



Bluetooth Demystified

S-72.4210 Postgraduate Course in Radio Communications

Er Liu

liuer@cc.hut.fi

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NILLINEN KORKEAKOULU
NISKÄ HÖGSKOLAN
SINKI UNIVERSITY OF TECHNOLOGY



TKK Tietoliikennelaboratorio
TH Telekommunikationslaboratoriet
HUT Communications Laboratory



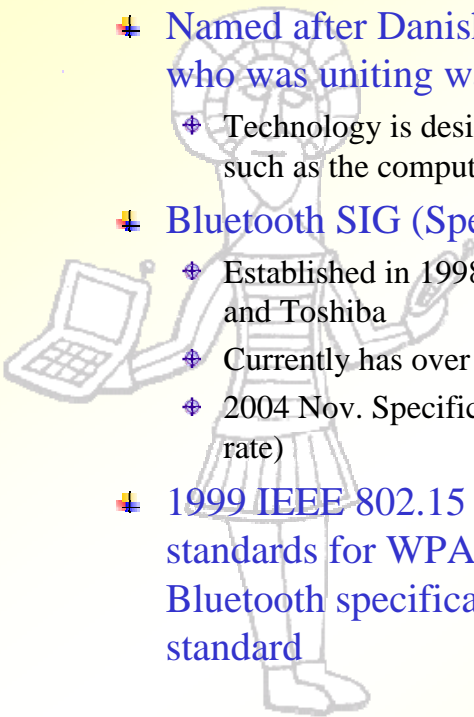
Content Outline

- ✚ Bluetooth History
- ✚ Bluetooth Market and Applications
- ✚ Bluetooth Protocol Stacks
 - ✦ Radio
 - ✦ Baseband
 - ✦ Link Management Protocol (LMP)
 - ✦ L2CAP (Logic Link Control and Adaptation Protocol)
- ✚ Bluetooth Profiles
- ✚ Bluetooth Implementation and Development
- ✚ Qualification Program and Requirement
- ✚ Summary
- ✚ Homework

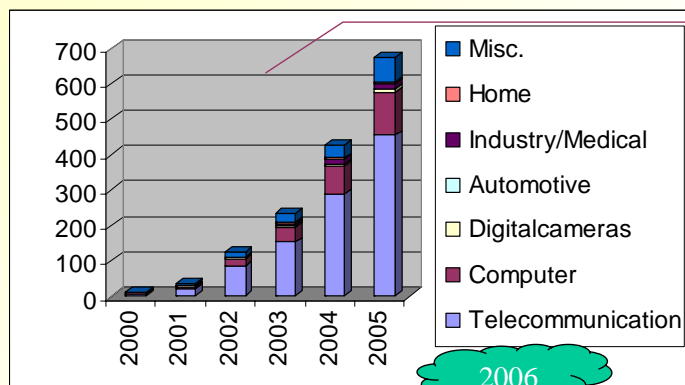


Bluetooth History

- ✚ Invented in 1994 by L. M. Ericsson
- ✚ Named after Danish King Harald Blatand or Harold Bluetooth, who was uniting warring factions together
 - ✚ Technology is designed to allow collaboration between different industries such as the computing, mobile phone and automotive markets
- ✚ Bluetooth SIG (Special Industry Group)
 - ✚ Established in 1998 by Ericsson, IBM, Intel, Microsoft, Motorola, Nokia and Toshiba
 - ✚ Currently has over 3400 members
 - ✚ 2004 Nov. Specification Core package version 2.0+EDR (enhanced data rate)
- ✚ 1999 IEEE 802.15 standards working group, communication standards for WPANs (wireless personal area networks). Bluetooth specification chosen as baseline of the 802.15.1 standard



