Institute for Infocomm Research
A*STAR

IEEE

# Bluetooth, Bluetooth Low Energy, IEEE 802.15.4(Zigbee) and IEEE 802.15.6 Comparison

**05 May 2014**

Prepared by **Fabio Di Franco**

# Personal Area Network (PAN) Technologies


**2**

| *PAN Standard* | Classic/EDR Bluetooth | Bluetooth Low Energy | Zigbee |
|---|---|---|---|
| Radio Frequency | 2.4 GHz | 2.4 GHz | 2.4 GHz<br>850/915 MHz |
| Data Rate | 1-3 Mbps | 1 Mbps | 250Kbps@2.4GHz |
| Nodes | 7 in slave modes | >65535 | 65535 |
| Security | E0 for encryption | 128b AES | 128b AES |
| Latency (from a non connected State) | ~100ms | ~4 ms | ~10 ms |
| Regulation | Worldwide | Worldwide | Worldwide |
| Certification Body | Bluetooth SIG | Bluetooth SIG | Zigbee Alliance |
| Network Topology | Scatternet | Star | Mesh |
| Peak Current Consumption in RX mode | >20mA | 14mA (nRF8001) | 18mA (CC2520) |
| Primary User Cases | Mobile phones, gaming, headsets, stereo audio streaming, automotive, PCs, consumer electronics | Mobile phones, gaming, PCs, watches, fitness, healthcare, consumer electronics | Building & home automation, AMI/Smart Energy, Fixed Local industrial |

# WiFi can be a Personal Area Network device?

**No**

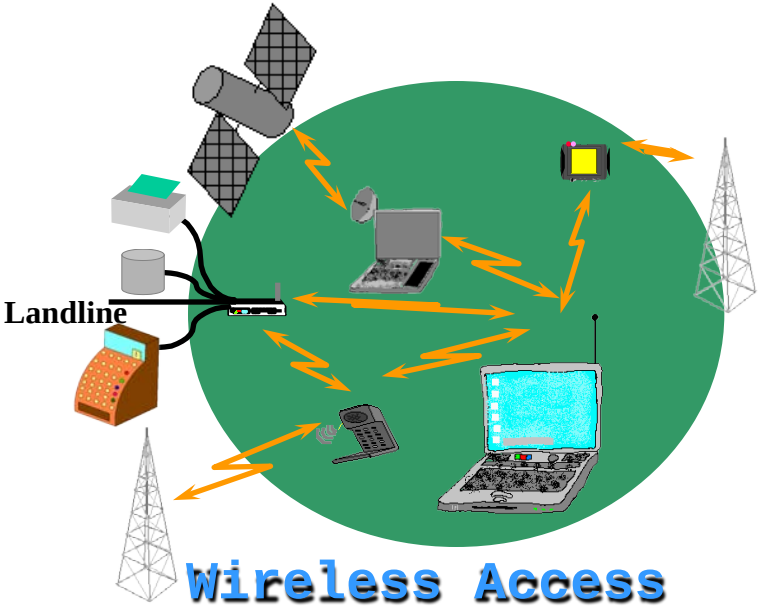
**WiFi is:**

- **the brand name for products using the *IEEE 802.11* family of standards**
- **commonly used for “wireless local area network” (WLAN)**

