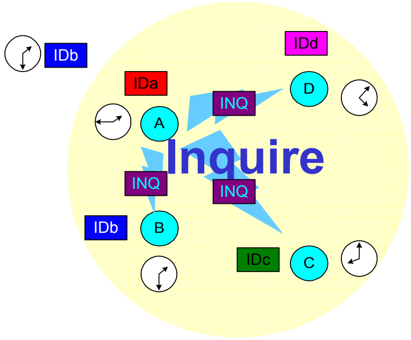
- Radio A Issues an Inquire (again)



Inquiring for Radios

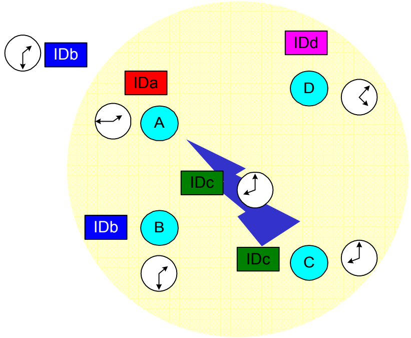
- **Radios C and D respond with FHS packets**
  - As radios C & D respond simultaneously packets are corrupted and Radio A won’t respond
  - Each radio waits a random number of slots and listens

Inquiring for Radios



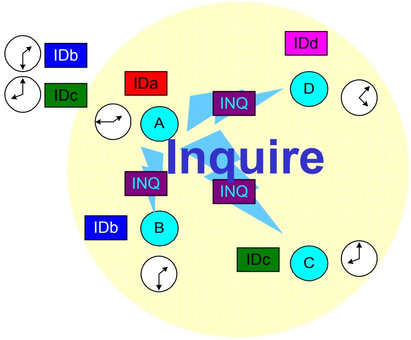
- **Radio A Wants to find other radios in the area**
  - Radio A Issues an Inquire (again)

Inquiring for Radios



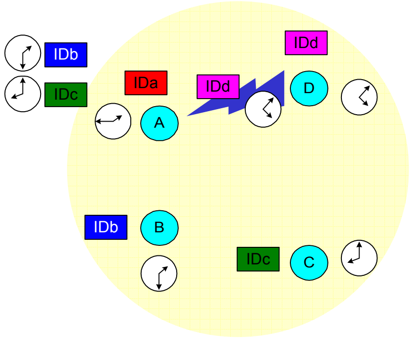
- **Radios C respond with FHS packets**

Inquiring for Radios



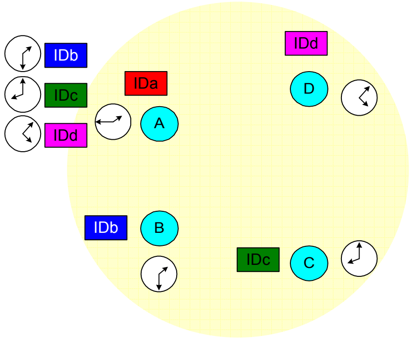
- **Radio A Wants to find other radios in the area**
  - Radio A Issues an Inquire (again)

