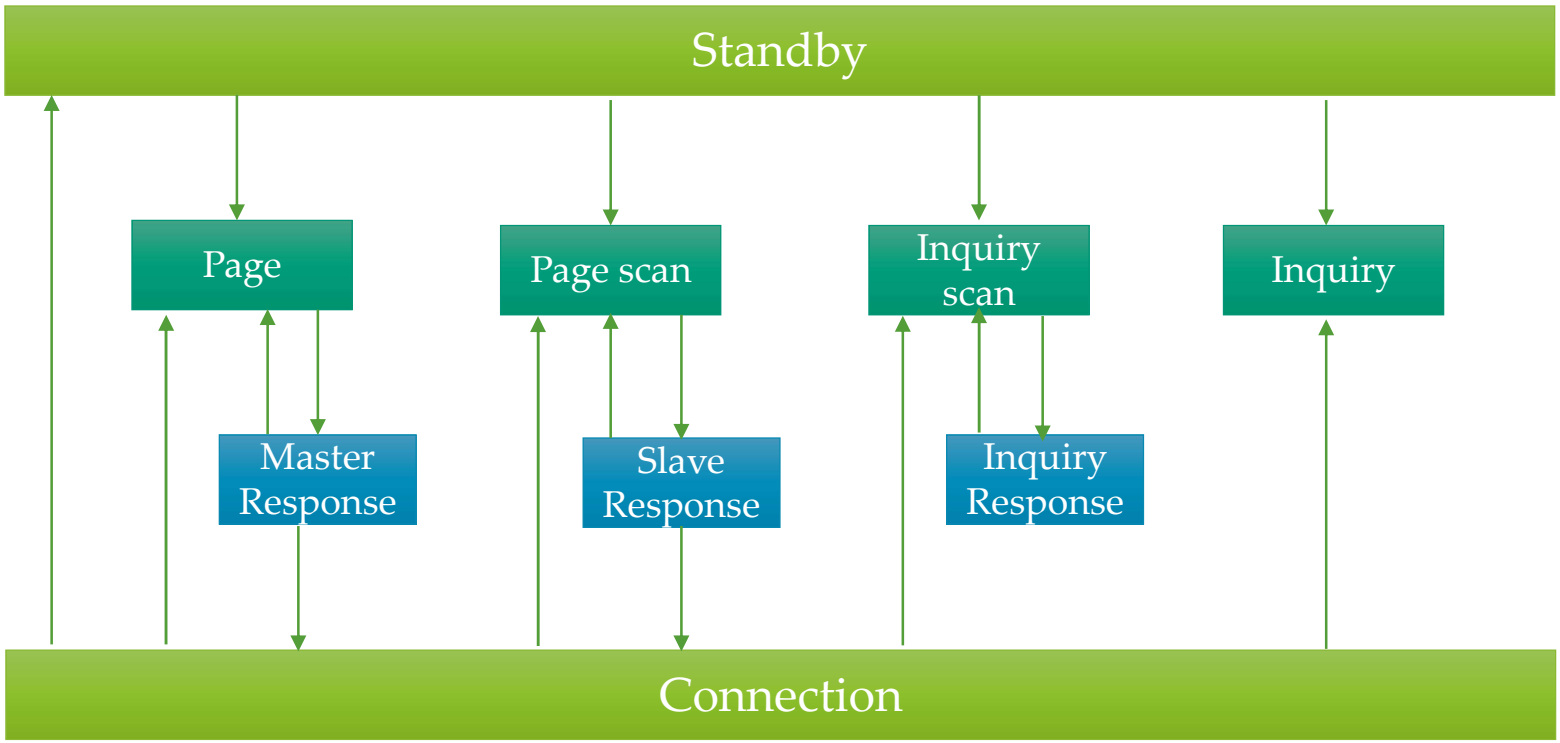
Channel Control

- The channel in the piconet is characterized entirely by the master of the piconet
- Master
  - Bluetooth unit that initiates the connection to one or more slaves
  - Any bluetooth unit can become a master of piconet
  - Once piconet has been established, master-slave role can be exchanged

