Bluetooth Technology and Applications

Outline

- Session 1: *Overview of Bluetooth*
- Session 2: *RF section*
- Session 3: *Baseband processing*
- Session 4: *Software considerations*
- Session 5: *Applying Bluetooth in real systems*

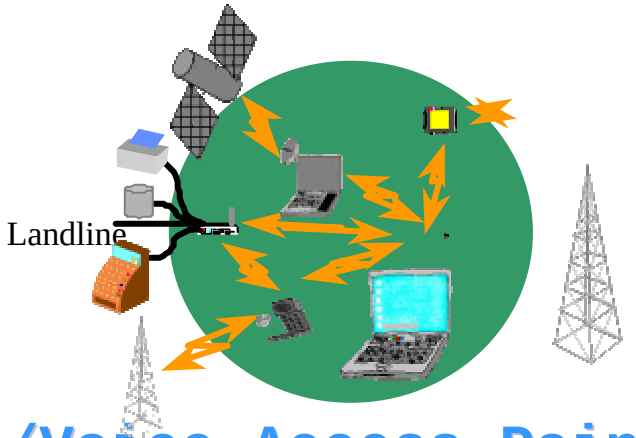
Session 1: Introduction

- **Introduction**
  - **What is Bluetooth?**
  - **What problems is it intended to solve?**
  - **Specifications vs. standards**
- **History and technical overview**
  - **Bluetooth at a glance**
  - **History & current organization**
  - **What does Bluetooth do - technically?**
  - **The Bluetooth protocols**
  - **Interoperability & profiles**
  - **IEEE 802.15.1**
  - **Summary**
- **Compatibility issues**

What is Bluetooth?

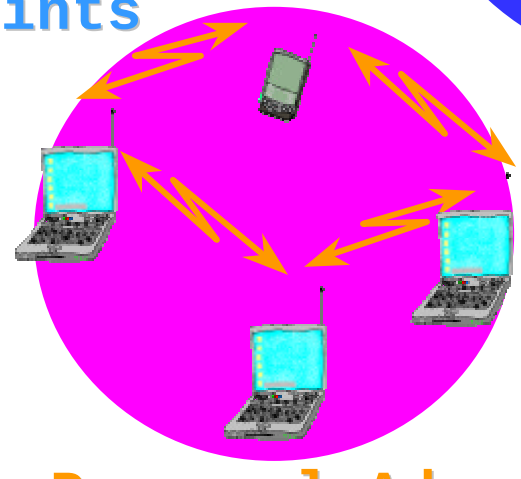
- A short-range wireless technology
- Designed for several needs
  - Interconnecting a computer and peripherals
    Clear the snake's nest behind the desk!
  - Interconnecting various handheld devices
    Laptop computer, cell phone, palmtop
    Preplanning of network is impractical
  - Any short-range application where low cost is essential
    Goal: $5 parts cost
  - Intended to be embedded in other devices
- What it is not
  - Another wireless LAN

What does Bluetooth do for me?



Data/Voice Access Points

Cable Replacement



Personal Ad-hoc Connectivity

Slide courtesy of Tom Siep, TI, and Chatschik Bisdikian, IBM

Usage scenarios: Headset

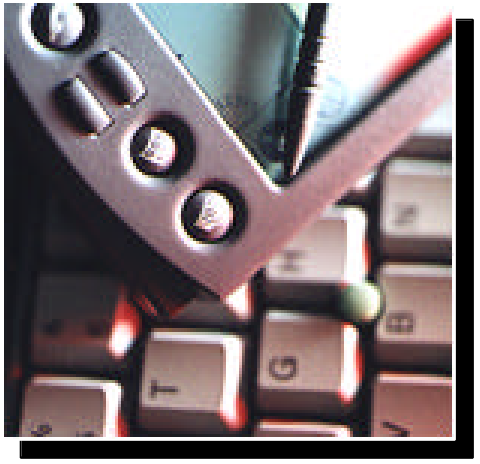
User benefits

- **Multiple device access**
- **Cordless phone benefits**
- **Hand's free operation**

Wireless Freedom…

Slide courtesy of Tom Siep, TI, and Chatschik Bisdikian, IBM

Usage scenarios: Synchronization



User benefits

- **Proximity synchronization**
- **Easily maintained database**
- **Common information database**

Sharing Common Data…

Slide courtesy of Tom Siep, TI, and Chatschik Bisdikian, IBM

Usage scenarios: Data access points

User benefits

- No more connectors
- Easy internet access
- Common connection experience

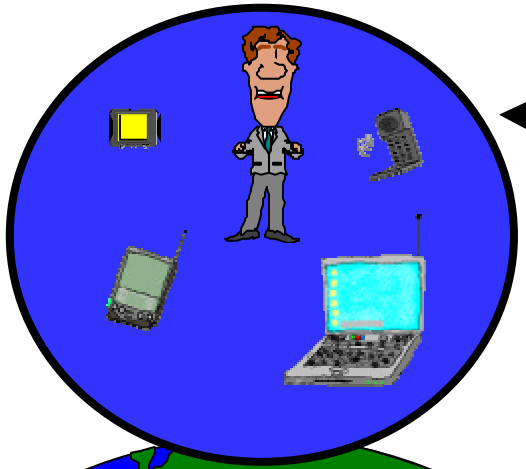
Remote Connections...

Slide courtesy of Tom Siep, TI, and Chatschik Bisdikian, IBM

Wireless Positioning

Wireless LAN

On-campus: Office, School, Airport, Hotel, Home



Bluetooth

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

Off-Campus Global Coverage

Remember Infra-Red?

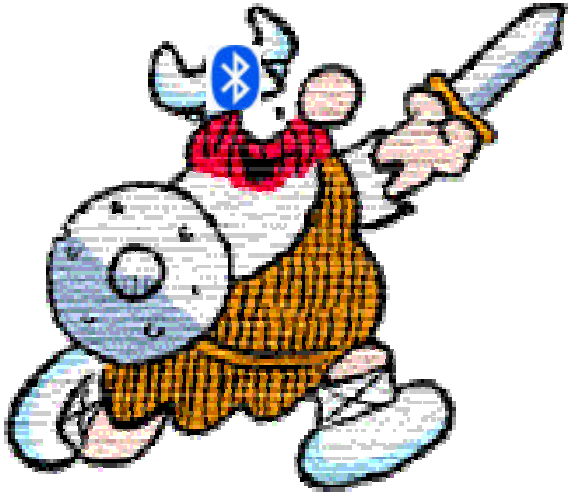
- A short-range wireless technology
- Low-cost, reasonable data rate
- Pushed by Hewlett-Packard
- Most laptops adopted it
- Lots of cellphones and most palmtops have it
- But no software for general connectivity
- Even HP printers don't have IR ports!
- MORAL: a very nonlinear process
  - Value is low until most devices have it (cf. adoption of fax)
  - People won't bother with it until probability of benefit is high

Will Bluetooth Be Universal?

- YES, if the size of the organization behind it means anything
- Original work at Ericsson in 1994: Sven Mattison and Jaap Haartsen
- Bluetooth SIG (Special Interest Group)
  - Original founding members: Ericsson, IBM, Intel, Nokia, Toshiba
    "Promoter" group adds: 3Com, Lucent, Microsoft, Motorola
  - Now over 2100 members
    Everyone you can think of
    Lots of companies you never heard of
  - Very modest cost to join, unlike some other consortia
  - Intellectual property pool
    Members agree to make their IP available to other members
    (if necessary to implement spec)

Where Did the Name Come From?

- A medieval Danish king, Harald Blaatand II or Bluetooth (940-981)
- Noted for unifying Denmark and Sweden



- **Don’t ask:** would the methods that the Vikings used to achieve consensus be admissible in the standards process today?

From Specification to Standard

- Initial work in the Bluetooth SIG
- Specification version 1.1 approved (replacing 1.0B)
- Foundation work joined by IEEE Project 802
  - Generate official standard
  - Deliberation and due process
  - Bluetooth SIG continues on
- 802.15 group already chartered for PANs (personal area networks)
  - SIG responded to call for proposals
- Agreement not to change the first version(s) of Bluetooth
  - Even if overall Project 802 requirements were not met
  - Avoided incompatible developments in Project 802 and SIG
  - Some contention with 802.11 (wireless LAN) group) which considered PANs to be within its charter
- Future technology: an issue
  - Both groups looking at faster rates: Radio 2 and 802.15 TG3
  - IP questions: IEEE doesn’t do patent pools

Specifications and Standards

What's the difference?

Specifications

- Can be written by any company or organization
- Used frequently as a purchasing document, to solicit bids
- As "standards":
  - Written by industry consortia
  - Subject only to their own review and rules of procedure
  - Can be generated quickly, can be flawed

Standards

- Written by groups chartered to do standards
- In U.S., under ANSI (American National Standards Institute)
- May cover only a part of full technology (IEEE 802 does layers 1 & 2)
- Well-specified due process (which may be slow)
- May be dictated by international treaties

Win Some, Lose Some

Official standards don't always make specifications obsolete--

Ethernet
- Blue Book v. 2 by DEC, Intel, and Xerox preceded IEEE 802.3
- 802.3 Physical layer changes accepted immediately
- 802.3 MAC layer changes not always used, even 20 years later
  - Compatibility issues have been handled well

ATM
- ATM Forum became the driving force in ATM
- Standards groups ratified most of what the Forum did, after the fact
- Efficient process made it possible to generate specifications faster than customers could absorb them
- Abandoned by users in favor of high-speed Ethernet
  - Except carriers, where ATM started

Cable Modems
- Official group (IEEE 802.14) solicited cable operators to participate
- Operators finally did, but felt the IEEE process was too slow
- Did their own spec (DOCSIS), which they (not suppliers) controlled
- 802.14 effort was ultimately abandoned

Which Way Will Bluetooth Go?

- Not like cable modems
  - Buyers not concentrated in small group
    Millions of individuals will buy Bluetooth equipment
- Not like ATM
  - No established “legacy” technology like Ethernet
    Infra-red exists but is not well established
  - Low cost will keep complexity bounded
- Probably like Ethernet (my opinion)
  - Coexistence of versions built to standard and original spec
  - Compatibility mechanisms needed
    Issue now: version 1.0b vs. version 1.1, later 1.2
  - Advanced versions (higher speed, longer range) from 802.15

Bluetooth at a glance

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

- **Specification for small-form factor, low-cost, low-power, short-range radio link between notebook PCs, cellular phones, PDAs and other portable devices.**
  - **Radio frequency (RF) technology for Personal Connectivity**
  - **Operates in the unlicensed 2.4GHz ISM band**
  - **Hardware/Software description & application framework.**

Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

A little bit of history

- The Bluetooth SIG (Special Interest Group) was formed in February 1998 by 5 promoter companies
  - Ericsson,IBM, Intel, Nokia, Toshiba
- The Bluetooth SIG went “public” in May 1998
- The Bluetooth SIG work (the spec: 1,600+ pages) became public on July 26, 1999 (ver. 1.0A)
  - ver. 1.0B was released on December 6, 1999
  - ver. 1.1 was released on March 1, 2001
- The promoter group increased in December 1999 to nine
  - added: 3Com, Lucent, Microsoft, Motorola
- There are 2,164 adopters (as of 3/15/2001)
  - adopters enjoy royalty free use of the Bluetooth technology

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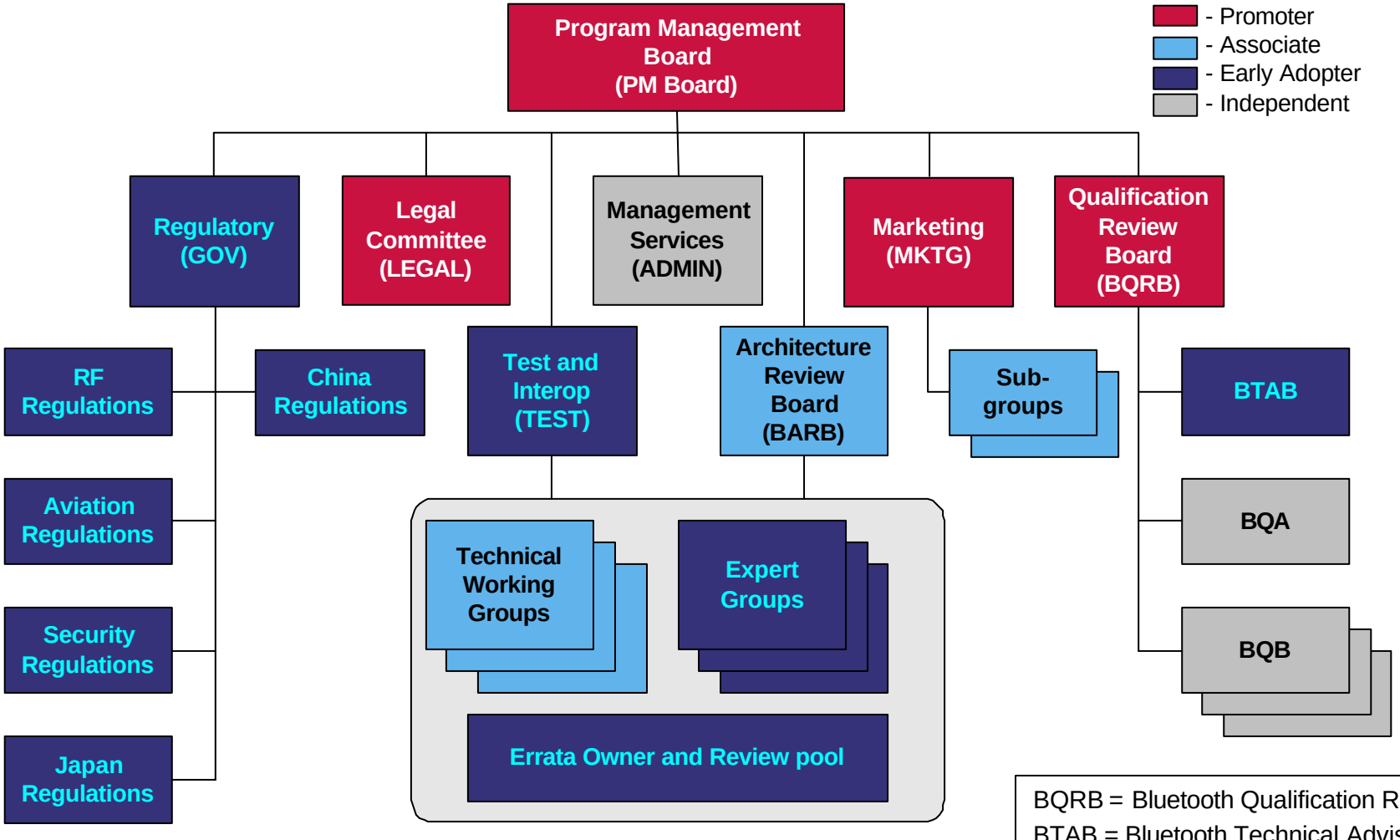
Bluetooth a.k.a. MC Link multi-communicator link

