

Smart Health – CSE 40816

University of Notre Dame
Spring 2020



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Bluetooth

- Universal radio interface for **ad-hoc wireless connectivity**
- Interconnecting computer and peripherals, handheld devices, cell phones – designed as replacement for IrDA
- Short range (~10m), low power consumption, **license-free 2.4 GHz ISM**
- Voice and data transmission



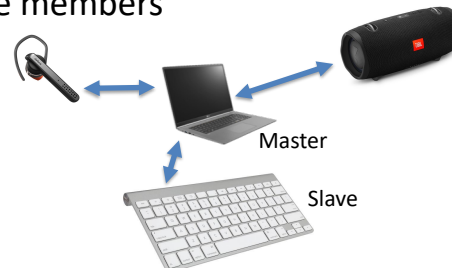
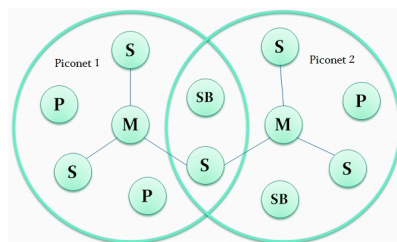
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Characteristics

- **2.4 GHz ISM band**
- **79 RF channels**
 - **Frequency hopping** (spread spectrum) with 1600 hops/s
 - Hopping sequence in a pseudo random fashion, determined by a **master**
- **Voice link – SCO (Synchronous Connection Oriented)**
 - **FEC (forward error correction)**, no retransmission
- **Data link – ACL (Asynchronous Connection Less)**
 - Acknowledgments
- Topology
 - Overlapping piconets (stars) forming a scatternet

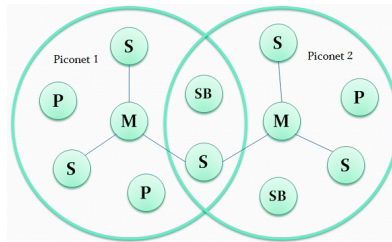
Piconet & Scatternet

- Master vs. slave devices
- Master determines “hopping pattern”
- Each piconet has a unique hopping pattern
- Original BT: up to 7 slaves (more parked/standby)
- Scatternet: piconets share members



Piconet & Scatternet

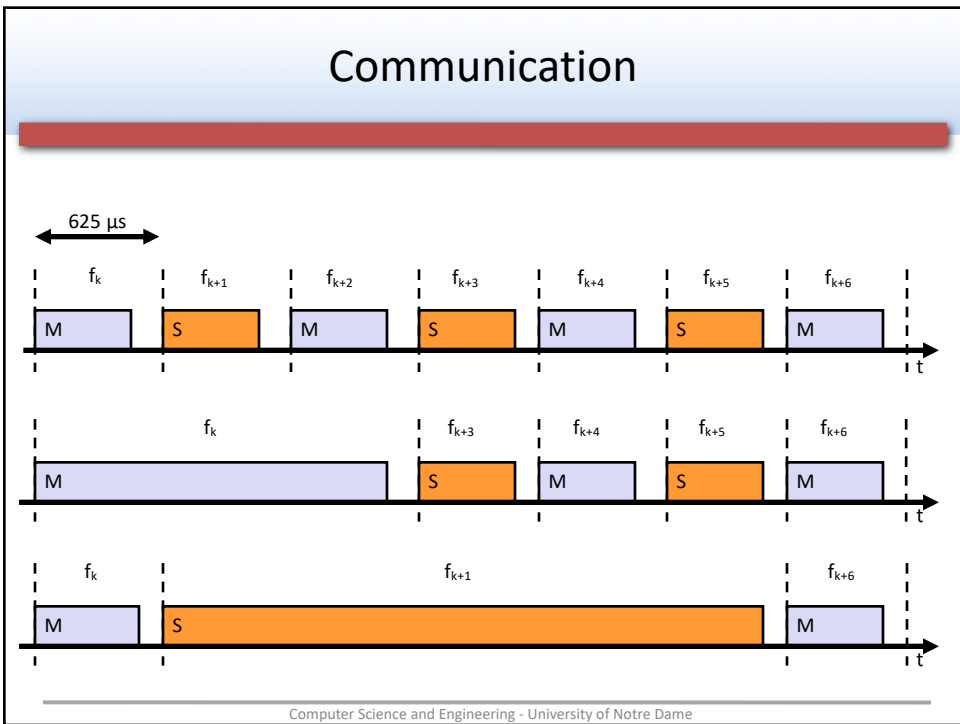
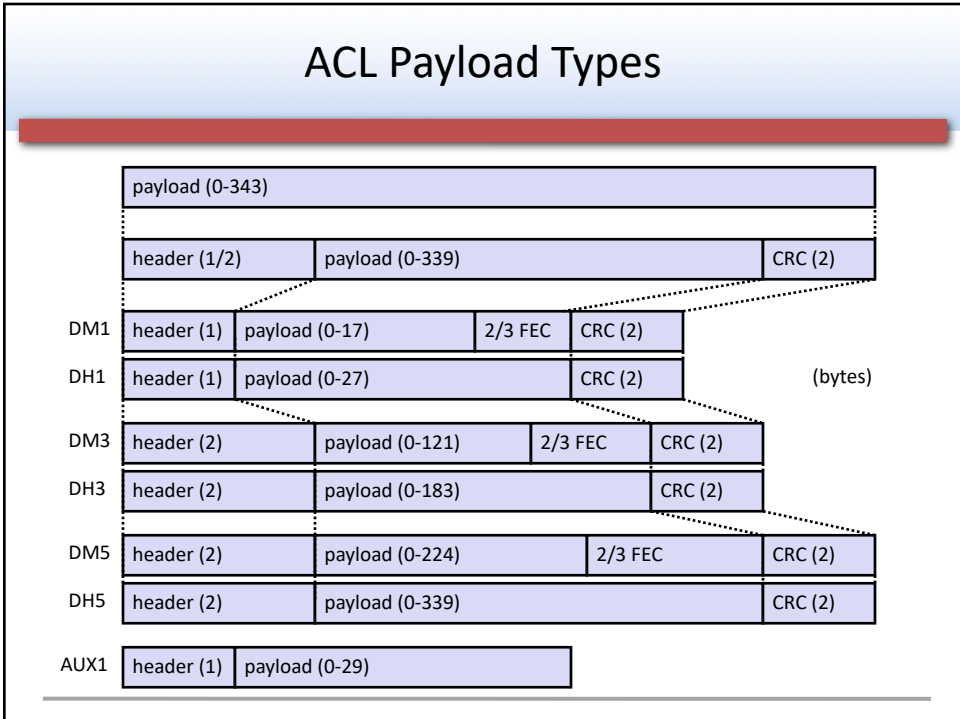
- All devices in a piconet hop together
 - Master gives slaves its **clock** and **device ID** (48-bit address)
- Scatternet: Linking of multiple co-located piconets through the sharing of common master or slave devices
 - Devices can be slave in two piconets or slave in one piconet and master of another
 - Devices “jump back and forth” between the piconets