**More technical reason:**

**Peak power Consumption is 120mA in RX mode (GainSpan GS1011 datasheet)**

# Which is your User Case?



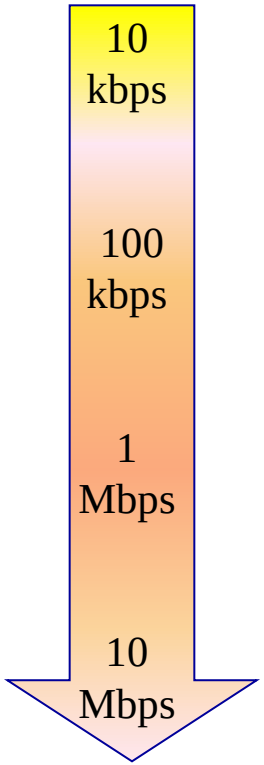

Wireless Access Points

Wireless Cable Replacement

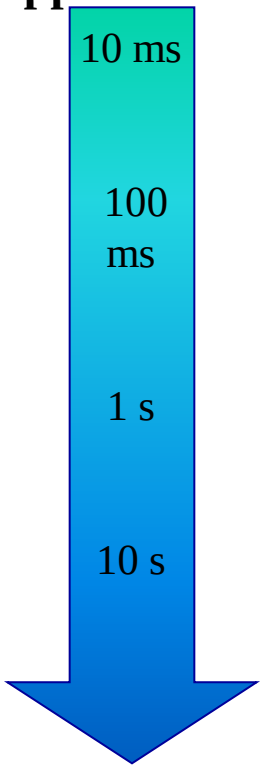


Body Sensors Networks

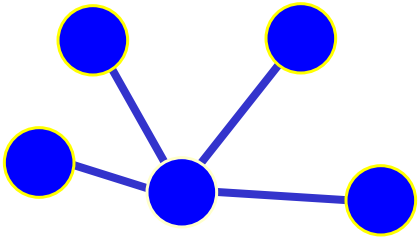
**Which is typical app Throughput?**



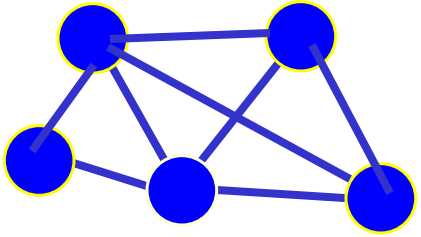

**Which is the latency acceptable for your app?**



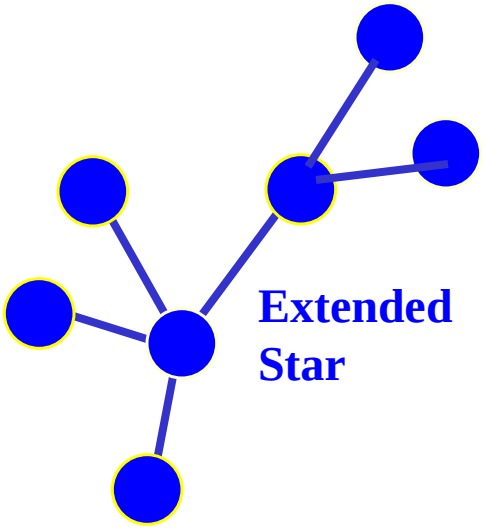

**Which topology do you need?**



**Star**



**Mesh**



**Extended Star**

**Other requirements?**

Coverage
Security (AAA, encryption)
Power Consumption
Proprietary/ Interoperable

# Fitness and Healthcare in Wireless Body Area Network (WBAN)

**Wireless thermometer**
**(Raiing Wireless Thermometer)**

**Wireless EMC**
**(Emotion EMC)**



**Pulse Oximeter**
**(Noninconnect)**

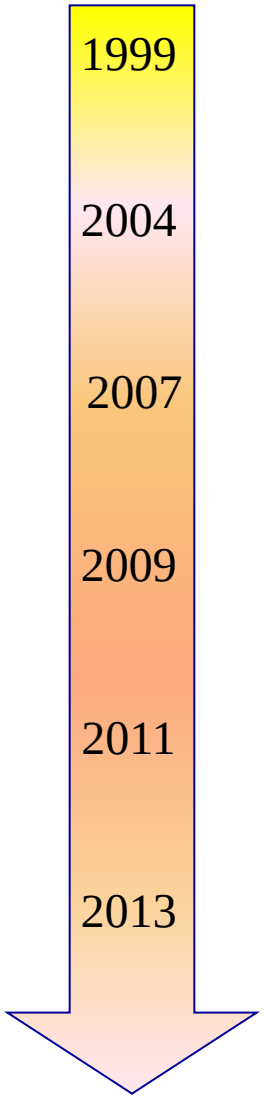
**Wireless EMG**
**(Zebris EMG-012)**

# Bluetooth and Bluetooth Low Energy

# IEEE 802.15.4(Zigbee)

# IEEE 802.15.6

# HISTORY



| | |
|---|---|
| 1999 | Version 1.0 of the Bluetooth specification |
| 2004 | Core Version 2.0 + EDR (New Physical layer up to 3Mbps) |
| 2007 | Core Version 2.1 (Add Simple Pairing) |
| 2009 | Core Version 3.0 (High Speed enables applications to use 802.11 MAC/PHY through addition of Generic Alternate MAC/PHP) |
| 2011 | Core Version 4.0 (Introduce Low Energy which enables new applications for healthcare, sport, fitness, home entertainment) |
| 2013 | Core Version 4.1 (Coexistence management with LTE, flexible reconnection timeout intervals) |

# What is Classic/EDR Bluetooth(1)

- A cable replacement technology
- Operates in the unlicensed ISM band at 2.4 GHz
- Frequency Hopping scheme (1600 hops/sec)
- 1-3 Mb/s symbol rate
- Single chip radio + baseband

# What is Classic/EDR Bluetooth(2)

Classic/EDR Bluetooth supports:

- Synchronous voice
- Asynchronous data channels.

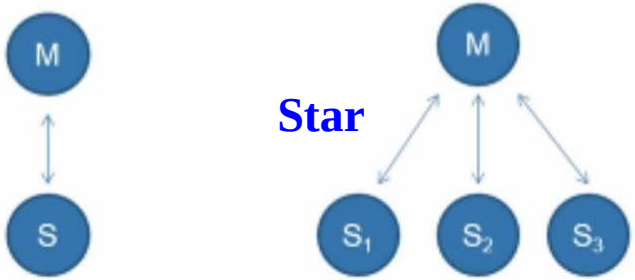
An asynchronous data can support up to 2.3Mbps (using 3Mbps symbol rate).

With Adaptive Frequency Hopping (AFH), only interference-free channel are used.

TX output power up to 10dBm (more than 30m.)

# Network Topology in Classic/EDR Bluetooth

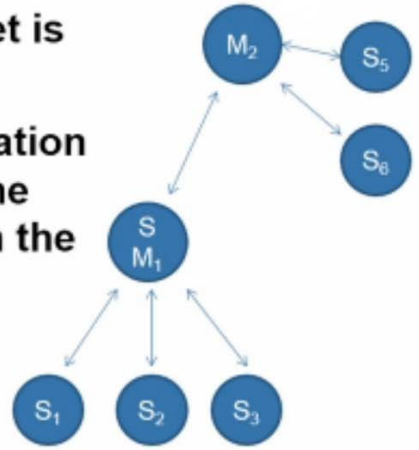
- One Master and up to 7 active slaves
- Master controls communication
- No slave-to-slave communication
- Master has to ensure not to “starve” slaves




Star

**Continuously poll the slaves.**
**In ACL connection a slave can be sent to sniff mode**

- Master of one piconet is slave in another
- No direct communication between slaves in one piconet with those in the other




Scatternet

# How much energy does traditional Bluetooth use?

- Traditional Bluetooth is *connection oriented.* When a device is connected, a link is maintained, even if there is no data flowing.

- Sniff modes allow devices to be sent to sleep (~100uA for 1 attempt every 1.28s-PAN1315)

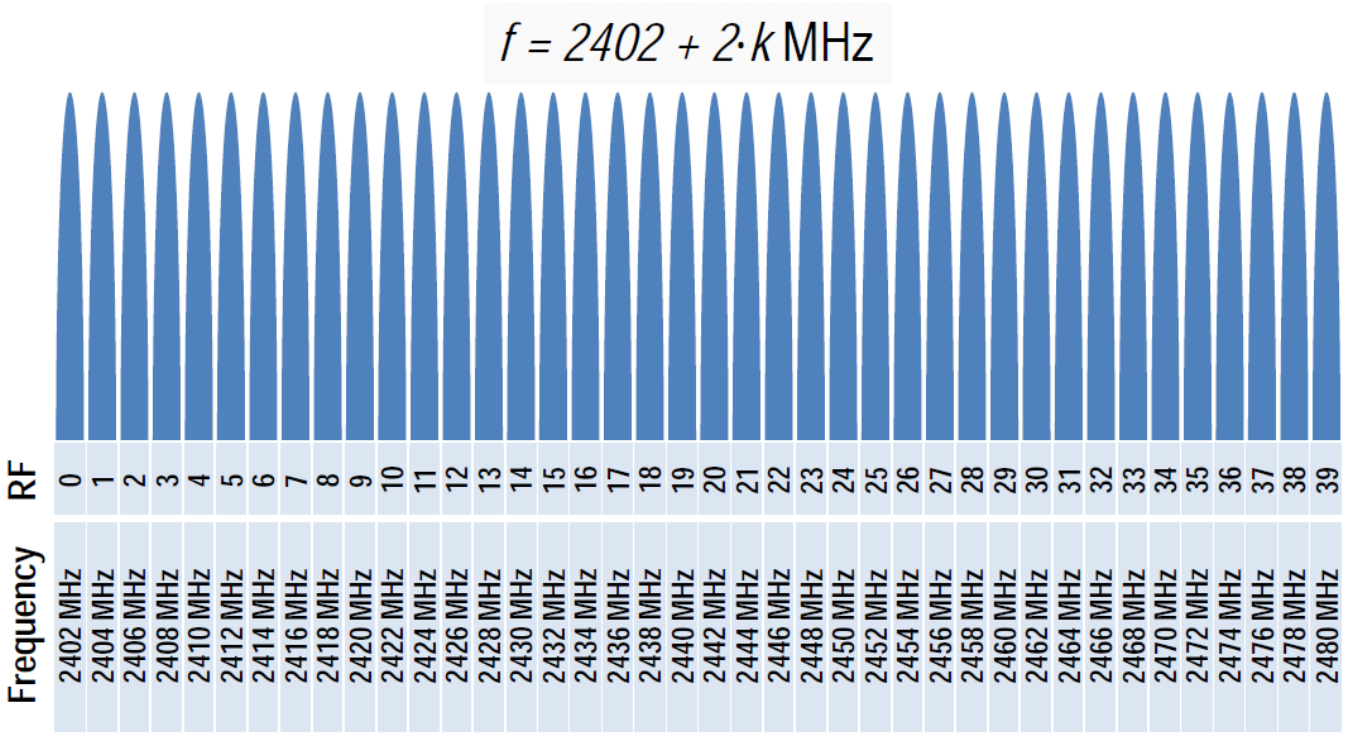
- Peak receive current is typically around 25mA

# What is Bluetooth Low Energy?

- Bluetooth low energy is a short range radio technology
  - Different to Bluetooth classic (BR/EDR)
  - Optimized for ultra low power
  - Enable coin cell battery use cases
    - <15mA peak current
    - Tens of uA average current
- A short packets: up to 39bytes payload
- Simple state machine and Single protocol