Inquiring for Radios



- **Radios D respond with FHS packets**

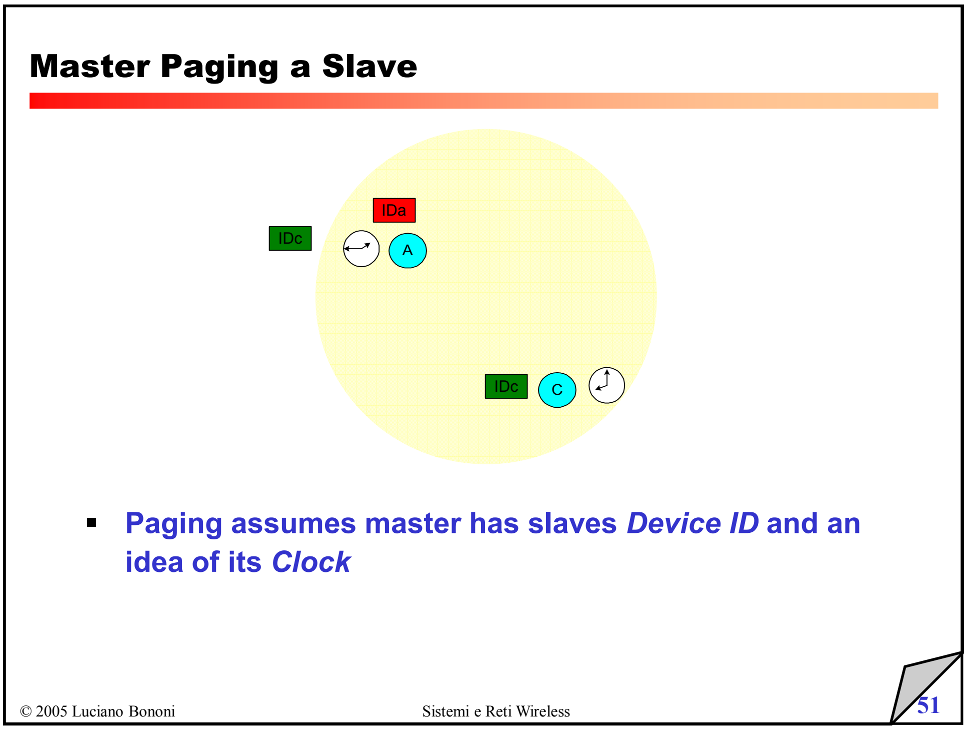
Inquiring for Radios



- Radio A now has information of all radios within range

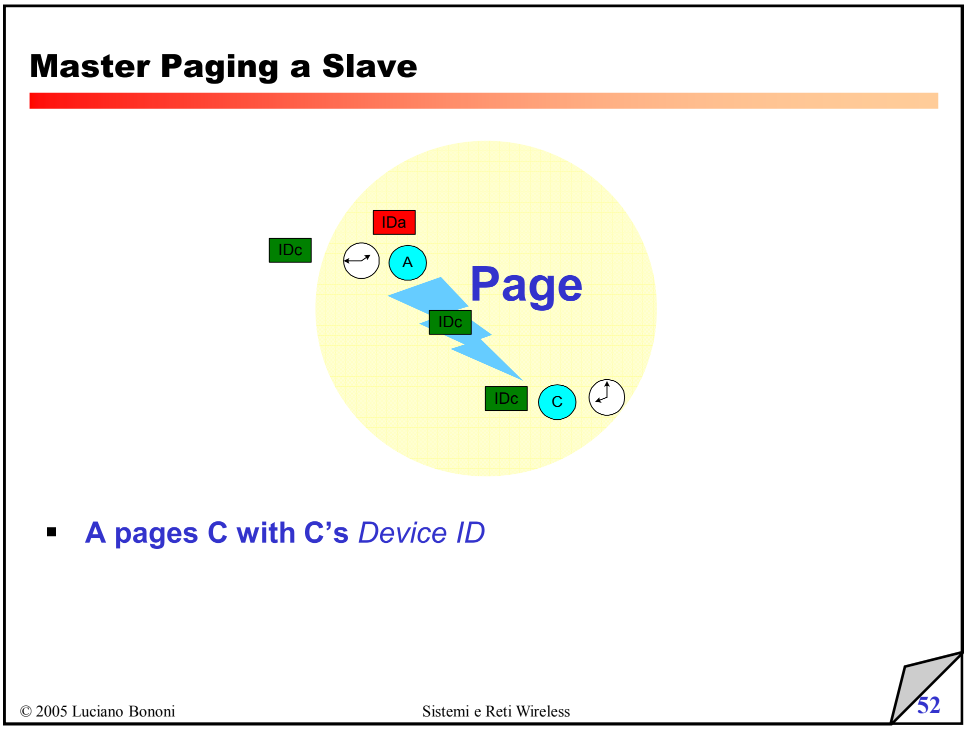
Master Paging a Slave

- Master pages slave (packet has slave ID) at slave page frequency (1 of 32)
  - Master sends page train of 16 most likely frequencies in slave hop set
    - Slave ID sent twice a transmit slot on slave page frequency
    - Master listens twice at receive slot for a response
  - If misses, master sends second train on remaining 16 frequencies
- Slave listens for 11 ms (page scan)
  - If correlater triggers, slave wakes-up and relays packet at response frequency
  - Master responds with FHS packet (provides master's ***Device ID*** and ***Clock***)
  - Slave joins piconet