States in Bluetooth Connection Establishment



Access Procedure

- New connection is established using paging and inquiry
  - Inquiry procedures are used to find the Bluetooth unit
  - Paging procedures are used to initiate actual connection
- Inquiry procedures
  - Broadcast inquiry IAC packet to discover nearby blue tooth units
  - It enters inquiry states
  - A blue-tooth unit which wants to be discovered enters Inquiry Scan state
  - When the unit in Inquiry Scan state receives inquiry message, it will reply with FHS packet
  - To establish connection, Paging procedure would be used

Access Procedure

- Paging procedure
  - If a unit wants to become a master, it will enter paging state
  - It will "page" desired bluetooth unit using Page packet to enter Master Response state
    - In this state, the unit wait the response from slave unit
  - Another unit, which will be a slave enters Page Scan to listen Page packet from other Bluetooth unit (which would be projected to be as master)
  - When this unit listen the page from other Bluetooth unit, it will enter Slave Response state
    - In this state, the unit will response the page unit from Master
  - Additional FHS packet exchange takes place
    - Master unit will send FHS packet
  - From now on, both enters Connection State
    - Connection starts with Master sending POLL packet to Slave

Access Procedure: Summarized

Step	Message	Direction	Hopping Sequence	Access Code and Clock
1	slave ID	master to slave	page	slave
2	slave ID	slave to master	page response	slave
3	FHS	master to slave	page	slave
4	slave ID	slave to master	page response	slave
5	1st packet master	master to slave	channel	master
6	1st packet slave	slave to master	channel	master

Logical Channel

- Link control (LC) :
  - Used to manage the flow of the packets over the link interface
  - Mapped into packet header
- Link manager (LM)
- User asynchronous (UA)
- User isochronous (UI)
- User synchronous (US)

Link Manager

- Manages various aspects of the radio link between a master and a slave
- Involves the exchange LMP PDUs (protocol data units)
- Procedures defined for LMP are grouped into 24 functional areas, which include
  - Authentication
  - Pairing
  - Encryption
  - Clock offset request
  - Switch master/slave
  - Name request
  - Hold or park or sniff mode

Logical link control and adaptation protocol (L2CAP)

- Provides a link-layer protocol between entities with a number of services
- Relies on lower layer for flow and error control
- Makes use of ACL links, does not support SCO links
- Provides two alternative services to upper-layer protocols
  - Connection service
  - Connection-mode service

L2CAP Logical Channels

- Connectionless
  - Supports connectionless service
  - Each channel is unidirectional
  - Used from master to multiple slaves
- Connection-oriented
  - Supports connection-oriented service
  - Each channel is bidirectional
- Signaling
  - Provides for exchange of signaling messages between L2CAP entities

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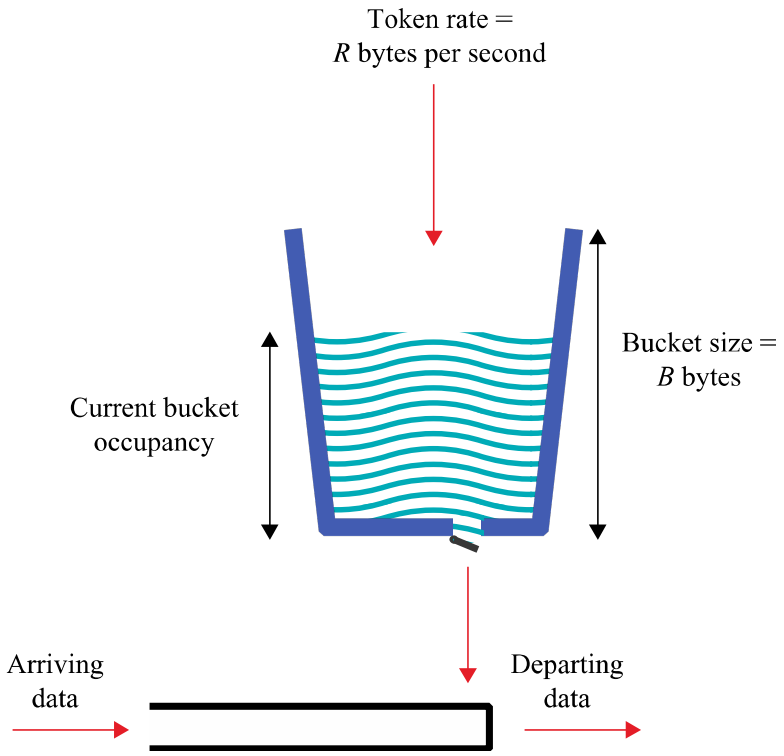
Quality of Service

