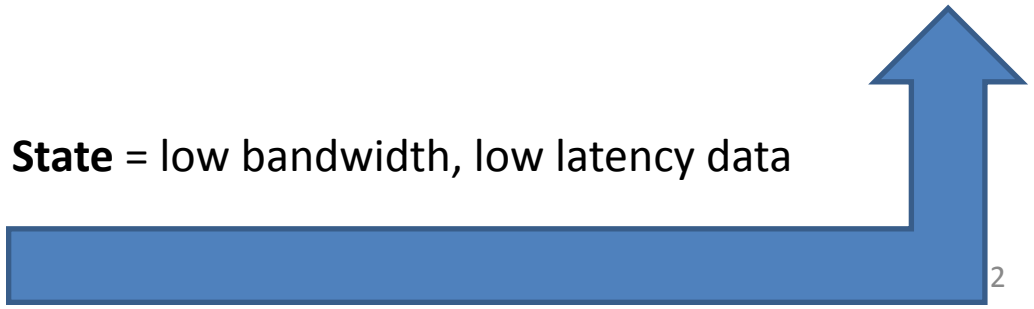
Bluetooth 4.0: Low Energy

Short range wireless application areas

	Voice	Data	Audio	Video	State
Bluetooth ACL/HS	x	Y	Y	x	x
Bluetooth SCO/eSCO	Y	x	x	x	x
Bluetooth low energy	x	x	x	x	Y
Wi-Fi	(VoIP)	Y	Y	Y	x
Wi-Fi Direct	Y	Y	Y	x	x
ZigBee	x	x	x	x	Y
ANT	x	x	x	x	Y



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 sleep, reducing power consumption to give months of battery life

- Peak transmit current is typically around 25mA

- Even though it has been independently shown to be lower power than other radio standards, it is still not low enough power for coin cells and energy harvesting applications

What is Bluetooth Low Energy?

- 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
    - < 5 uA average current

Basic Concepts of Bluetooth 4.0

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

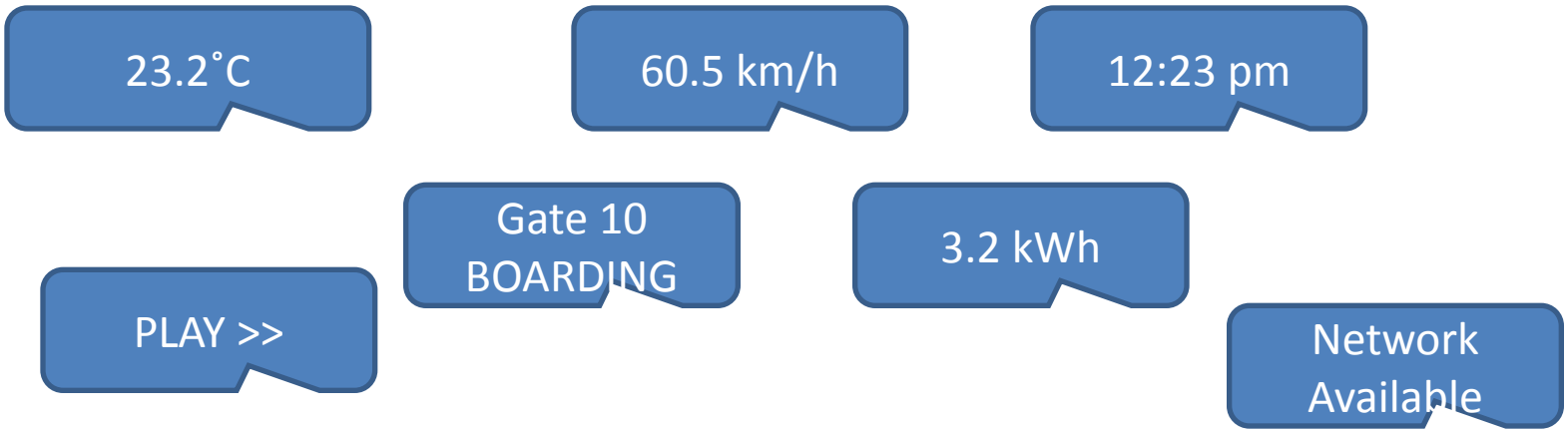
Bluetooth low energy factsheet

Range:	~ 150 meters open field
Output Power:	~ 10 mW (10dBm)
Max Current:	~ 15 mA
Latency:	3 ms
Topology:	Star
Connections:	> 2 billion
Modulation:	GFSK @ 2.4 GHz
Robustness:	Adaptive Frequency Hopping, 24 bit CRC
Security:	128bit AES CCM
Sleep current:	~ 1µA
Modes:	Broadcast, Connection, Event Data Models, Reads, Writes

Bluetooth low energy factsheet #2

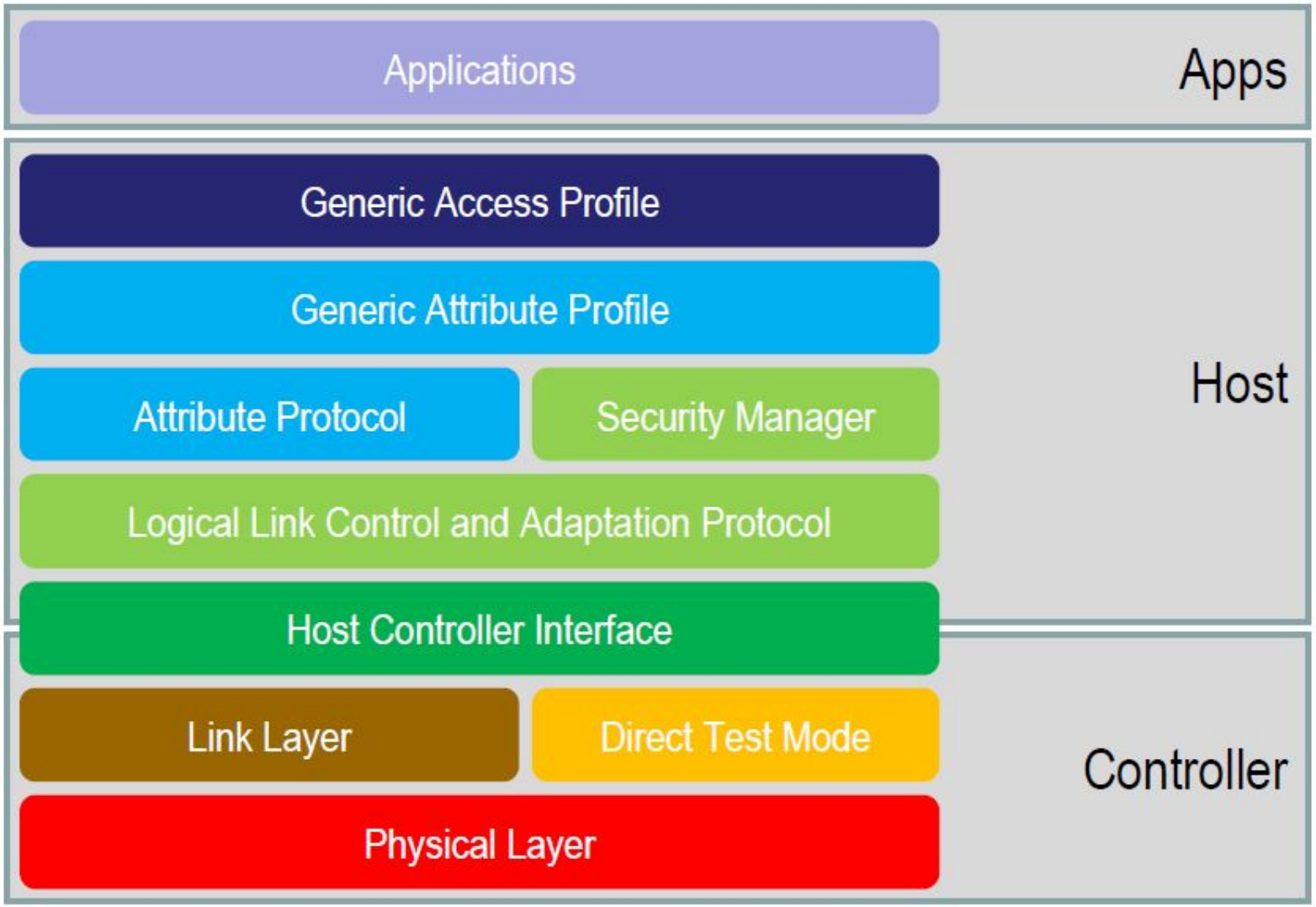
- Data Throughput
  - For Bluetooth low energy, data throughput is not a meaningful parameter. It does not support streaming.
  - It has a data rate of 1Mbps, but is not optimized for file transfer.
  - It is designed for sending small chunks of data (exposing state)