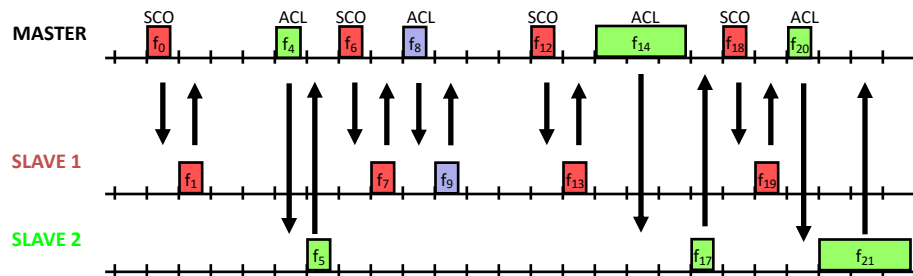
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SCO Payload Types

	payload (30)				
HV1	audio (10)	FEC (20)			
HV2	audio (20)	FEC (10)			
HV3	audio (30)				
DV	audio (10)	Header (1)	Payload (0-9)	2/3 FEC	CRC (2)



Communication Example

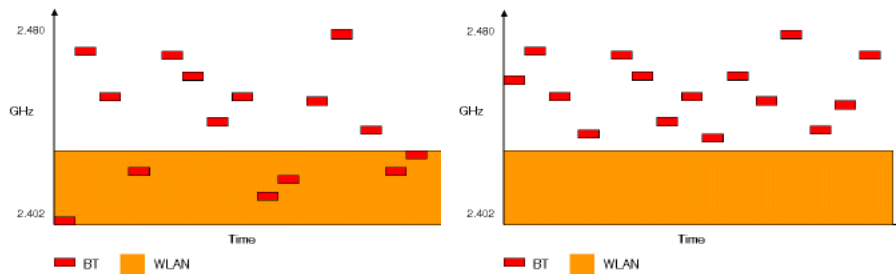


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Bluetooth Versions

- Bluetooth 1.1
 - also IEEE Standard 802.15.1-2002
 - initial stable commercial standard
- Bluetooth 1.2
 - also IEEE Standard 802.15.1-2005
 - eSCO (extended SCO): higher, variable bitrates, retransmission for SCO
 - AFH (adaptive frequency hopping) to avoid interference
- Bluetooth 2.0 + EDR (2004, no more IEEE)
 - EDR (enhanced data rate) of 3.0 Mbit/s for ACL and eSCO
 - lower power consumption due to shorter duty cycle
- Bluetooth 2.1 + EDR (2007)
 - better pairing support, e.g., using NFC
 - improved security

Adaptive Frequency Hopping



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Bluetooth Versions

- Bluetooth 3.0 + HS (2009)
 - speeds up to 24Mbps (using co-located Wi-Fi link!)
- Bluetooth 4.0
 - Classic Bluetooth
 - Bluetooth High Speed
 - Bluetooth Low Energy
- **Bluetooth Low Energy (BLE):**
 - Marketed as **Smart Bluetooth**
 - Lower power, lower cost
 - Use in **healthcare**, fitness, security, entertainment devices
 - 40 channels

Bluetooth Low Energy (BLE)

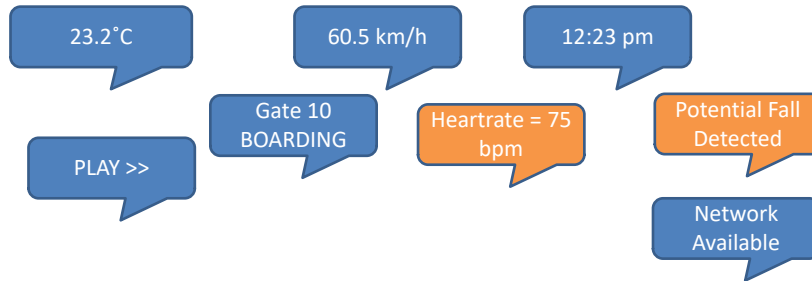
- Bluetooth low energy is a new, open, short range radio technology
 - Blank sheet of paper design
 - Different to Bluetooth classic (BR/EDR)
 - Optimized for **ultra low power**
 - Enable coin cell battery use cases
 - < 20mA peak current
 - < 5uA average current