Master Paging a Slave

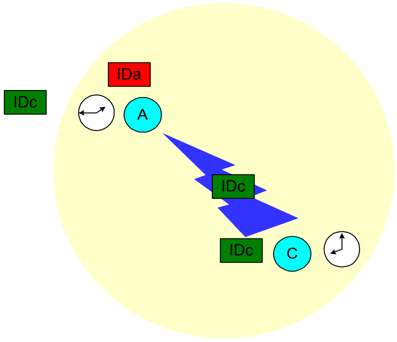
- Paging assumes master has slaves *Device ID* and an idea of its *Clock*



Master Paging a Slave

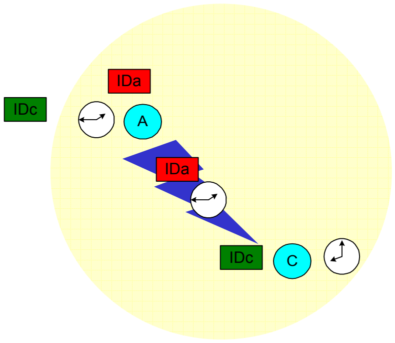
- A pages C with C's *Device ID*

Master Paging a Slave



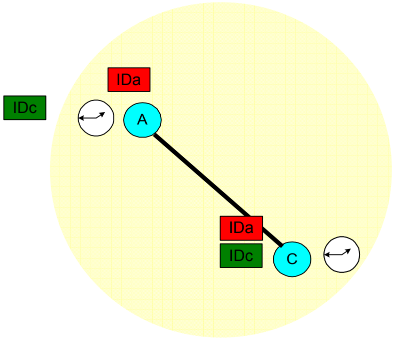
- C Replies to A with C’s *Device ID*

Master Paging a Slave



- A sends C its *Device ID* and *Clock* (FHS packet)

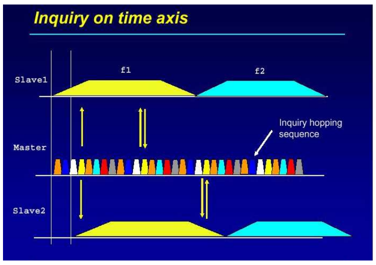
Master Paging a Slave

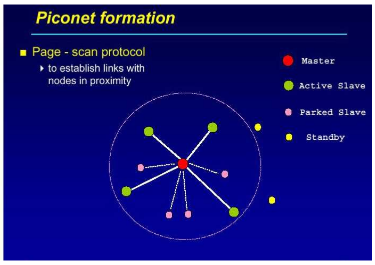


- **A connects as a master to C**

Paging Procedure

- **Each slave page scans on unique sequence of 32 channels f_k**
  - Master pages 16 most likely channels for entire sleep period (nominally 1.25 seconds)
- **If clocks are off, then second train sent on last 16 frequencies for entire sleep period**

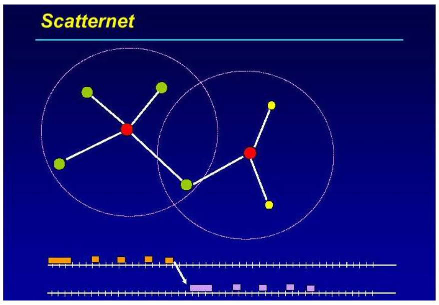


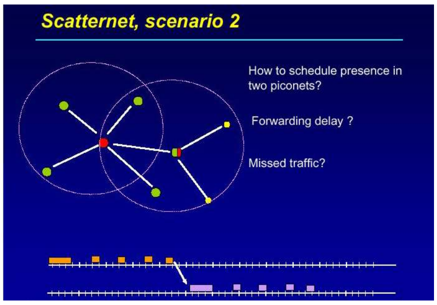


- Page - scan protocol
  - to establish links with nodes in proximity

Scatternet Formation

- **Scatternet Formation**
  - Gateway node management and synchronization?



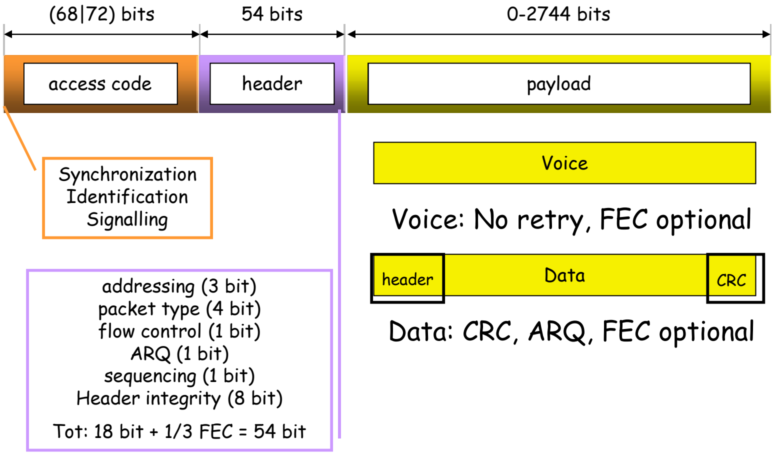


How to schedule presence in two piconets?