Bluetooth Market and Applications



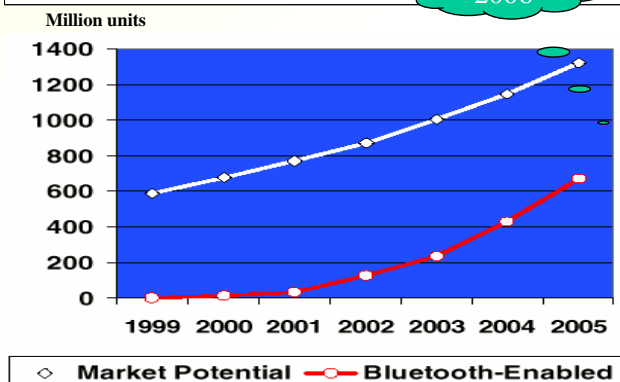
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Estimation of potential volume for Bluetooth devices

Around \$5/chip

Applications:

- ✚ Synchronizing data
- ✚ Voice call
- ✚ Printing
- ✚ Mp3 player
- ✚ Home Entertainment
- ✚ Payment system
- ✚ Scanner
- ✚ Mobile E-commerce
- ✚ Automotive
- ✚ Internet
- ✚ Etc...



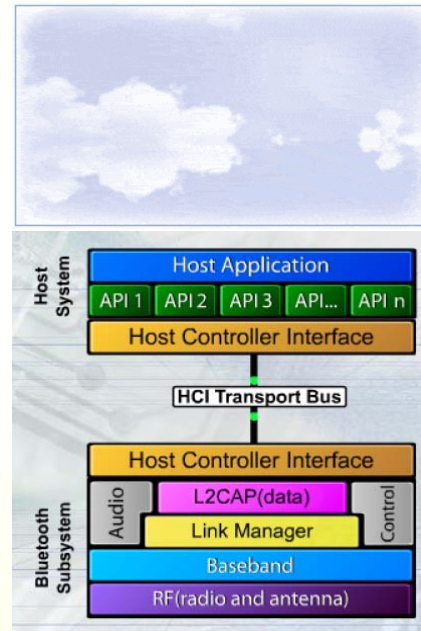
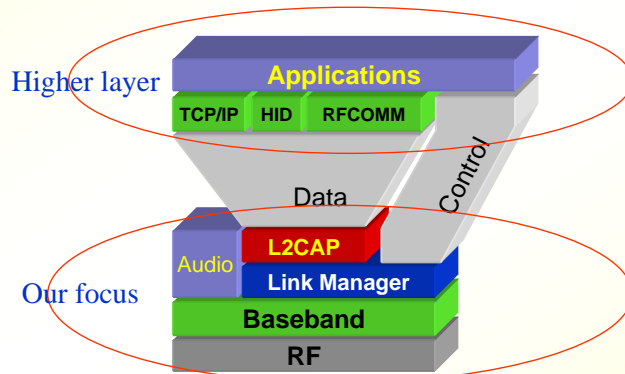
Source: Cahners IN-STAT Group



Bluetooth Protocol Stacks

Protocol stacks

- ✦ Radio Frequency
- ✦ Baseband
- ✦ Link Management
- ✦ L2CAP
- ✦ HCI
- ✦ Higher layer protocols



Radio

Operated in 2.4G ISM band

- ✦ Frequency Hopping Spread Spectrum (FHSS)
- ✦ Time Domain Duplex (TDD)
- ✦ 1600 hops/sec (625 msec) frequency hopper
- ✦ 2400 - 2483.5 MHz allows world wide (almost) operation
- ✦ 79 1-MHz channels (23 in France, Japan)
- ✦ Data rates
 - 1 M symbol/s (Basic rate) – GFSK modulation
 - 2 or 3Mbps (Enhanced data rate) – GFSK, 4/ π -DQPSK and 8-DPSK modulations
- ✦ Tx power 0 dBm (<10m) to 20 dBm (<100m)
 - Range 10 cm to 10 m at low power (0dBm)
 - Power classes