- **“In 1994, Ericsson Mobile Communications AB in Lund, Sweden, initiated a study to investigate the feasibility of a low-power, low-cost radio interface between mobile phones and their accessories. The intention was to eliminate cables between phones and PC cards, wireless headsets, and so forth. The study was part of a larger project that investigated multi-communicators connected to the cellular network via cellular telephones. The last link in the connection between a communicator and the cellular network was a short-range radio link to the phone - thus, the link was called the multi-communicator link or MC link. As the MC link project progressed, it became clear that there was no limit to the kinds of application that could use a short-range radio link. Cheap, short-range radios would make wireless communication between portable devices economically feasible.” Jaap Haartsen, Ericcson Review No. 3, 1998**

Bluetooth SIG Structure



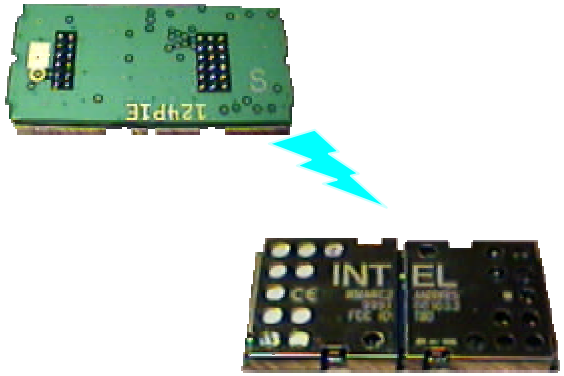
Bluetooth SIG - Key Groups

Policy Groups
- Architecture Review Board (arch)
- Measurement Initiative (mi)
- Regulatory (gov)
- Qualification Program (qp)
- Qualification Review Board (bqrb)
- Test Initiative (ti)

Working Groups
- Radio 2.0 (radio)
- Car Profile (car)
- PAN Profile (pan)
- Human Interface Device (hid)
- Co-existence/Interoperability with 2.4 GHz ISM Devices (coexist)
- Richer Audio/Voice/Video (av)
- Printing Profile (printing)
- Still Image Profile (imaging)
- Extended Service Discovery Profile (esdp)
- Local Positioning Profile (lp)
- UDI for Japanese 3G Handsets (udi)

Expert Groups
- Automotive Expert Group (car) (charter)
- Security Expert Group (sec)

Study Groups
- ATM Study Group (atm)
- Host Controller Interface Study Group (hci)
- Industrial Automation Study Group (ia)
- ISDN Study Group (isdn)
- Quality of Service Study Group (qos)



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)

Cable Replacement

Characteristics

•Operates in the **2.4 GHz** band at a data rate of **720Kb/s**.

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

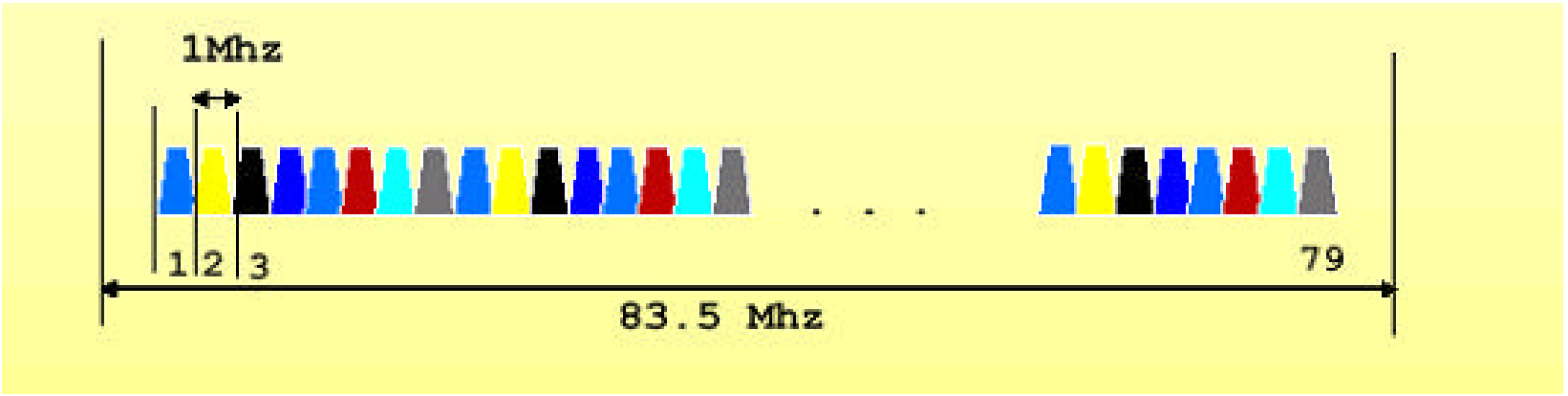
•Radio transceivers **hop** from one channel to another in a **pseudo-random fashion, determined by the master**.

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

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

Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

Bluetooth Frequency Spectrum



- frequency hopping spread spectrum
- 2.402 GHz +k MHz, k= 0,…,78
- 1,600 hops per second
- GFSK modulation
- 1 Mb/s symbol rate
- transmit power
- 0 dbm (up to 20dbm with power control)

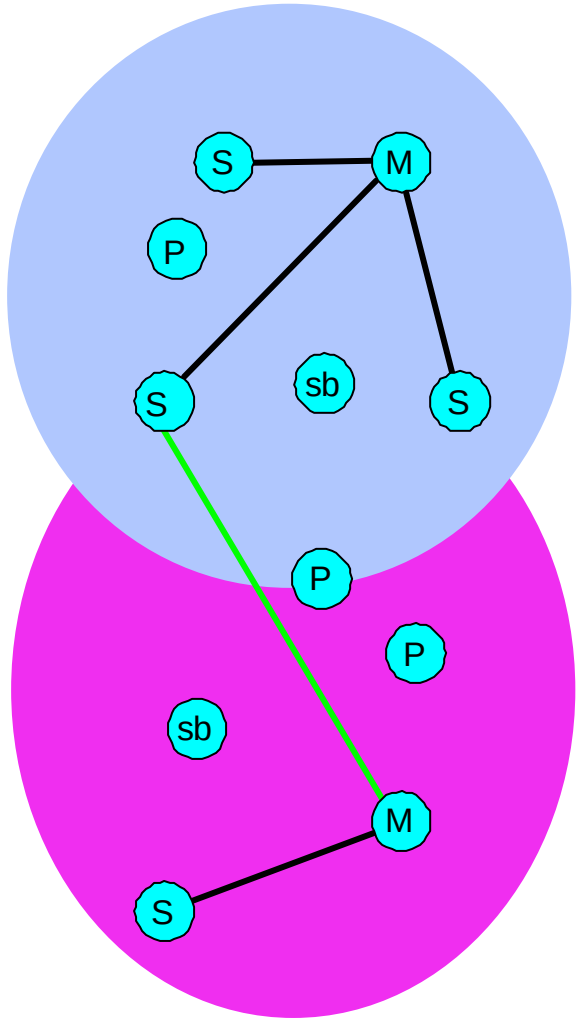
The “lower” layer transports

- **Radio (RF)**
  - **The Bluetooth radio front-end**
    2.4GHz ISM band; 1Mbps
    1,600hops/sec; 0dBm (1mW) radio (up to 20dBm)
- **Baseband (BB)**
  - **Piconet/Channel definition**
  - **“Low-level” packet definition**
  - **channel sharing**
- **Link Management (LM)**
  - **Definition of link properties**
    encryption/authentication
    polling intervals set-up
    SCO link set-up
    low power mode set-up

Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

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 (1 MSps)
  - Unique hopping pattern/ID
- **Scatternet**
  - Piconets can coexist in time and space



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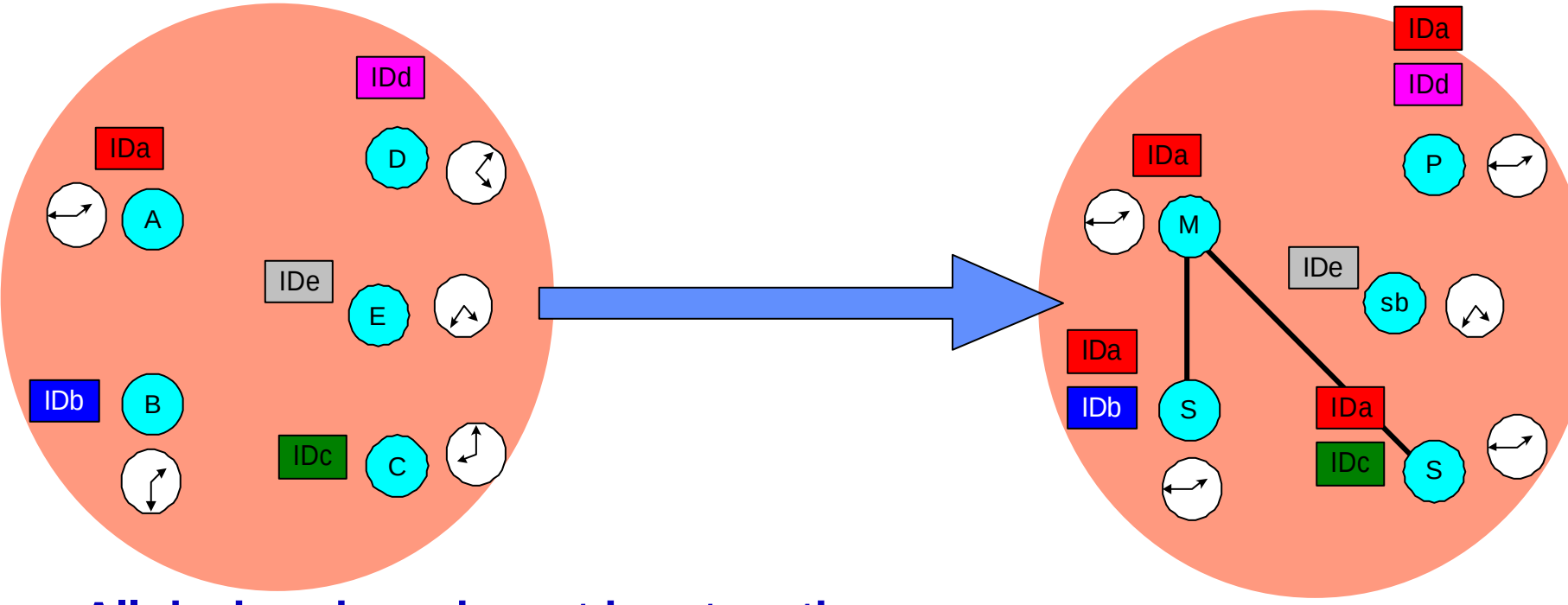
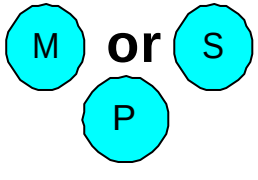
The piconet