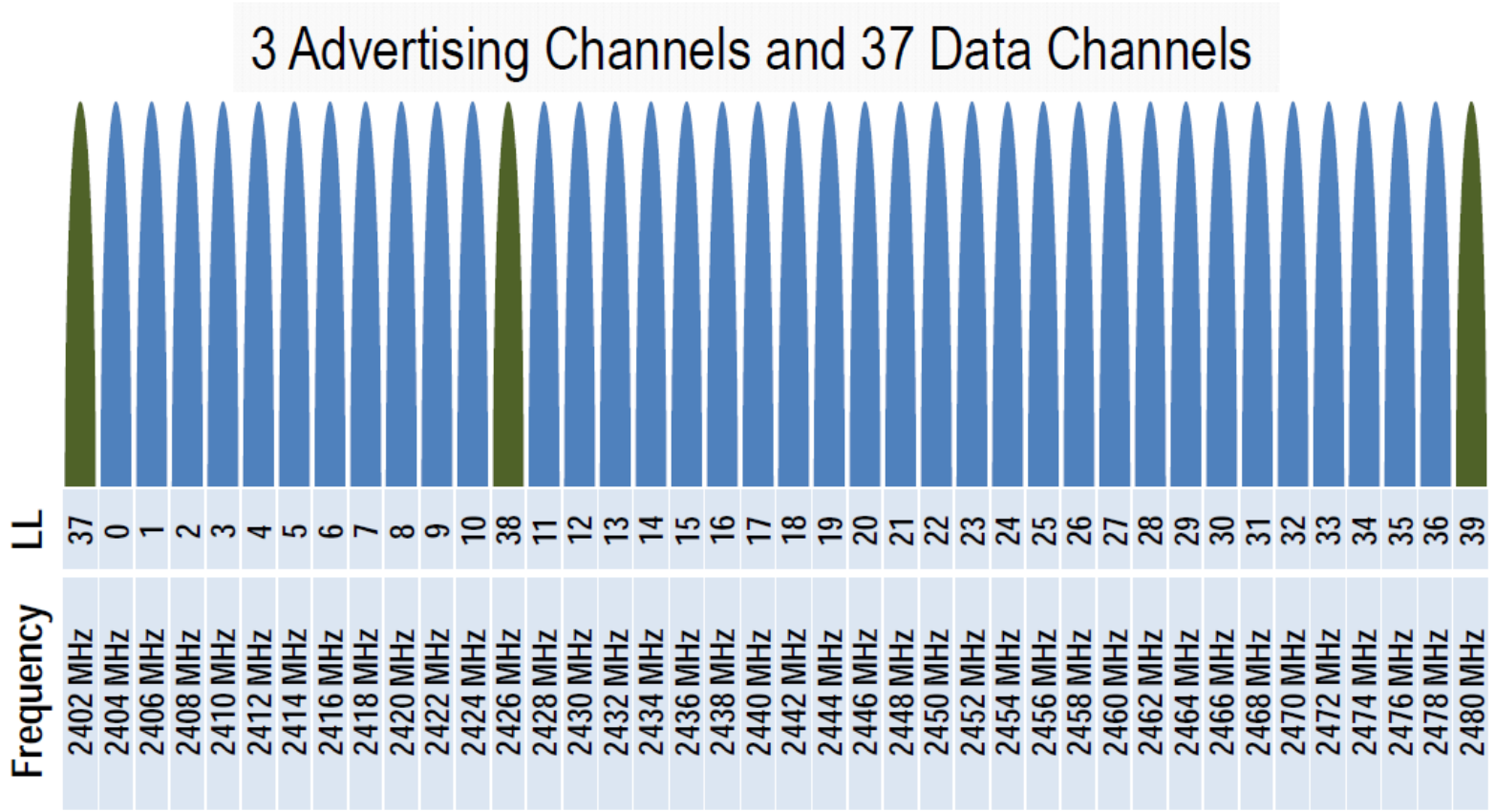
# Physical Layer

- 2.4 GHz ISM band
- 1Mbps GFSK
- 40 Channels on 2 MHz spacing



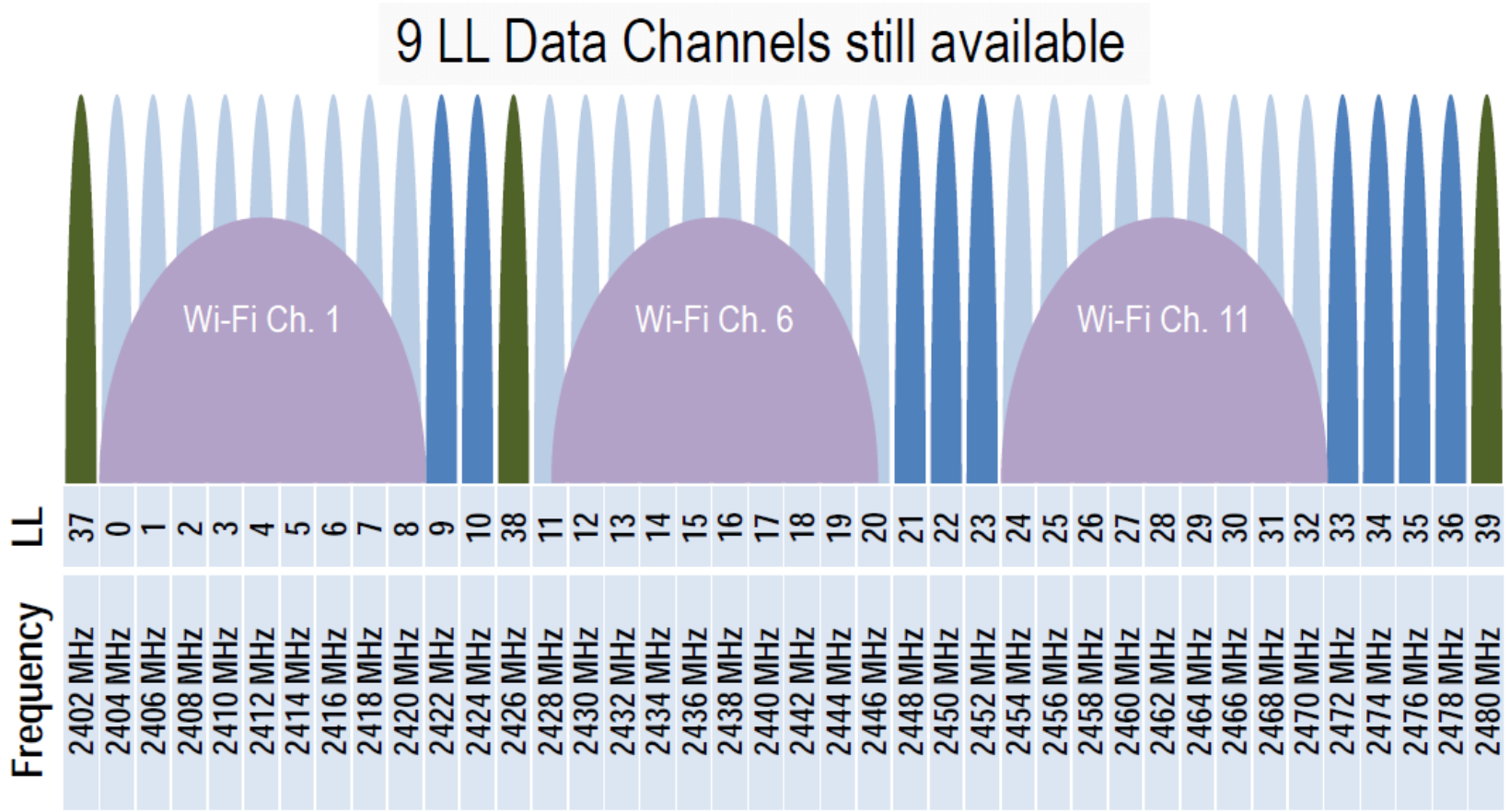
# Physical Channels

- Two types of channels



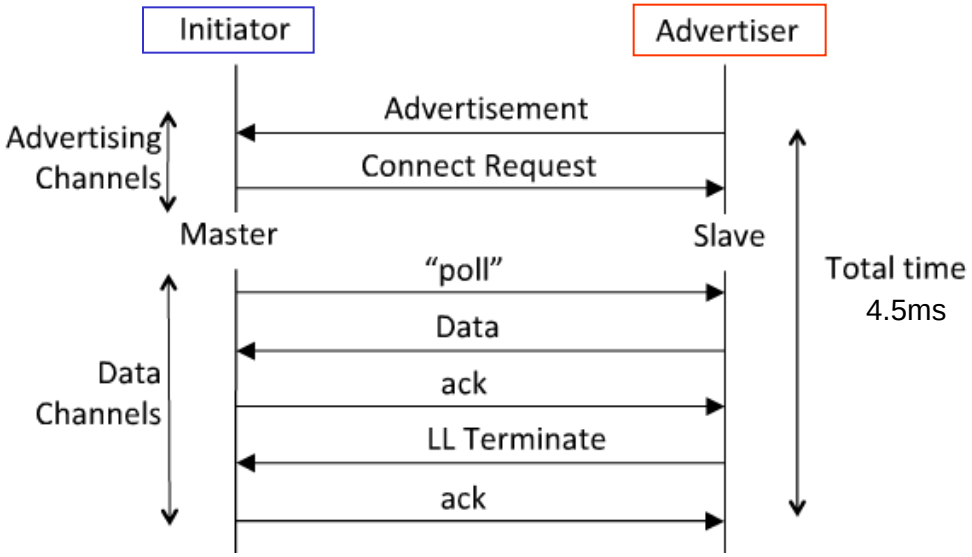