Forwarding delay ?

Missed traffic?

Baseband packet



Synchronization
Identification
Signalling

addressing (3 bit)
packet type (4 bit)
flow control (1 bit)
ARQ (1 bit)
sequencing (1 bit)
Header integrity (8 bit)

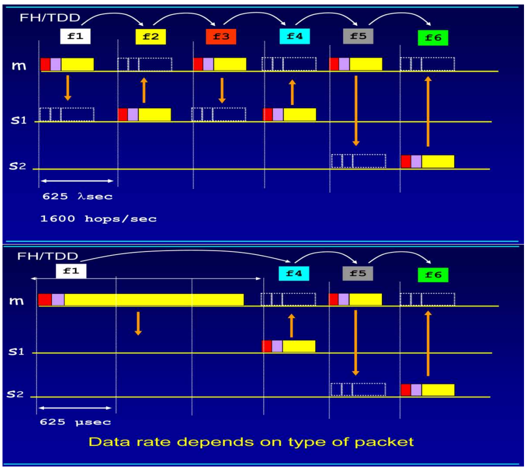
Tot: 18 bit + 1/3 FEC = 54 bit

Voice: No retry, FEC optional

Data: CRC, ARQ, FEC optional

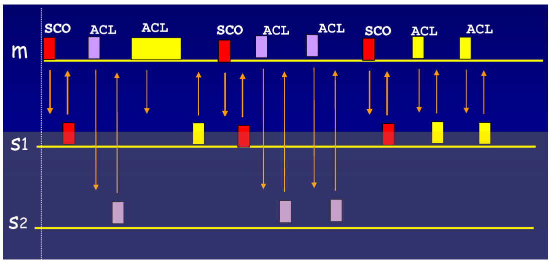
Baseband packet transmission

- **Polling-based (TDD) packet transmissions**
  - 1 slot: 0.625msec (max 1600 slots/sec)
  - master/slave slots (even-/odd-numbered slots)
  - polling: master always “polls” slaves

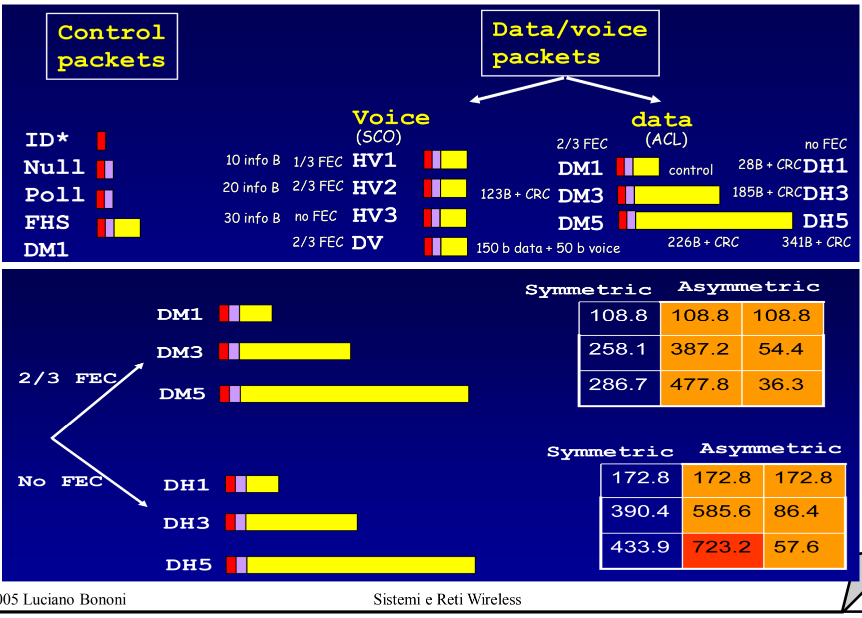


Baseband packet links

- **Synchronous connection-oriented (SCO) link**
  - “circuit-switched”: periodic single-slot packet assignment
  - symmetric 64Kbps full-duplex
  - Up to 3 for one master and 2-3 for one slave
- **Asynchronous connection-less (ACL) link**
  - packet switching, asymmetric bandwidth
    - variable packet size (1-5 slots)
      - max. 721 kbps (57.6 kbps return channel), 108.8 - 432.6 kbps (symmetric)