- Different connections requirement can be communicated through configuration option field in L2CAP packet
- Flow specification
  - Service type
  - Token rate (bytes/second)
  - Token bucket size (bytes)
  - Peak bandwidth (bytes/second)
  - Latency (microseconds)
  - Delay variation (microseconds)

Quality of Service: Flow parameter



Bluetooth High Speed

- Bluetooth 3.0+HS
- Up to 24 Mbps
- New controller compliant with 2007 version of IEEE 802.11
- Known as Alternative MAC/PHY (AMP)
  - Optional capability
- Bluetooth radio still used for device discovery, association, setup, etc.
- Allows more power efficient Bluetooth modes to be used, except when higher data rates are needed

Bluetooth Smart

- Bluetooth 4.0
- Previously known as Bluetooth Low Energy
- An intelligent, power-friendly version of Bluetooth
- Can run long periods of time on a single battery
  - Or scavenge for energy
- Also communicates with other Bluetooth-enabled devices
  - Legacy Bluetooth devices or Bluetooth-enabled smartphones
- Possible successful technology for the Internet of Things
  - For example, health monitoring devices can easily integrate with existing smartphones

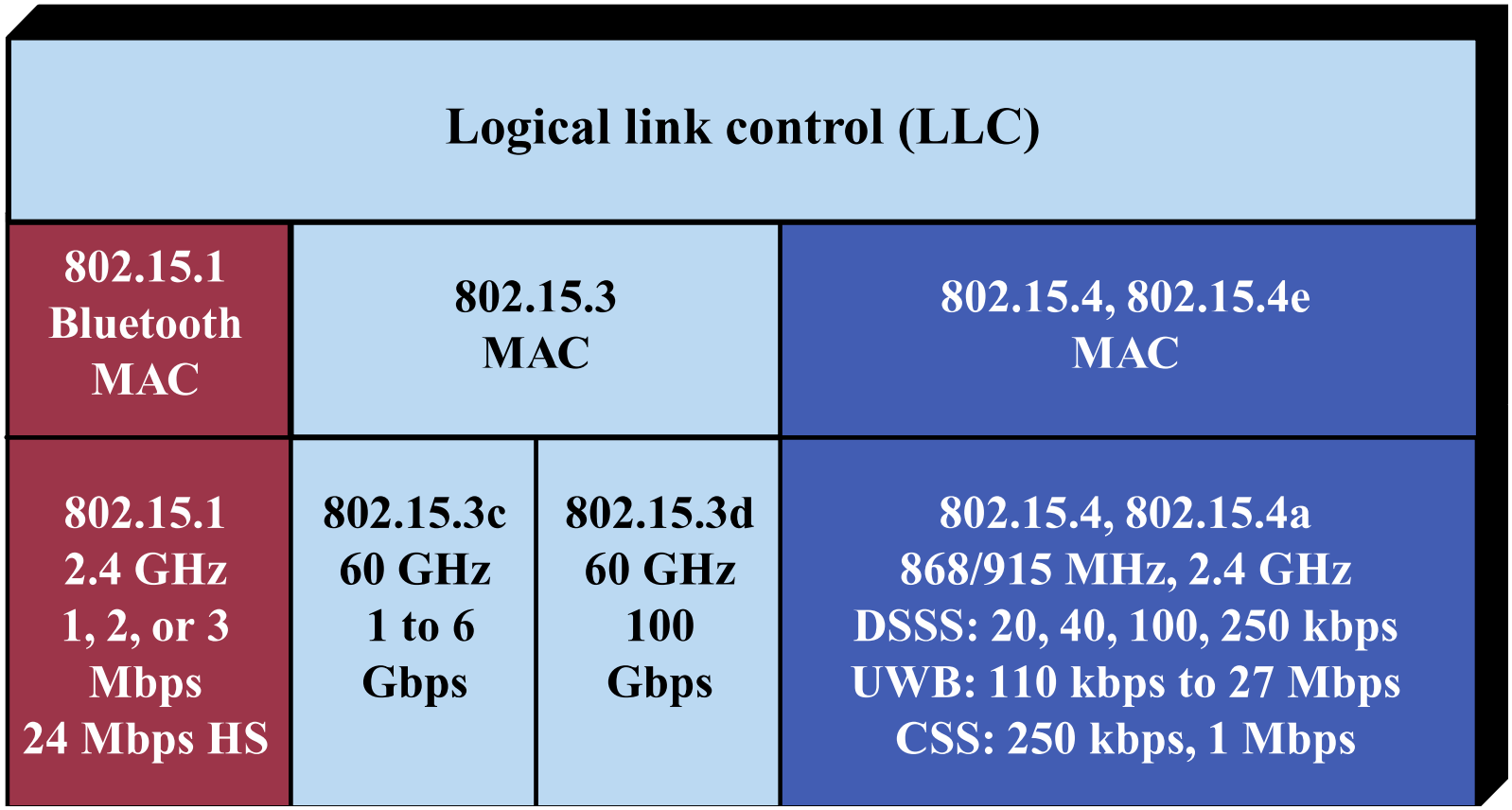
Bluetooth Smart

- Same 2.4 GHz ISM bands as Bluetooth BR/EDR
  - But uses 40 channels spaced 2 MHz apart instead of 79 channels spaced 1 MHz apart
- Devices can implement a transmitter, a receiver, or both
- Implementation
  - Single-mode Bluetooth Smart functionality
    - Reduced cost chips that can be integrated into compact devices.
  - Dual-mode functionality to also have the Bluetooth BR/EDR capability
  - 10 mW output power
  - 150 m range in an open field
  - New advertising mechanism or efficient device discovery
  - New asynchronous connectionless MAC to provide low delay and fast transactions