BLE Basic Concepts

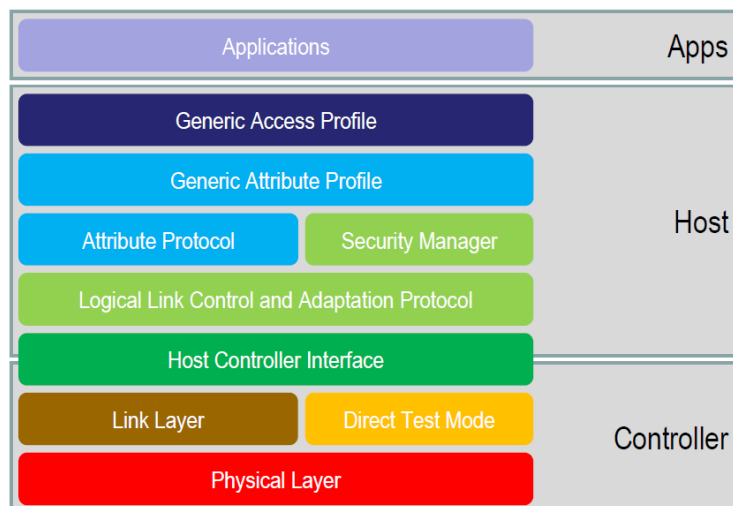
- Everything is optimized for lowest power consumption
 - Short packets reduce TX peak current
 - Short packets reduce RX time
 - Fewer RF channels to improve discovery and connection time
 - Simple protocol and state machine

“Exposing State”



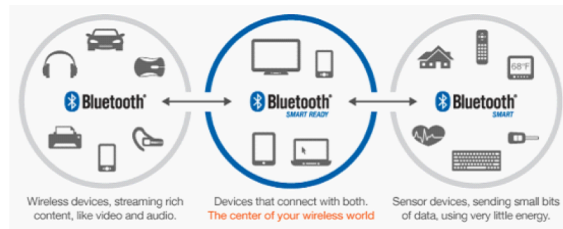
- Good at small, discrete data transfers
- Data can triggered by local events
- Data can be read at any time by a client

BLE Architecture / Protocol Stack



BLE Device Modes

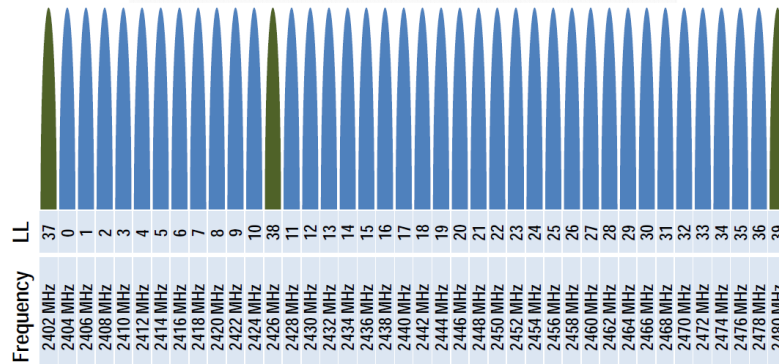
- Dual Mode
 - Bluetooth BR/EDR and LE
 - Used anywhere BR/EDR is used today
- Single Mode
 - Implements only Bluetooth Low Energy
 - Will be used in new devices/applications