Designed for exposing state



- It’s good at small, discrete data transfers.
- Data can triggered by local events.
- Data can be read at any time by a client.
- Interface model is very simple (GATT)

Bluetooth Low Energy Architecture



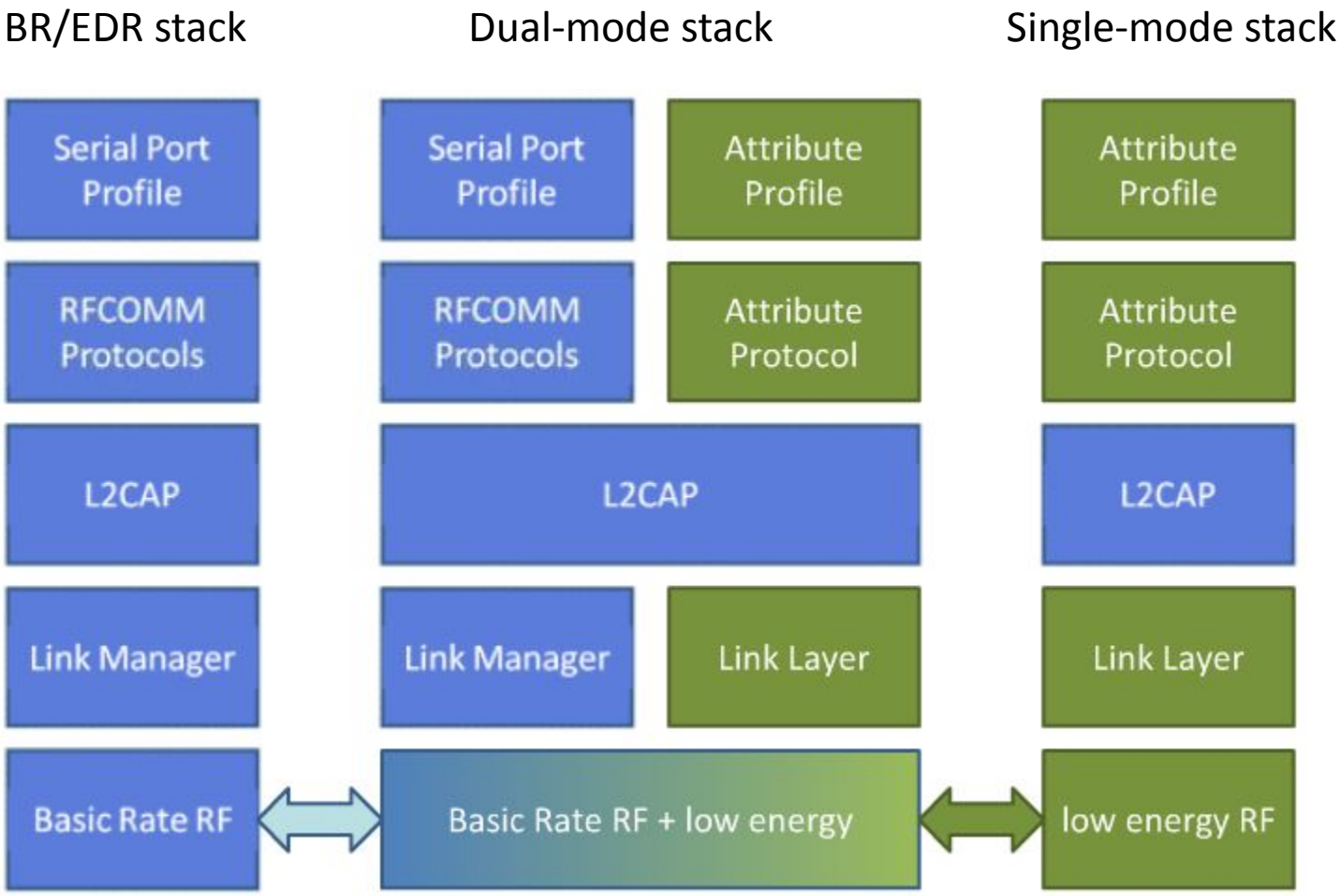
Device Modes

- Dual Mode
  - Bluetooth BR/EDR and LE
  - Used anywhere that BR/EDR is used today

- Single Mode
  - Implements only Bluetooth low energy
  - Will be used in new devices / applications