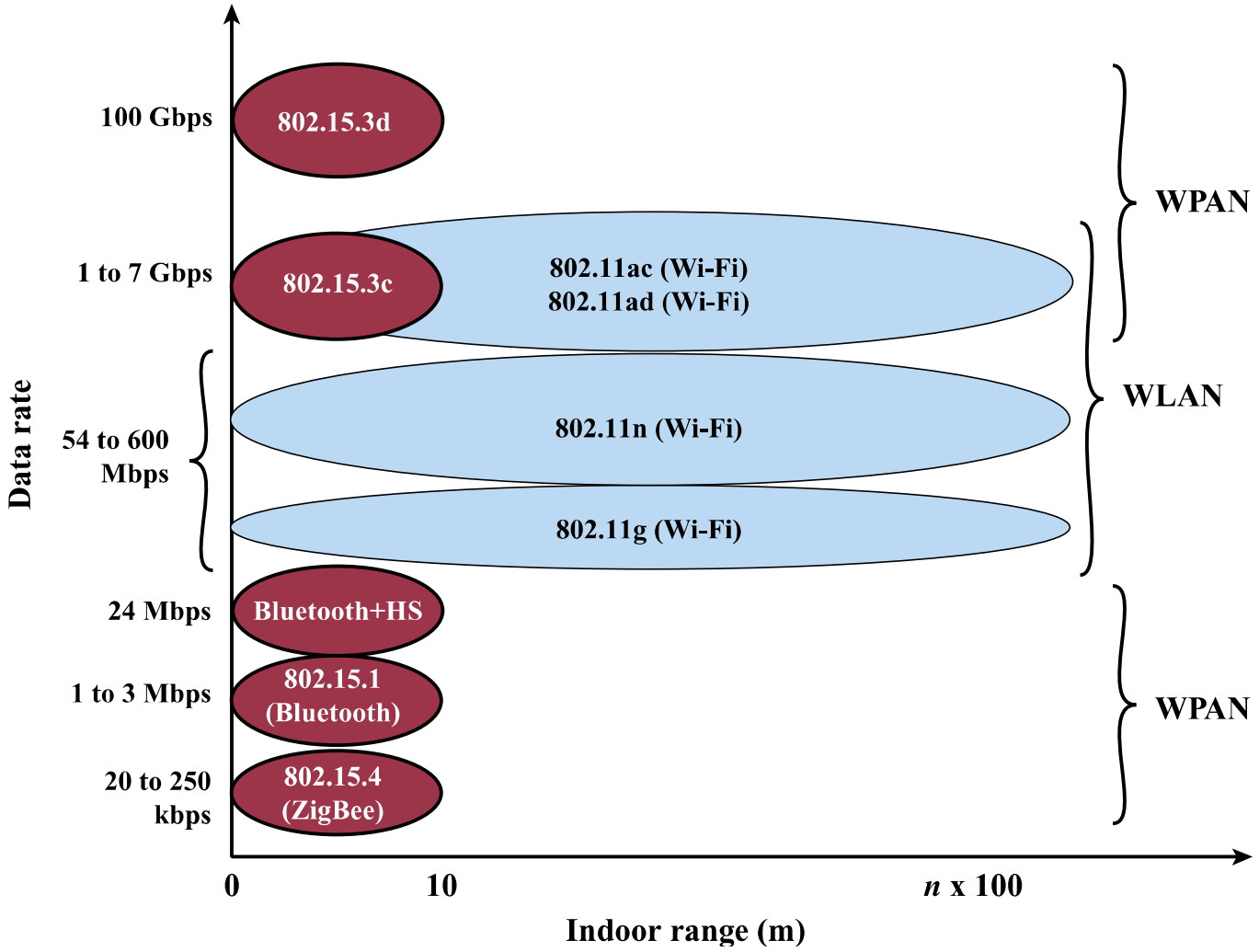
IEEE 802.15

- A working group to create standards for Wireless Personal Area Networks (WPANs)
- IEEE 802.15.1 standards becomes the basis for Bluetooth specification which is further developed by SIG
- After 802.15.1, work went two directions
- 802.15.3
  - Higher data rates than 802.15.1
  - But still low cost, low power compared to 802.11
- 802.15.4
  - Very low cost, very low power compared to 802.15.1

IEEE 802.15 : Protocol Architecture



Wireless Local Network



IEEE 802.15.3

- High data rate WPANs
  - Digital cameras, speakers, video, music
- Piconet coordinator (PNC)
  - Sends beacons to devices to connect to the network
  - Uses superframes like 802.11
  - QoS based on TDMA
  - Controls time resources but does not exchange data
- 802.15.3c
  - Latest standard
  - Uses 60 GHz band, with same benefits as 802.11ad
  - Single-carrier and OFDM PHY modes

IEEE 802.15.4

- Low data rate, low complexity
  - Competitor to Bluetooth Smart
- PHY options in 802.15.4 and 802.15.4a
  - 868/915 MHz for 20, 40, 100, and 250 kbps
  - 2.4 GHz for 250 kbps
  - Ultrawideband (UWB).
    - It operates in unlicensed UWB sub gigahertz(249.6 to 749.6 MHz),low band(3.1 to 4.8 GHz), and High band(5.8 to 10.6 GHz)
    - Uses very short pulses with wide bandwidth
      - Low energy density for low interference with others
    - 851 kbps and optionally 110 kbps, 6.81 Mbps, or 27.234 Mbps
  - 2.4 GHz chirp spread spectrum for 1 Mbps and optionally 250 kbps
    - Sinusoidal signals that change frequency with time

IEEE 802.15.4

- Many other creative and practical activities
- IEEE 802.15.4f – Active Radio Frequency Identification Tags (RFIDs)
  - Attached to an asset or person with a unique identification
  - An Active RFID tag must employ some source of power
- IEEE 802.15.4g – Smart Utility Networks (SUN)
  - Facilitates very large scale process control applications such as the utility smart-grid network
- IEEE 802.15.4j – Medical Body Area Networks
- EEE 802.15.4k – Low Energy Critical Infrastructure Networks (LECIM)
  - To facilitate point to multi-thousands of points communications for critical infrastructure monitoring devices with multi-year battery life.
- IEEE 802.15.4p – Positive Train Control
  - Sensor, control and information transfer applications for rail transit