BLE Physical Layer

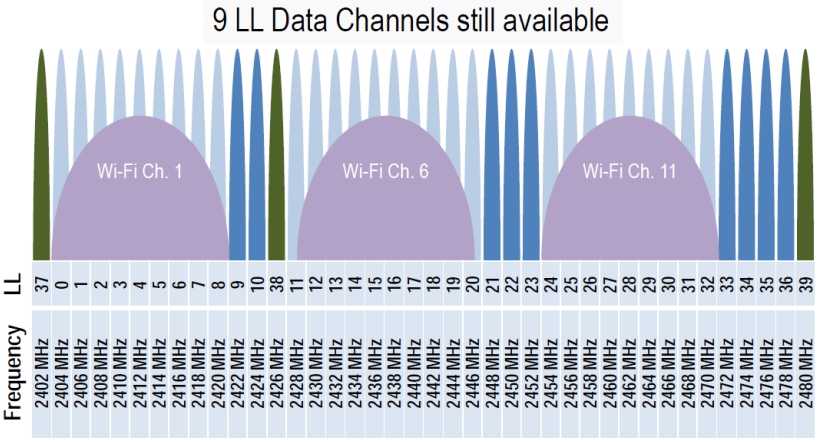
- Two types of channels

3 Advertising Channels and 37 Data Channels



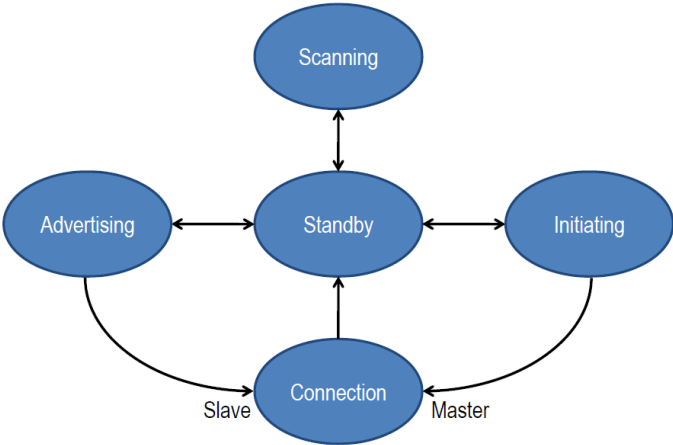
BLE Physical Layer

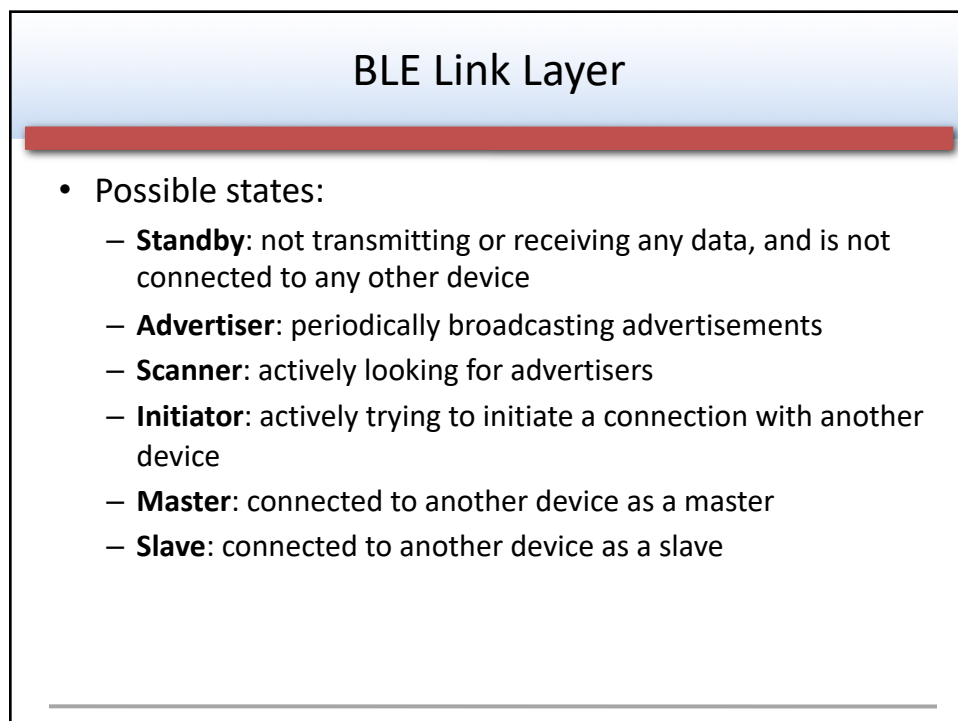
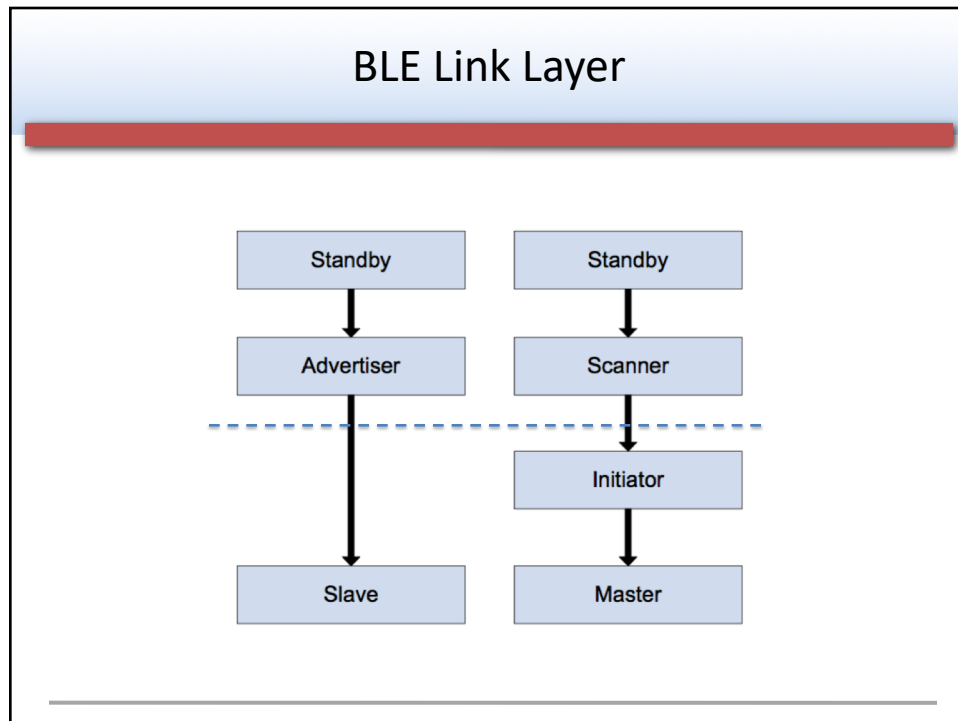
- Advertising channels avoid 802.11