# Physical Channels

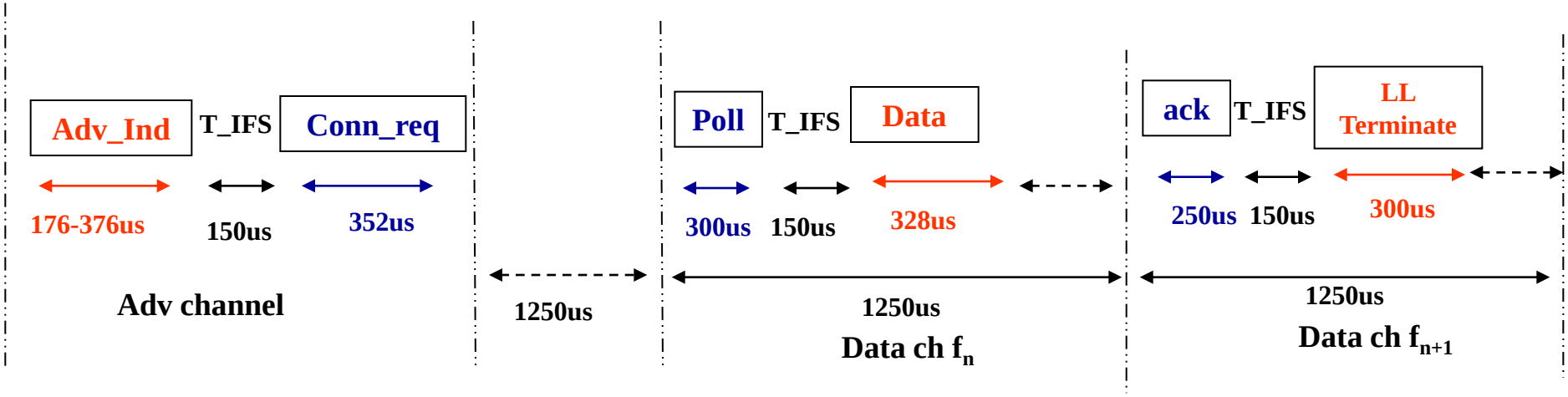
- Advertising channels avoid 802.11



# VERY LOW LATENCY CONNECTIONS

**The radio is on only for about 1.5ms**



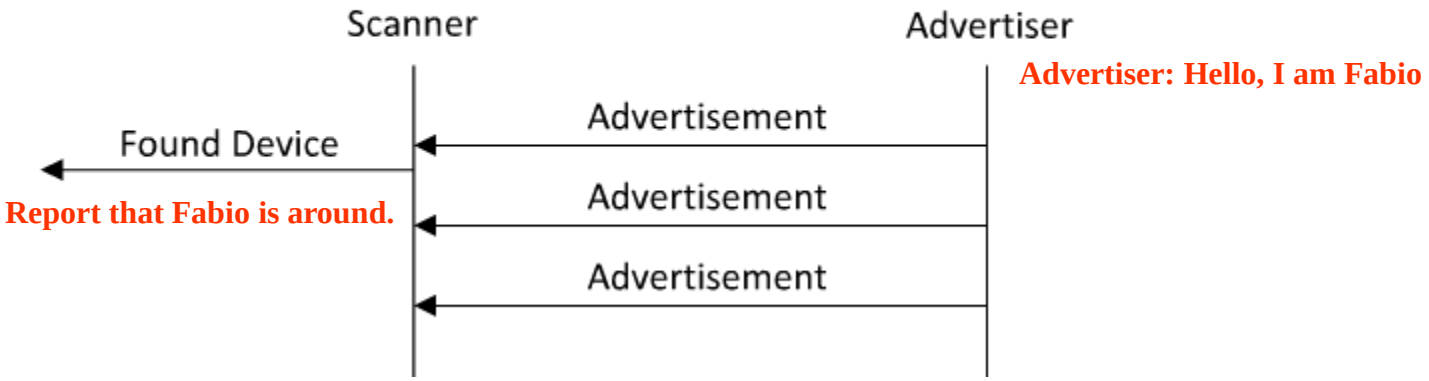
# How long does a battery last with BLE basic transactions?