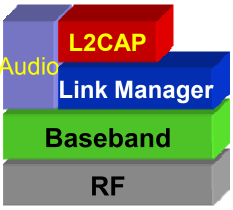
Baseband packet types



Symmetric	Asymmetric	
108.8	108.8	108.8
258.1	387.2	54.4
286.7	477.8	36.3

Symmetric	Asymmetric	
172.8	172.8	172.8
390.4	585.6	86.4
433.9	723.2	57.6

The Link Management layer

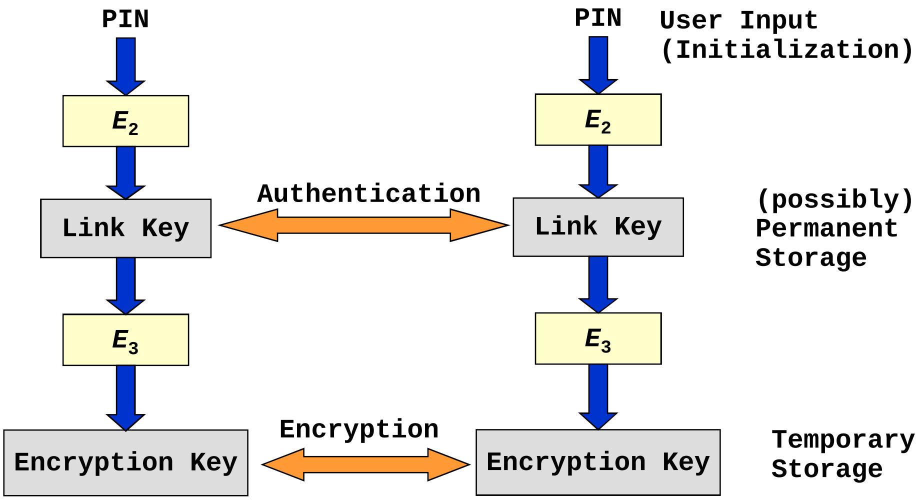


- **Link Management (LM)**
  - piconet management
  - link configuration: link properties
    - polling intervals set-up
    - SCO link set-up
    - low power mode set-up (parked slaves)
    - QoS
    - Packet type
  - security
    - encryption/authentication

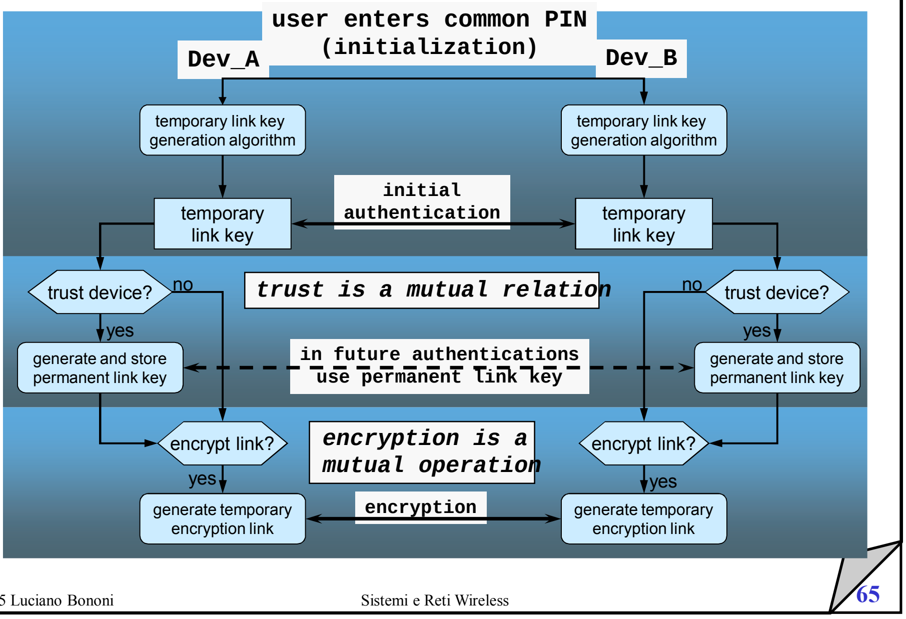
Bluetooth security features

- Initialization
  - shared key(s): authetication and cyphering
  - PIN entry by user
- Authentication of remote device
  - based on link key (128 bit)
  - challenge/response (shared secret)
  - may be performed in both directions
- Encryption of payload data
  - stream cipher algorithm (≤ 128 Bit)
    - Safer+ (Massey and Rueppel)
  - affects all traffic on a link