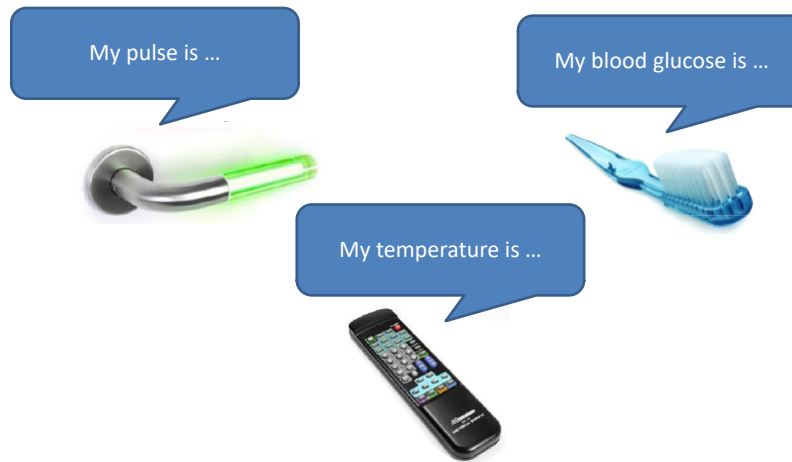
BLE Link Layer

- Link Layer state machine





BLE and Smart Health



Bluetooth in Health Care

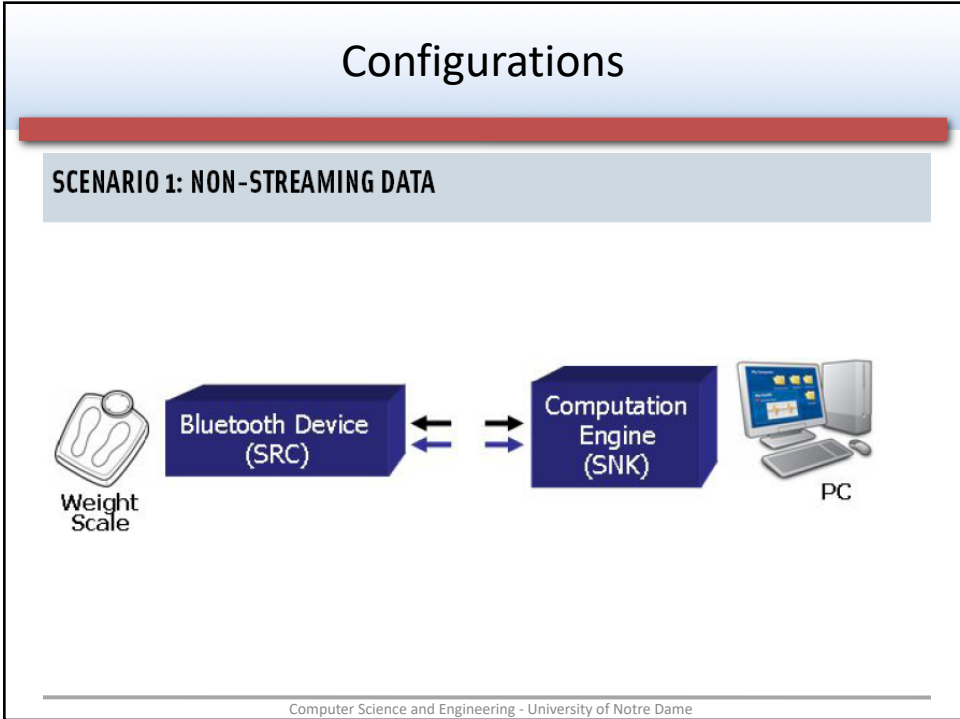
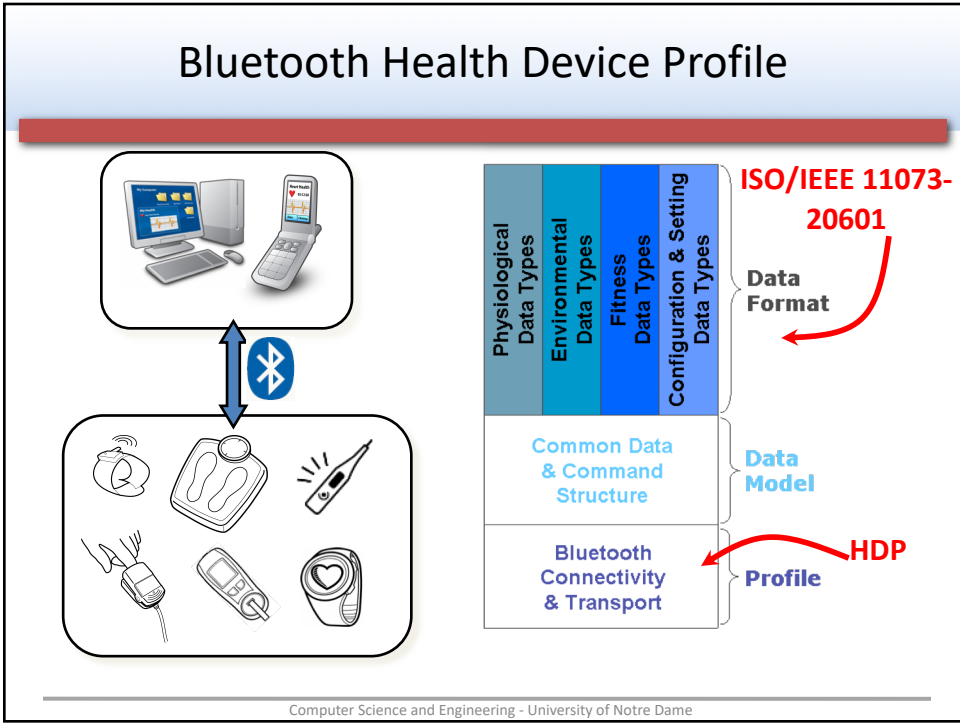
- Workgroup formed in 2006 to develop standard to support existing and emerging medical devices and to bring compatibility and interoperability
- Medical device manufacturers, silicon suppliers, and other supporters of the Bluetooth standard worked together to produce a **Health Device Profile** that was approved in 2008