Operation under unlicensed international rules

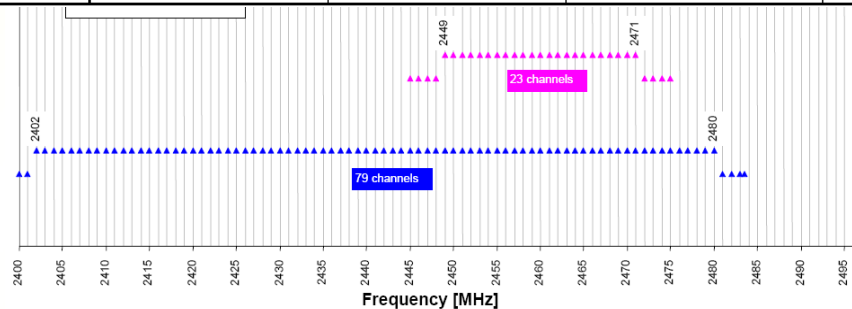
- ✦ US: FCC Part 15
- ✦ Europe: ESTI 300-328



Power Class And Spectrum Allocation

Geography	Regulatory Allocation	Blue Tooth Channels
USA	2.400 – 2.4835 GHz	$f = 2402 + k \text{ MHz}$ $k = 0 \dots 78$
Europe	2.400 – 2.4835 GHz	$f = 2402 + k \text{ MHz}$ $k = 0 \dots 78$
Spain	2.445 – 2.475 GHz	$f = 2449 + k \text{ MHz}$ $k = 0 \dots 22$
France	2.4465 – 2.4835 GHz	$f = 2454 + k \text{ MHz}$

Power Class	Maximum Power	Nominal Power	Minimum Power (at Max Pwr setting)	Power Control
1	100 mW (20 dBm)	N/A	0 dBm	4 dBm – 20 dBm -30 dBm - 0 dBm (optional)
2	2.5 mW (4 dBm)	0 dBm	0.25 mW (-6 dBm)	-30 dBm - 0 dBm (optional)
3	1 mW (0 dBm)	N/A	N/A	-30 dBm - 0 dBm (optional)



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Competitive Systems

✚ The main parameters of

- ✚ HomeRF
- ✚ WLAN
- ✚ DECT
- ✚ Bluetooth

is compared

	HomeRF	IEEE 802.11	DECT	Bluetooth
Frequency range	2,4 GHz	2,4 GHz	1,9 GHz	2,4 GHz
Modulation	GFSK	GFSK	GFSK	GFSK
Power	100 mW	100 mW	250 mW	100 mW
Data rate	0,8 - 1,6 Mbps	2 Mbps	1,152 Mbps	1 Mbps

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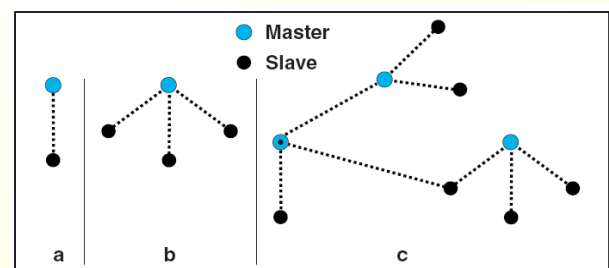
Bluetooth Topology

+ Piconet

- ✦ 2 or more Bluetooth devices form a piconet
 - Connected device can be master or slave
 - master can connect to max. 7 slaves per piconet simultaneously
- ✦ A specific hopping sequence using all 79 RF channels is used for the connection
- ✦ In forming a piconet, master gives slaves its clock and device ID
 - Unique hopping pattern for each piconet
 - all devices in a piconet hop together
- ✦ Each piconet has a maximum gross data rate of 1 Mbit/s

+ Scatternet

- ✦ 2 or more piconets form a scatternet
- ✦ Bluetooth devices can share different piconets



Baseband

+ Physical layer of Bluetooth, it manages

- ✦ physical channels and links apart from other services like error correction, hop selection, etc

+ Bluetooth uses both circuit and packet switched links

- ✦ SCO (synchronous connection-oriented) link
 - Real-time voice (mainly) & Multimedia traffic
 - 3 x 64 kbps
 - PCM (Pulse Code Modulation) or CVSD (continuous Variable Slope Delta)
 - FEC
- ✦ ACL (asynchronous connection-less) link
 - Best effort based
 - Synchronous mode: 433.9 kbps for both directions
 - Asynchronous mode: 723.2 kbps/56.7 kbps