Key generation and usage



Bluetooth authentication and encryption



user enters common PIN (initialization)

Dev_A

Dev_B

temporary link key generation algorithm

temporary link key generation algorithm

temporary link key

initial authentication

temporary link key

trust device?

no

yes

trust is a mutual relation

no

trust device?

yes

generate and store permanent link key

in future authentications use permanent link key

generate and store permanent link key

encrypt link?

encryption is a mutual operation

encrypt link?

yes

yes

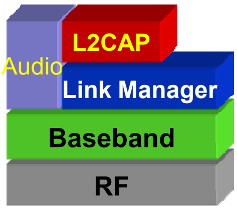
generate temporary encryption link

encryption

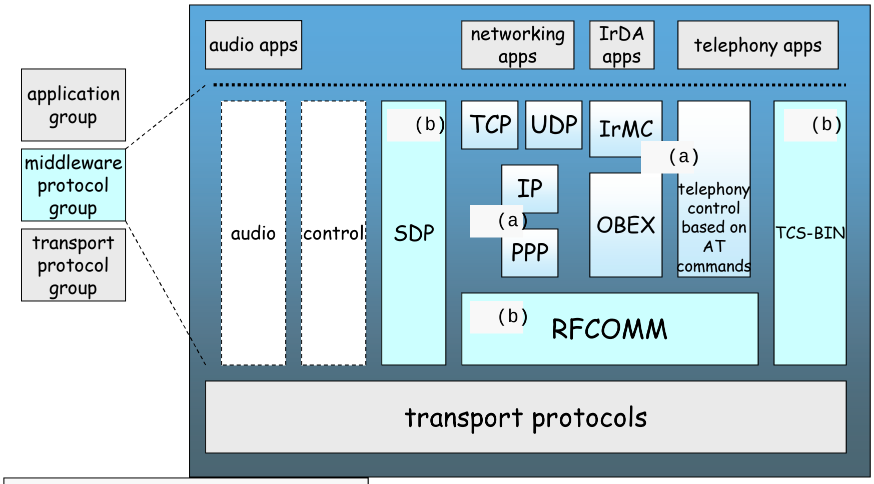
generate temporary encryption link

The LLC and Adaptation layer

- **Link Layer Control & Adaptation (L2CAP)**
  - A simple data link protocol on top of the baseband
    - connection-oriented & connectionless
    - protocol multiplexing
    - segmentation & reassembly
    - QoS flow specification per connection (channel)
    - group abstraction



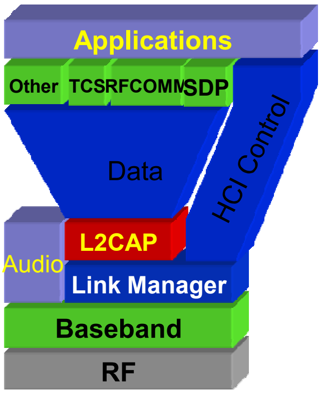
The middleware protocols



```
a: adopted protocol
b: Bluetooth specific protocol
```

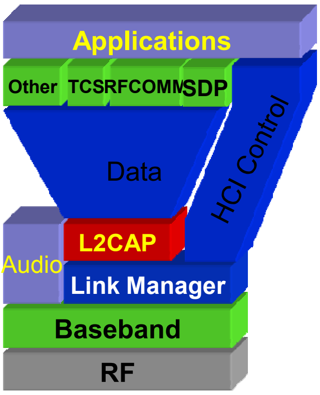
The middleware protocols

- **Host Controller Interface (HCI)**
  - provides a common interface between the Bluetooth host and a Bluetooth module
    - Interfaces in spec 1.0: USB; UART; RS-232