BT Health Device Profile

- The Bluetooth Health Device Profile works with Bluetooth chips that support streaming data rates of up to 2.1Mbps
- That means that it can support medical devices as complex as ECGs, which need to stream data
- It is equally applicable for simple devices such as weight scales that only need to transmit small quantities of information
- It builds on the underlying capabilities of the Bluetooth standard, which include:
 - excellent **resistance to interference** from wireless LANs, through the use of adaptive frequency hopping
 - **best-in-class security**, including immunity from “man-in-the-middle” attacks, by utilizing public key cryptography
 - **low power** consumption (devices frequently enter low power sleep states)
 - a rigorous qualification program to ensure **interoperability**
 - excellent **range** – up to 1km range products are available
 - global applicability, using the 2.4GHz band
 - low cost

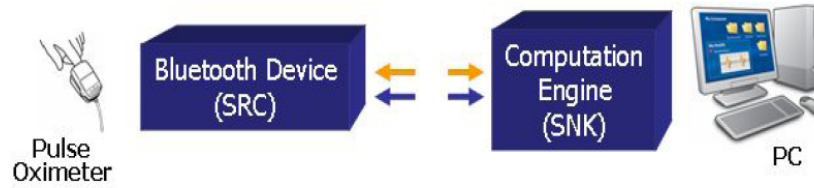
Device Standards

- **IEEE11073** is a standard that describes how data is represented by medical devices and how these devices connect to each other
- **Real-time**: data from multiple devices can be retrieved, time correlated, displayed, and processed in fractions of a second
- **Plug-and-play**: devices detect, configure, and communicate without human interaction



Configurations

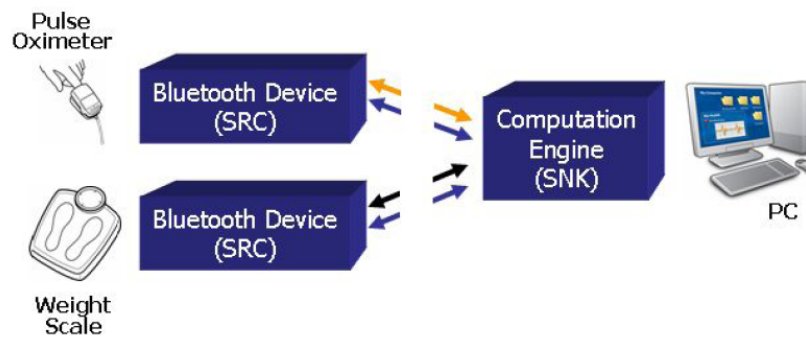
SCENARIO 2: STREAMING DATA



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Configurations

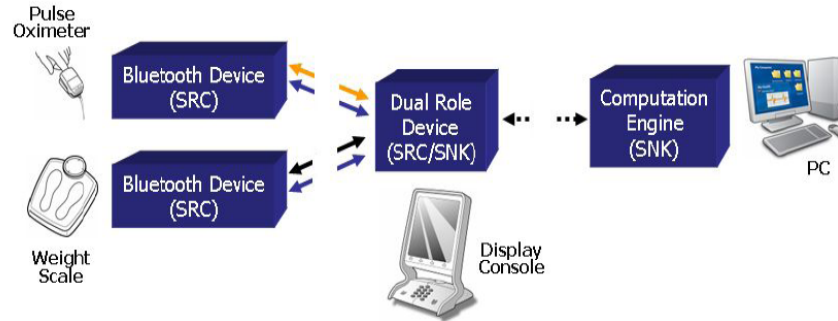
SCENARIO 3: CONCURRENT STREAMING AND NON-STREAMING DATA