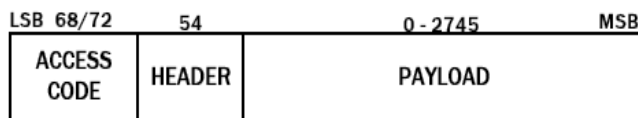
Baseband Packet Format

Modulation

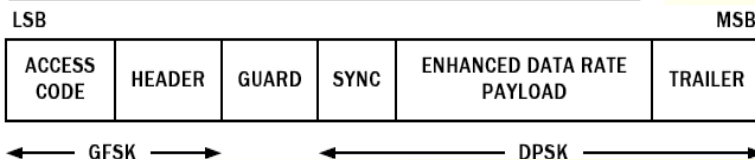
- ⊕ Basic rate
 - All using GFSK, 1 Mbps
- ⊕ Enhanced Data Rate
 - GFSK for Access code and Header, DPSK for the following data, 2 or 3 Mbps

Packet types

- ⊕ Voice packets: HV1, HV2, HV3
- ⊕ Mixed voice/data: DV
- ⊕ Protected data packets: DM1, DM3, DM5
- ⊕ Unprotected data packets: AUX1, DH1, DH3, DH5
- ⊕ Baseband control packets: NULL, POLL, ID, FHS



Basic Rate



Enhanced Data Rate



Data Rate VS. Channel Combination

• ACL packets

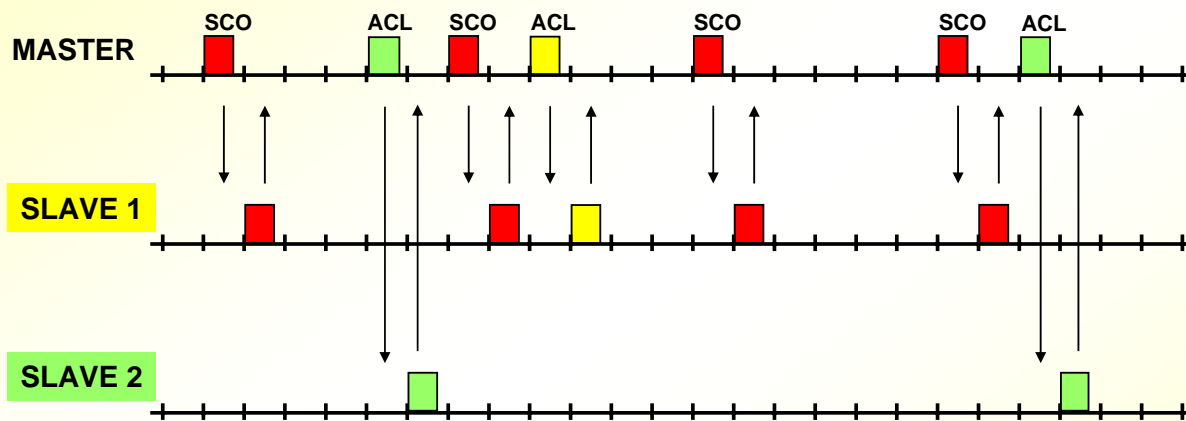
	Type	Payload Header (bytes)	User Payload (bytes)	FEC	CRC	Symmetric Max. Rate (kb/s)	Asymmetric Max. Rate (kb/s)	
							Forward	Reverse
1 slot packets	DM1	1	0-17	2/3	yes	108.8	108.8	108.8
	DH1	1	0-27	no	yes	172.8	172.8	172.8
3 slot packets	DM3	2	0-121	2/3	yes	258.1	387.2	54.4
	DH3	2	0-183	no	yes	390.4	585.6	86.4
5 slot packets	DM5	2	0-224	2/3	yes	286.7	477.8	36.3
	DH5	2	0-339	no	yes	433.9	723.2	57.6
	AUX1	1	0-29	no	no	185.6	185.6	185.6

• SCO packets

Type	Payload Header (bytes)	User Payload (bytes)	FEC	CRC	Symmetric Max. Rate (kb/s)
HV1	na	10	1/3	no	64.0
HV2	na	20	2/3	no	64.0
HV3	na	30	no	no	64.0
DV*	1 D	10+(0-9) D	2/3 D	yes D	64.0+57.6 D