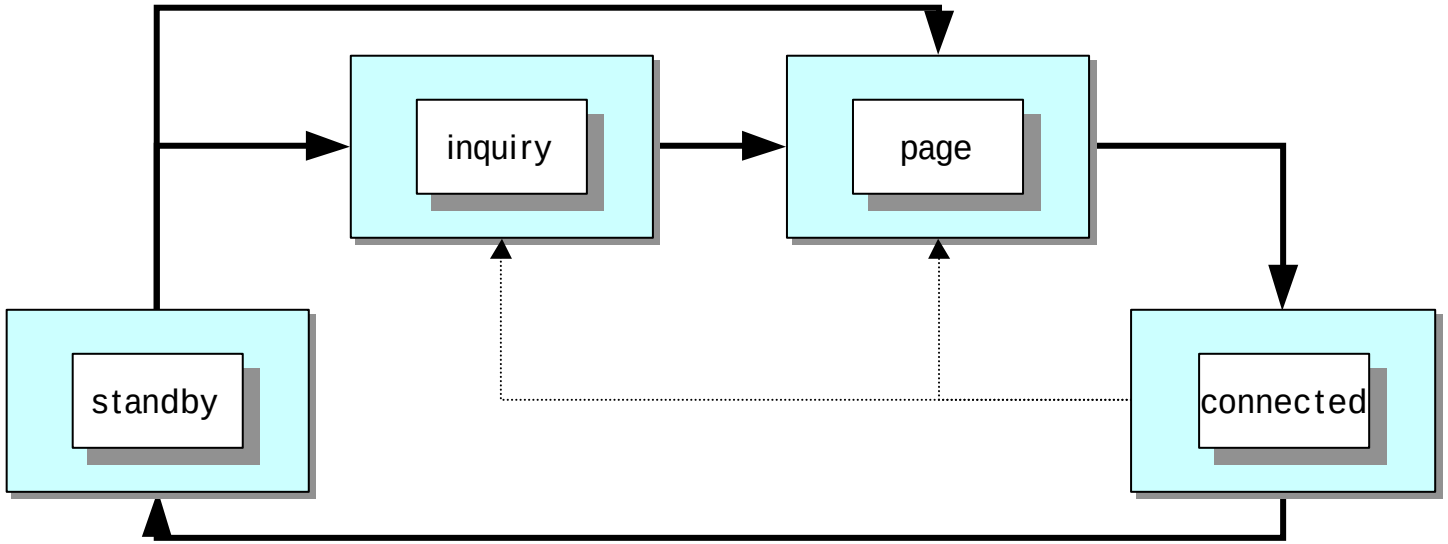


- **All devices in a piconet hop together**
  - **To form a piconet: master gives slaves its *clock* and *device ID***
    - **Hopping pattern determined by *device ID* (48-bit)**
    - **Phase in hopping pattern determined by *Clock***
- **Non-piconet devices are in standby**
- **Piconet Addressing**
  - **Active Member Address (AMA, 3-bits)**
  - **Parked Member Address (PMA, 8-bits)**



Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

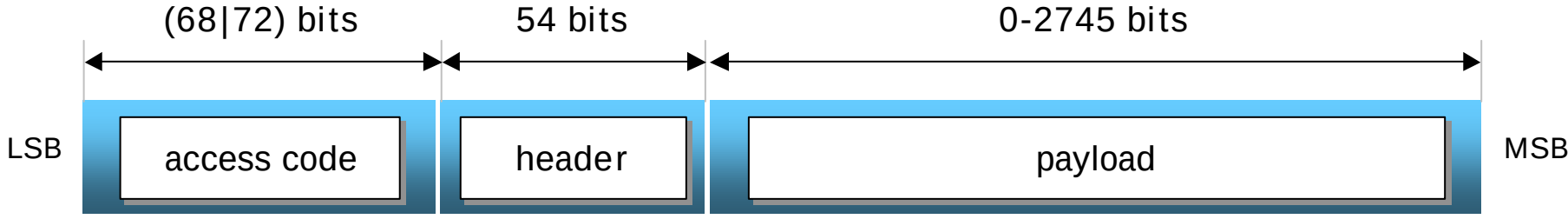
The baseband states



- **Standby**
  - **do nothing**
- **Inquire**
  - **search for other devices in the vicinity**
- **Page**
  - **connect to a specific device**
- **Connected**
  - **participate in a piconet (master or slave)**

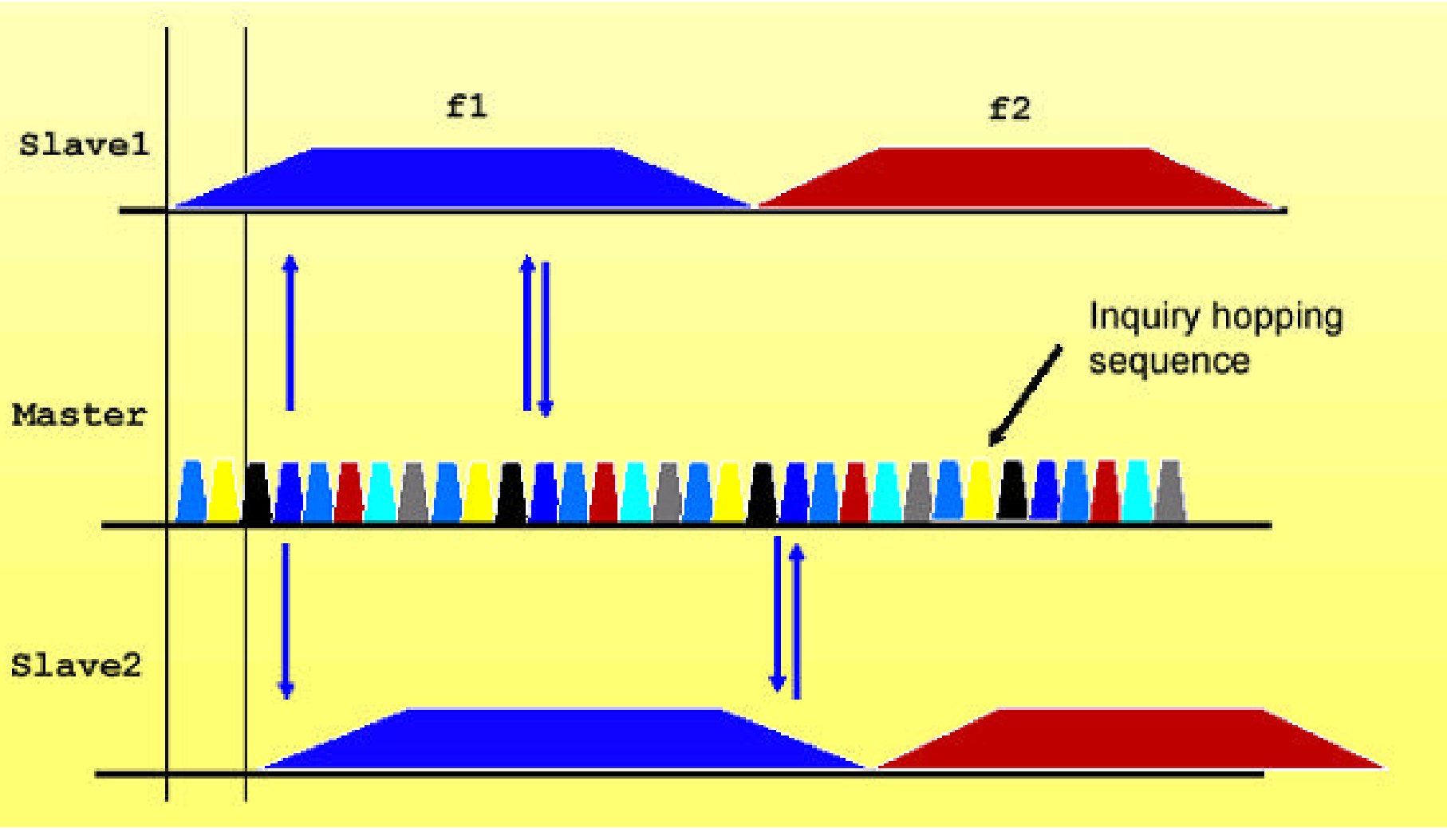
Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

Baseband packet

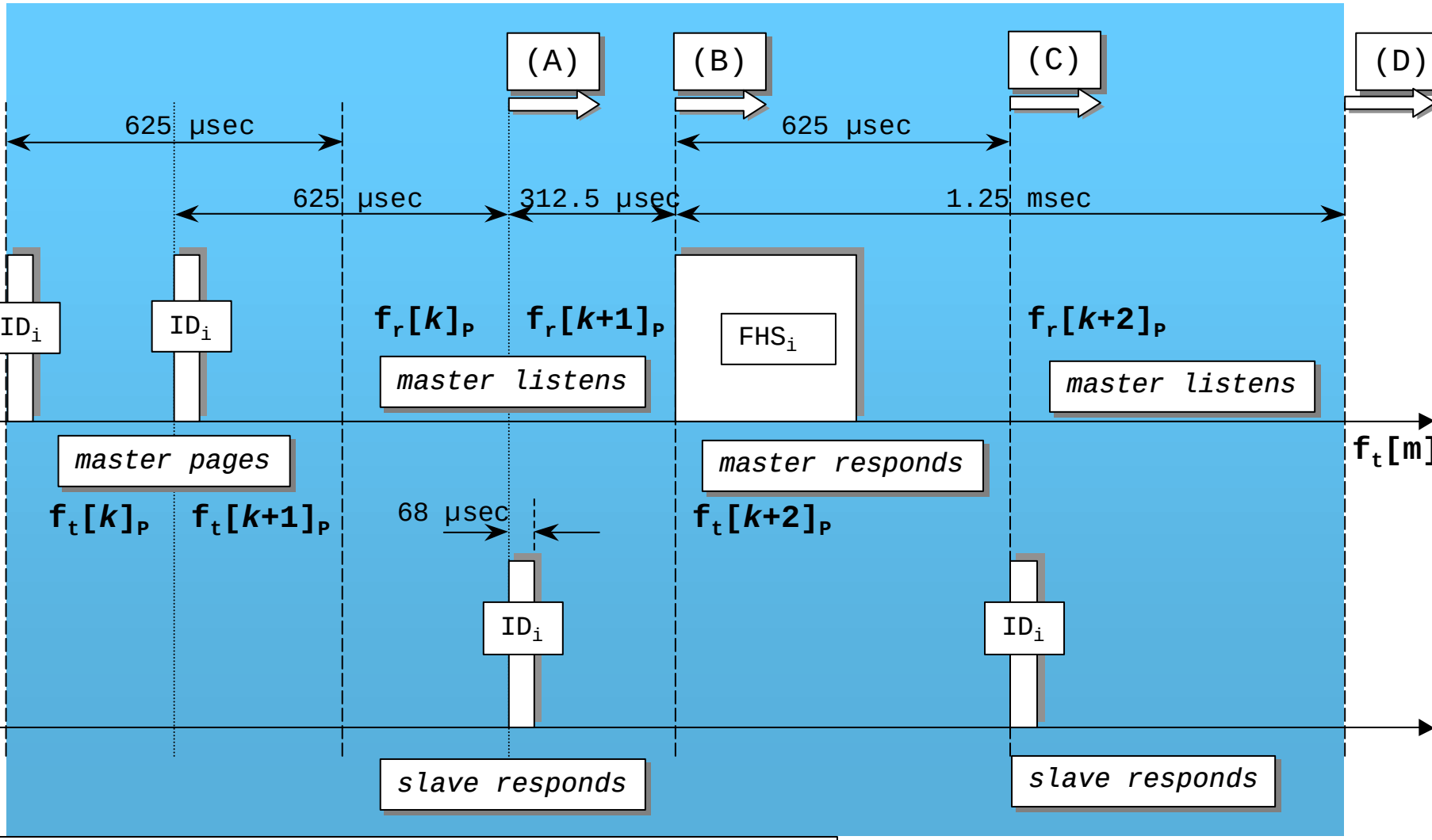


Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

Inquiry Process



Paging sequence

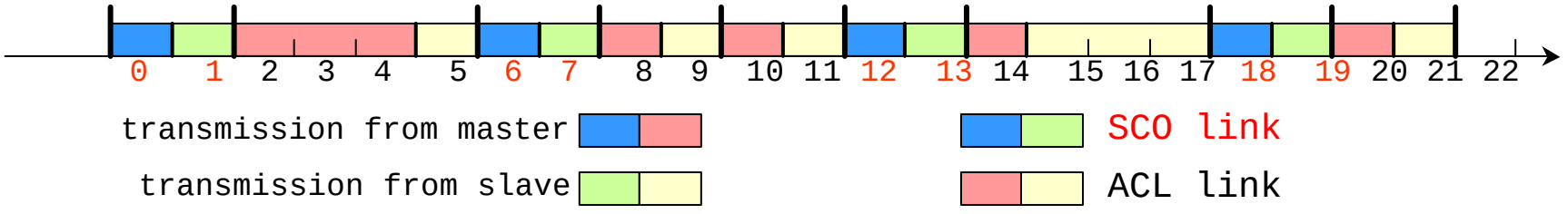


A: slave acquires half-slot synchronization
B: slave acquires full-slot synchronization
C: slave capable to join master's piconet

Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

Baseband link types

- **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
- **Synchronous connection-oriented (SCO) link**
  - “circuit-switched”
    periodic single-slot packet assignment
  - symmetric 64Kbps full-duplex
- **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)



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What is a Piconet?

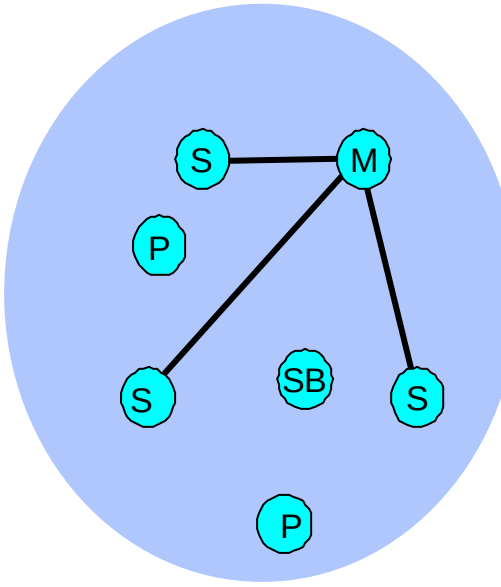
- A **collection** of devices connected in an **ad hoc** fashion.