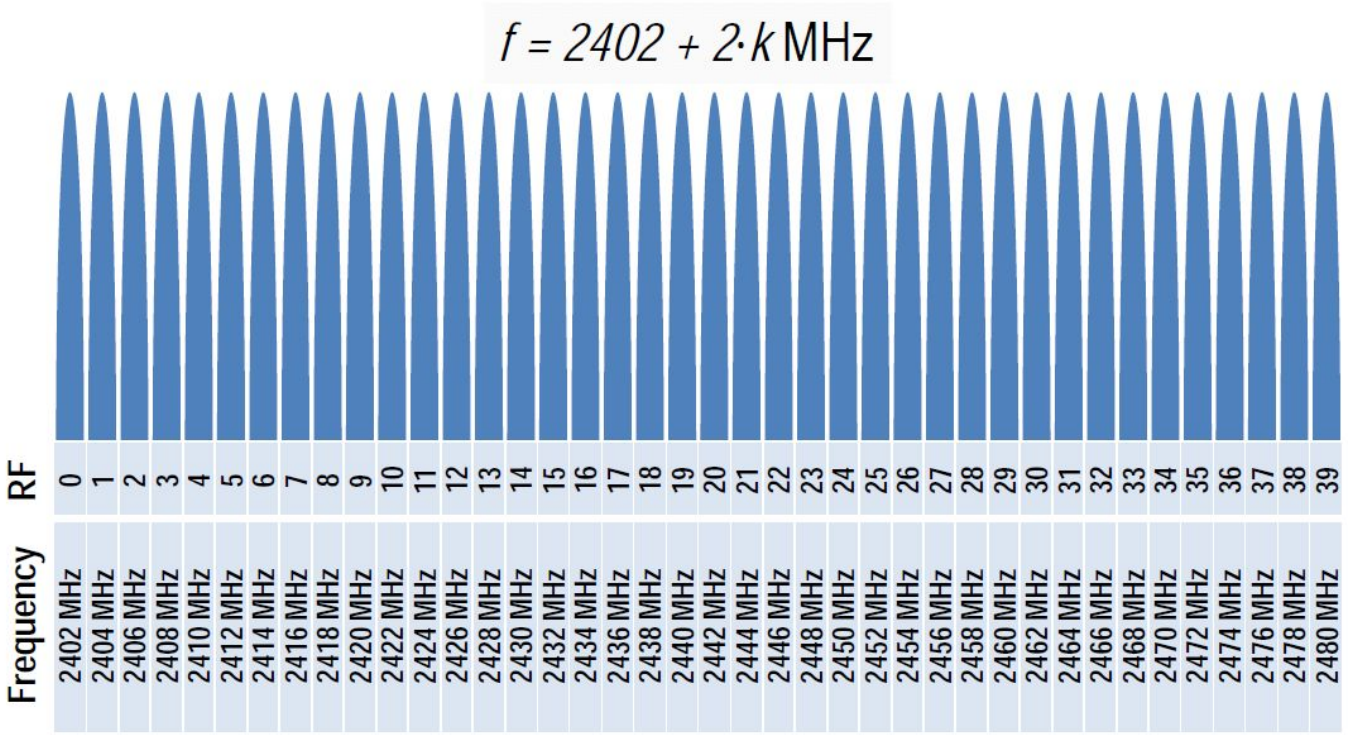
Device Modes

- Dual mode + single modes



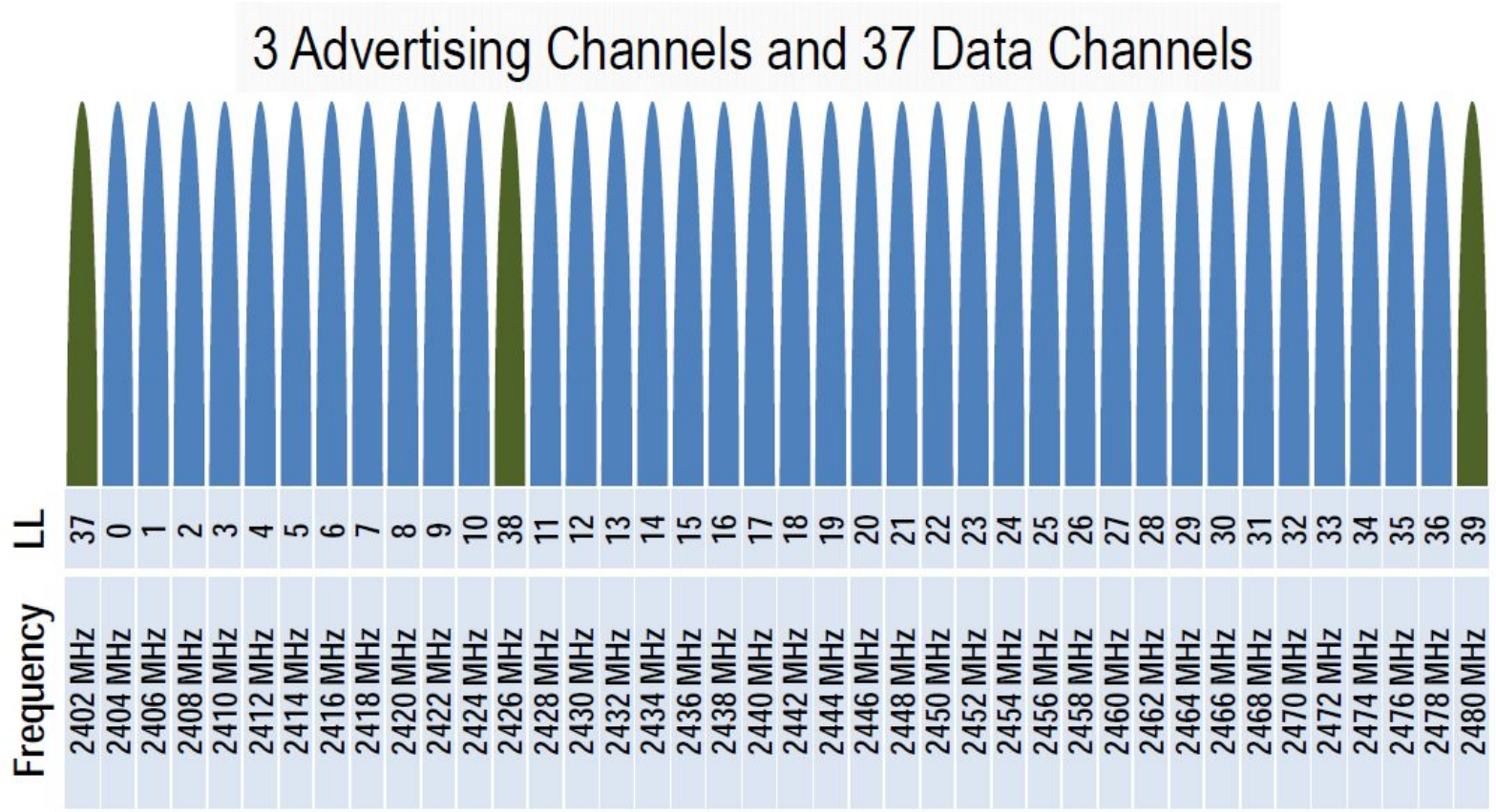
Physical Layer

- 2.4 GHz ISM band
- 1Mbps GFSK
  - Larger modulation index than Bluetooth BR (which means better range)
- 40 Channels on 2 MHz spacing