Bluetooth Physical Links



✦ SCO: Synchronous Connection-Oriented link

- point to point between master and a single slave
 - uses reserved time slots
 - can be considered as a circuit switched connection
 - mainly used for voice

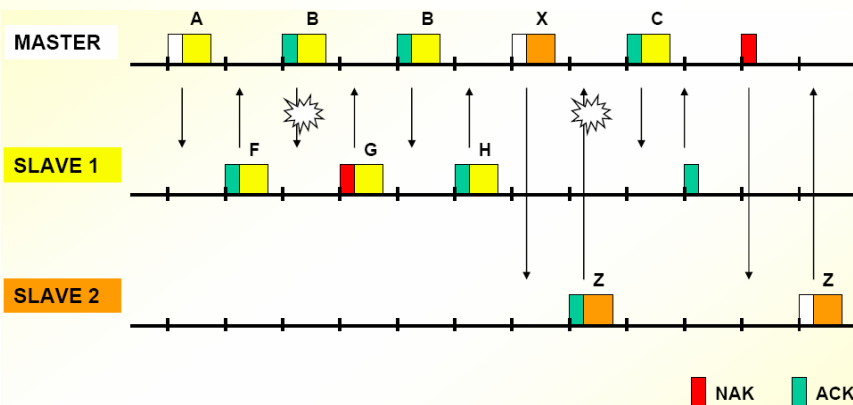
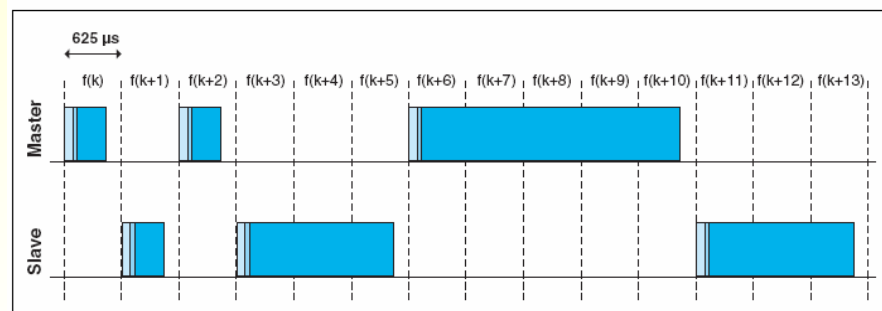
✦ ACL: Asynchronous Connection-Less link

- point-to-multipoint between master and all slaves
 - uses remaining time slots
 - packet switched connection
 - used for data



Retransmission and Multislot Transmission

Multislot Transmission



Retransmission



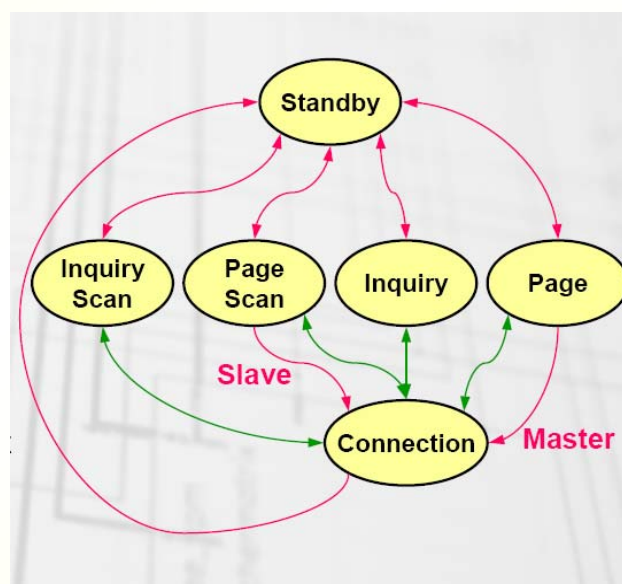
Link Management

- ✚ It discover other remote LM entities and communicates with them through the Link Manager Protocol (LMP).
- ✚ It carries out:
 - ✦ Link Configuration
 - Supported features
 - Power Control
 - QoS Control
 - ✦ Security Functions
 - Authentication
 - Encryption and Key Management
 - ✦ Piconet Management
 - ACL Link setup and detach
 - SCO Link setup and detach
 - Master/Slave Switch
 - Low Power Modes
 - Sniff
 - Hold
 - Park