- Calculate energy per transaction
  - Assuming an active (Tx/Rx) period of 1.5ms, 3ms in standby state, each transaction takes an average of 8mA for the 4.5ms, 36uAs=10nAh
- How long could a sensor last on a battery?
  - An example battery: CR2032, 3V, 220mAh, <<0.2$
  - 220mAh/10nAh=22M transactions
  - Suppose this sensor sends a report every 1minute = 1440/day
  - For just the BLE transactions, this is 15,000 days, or > 40 years
  - This far exceeds the life of the battery and/or the product


Capacity: 220mAh
Diameter: 20mm
Height 3.2mm
Weight: 3.2g

**The scanner passively listens to and reports to the host the adverting devices in that area.**

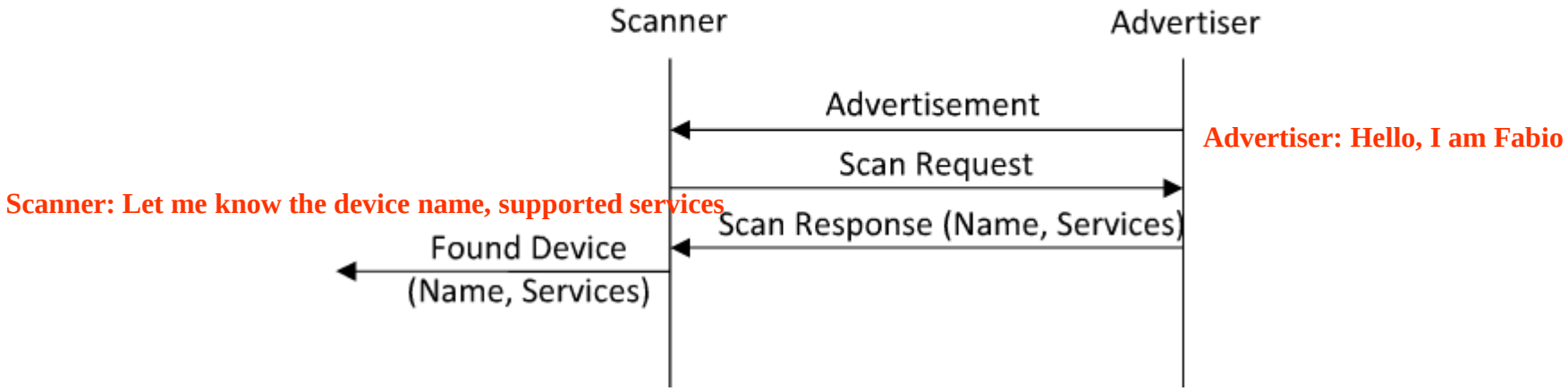
## DISCOVERING DEVICES - PASSIVE SCANNING




When in passive scanning, the Link Layer will only receive packets; it shall not send any packets.

**A device may use active scanning to obtain more information about devices that may be useful to populate a user interface. Active scanning involves more link layer advertising messages.**

## DISCOVERING DEVICES – ACTIVE SCANNING



Bluetooth SMART

## Garmin GPS Hiking Watch


Bluetooth technology let hikers wirelessly share tracks, waypoints, routes and geocaches with their smartphone

## Nike+ basketball and training shoes

Each shoe has four pressure sensors that gather information from different parts of the foot and send it via Bluetooth wireless technology

## Heart-rate Monitors


Heart rate sensors provides live heart rate to mobile training app

## Pulse Oximeter Monitor


Nonin Medical Pulse Oximeter which provides clinically proven accurate SpO2 and pulse rate readings over a secure wireless connection

Bluetooth®
SMART READY


## MacBook Air



Native integration of Bluetooth 4.0 in Windows 8 products

# Bluetooth and Bluetooth Low Energy

## IEEE 802.15.4(Zigbee)

## IEEE 802.15.6

# IEEE 802.15.4 basics

- 802.15.4 is a simple packet data protocol for lightweight wireless networks
  - Channel Access is via Carrier Sense Multiple Access with collision avoidance (CSMA/CA) and optional time slotting
  - Message acknowledgement
  - Optional beacon structure
  - Payload: up to 127bytes
  - Star, Tree or Mesh topology
  - Fully handshaked protocol for transfer reliability.

# IEEE 802.15.4 defines two different device types:

- Full function device (FFD): **Device, Coordinator**
  - Any topology
  - Network coordinator capable
  - Talks to any other device

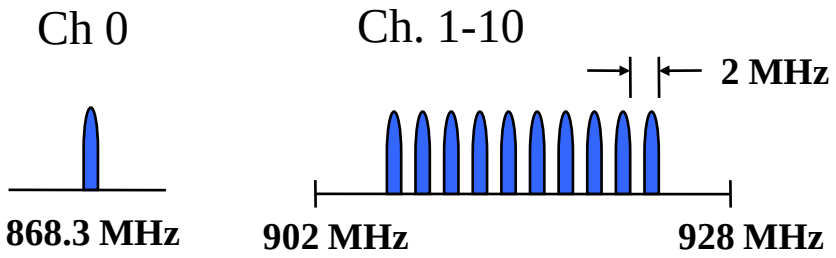
- Reduced function device (RFD): **Device**
  - Limited to star topology
  - Cannot become a network coordinator
  - Talks only to a network coordinator
  - Very simple implementation

# IEEE 802.15.4 PHY Overview

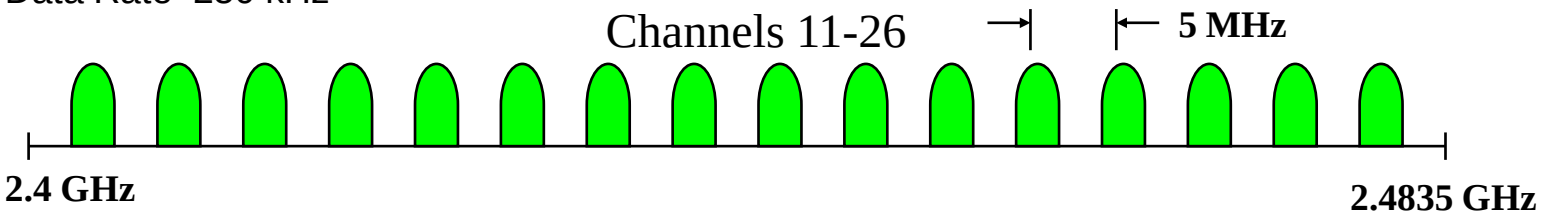
- Operating frequency bands

European band 868MHz
Data Rate 20 kHz

North America 915MHz
Data Rate 40 kHz

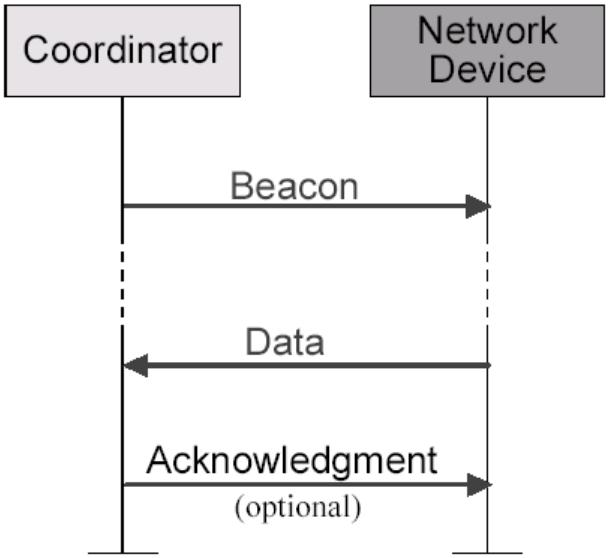



Worldwide 2450MHz
Data Rate 250 kHz



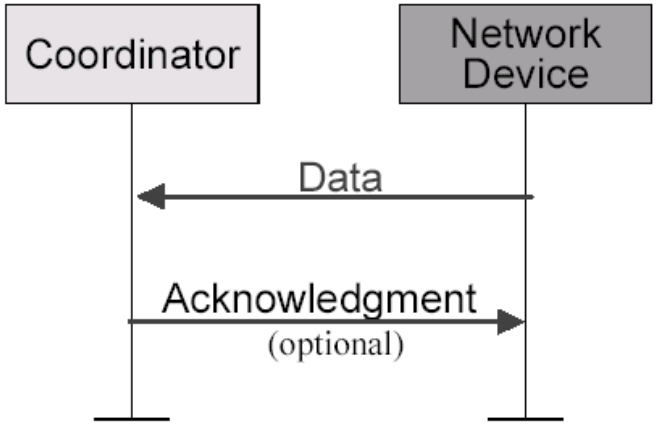
# Data Transfer Model (I)