- 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

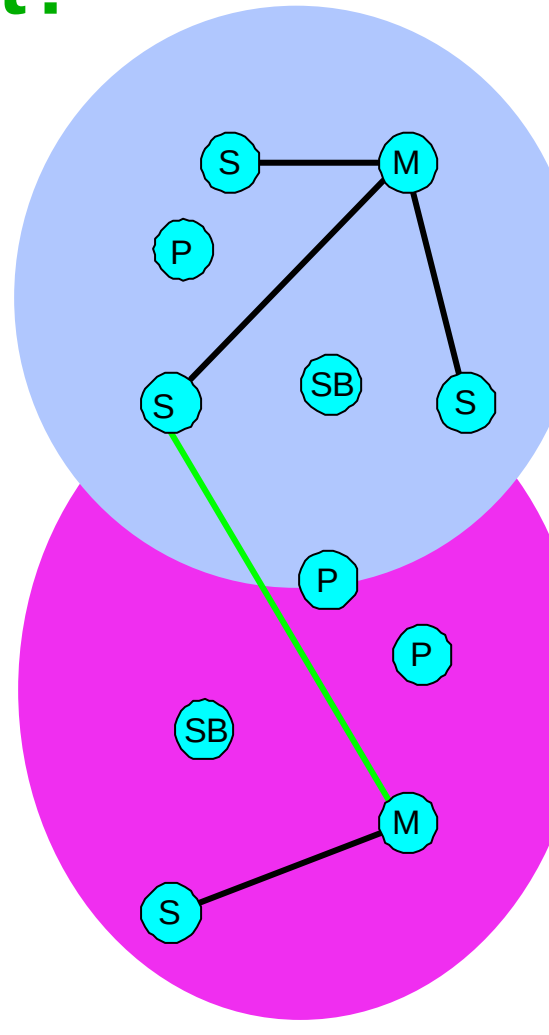


M=Master P=Parked
S=Slave SB=Standl

Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

What is a Scatternet?

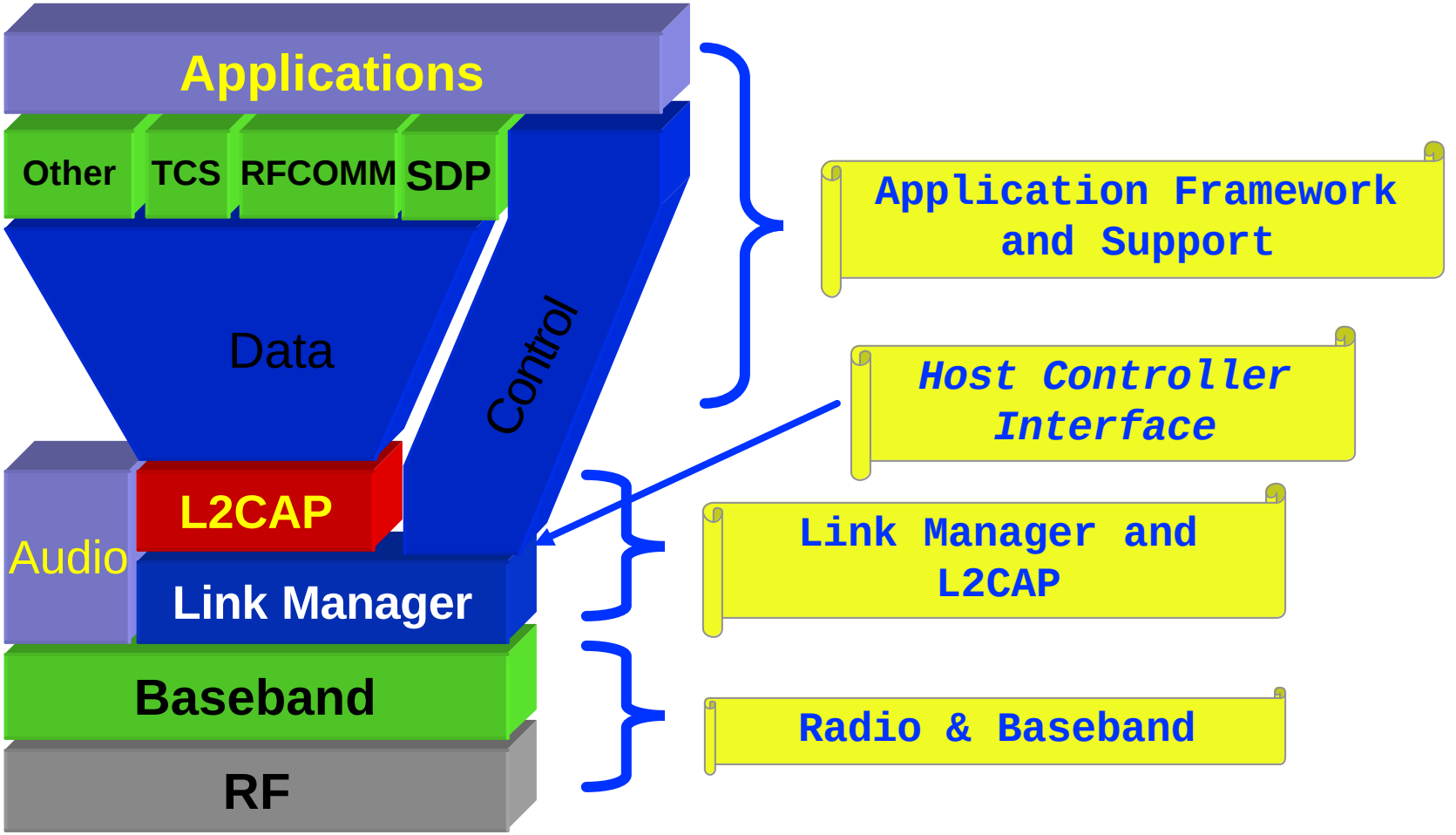
- A **Scatternet** is the **linking** of multiple **co-located piconets** through the sharing of common master or slave devices.
- A device can be both a **master** and a **slave.**
- Radios are **symmetric** (same radio can be master or slave)
- **High capacity system**, each piconet has maximum capacity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



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

Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

The Bluetooth protocols



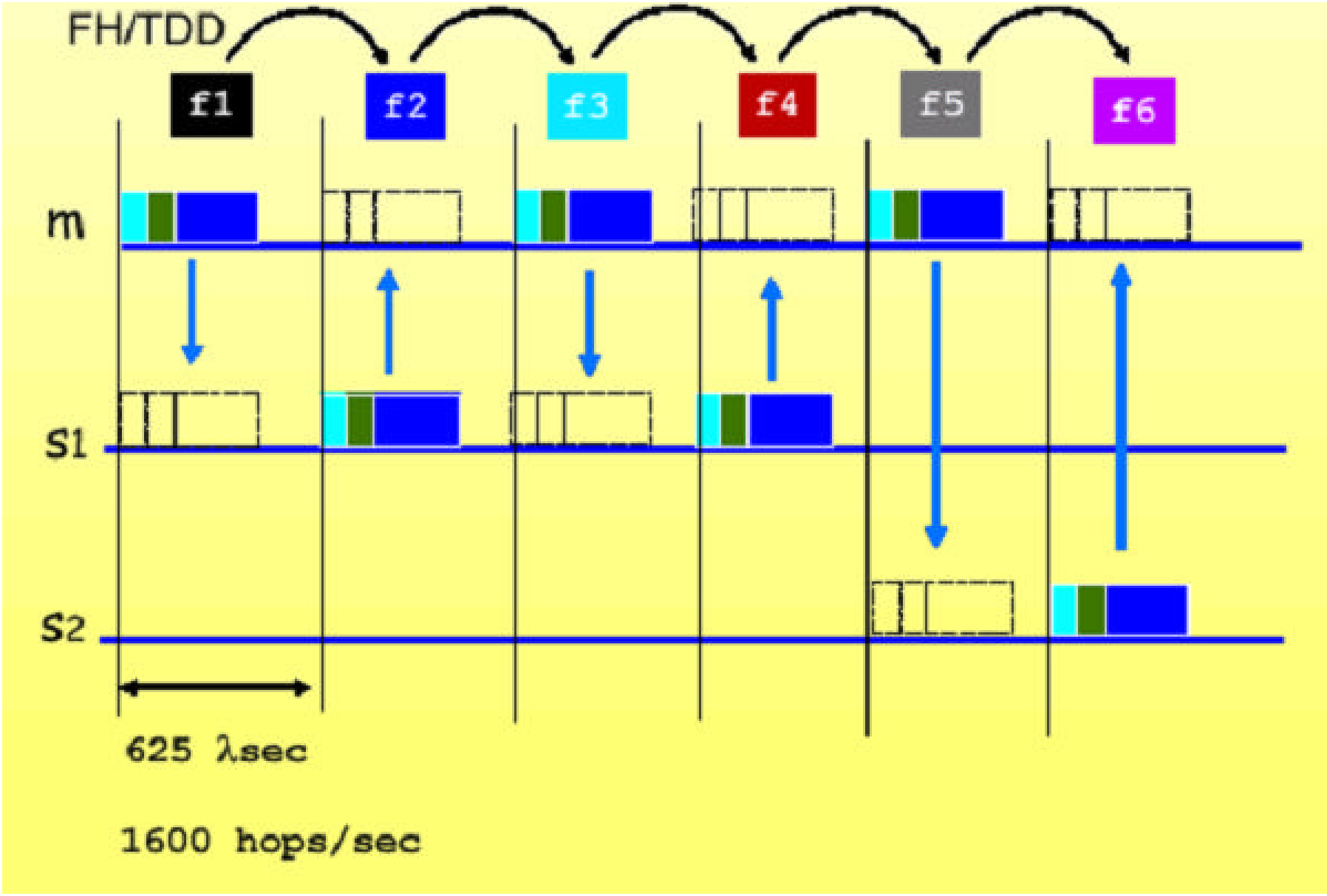
- A hardware/software description
- An application framework

Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

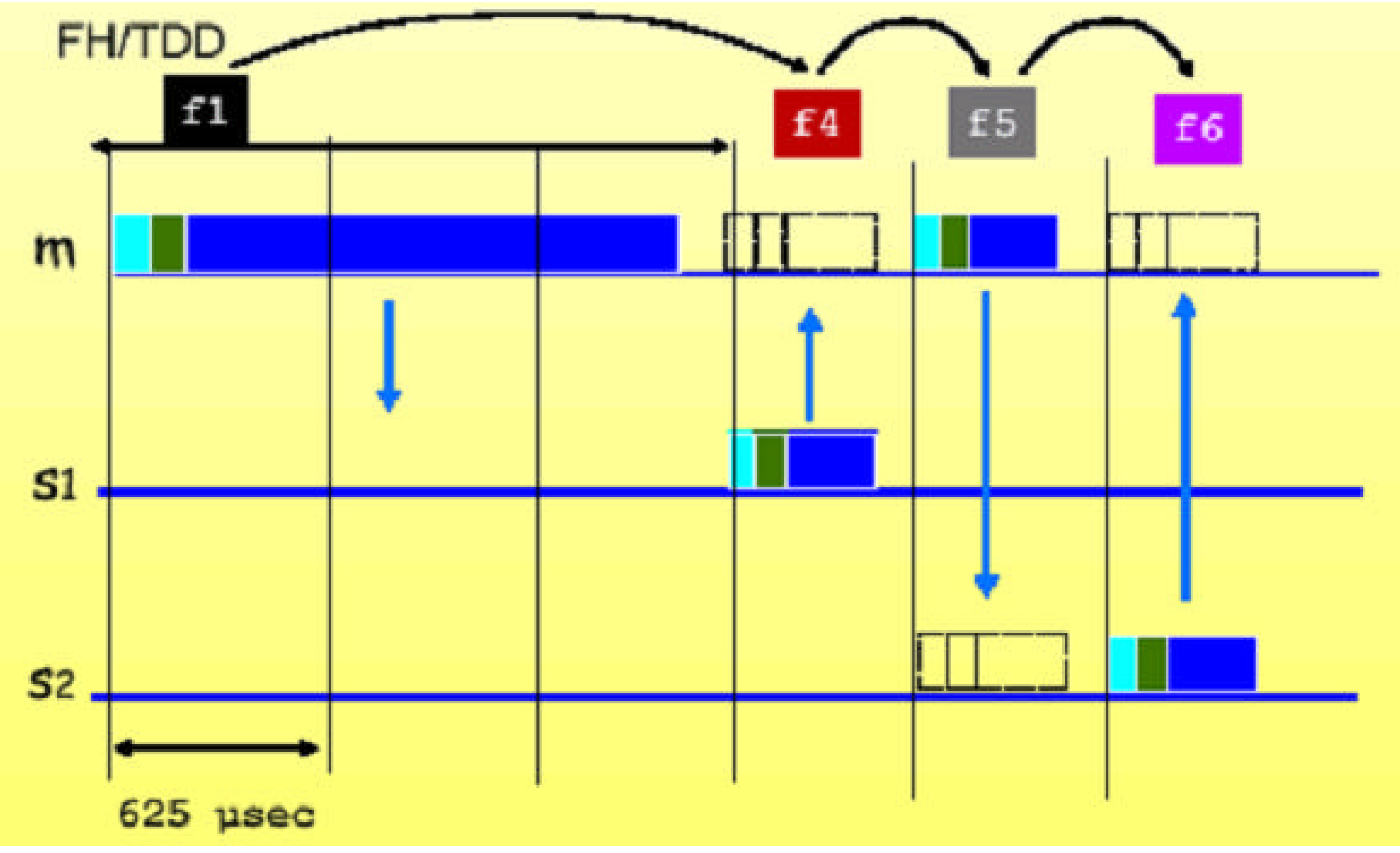
Bluetooth Addressing

- Bluetooth device address (BD_ADDR)
  - 48-bit IEEE MAC address
- Active Member address (AM_ADDR)
  - 3-bit active slave address
  - All zero broadcast address
- Parked Member address(PM_ADDR)
  - 8-bit parked slave address