Link Management -- States

- ✚ **Standby**
 - ✦ Device powered on
- ✚ **Inquiry**
 - ✦ Discover devices in the area
 - ✦ Collect addresses
- ✚ **Page**
 - ✦ Connect to a specific device
- ✚ **Inquiry scan**
 - ✦ Discoverable state
- ✚ **Page scan**
 - ✦ Device waiting to join a piconet
- ✚ **Connection**
 - ✦ Actively on a piconet
 - ✦ Master or slave





Low Power Modes

✚ Modes in connection state

- ✦ Active
 - Maximum 7 slaves, normal case
- ✦ Sniff
 - Device remains active, but low power active mode
 - Device wakes up at assigned Sniff Interval to exchange packets
 - LMP sets Sniff Mode parameters
 - Least efficient power-saving mode
- ✦ Hold
 - Master assigns hold time, after hold time slave wakes up and synchronizes with traffic on the channel
 - ACL packets no longer supported, SCO packets can still be exchanged
- ✦ Park
 - “Deeper Sleep” than Hold Mode
 - Device is no longer active
 - Master establishes a Beacon Channel when a device is parked, and communicate via this channel
 - The most efficient power-saving mode



Battery Life Time

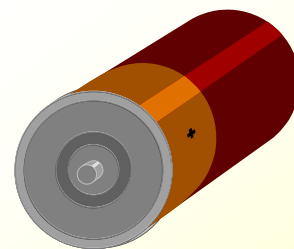
✚ Low power consumption

(Estimates calculated with 600 mAh battery, power will vary with implementation)

- ✦ Standby current < 0.3 mA
 - 3 months
- ✦ Voice mode current 10 mA
 - 60 hours
- ✦ Data mode average 6 mA
 - 100 hours

✚ Low Power Architecture

- ✦ Hold and Park modes 60 μ A
 - Devices connected but not participating
 - Device can participate within 2 ms
 - 1 year battery life time

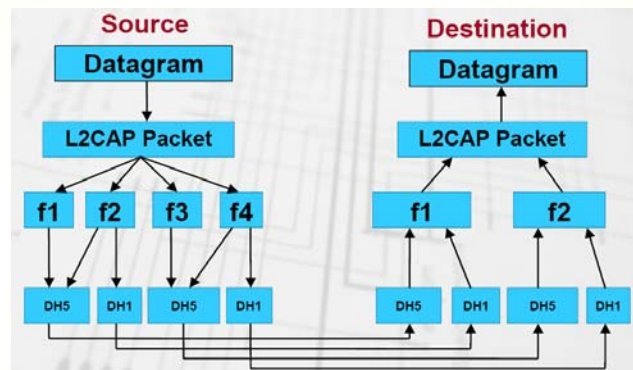




L2CAP

- ✦ Logical Link Control and Adaptation Layer Protocol
- ✦ Layered over baseband protocol and LMP
- ✦ Supports services

- ✦ Segmentation/reassembly
 - Baseband packets are size-limited
 - Segment and reassemble Baseband packets for data link layer
- ✦ Protocol multiplexing
 - Baseband protocol treats all data packets equally
 - L2CAP needs to distinguish packets for different upper layer protocols: SDP, RFCOMM, Telephony Control
- ✦ Quality-of-Service (QoS)
 - Negotiate and enforce QoS contracts



- ✦ Group abstractions
 - Group abstraction allows mapping of baseband protocol groups to piconets