- Data transferred from device to coordinator
  - In a beacon-enable network, a device finds the beacon to synchronize to the superframe structure. Then it uses slotted CSMA/CA to transmit its data.
  - In a non-beacon-enable network, device simply transmits its data using unslotted CSMA/CA




**Communication to a coordinator**

**In a beacon-enabled network**

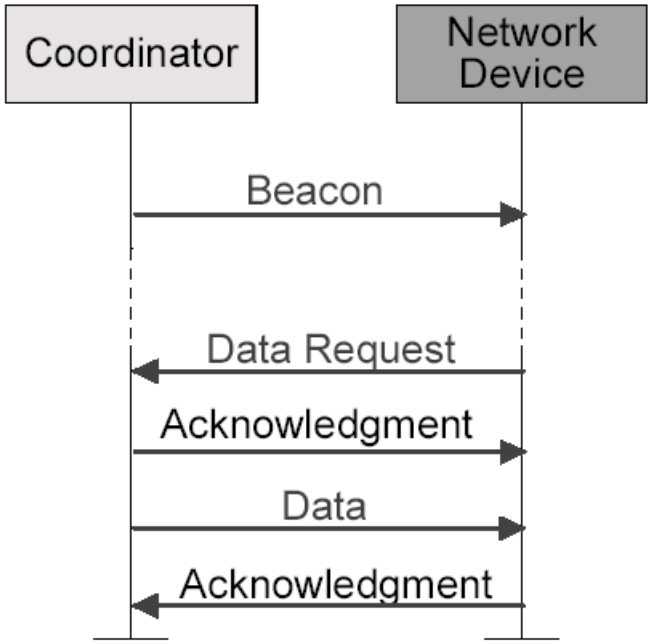



**Communication to a coordinator**

**In a non beacon-enabled network**

# Data Transfer Model (II)

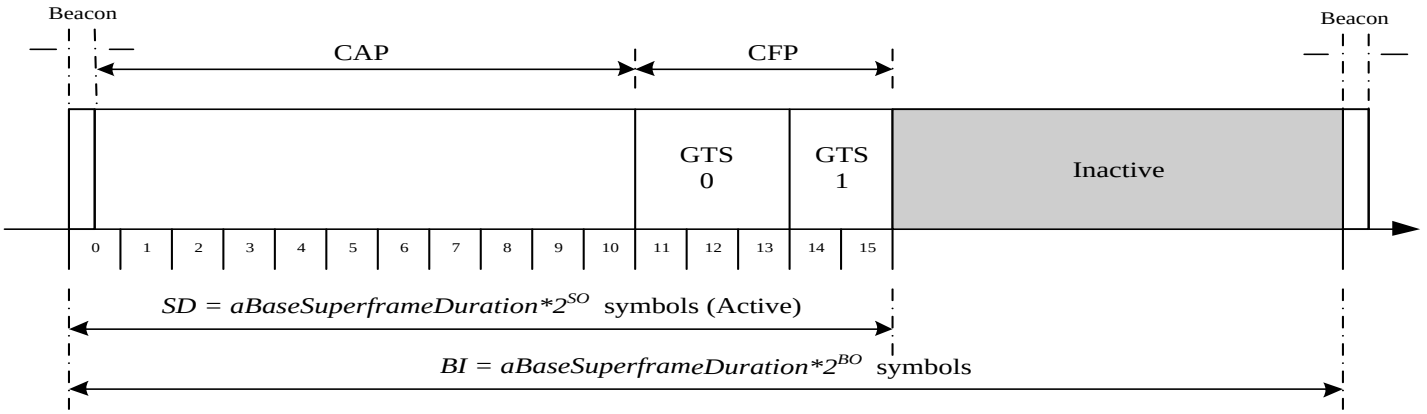
- Data transferred from coordinator to device in a beacon-enabled network:
  - The coordinator indicates in the beacon that some data is pending.
  - A device periodically listens to the beacon and transmits a Data Request command using slotted CSMA/CA.
  - Then ACK, Data, and ACK follow …




**Communication from a coordinator**

**In a beacon-enabled network**

# Superframe




In a **superframe,** the network coordinator transmits superframe beacons in predetermined intervals

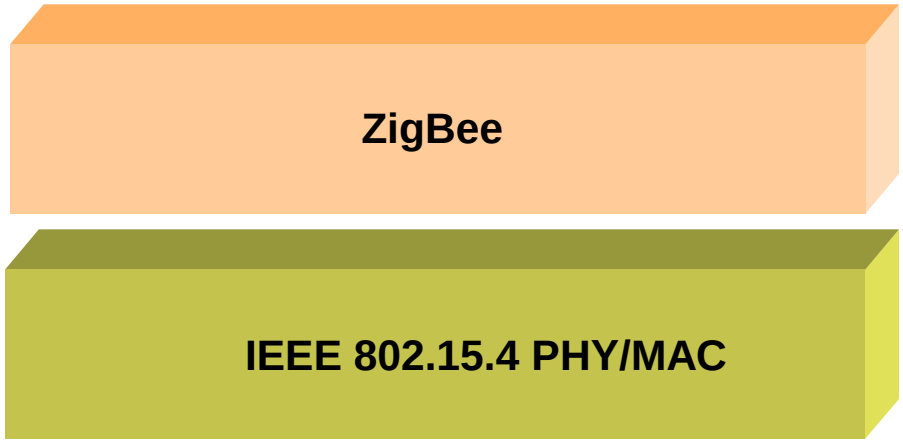
- Intervals as short as 15 ms or as long as 245 s
- Slotted CSMA/CA is employed
- Time between two beacons is divided into 16 equal time slots independent of the duration of the superframe
- Time slots are split into contention access period **(CAP)** and contention free period **(CFP)**

Guaranteed time slots (GTS) are concatenated contention free slots:

- Allow low latency and dedicated bandwidth applications

# So what is Zigbee?

- ZigBee is a specification for a high level protocol stack using small, low-power and low-cost radios. It based on IEEE 802.15.4 standard for Personal Area Network.
- ZigBee standard maintained by ZigBee Alliance
- Usually vendors of ZigBee devices use system-on-chip (SoC) solutions with integrated radio and 60-250KB of flash memory

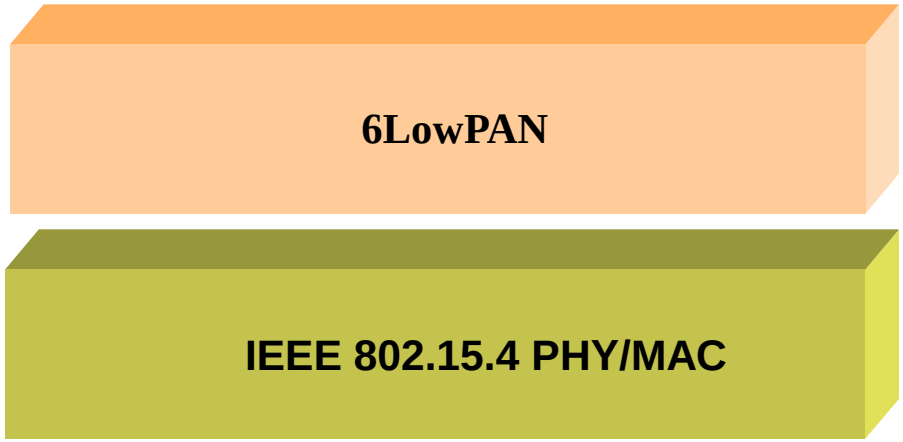



- **Network Routing**
- **Address translation**
- **Packet Segmentation**
- **Profiles**