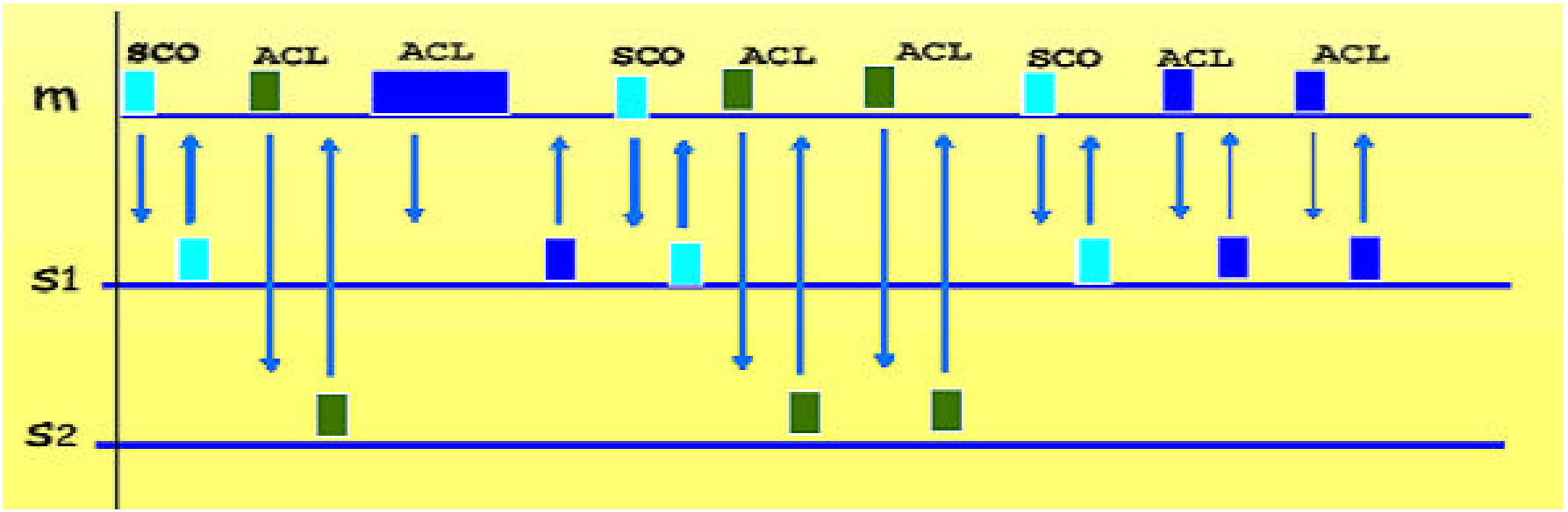
Piconet Channel



Multi-slot packets



Physical Link Types

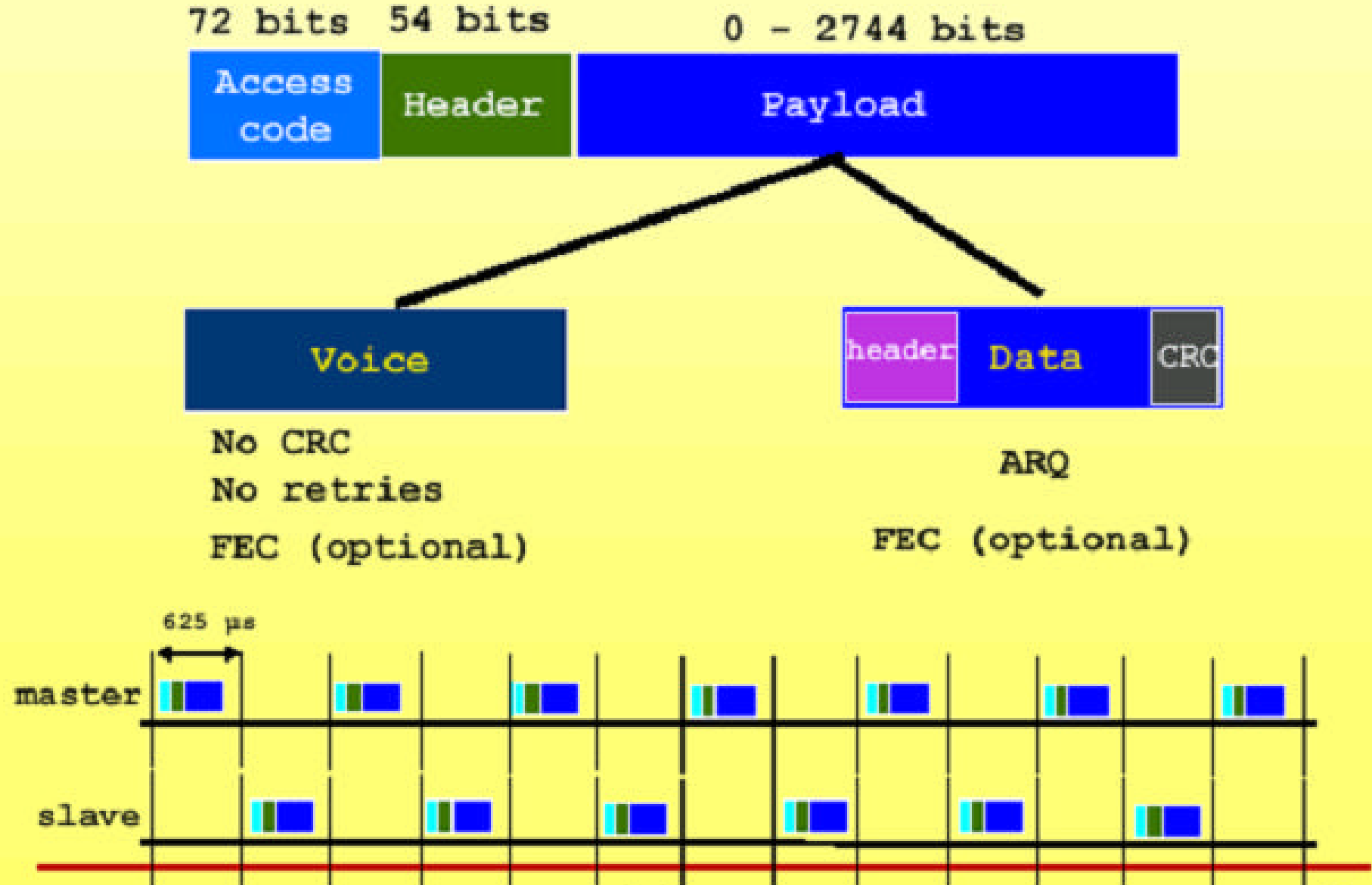


- Synchronous Connection Oriented (SCO) Link
  - ➢ Slot reservation at fixed intervals
- Asynchronous Connection-less (ACL) Link
  - ➢ Polling access method

Packet Types

- Control Packets
  - ID*
  - NULL
  - Poll
  - FHS
  - DM1
- Voice/Data Packets
  - HV1 -- DM1
  - HV2 -- DM3
  - HV3 -- DM5
  - DV -- DH1
  - -- DH3
  - -- DH5

Packet Format



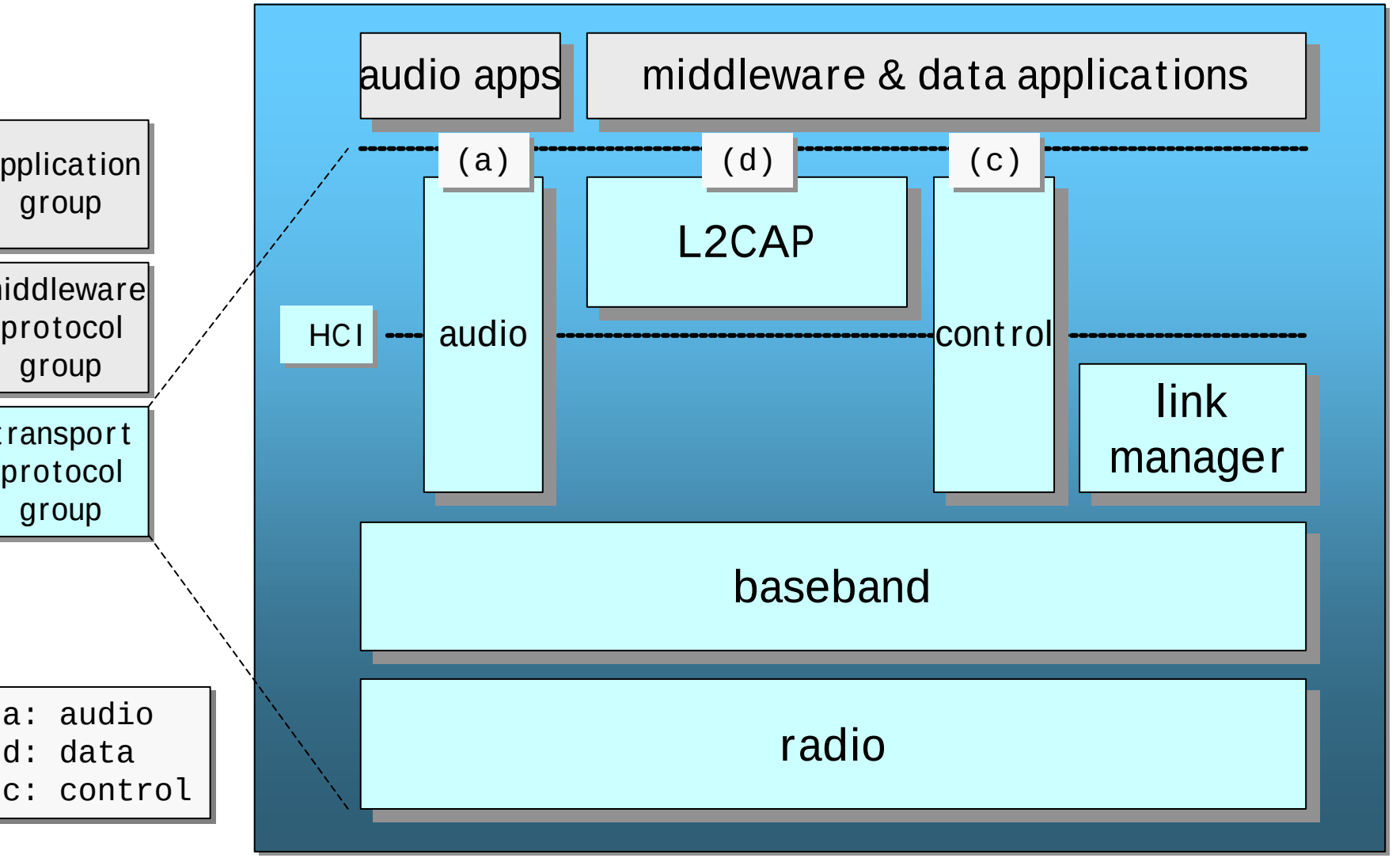
Access Code

- Purpose:
  - Synchronization
  - DC offset compensation
  - Identification
  - Signaling
- Types:
  - Channel Access Code (CAC)
  - Device Access Code (DAC)
  - Inquiry Access Code (IAC)

Packet Header

- Addressing (3) ⟶ Max 7 active slaves
- Packet types (4) ⟶ 16 packet types (some unused)
- Flow control (1)
- 1-bit ARQ ⟶ broadcast packets are not ACKed
- Sequencing ⟶ filtering retransmitted packets
- HEC (8) ⟶ verify header integrity