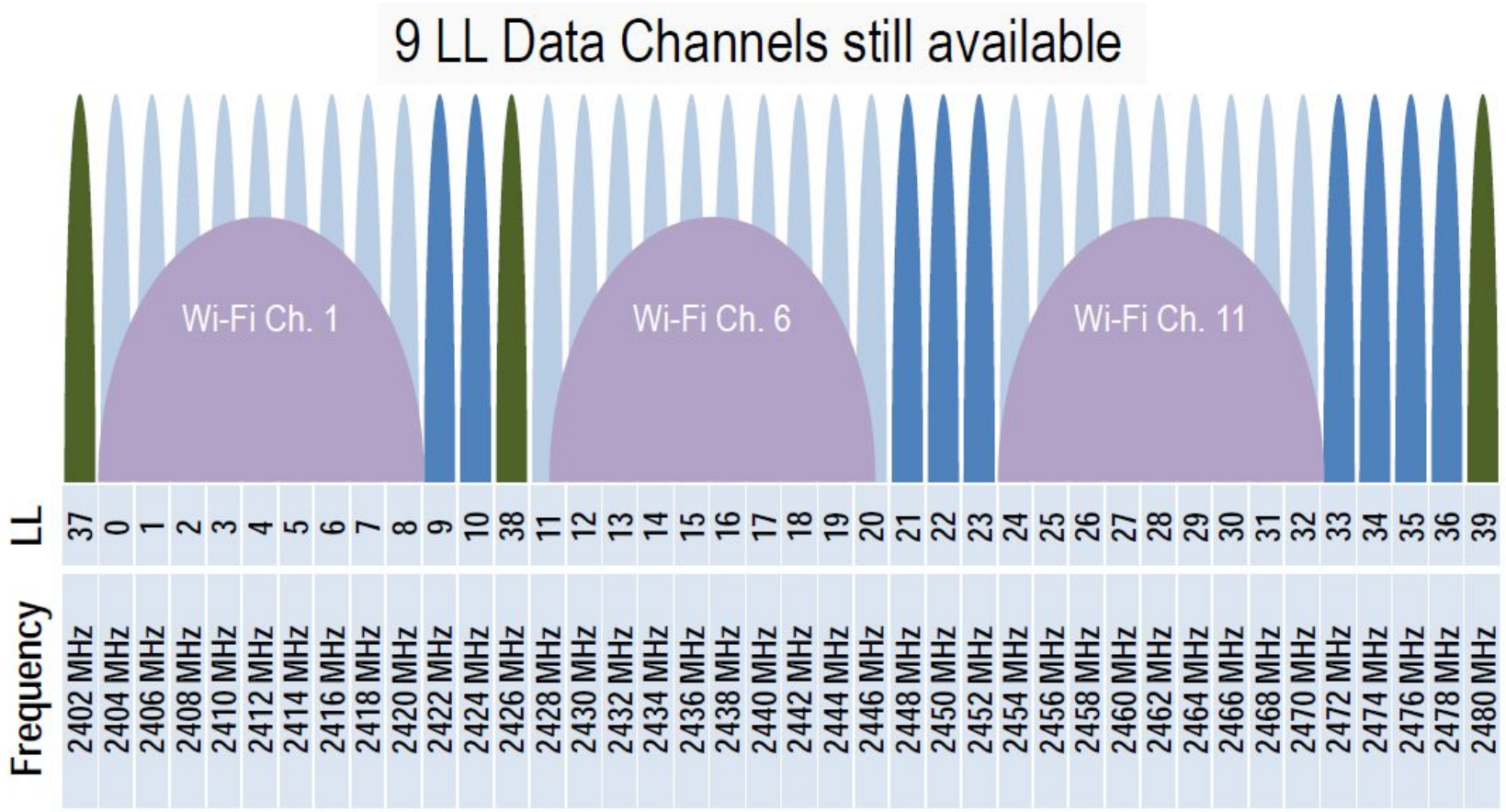
Physical Channels

- Two types of channels



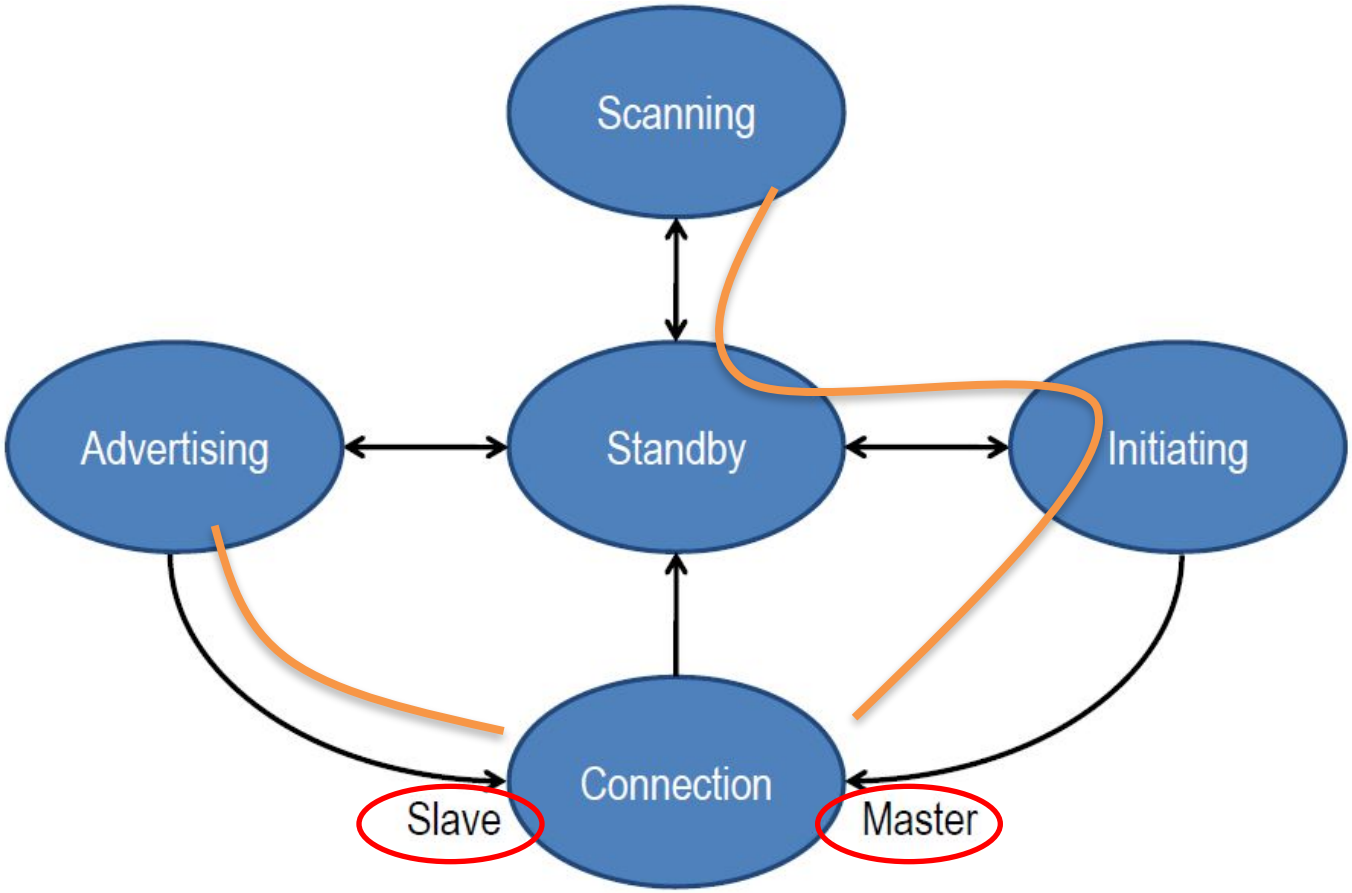
Physical Channels

- Advertising channels avoid 802.11

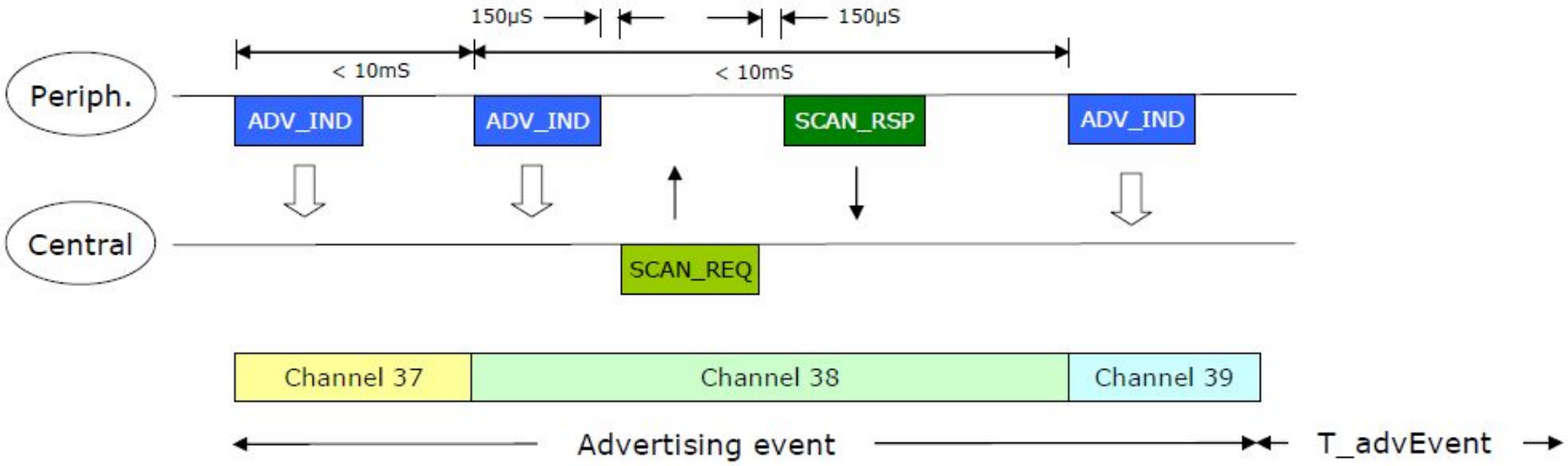


Link Layer

- Link Layer state machine

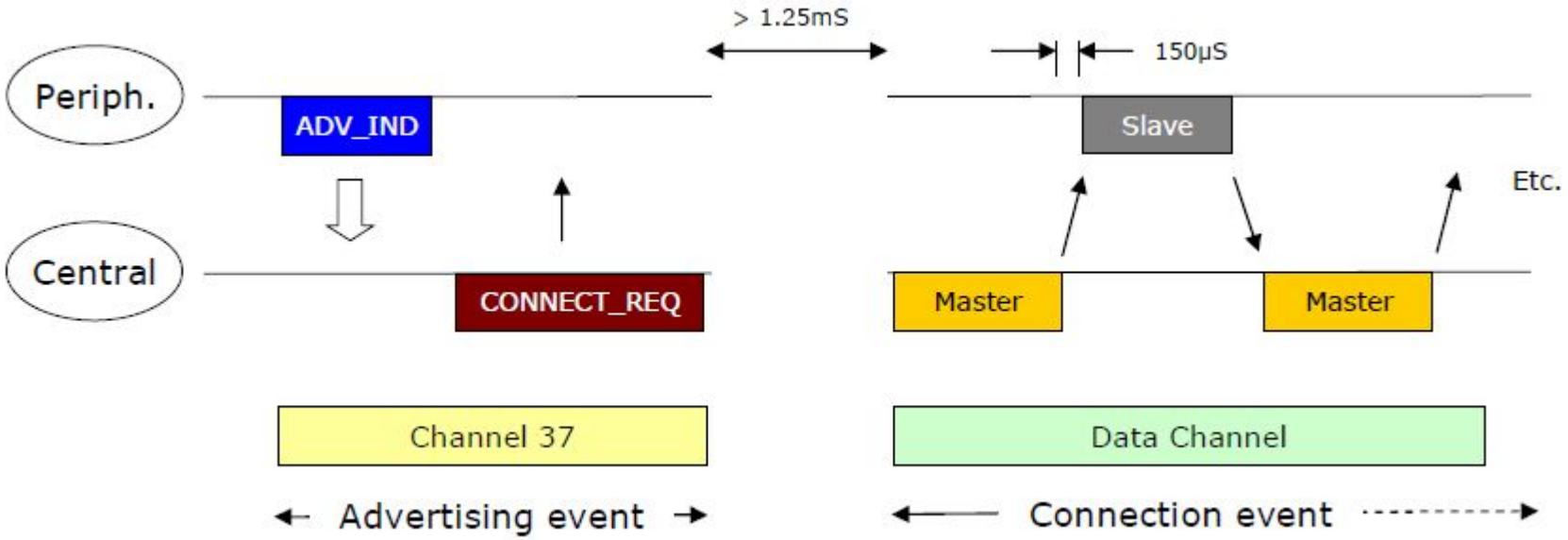


Advertising



- Devices can advertise for a variety of reasons:
  - To broadcast promiscuously
  - To transmit signed data to a previously bonded device
  - To advertise their presence to a device wanting to connect
  - To reconnect asynchronously due to a local event