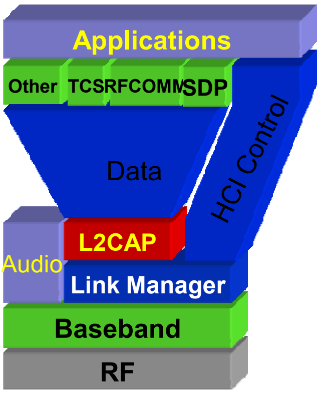
Middleware protocols

- **Service Discovery Protocol (SDP)**
  - Defines an inquiry/response protocol for discovering services
    - Searching for and browsing services
  - Defines a service record format
    - Information about services provided by *attributes*
    - Attributes composed of an ID (name) and a value
    - IDs may be universally unique identifiers (UUIDs)



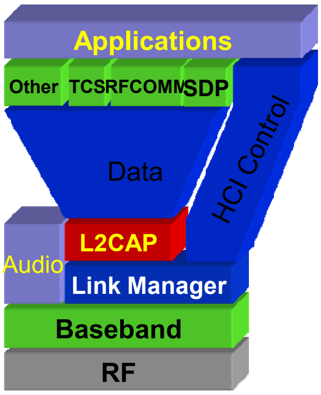
Middleware protocols

- **RFCOMM (based on GSM TS07.10)**
  - emulates a serial-port to support a large base of legacy (serial-port-based) applications
  - allows multiple “ports” over a single physical channel between two devices
  - similar to HDLC

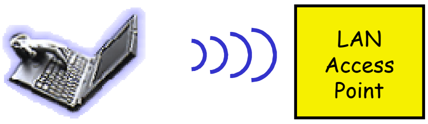


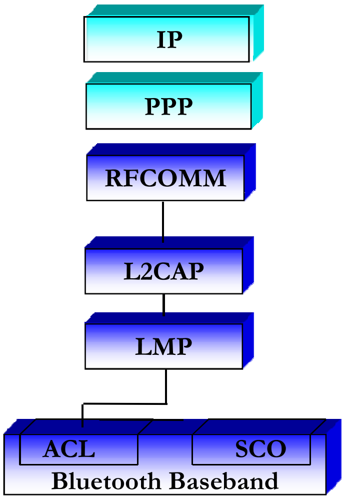
Middleware protocols

- **Telephony Control Protocol Spec (TCS)**
  - call control (setup & release)
  - group management for gateway serving multiple devices
- **Legacy protocol reuse**
  - reuse existing protocols, e.g., IrDA's OBEX, or WAP for interacting with applications on phones



LAN access point profile



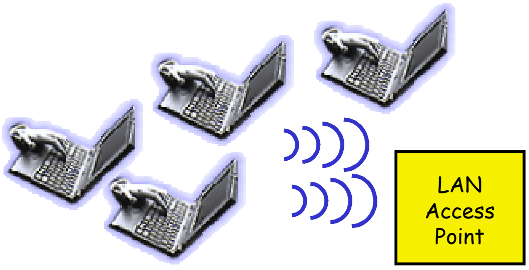


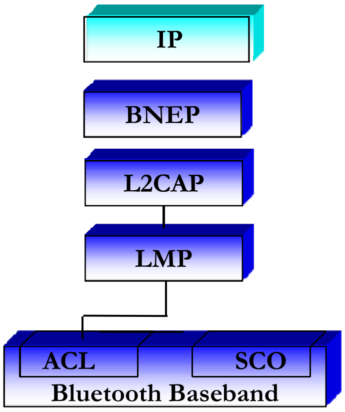
PPP: security, authentication, access control