# 6LoWPan: an alternative for IoT over IEEE 802.15.4

6LoWPAN offers IPv6 communications over low-power wireless devices

- Stateless 40-bytes IPv6 Header Compression down to 2 bytes
- Packet Segmentation from 1280 byte to IEEE802.15.4 max MTU (127 bytes)




- **Ipv6 Header Compression**
- **Address translation**
- **Packet Segmentation**

**More details in RFC4944**

# Bluetooth and Bluetooth Low Energy

# IEEE 802.15.4(Zigbee)

# IEEE 802.15.6

# IEEE 802.15.6 Standard **Released in Feb2012**

The purpose is to provide **an international standard for a short-range (i.e., about human body range), low power, and highly reliable wireless communication for use in close proximity to, or inside, a human body.**

Data rates, typically up to 10Mbps, can be offered to satisfy an evolutionary set of entertainment and healthcare services.

**IEEE 802.15.6 is the standard for Wireless Body Area Network (WBAN)**

# Why not use Bluetooth LE?

802.15.6 Narrowband and BTLE are designed for different use cases.

## Bluetooth LE

Infrequent sending of small amounts of data via a mobile phone and/or to a web service.

Not designed for:

- streaming or applications requiring higher data rates (>20kbps)
- applications requiring high reliability (BTLE has no FEC, operates in noisy 2.4GHz band)

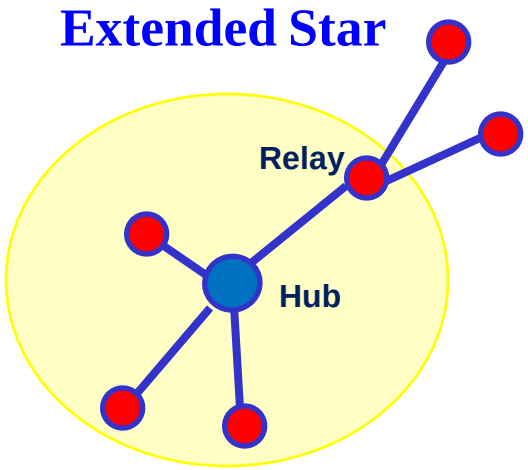
## 802.15.6 Narrowband

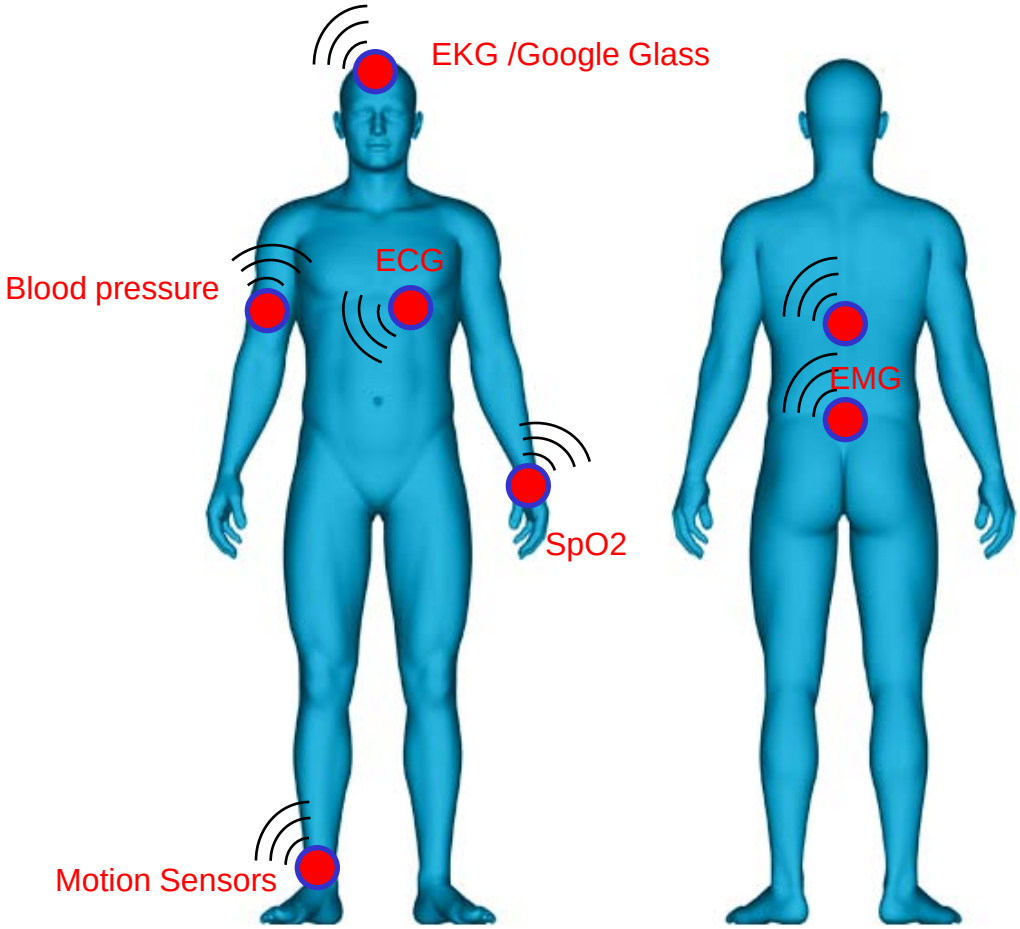
Focussed on medical applications requiring short range bidirectional wireless data transfer. Typically at least one end of the wireless link is on or in the human body.

It is designed to:

- provide a highly reliable wireless connection (FEC & operation in quiet MBAN band)
- support streaming

# WBAN Topology and sensor location



# IEEE802.15.6 Narrowband

## Wearable

- Replace cables with ***highly reliable*** wireless
- One or both ends of the wireless link on the human body

**Patient tethered to monitor**

**Patient monitored wirelessly**

**(no cables)**

## Implantable

- **Develop a wireless standard for implantable unified with wearable.**
- **Implantable currently has a band but no standard**