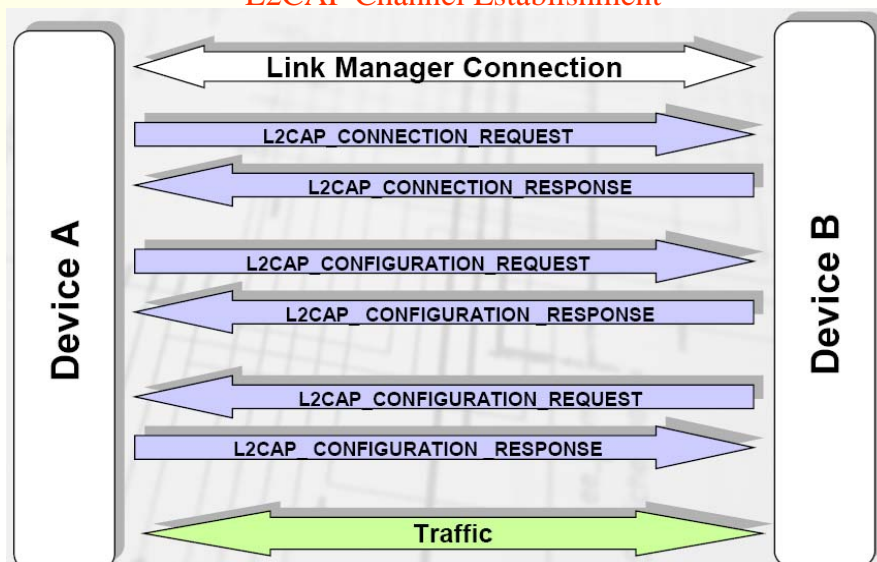


L2CAP Channel Establishment

L2CAP Packet Format

Length (16 bits)	DCID (16 bits)	Payload (0-65535 bytes)
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L2CAP Channel Establishment





Bluetooth Profiles

Profile

- ✦ usage model
- ✦ define specific messages and procedures used to implement a feature
- ✦ regardless of manufacturers

4 general profiles

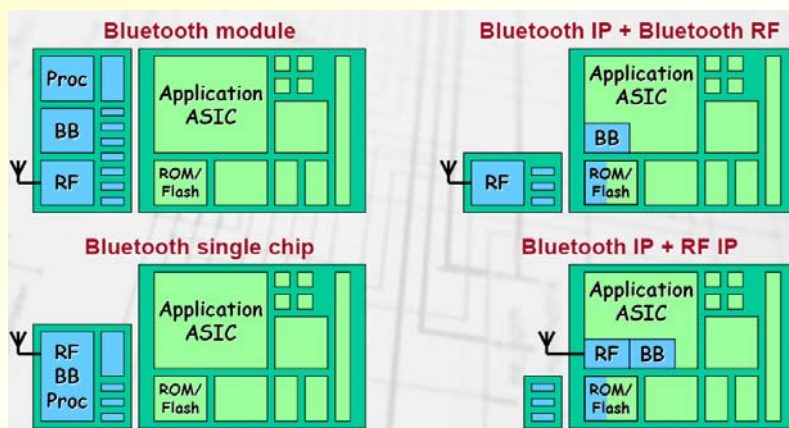
- ✦ Generic Access Profile (GAP)
 - Basic one
 - If not applied with other profile, this must be applied
- ✦ Serial Port Profile (SPP)
 - For cable replacement usage
- ✦ Service Discover Application Profile (SDAP)
 - To discover the service registered in other BT devices and retrieve information about these service



- ✦ Generic Object Exchange Profile (GOEP)
 - How BT devices support the object exchange usage model, such as file transfer profile, object push profile, and synchronization profile