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Configurations

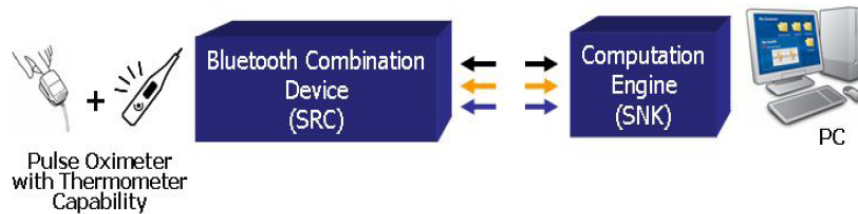
SCENARIO 4: DUAL ROLE DEVICE



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Configurations

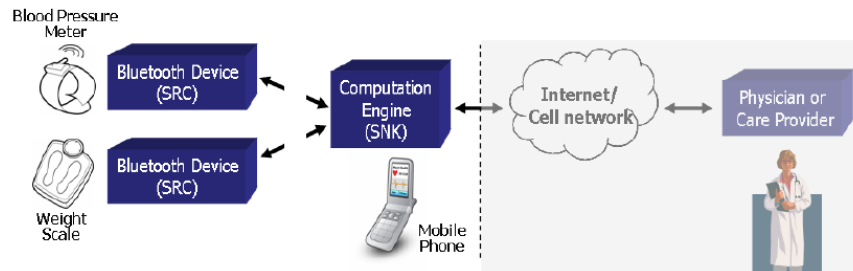
SCENARIO 5: COMBINATION DEVICE



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Configurations

SCENARIO 6: SHARING OF DATA WITH REMOTE CARE PROVIDER



Not Part of Profile Spec, but requires coordination with other standards bodies

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ZigBee

- IEEE 802.15.4 (similar to Bluetooth and IEEE 802.15.1)
- Pushed by Chipcon (now TI), Ember, Freescale (Motorola), Honeywell, Mitsubishi, Motorola, Philips, Samsung...
- More than 260 members
 - about 15 promoters, 133 participants, 111 adopters
 - must be member to commercially use ZigBee spec
- ZigBee platforms comprise
 - IEEE 802.15.4 for layers 1 and 2
 - ZigBee protocol stack up to the applications



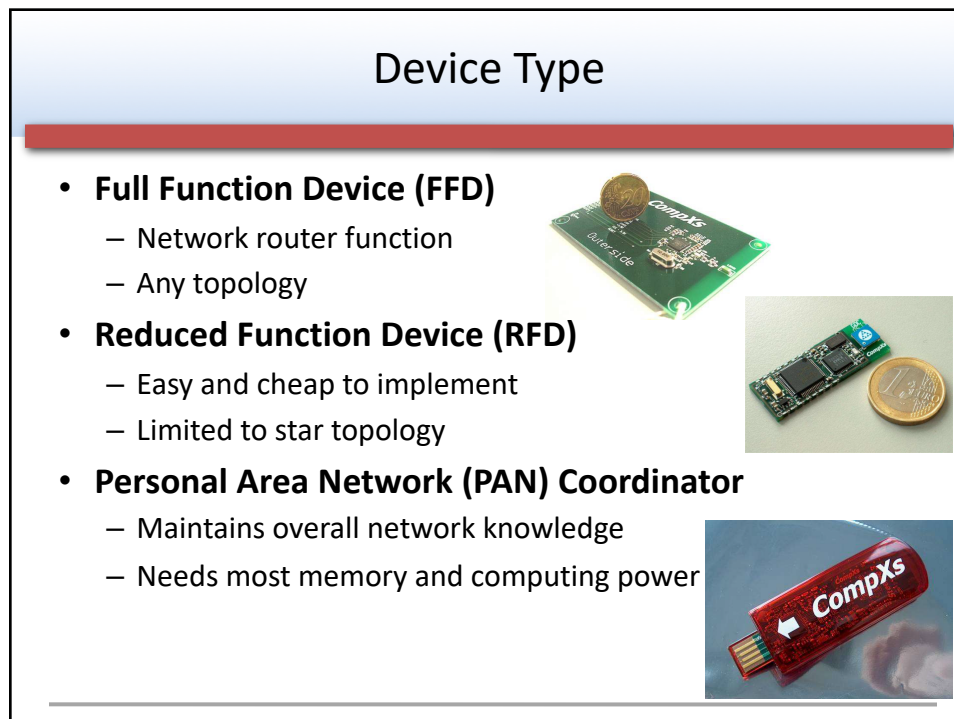
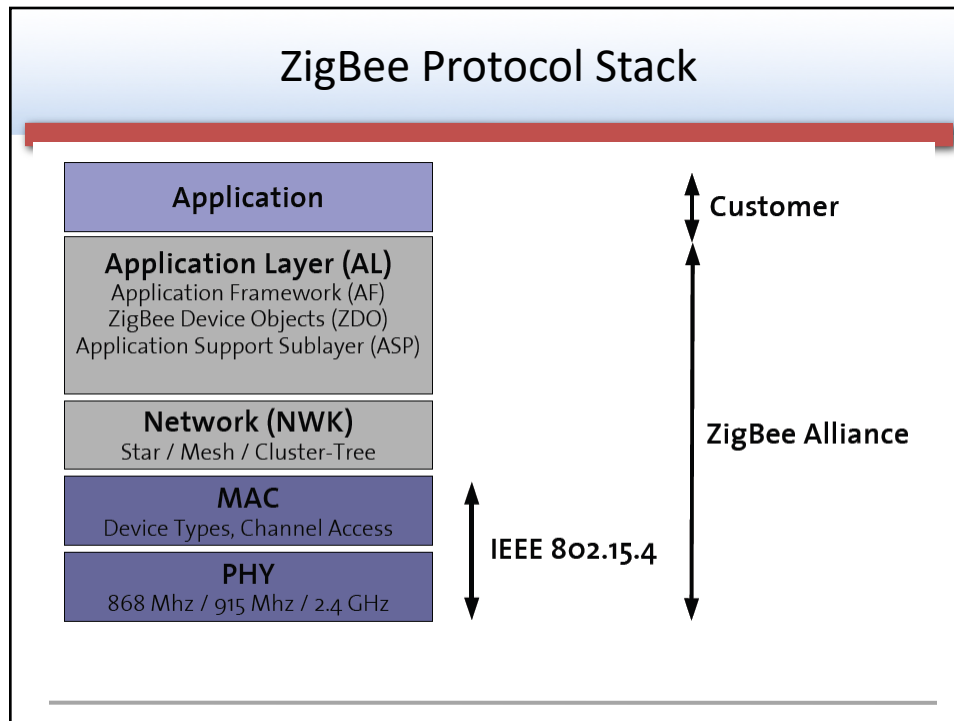
ZigBee