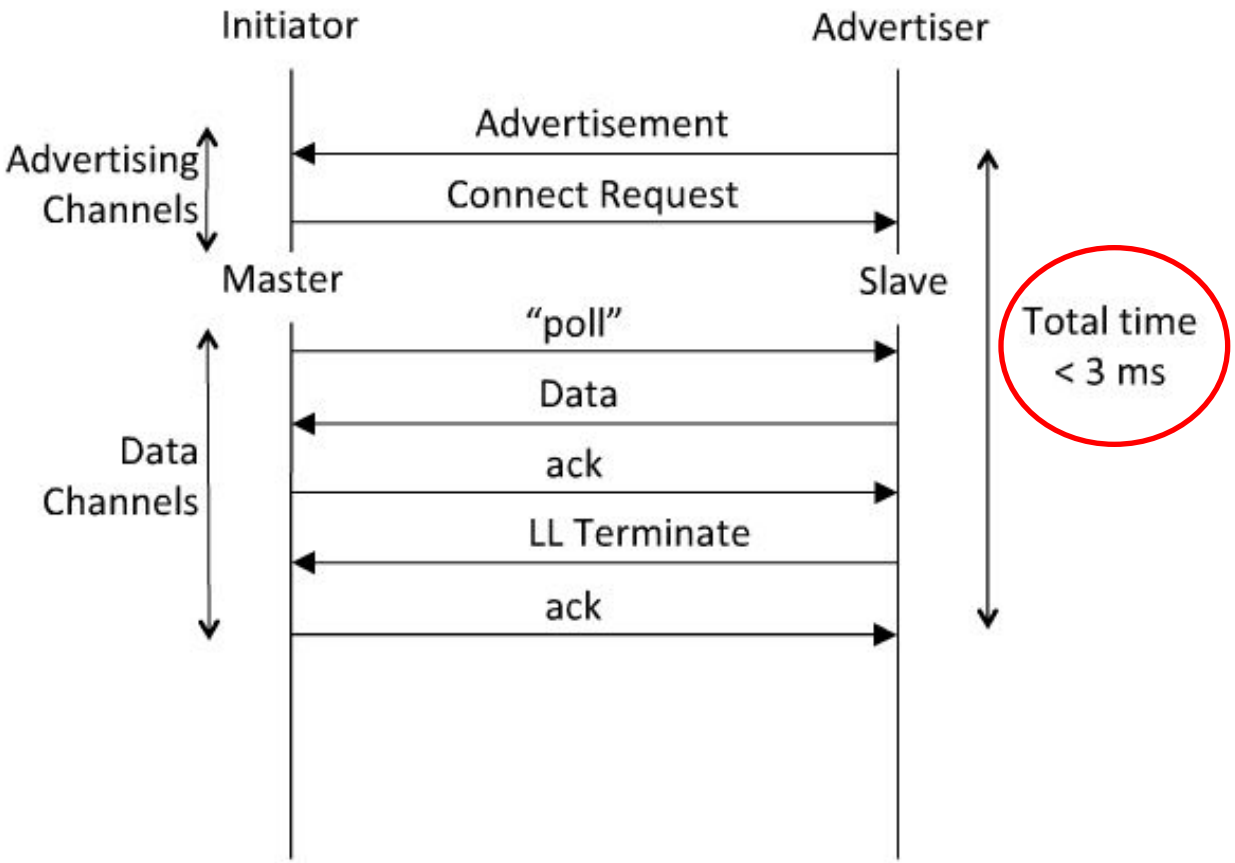
Data transactions



- Once a connection is made:
  - Master informs slave of hopping sequence and when to wake
  - All subsequent transactions are performed in the 37 data channels
  - Transactions can be encrypted
  - Both devices can go into deep sleep between transactions

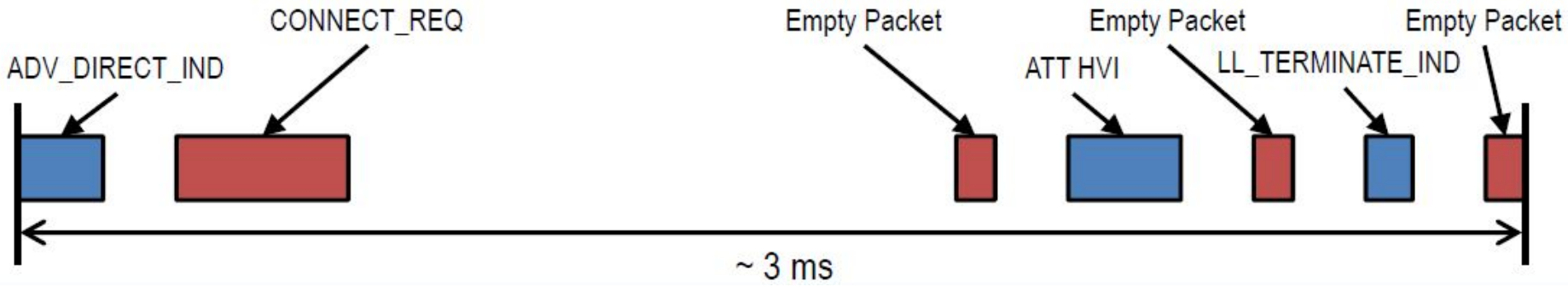
Link Layer Connection

- Very low latency connection



Time From Disconnected to Data ~ 3ms

Time (us)	Master Tx	Radio Active (us)	Slave Tx
0		176	ADV_DIRECT_IND
326	CONNECT_REQ	352	
1928	Empty Packet	80	
2158		144	Attribute Protocol Handle Value Indication
2452	Empty Packet (Acknowledgement)	80	
2682		96	LL_TERMINATE_IND
2928	Empty Packet (Acknowledgement)	80	



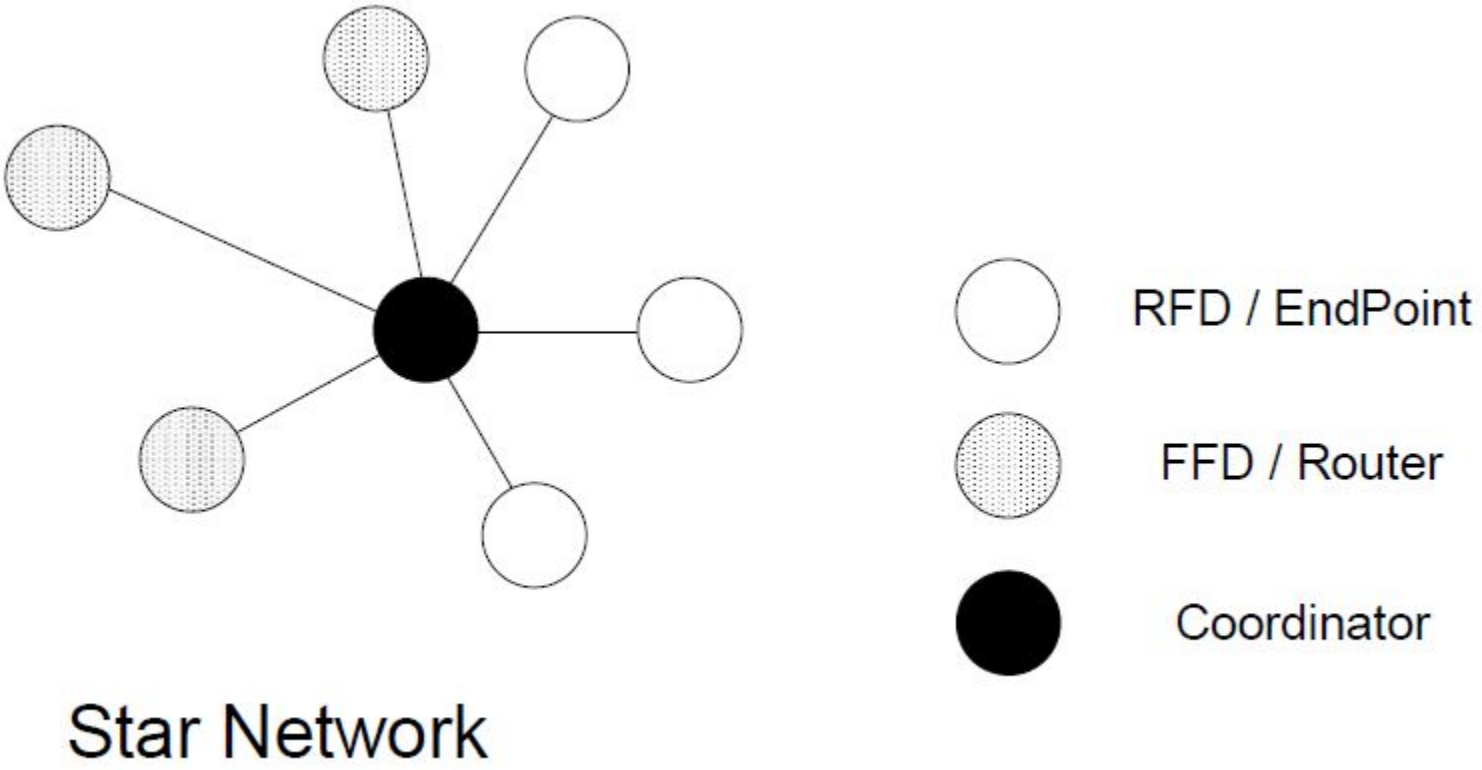
How low can the energy get?