The transport protocols



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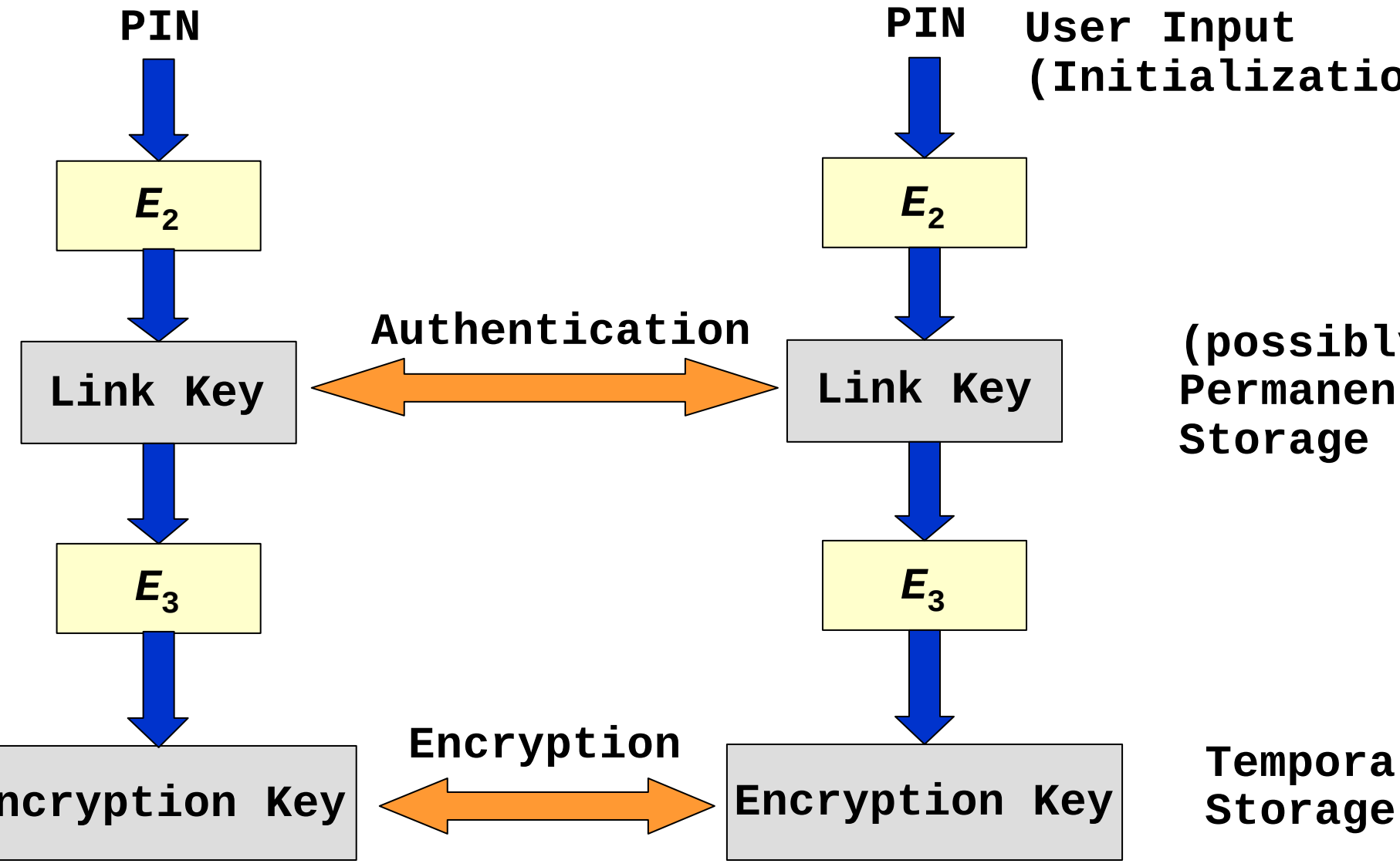
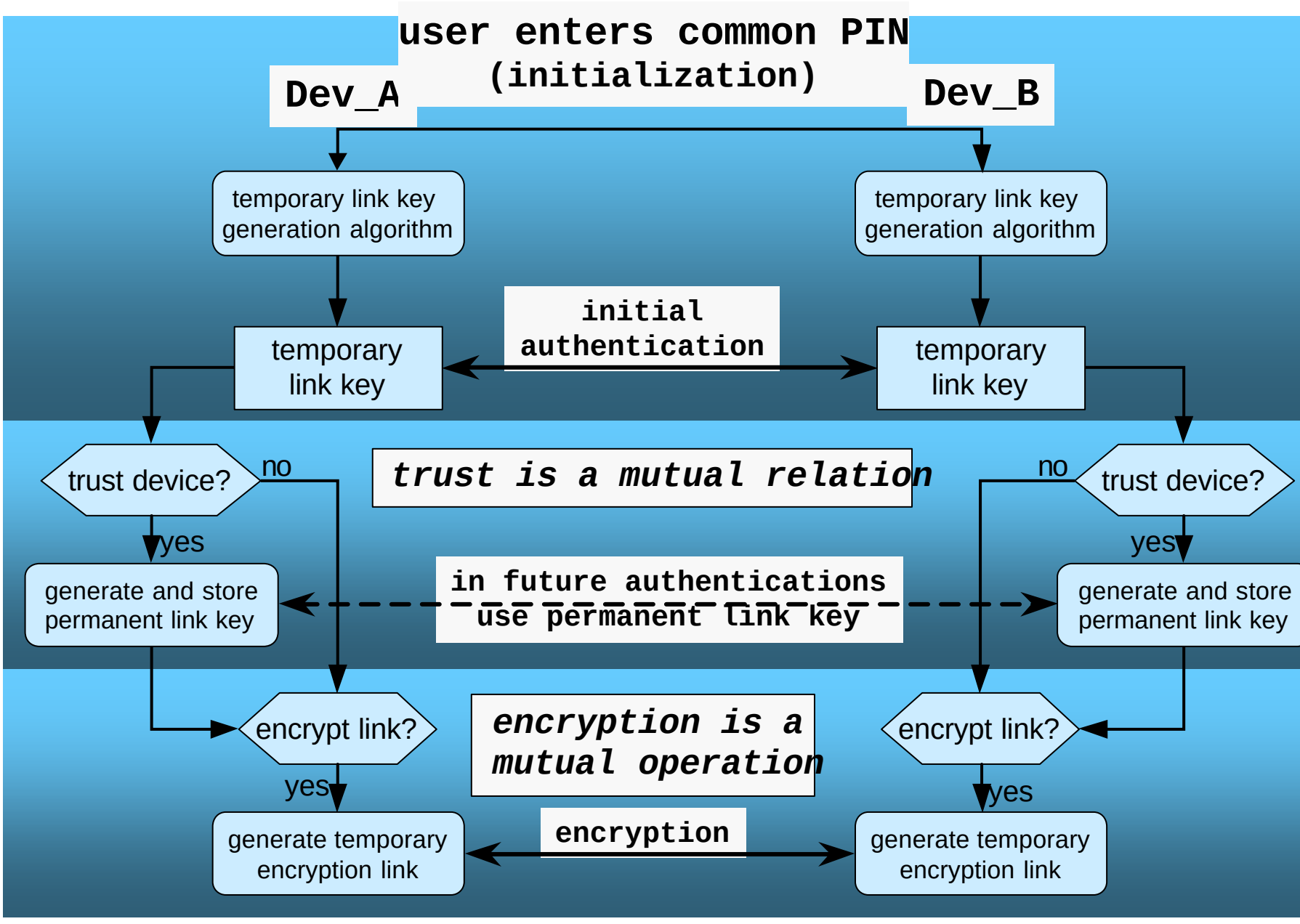
Key generation and usage



Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>



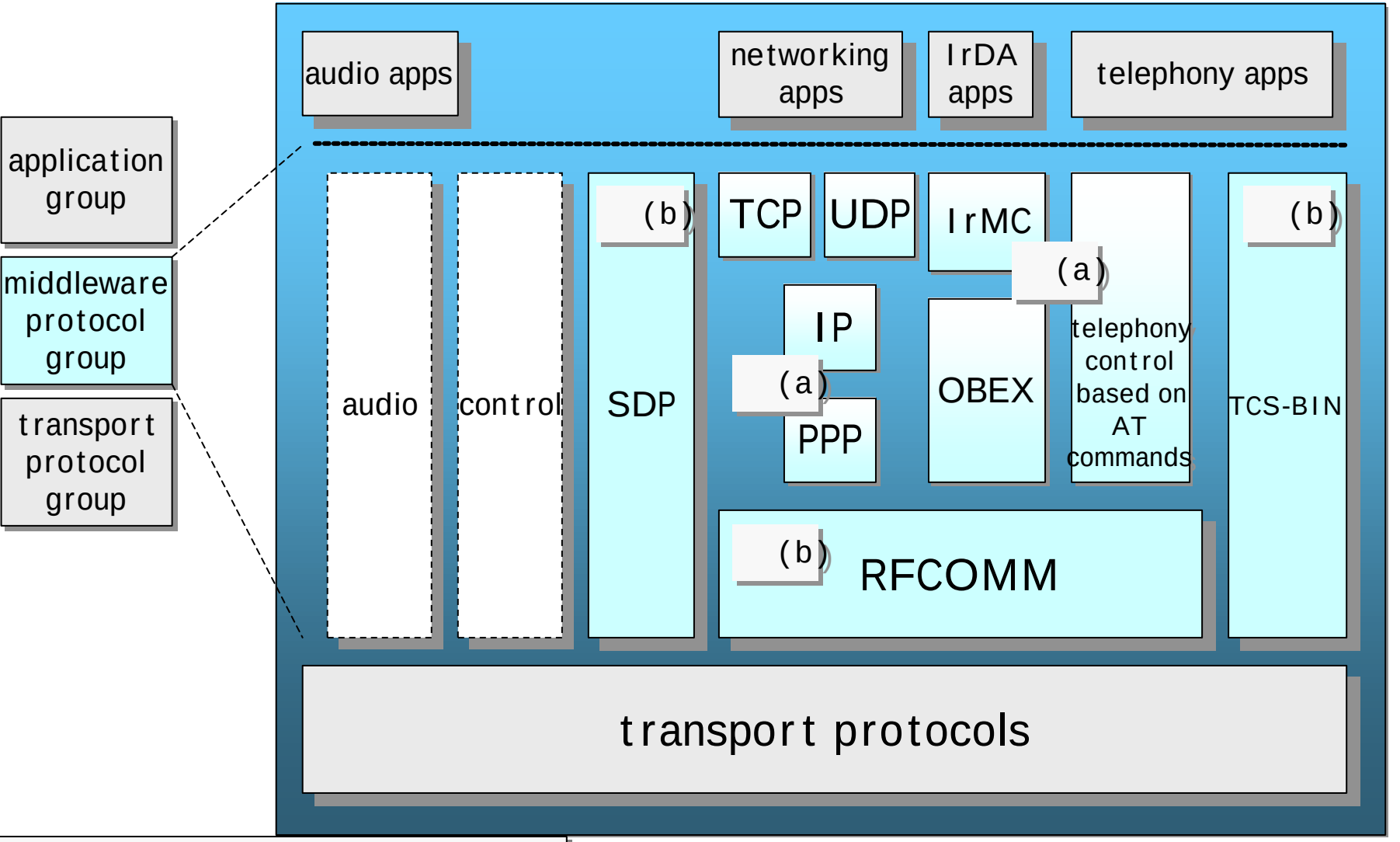
Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

The “upper” layer transports

- **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
- **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

Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

The middleware protocols



a: adopted protocol
b: Bluetooth specific protocol

Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

Middleware protocols (1)

- **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)**

Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

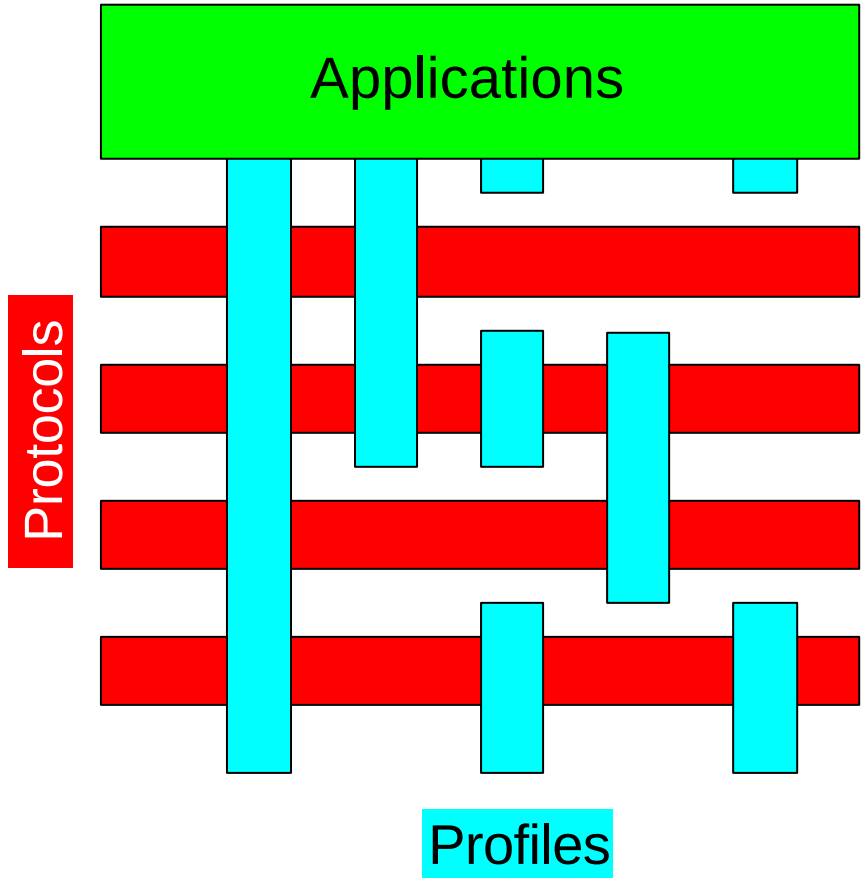
Middleware protocols (2)

- **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**
- **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**

Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

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**



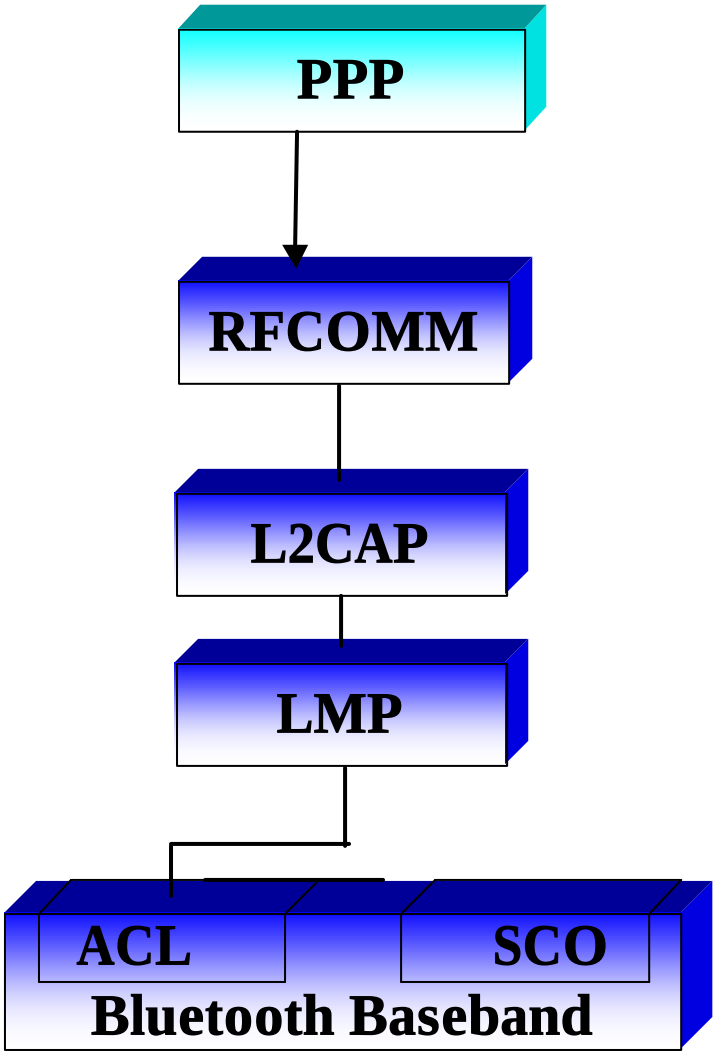
Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

Profiles (spec v.1)

- Generic Access Profile
  - Service Discovery Application Profile
  - Serial Port Profile
    - Dial-up Networking Profile
    - Fax Profile
    - Headset Profile
    - LAN Access Profile (using PPP)
    - Generic Object Exchange Profile
      - File Transfer Profile
      - Object Push Profile
      - Synchronization Profile
  - *TCS_BIN-based profiles*
    - Cordless Telephony Profile
    - Intercom Profile

Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

LAN access point profile



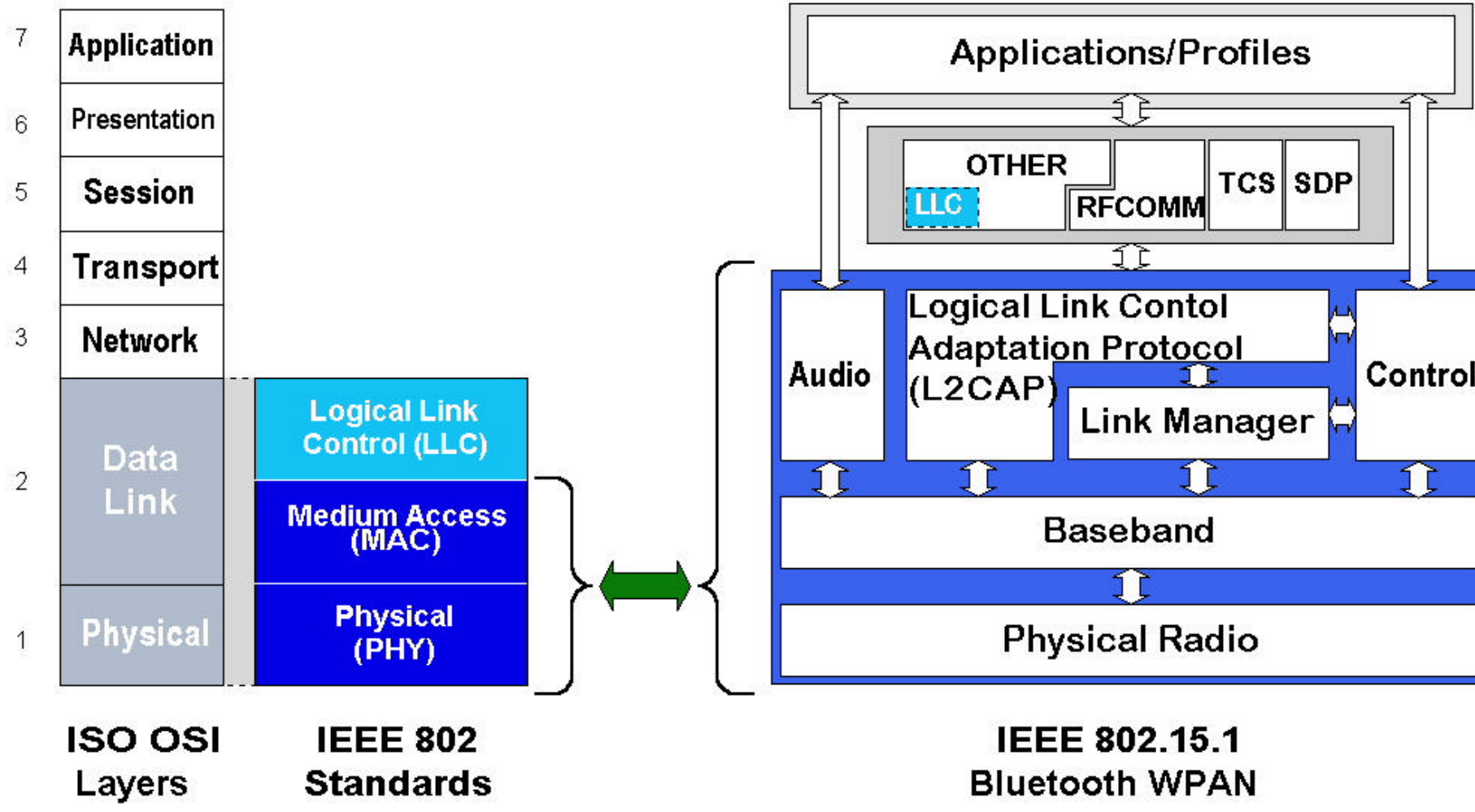
Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

Profiles (spec v.2)

- Radio 2 (next generation radio)
  - backward compatible
- Car Profile
- PAN Profile
- Human Interface Device
- Co-existence/Interoperability with 2.4 GHz ISM Devices
- Richer Audio/Voice/Video
- Printing Profile
- Still Image Profile
- Extended Service Discovery Profile
- Local Positioning Profile
- UDI for Japanese 3G Handsets

Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

The 802.15.1 standard



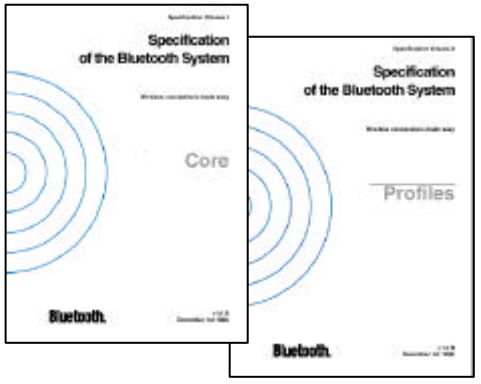
Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

Summary

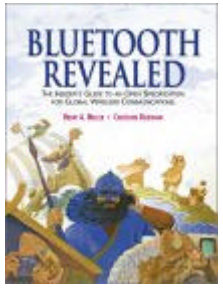
- **Bluetooth is a global, RF-based (ISM band: 2.4 GHz), short-range, connectivity solution for portable, personal devices**
  - **it is not just a radio, it is an end-to-end solution**
- **The Bluetooth spec comprises**
  - **a HW & SW protocol specification**
  - **usage case scenario profiles and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

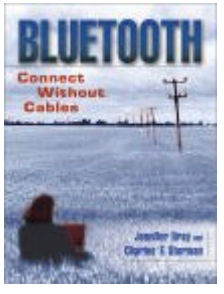
Source: Dr. Chatschik Bisdikian <bisdik@us.ibm.com>

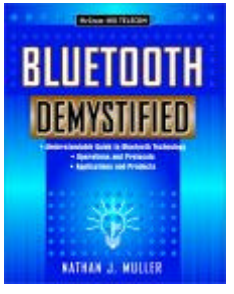
More on Bluetooth?

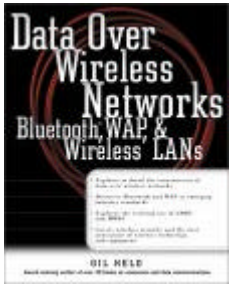


- **More Info:**
- **http://www.bluetooth.com/developer/specification/specification.asp**









- **More Info:**
- **http://internet.motlabs.com/books.htm**

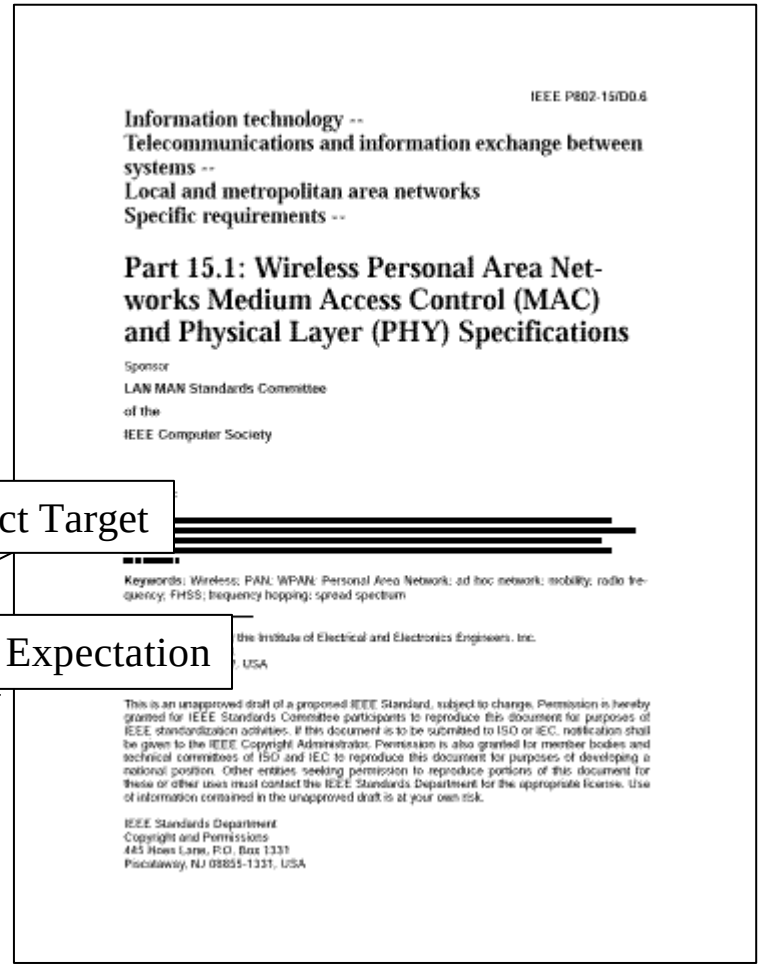
More on Bluetooth? (cont)

- **Join the Bluetooth SIG and participate**
  - **http://www.bluetooth.org**
- **Join the IEEE WG for WPANs and participate**
  - **http://ieee802.org/15**
- **Join the IETF IP over Bluetooth (IPoBT) BoF**
  - **http://internet.motlabs.com**

- **Also visit the Bluetooth(TM) Weblog**
  - **http://bluetooth.weblogs.com/**

More on IEEE 802.15.1?