- Design goal
 - Low power consumption
 - Simple Design
 - Low cost
- History
 - ZigBee-style networks began ~1998
 - IEEE 802.15.4 was first completed in 2003
 - ZigBee Alliance was established in 2002

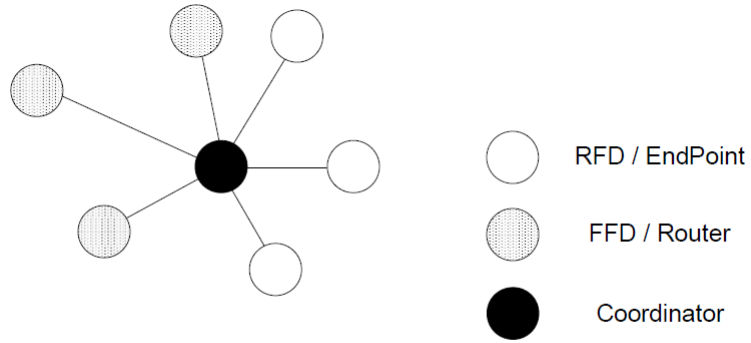
ZigBee Core Market

- **Industrial and Commercial**
 - Monitors
 - Movement sensors
 - Automation
- **Personal Healthcare**
 - Patient monitors
 - Remote diagnosis
 - Data loggers
- **Building Automation**
 - Security
 - Lighting
 - Fire and safety systems
- **Automotive**
 - Service controls
 - Inventory tracking



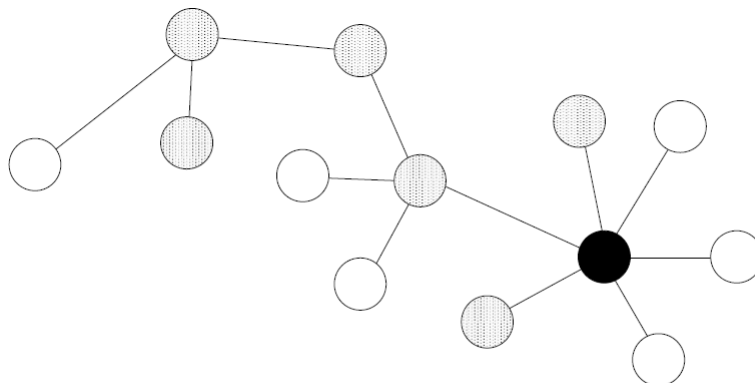


Basic Topology

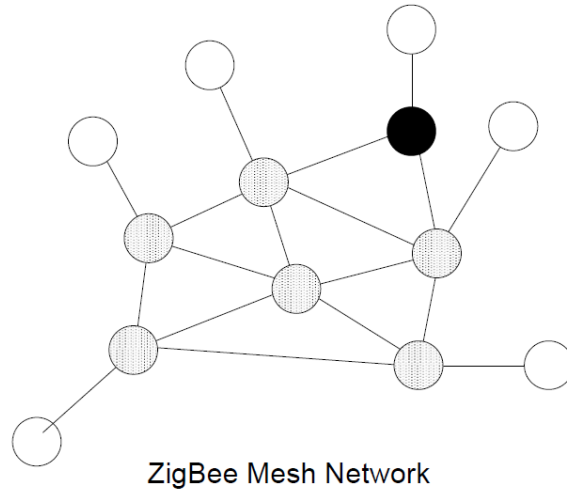


Star Network

Cluster Tree Network



ZigBee PRO: Mesh Network



ZigBee Mesh Network

Comparison

Technology	Classic Bluetooth technology (BR/EDR) ¹	Bluetooth low energy technology ²	ZigBee
Radio Frequency	2.4 GHz	2.4 GHz	2.4 GHz
Distance / Range	10 to 100 meters ³	10 to 100 meters ³	10 to 200 meters ⁴
Over the air Data Rate	1-3Mbps	1Mbps	250kbps at 2.4 GHz
Application Throughput	0.7-2.1 Mbps	0.2 Mbps	<0.1 Mbps
Nodes/Active Slaves	7 / 16777184 ⁵	Unlimited ⁶	65535 ⁷
Security	64b/128b and applications layer user defined	128b AES and application layer user defined	128b AES and application layer user defined
Robustness	Adaptive fast frequency hopping, FEC, fast ACK	Adaptive fast frequency hopping	DSSS, Uses only 16 ch. in ISM band, optional mesh topology has long recovery time
Latency (from a non connected state)			
Total time to send data (det. battery life) ⁸	100ms	<3ms	<10ms
Government Regulation	Worldwide	Worldwide	Worldwide
Certification Body	Bluetooth SIG	Bluetooth SIG	ZigBee Alliance
Voice capable	Yes	No	No
Network topology	Scatternet	Star-bus	Star or Mesh
Power Consumption	1 as the reference	0.01 to 0.5(depend on use-case)	2 (router) / 0.1 (end point)
Peak current consumption (max 15 mA to run on coin cell battery)	<30 mA	<15 mA	<15 mA
Service discovery	Yes	Yes	No
Profile concept	Yes	Yes	Yes
Primary Use Cases	Mobile phones, gaming, headsets, stereo audio streaming, automotive, PCs, consumer electronics, etc.	Mobile phones, gaming, PCs, watches, sports & fitness, healthcare, automotive, consumer electronics, automation, industrial, etc.	Fixed location industrial, building & home automation, AMI/SmartEnergy