Slide From 802.15.6 Mentor Tutorial

# 802.15.6 Narrowband can use quiet spectrum…

**2.4 – 2.5GHz ISM band**

**Wi-Fi**

**Bluetooth**

**Microwave oven**

**ZigBee**

**2.36 – 2.4GHz MBAN band**

**Primary users**:

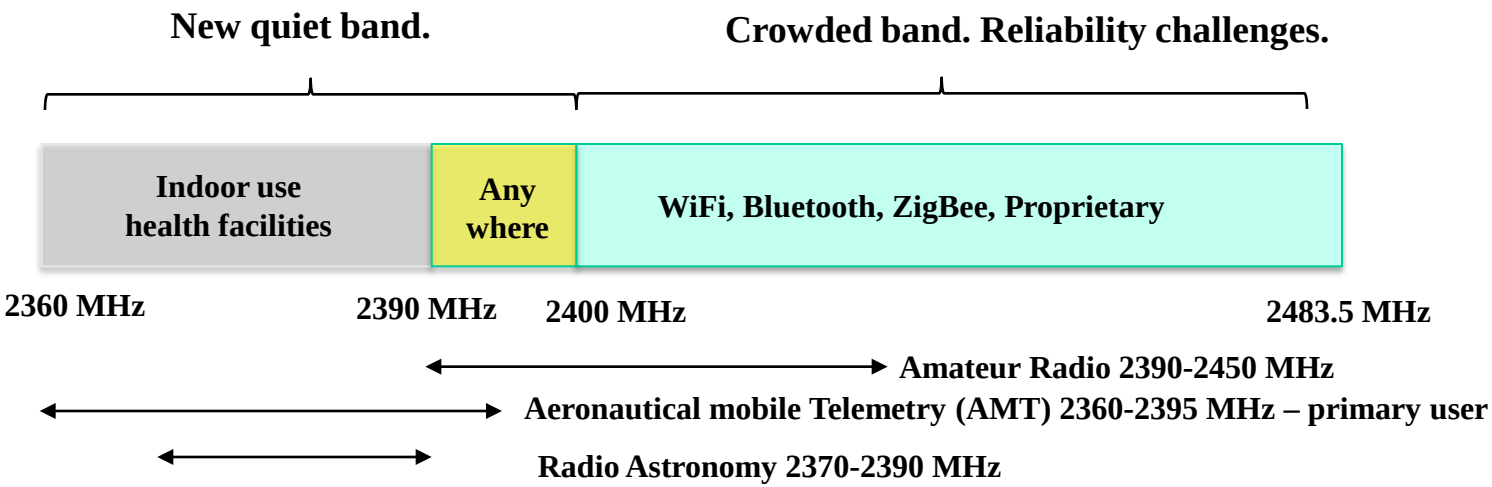
- Aeronautical mobile telemetry
- Radio astronomy

**Secondary users:**

- 802.15.6 enabled medical devices

(they may not cause interference to and must accept interference from primary users of these frequency band)

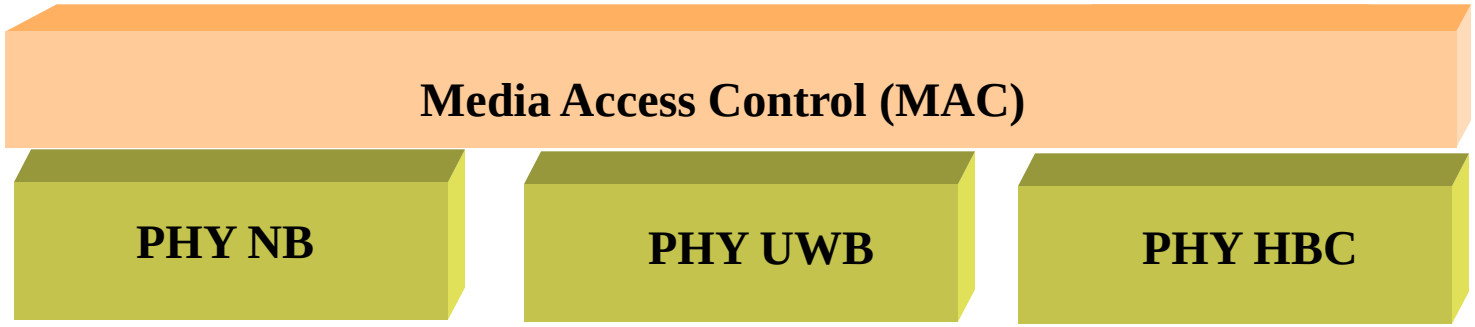
# Medical BAN (MBAN) band in US




In September 2012 FCC included the 2360-2400 MHz band of a Medical Body Area Network (MBAN) (47 CFR part 95 Subpart E and I)

- MBANs are used for the purpose of measuring and recording physiological parameters
- Limited to transmission of data (no voice) for medical applications
- Operation by duly authorized health care professionals and prescription
- 2360-2390 MHz operation permitted indoors at hospitals subject to coordination, radio propagation, eKey/beacon, transition plans and other proposed rule elements
- 2390-2400 MHz MBAN operation permitted anywhere - hospitals, home etc.

# 802.15.6: common MAC but 3 PHYs




| Physical Layers (PHY) | Frequency band (MHz) | Data rate (kbps) |
|---|---|---|
| Narrowband (NB) | 400,600,800,900,2360, 2400 | 75.9 - 971.4 |
| Ultra-wideband (UWB) | 6000 – 10600<br>3100 - 4800 | 390 - 12600 |
| Human body communication (HBC) | 21 | 164 -1312.5 |

# 802.15.6 Narrowband Channels

| Frequency Band (MHz) | Number of Channels | Channel bandwidth | |
|---|---|---|---|
| 402 – 405 | 10 | 300 kHz | Implantable |
| 420 – 450 | 12 | 320 kHz | |
| 863 – 870 | 14 | 400 kHz | |
| 902 – 928 | 60 | 400 kHz | |
| 950 – 958 | 16 | 400 kHz | Wearable |
| 2360 – 2400 | 39 | 1 MHz | |
| 2400 – 2483.5 | 79 | 1 MHz | |

Data rate will adapt to the channel condition. Higher spreading factor and/or more resilient modulation is used for poor channel condition.

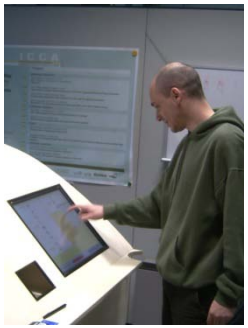
# UWB PHY

- The wideband PHY is based on UWB technology
- In particular impulse radio (IR-UWB) and wideband FM (FM-UWB)
  - IR-UWB is based on transmission of either a single pulse (new paradigm) or a burst of pulses (legacy) per information symbol.
  - FM-UWB combines CP-GFSK modulation with wideband FM.

**Data rate: up to 12 Mbps for IR-UWB**

# Human Body Communication (HBC)

- The electrode in contact with the body is used for transmitting or receiving an electrical signal through the body to a device (e.g. smartphone)



**e-Payment via touch screen**

**Exchange e-business cards via handshake**

- HBC uses 21MHz band

| **Data Rate** ( 21MHz ) |
|---|
| 164 kbps |
| 328 kbps |
| 656 kbps |
| 1.3125 Mbps |

# MAC Features

- Supports Quality of Service (QoS)
- Supports MICS band communication support
- Supports Emergency Communications
- Supports hub to node as well as hub to node to node
- Strong Security
- Macroscopic and microscopic power management
- Coexistence and interference mitigation

# MAC support of Priority

## BAN Priority field encoding

| Field value in decimal | BAN services |
|---|---|
| 0 | Non-medical services |
| 1 | Mixed medical and non-medical services |
| 2 | General health services |
| 3 | Highest priority medical services |

## User priority mapping

| Priority | User Priority | Traffic designation | Frame type |
|---|---|---|---|
| Lowest | 0 | Background (BK) | Data |
| | 1 | Best effort (BE) | Data |
| | 2 | Excellent effort (EE) | Data |
| | 3 | Video (VI) | Data |
| | 4 | Voice (VO) | Data |
| | 5 | Medical data or network control | Data or management |
| | 6 | High priority medical data or network control | Data or management |
| Highest | 7 | Emergency or medical event report | Data |

# IEEE 802.15.6: a flexible standard for Body Area Network
## Overcome many limitations found in IEEE 802.15.4

- Unlimited number of devices in the scheduled allocation communication : only 7 scheduled allocations in Zigbee
- Node can wake up every n superframes
- Supports Emergency Communications
- Coexistence mitigation: beacon shifting
- Interference mitigation: channel hopping

# Thanks