Efficiency

Auto-configuration

IP over Bluetooth



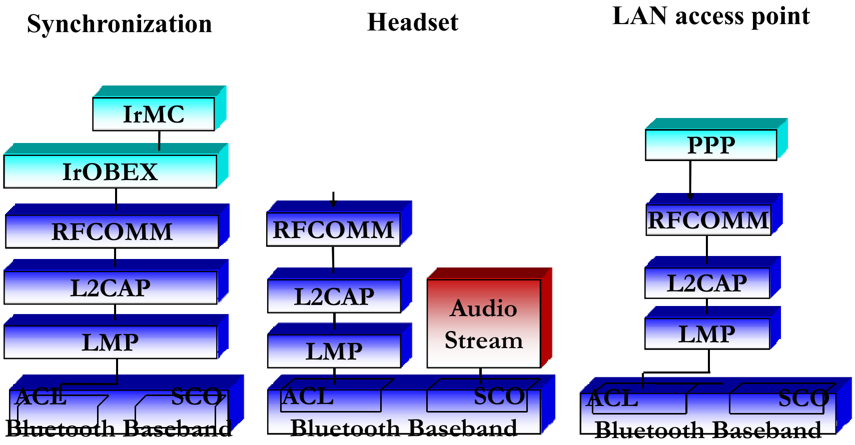


BNEP: Bluetooth Network Encapsulation Protocol: Ethernet emulation over L2CAP

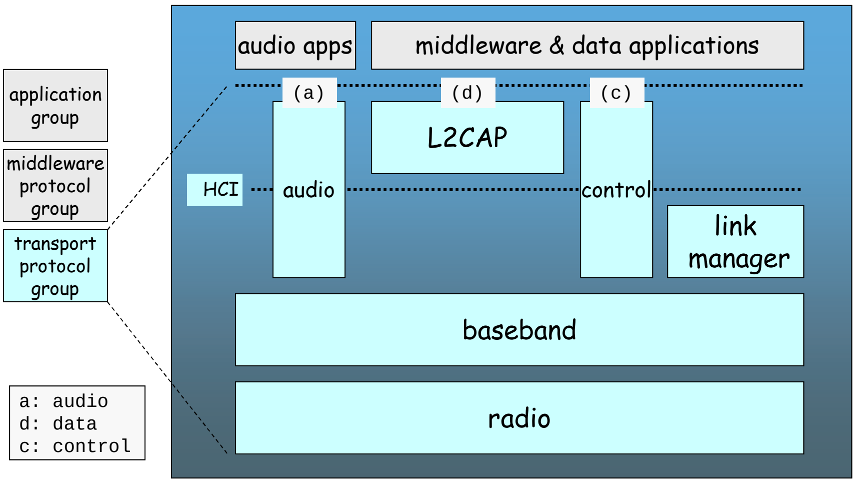
48 bit MAC address

BNEP frame encapsulation in L2CAP

e.g. other profiles



The protocol scheme



application group

middleware protocol group

transport protocol group

a: audio
d: data
c: control

audio apps

middleware & data applications

(a)

(d)

(c)

L2CAP

HCI

audio

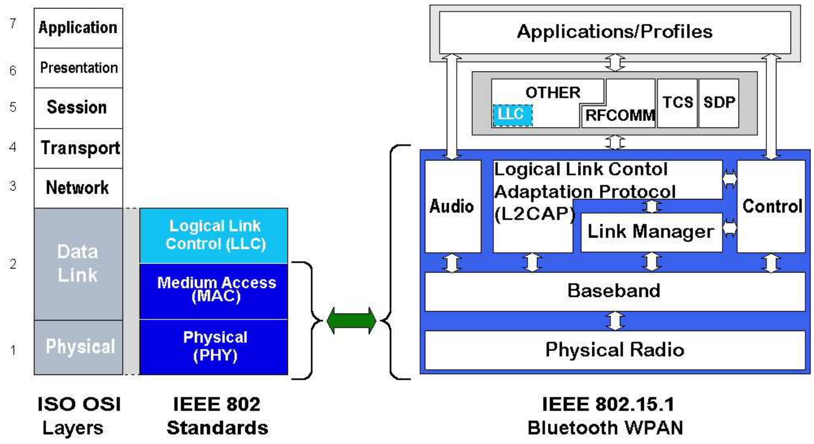
control

link manager

baseband

radio

The 802.15.1 standard



7 Application

6 Presentation

5 Session

4 Transport

3 Network

2 Data Link

1 Physical

Logical Link Control (LLC)

Medium Access (MAC)

Physical (PHY)

Applications/Profiles

OTHER

LLC

RFCOMM

TCS

SDP

Audio

Logical Link Contol Adaptation Protocol (L2CAP)

Link Manager

Control

Baseband

Physical Radio

ISO OSI Layers

IEEE 802 Standards

IEEE 802.15.1 Bluetooth WPAN

Summary

- **Bluetooth is a global, RF-based (ISM band: 2.4 GHz), short-range, connectivity solution for portable, personal devices**
  - it is not just a radio, it is an end-to-end solution
- **The Bluetooth spec comprises**
  - a HW & SW protocol specification
  - usage case scenario profiles and interoperability requirements
- **IEEE 802.15.1 is working on standardizing the PHY and MAC layers in Bluetooth**
- ***http://www.bluetooth.org***