- Jul99
  - Initial Discussion on Proposals.
- Nov99
  - Initial draft ready for WG ballot.
- Jan00
  - First Ballot complete, second ballot kicked off.
- Mar01
  - Draft ready for IEEE sponsor ballot.
- Jul01
- Sep01
  - Approval by IEEE Standards Board
- Nov01
- Dec01
  - Approval by IEEE Standards Board


IEEE P802-15/D0.6

Information technology --
Telecommunications and information exchange between systems --
Local and metropolitan area networks
Specific requirements --

Part 15.1: Wireless Personal Area Networks Medium Access Control (MAC) and Physical Layer (PHY) Specifications

Sponsor
LAN MAN Standards Committee
of the
IEEE Computer Society

Keywords: Wireless; PAN; WPAN; Personal Area Network; ad hoc network; mobility; radio frequency; FHSS; frequency hopping; spread spectrum

the Institute of Electrical and Electronics Engineers, Inc.
, USA

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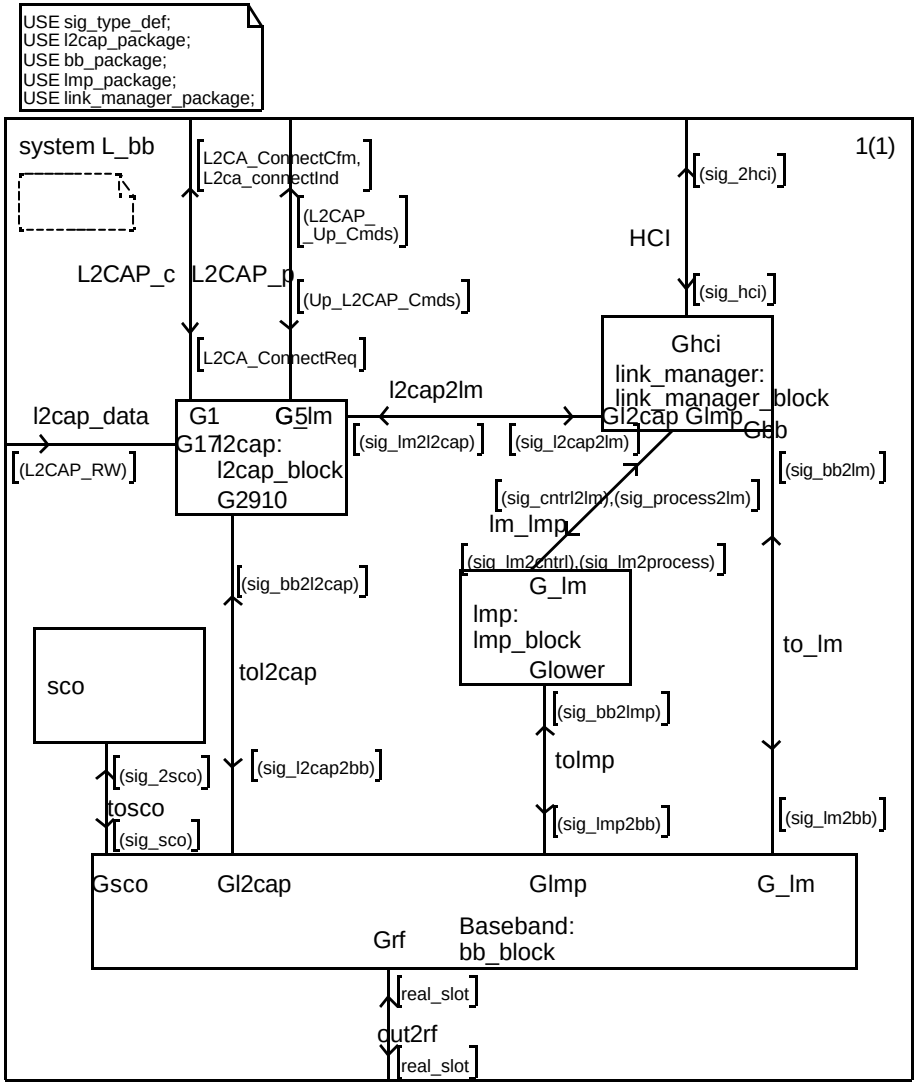
802.15.1 Project Target

802 Sponsor Expectation

IEEE 802.15.1 SDL Overview

- **What is SDL?**
  - **Specification and Description Language**
  - **Standardized by ITU-T in the Z-series Mainly ITU-T Recommendation Z.100**
- **Why use SDL?**
  - **Provides Clear and Unambiguous Description of … (e.g. Protocols, or Systems)**
  - **Simulation, Validation, and Verification tools available for SDLs**
  - **Conversion tools available to take SDL in and generate "useable code" or "TTCN tests"**
- **When to create SDLs?**
  - **In the beginning**
  - **Not after the protocol is described by other means (e.g. English text)**
  - **After English text to aid in protocol review, validation, and testing.**

The IEEE Draft P802.15.1/D0.9.1 SDL is 579 pages out of 1159 pages. Currently it is normative.



Compatibility and Interference Issues

- **Compatibility: devices you want to communicate with**
  Interference: devices you don't

- **Bluetooth is in an unlicensed band -- this is good and bad**
  - **Good in that there's no red tape, devices can go most anywhere**
  - **Bad in that other simultaneous usage is unpredictable**

- **ISM band: Industrial, Scientific, and Medical**
  - **All sorts of uses, many predating data communication**
    Examples: microwave ovens, RF plasma lighting
  - **FCC mandates spread spectrum to spread the pain of interference**
    All users get some interference rather than some a lot and some none at all

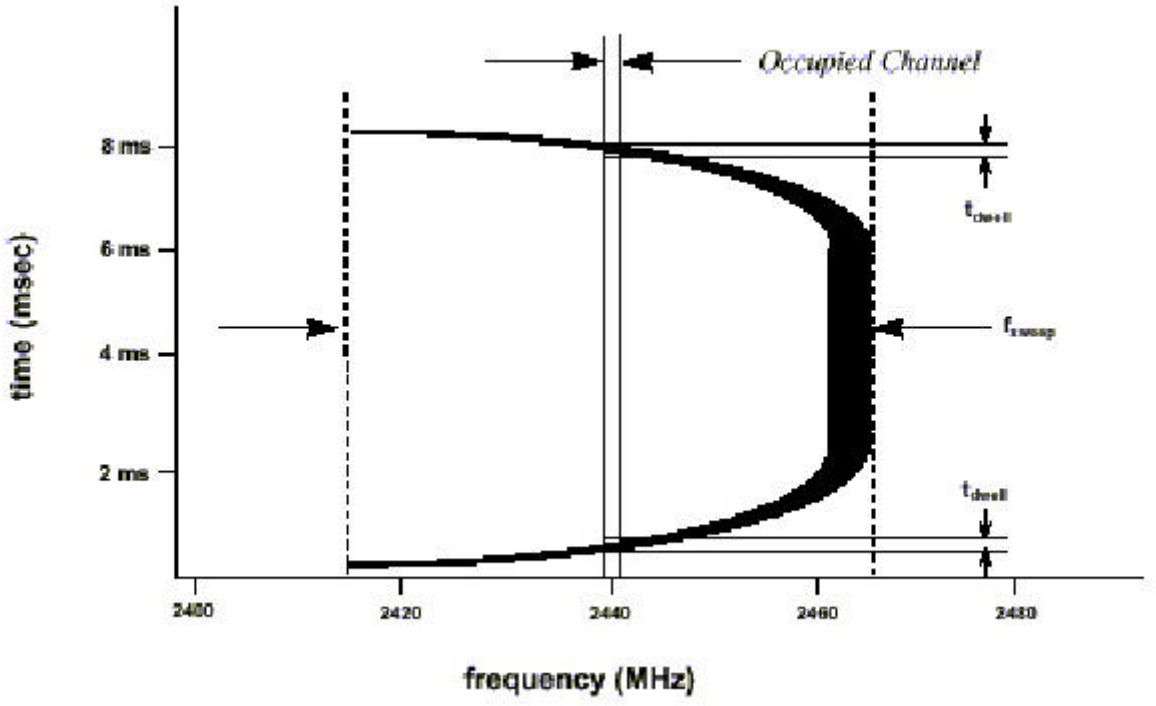
Frequency Hopping

- One way to spread the spectrum
- Used by Bluetooth, HomeRF, and the original (1 or 2 Mbps) version of 802.11
- Frequency changes after many bits are sent
  - Relatively easy to implement
- Alternative: Direct Sequence
  - Frequency changes faster than bit rate
  - Efficient but complex; used by newer versions of 802.11
- Unless spectrum is very crowded, probability of two users at same time at same frequency is low
- Other wireless technologies use different hopping rate
  - Bluetooth: 1600 hops per second
  - HomeRF: 8 hops per second

Microwave Ovens

- Use RF induction heating, in the same frequency band as Bluetooth
- Do their own version of spread spectrum, varying the frequency as the AC line voltage rises from zero to peak

Data from NTIA, courtesy of Intersil



Microwave Lighting

- The next big thing in lighting, but RF emissions could be a problem
  - Argon plasma transfers energy to sulfur, which radiates light
- ISM band is legitimate for such applications
- Strong incentives for adopting microwave lighting
  - Most efficient broad-spectrum light known (6x more than incandescent)
  - Sunlight appearance
  - High output
  - Very compact
- Emission limits established in Europe
- FCC working on the issue

Fusion Lighting, Inc.

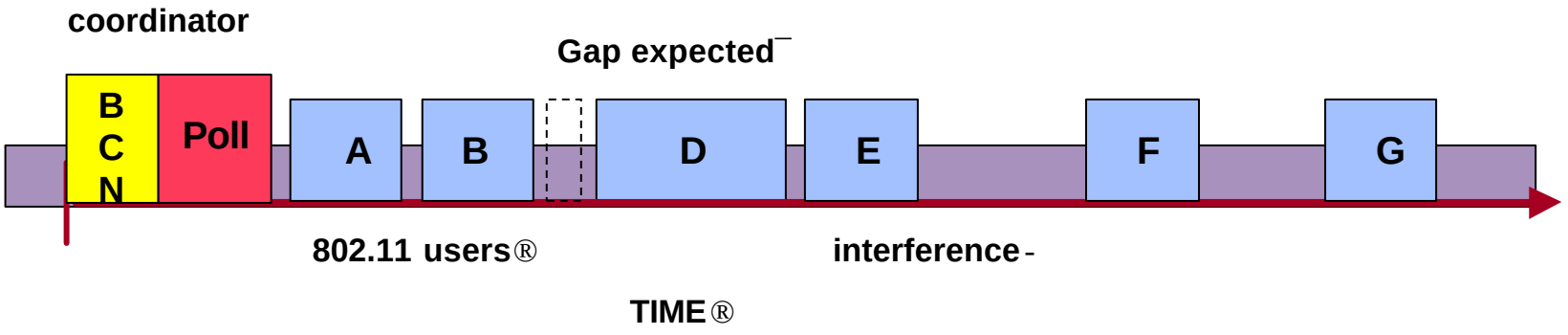
The Radio Jam

Lots of different types of networks, all using the ISM band
How badly will they interfere with each other?

- **IEEE 802.11 wireless LAN**
- **Bluetooth/802.15**
- **HomeRF**
  - **A consortium developing in-home wireless networks**
  - **RF technology is simplified 802.11**
  - **Based on assumption that full 802.11 is too costly**
  - **Back in the game after 9/00 FCC decision for wideband FH**
- **ETSI Hiperlan wireless LAN**
- **IEEE 802.16.4 “Wireless HUMAN” -- just started up**
  - **High-speed unlicensed metropolitan area network**
  - **Wireless access network aimed at home Internet users**
  - **Sentiment is in favor of using 802.11 physical layer**
  - **Signals will be strong near antenna towers**

Interference Concerns

- Two levels of interference
  - Physical layer: interfering signal acts like noise
    Spread spectrum technology minimizes this
    Interference for a brief interval, then one or both systems move on
    Error-correcting code may correct garbled section
  - MAC layer
    Interfering signal may look like a rogue member of the network
    For example, Bluetooth might confuse 802.11



Working on Coexistence

- **Work in IEEE 802 to develop coexistence strategies: 802.15 TG 2**
- **Methods include channel selection and adaptive hopping sequence**

Submission #	Presenter	Title	Non- / Collaborative	Author	Classification
01/079r1	NIST	802.11b Deterministic Frequency Nulling	Collaborative	R.E. Van Dyck	PHY -- Option
~~00/360r0~~	Mobilian	Method for Coexistence	Collaborative	J. Lansford	Time Domain Scheduling
~~01/025r0~~	Symbol	TDMA of BT and 802.11	Collaborative	S. Shellhammer	Time Domain Scheduling
01/164r0	**Combined proposal**				
01/080r0	TI	Proposal for Collaborative Bluetooth and 802.11b MAC Mechanisms for Enhancing Coexistence	Collaborative	J. Liang	Time Domain Scheduling
01/26r0	TI	Proposal for Non-Collaborative Bluetooth Mechanisms for Enhancing coexistence	Non-Collaborative	J. Liang	Adaptive Packet Selection, Scheduling
~~01/063r0~~	NIST	Power Control and Packet Scheduling for Bluetooth	Non-Collaborative	N. Golmie	Scheduling, Power Control (PC)
01/143r0	**Combined proposal**				
00/367r0	Bandspeed	Adaptive Frequency Hopping	Non-Collaborative	H. Gan, B. Treister	AFH -- Adaptive Frequency Hopping
01/057r0	IPC, Inc.	Selective Hopping for Hit Avoidance	Non-Collaborative	K.C. Chen	AFH, Scheduling
01/082r0	TI	Proposal for Intelligent Bluetooth Frequency Hopping for Enhancing Coexistence	Non-Collaborative	A. Batra, J. M. Ho, K. Anim-Appiah	AFH
~~01/092r0~~	TI	Power Control for Enhanced Coexistence	Non-Collaborative	O. Eliezer	AFH
01/162r0					
01/081r0	TI	Proposal for 802.11b Power Control for Enhancing Coexistence	Non-Collaborative	M. Shoemake	Power Control (PC), Data Rate Scaling (DRS)

Source: Nada Golmie, NIST, presentation to IEEE 802.15

Interoperability Problems

- Two versions of Bluetooth now in the field
  - 1.0b and 1.1
  - 1.1 just approved, but many implementers started with that
  - Lack of full interoperability was embarrassing at Consumer Electronics Show
  - But not a real problem: numbers of units produced so far is miniscule compared to ultimate production