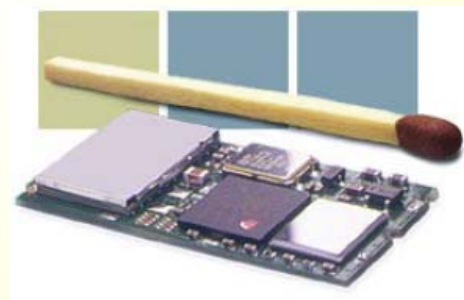


Bluetooth Implementation Choice



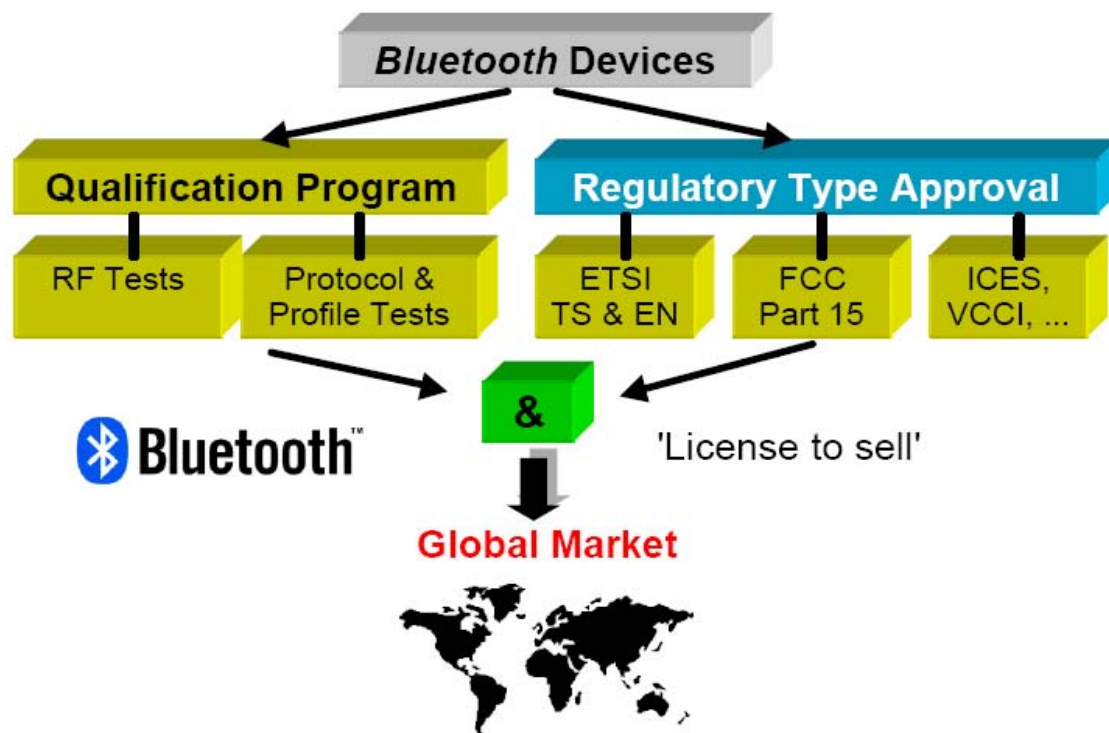
- ✦ Trade-offs
 - ✦ Flexibility
 - ✦ cost
 - ✦ Performance
 - ✦ Size
 - ✦ Power consumption
 - ✦ Etc ...

A single-chip solution is the ultimate goal





Qualification Program and Requirement



Summary

- ✚ Bluetooth provides robust, short-range communications
- ✚ Flexible configuration and profiles can support multiple applications
- ✚ Success of device depends on
 - ✦ The supplier's ability to deliver implementation at a low price point
 - ✦ Application development that is easily integrated with today's infrastructure
 - ✦ Ability of Bluetooth to meet market's expectations



Reference

- ✦ The official Bluetooth membership site
<https://www.bluetooth.org/>
- ✦ XILINX Bluetooth tutorial
<http://www.xilinx.com/esp/wireless/bluetooth/tutorials.htm>
- ✦ NewLogic Bluetooth Tutorial
<http://www.newlogic.com/products/Bluetooth-Tutorial-2001.pdf>
- ✦ Dennis Sweeney, Max Robert, Bluetooth Tutorial
http://www.mprg.org/Tech_xfer/ppt/bt_tut.pdf
- ✦ Bluetooth Core Specification v2.0+EDR
https://www.bluetooth.org/foundry/adopters/document/Bluetooth_Core_Specification_v1.2
- ✦ Nathan J.Muller, "Bluetooth Demystified," McGraw-Hill Professional Publishing, Sep. 2000



Homework

- ✦ The presentation is focus on lower layer of Bluetooth protocols, please give the brief description of following upper layer protocols:
 - ✦ SDP
 - ✦ RFCOMM
- ✦ Headset Profile is used for Bluetooth enabled headset. Please describe briefly about:
 - ✦ Protocol stacks in headset profile
 - ✦ Basic operation procedures

Any Questions ?

Thank you !



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