- From the previous slide, calculate energy per transaction
  - Assume an upper bound of 3ms per minimal transaction
  - Estimated TX power is 15mW (mostly TX power amp for 65nm chips)
  - For 1.5v battery, this is 10mA. 0.015W * 0.003 sec = 45 micro Joule
- How long could a sensor last on a battery?
  - An example battery: Lenmar WC357, 1.55v, 180mAh, $2-5
  - 180mAh/10mA = 18Hr = 64,800 seconds = 21.6M transactions
  - Suppose this sensor sends a report every minute = 1440/day
  - For just the BT LE transactions, this is 15,000 days, or > 40 years
  - This far exceeds the life of the battery and/or the product
- This means that battery will cost more than the electronics
  - This sensor could run on scavenged power, e.g. ambient light

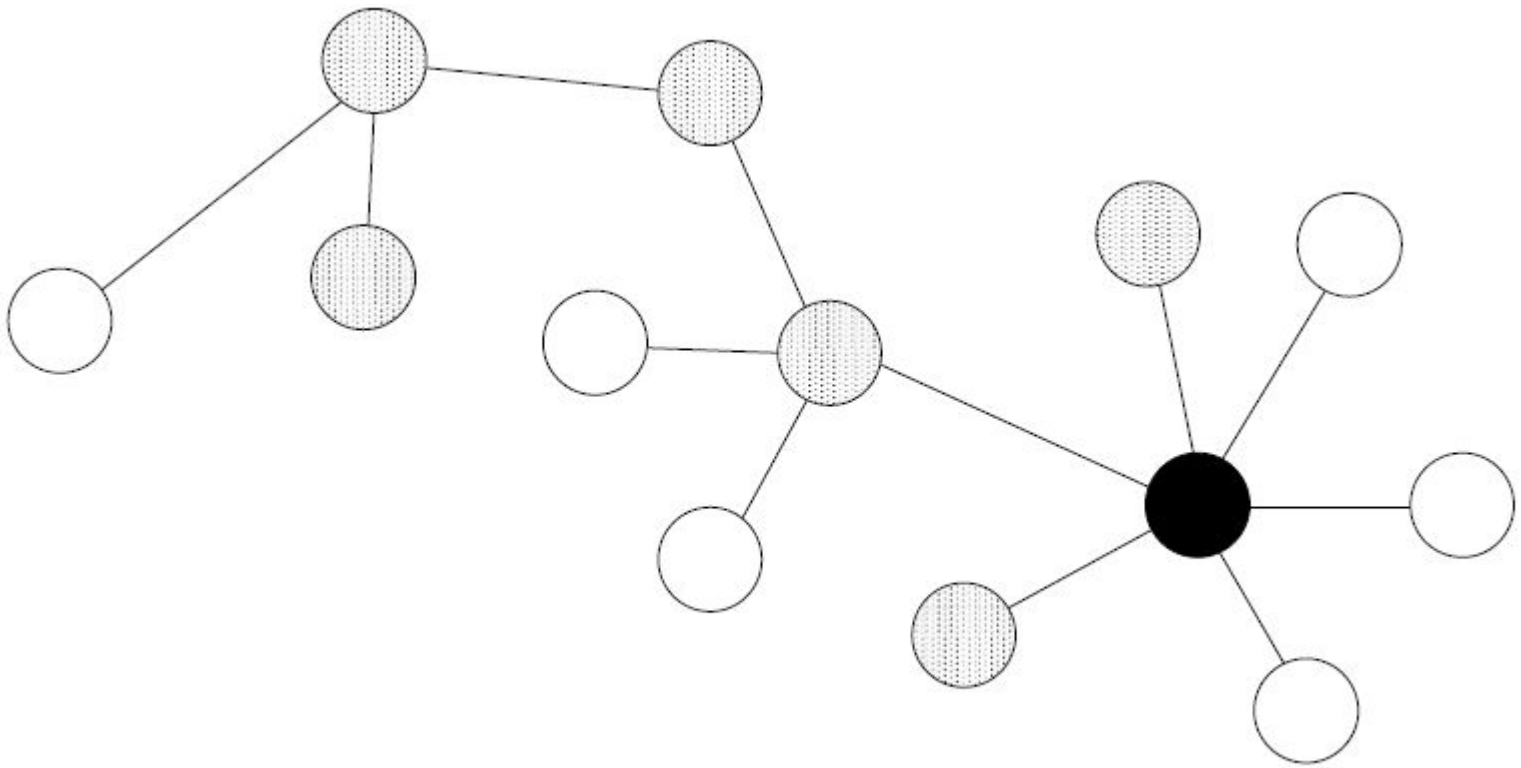
Competitive perspective

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(depending 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

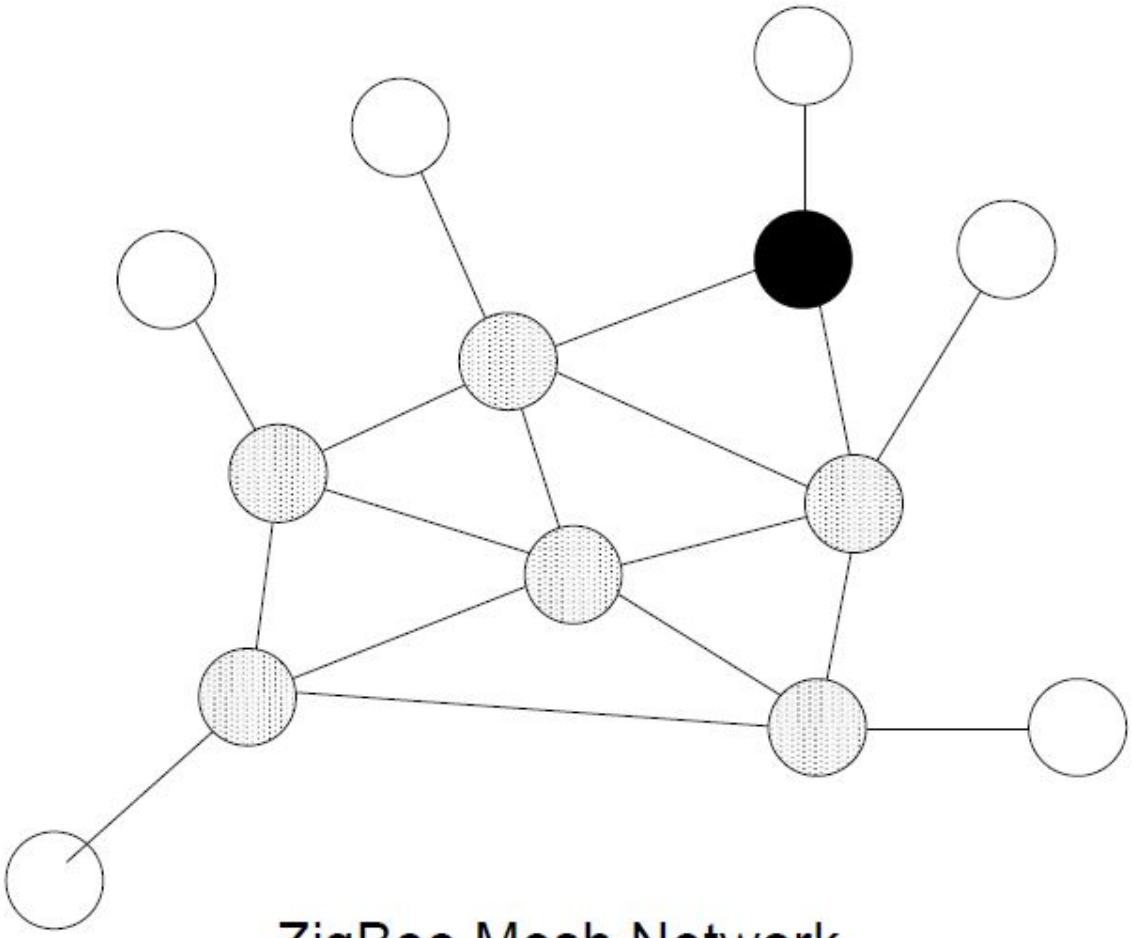
Basic topology of 802.15.4



ZigBee: Cluster tree network

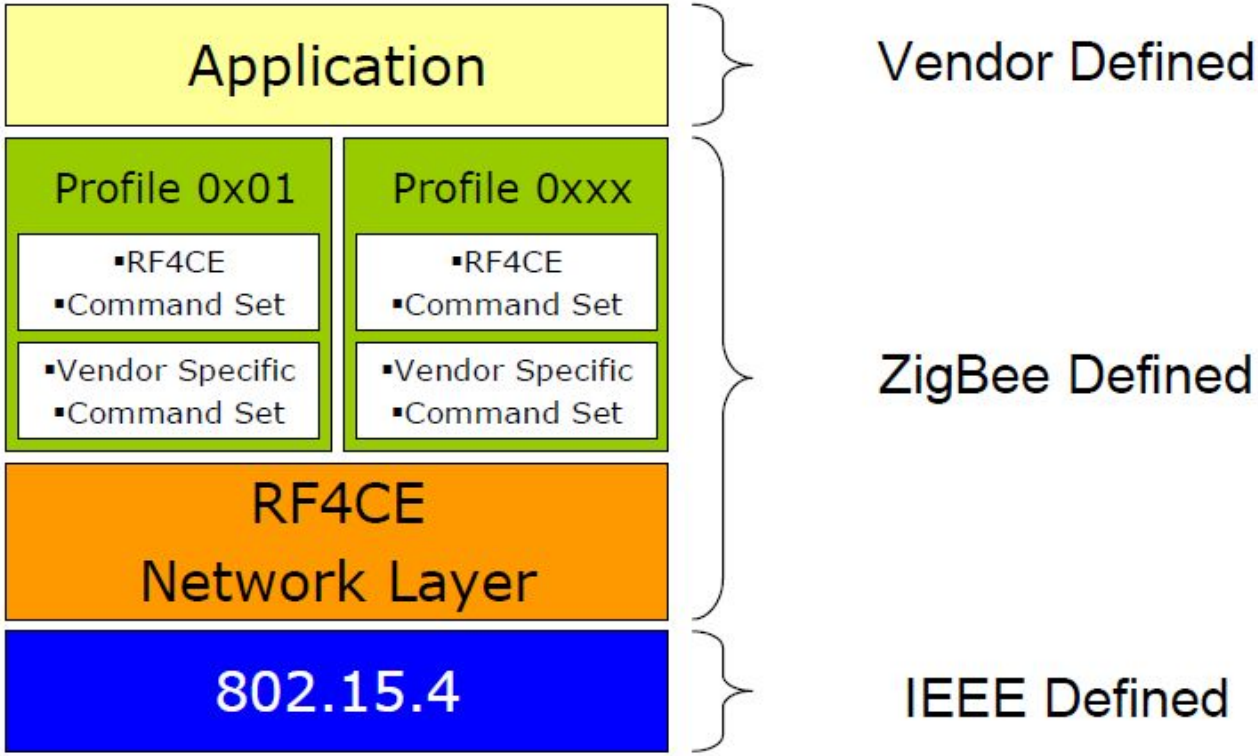


ZigBee PRO: mesh



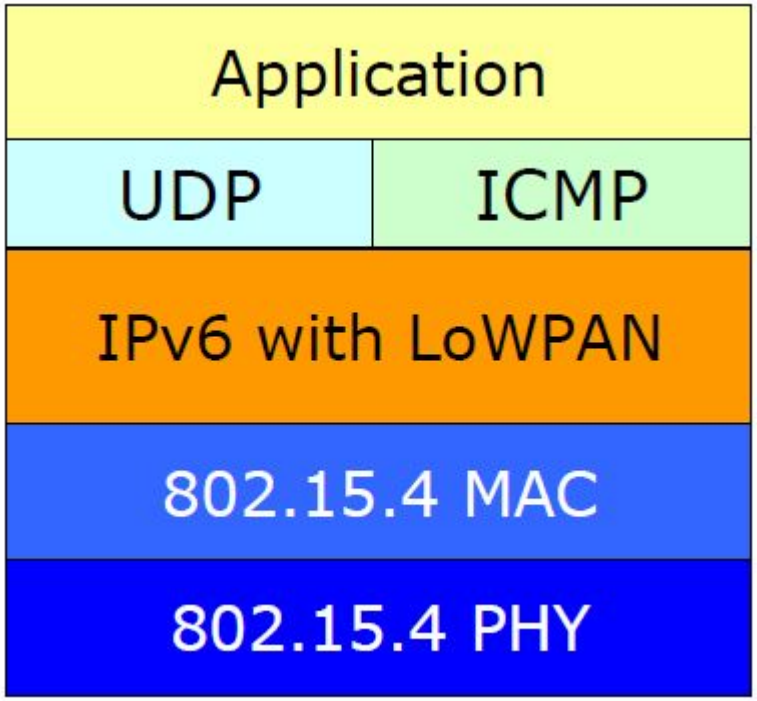
ZigBee Mesh Network

Future ZigBee: RF4CE



- Targeted at Remote Control
- Uses three channels only – 15,20 and 25

Future ZigBee: 6LoWPAN



- An initiative to “squeeze” IPv6 addressing into reasonably sized wireless packets
- Being adopted for ZigBee’s Smart Energy Profile 2.0

ZigBee and Bluetooth Low Energy

- Business comparison:
  - ZigBee is older. It has gone through some iterations
  - ZigBee has market mindshare, but not a lot of shipments yet.
  - Market barriers: connectivity – ZigBee is not in PCs or mobile phones yet.
- Technical comparison:
  - Zigbee is low power; Bluetooth LE is even lower. Detailed analysis depends on specific applications and design detail, no to mention chip geometry.
  - ZigBee stack is light; the Bluetooth LE/GATT stack is even simpler
- Going forward:
  - ZigBee has a lead on developing applications and presence
  - Bluetooth low energy has improved technology, and a commanding presence in several existing markets: mobile phones, automobiles, consumer electronics, PC industry
  - Replacing “classic Bluetooth ” with “dual mode” devices will bootstrap this market quickly

What are the USE CASES planned for BT 4.0?

- Proximity
- Time
- Emergency
- Network availability
- Personal User Interface
- Simple remote control
- Browse over Bluetooth
- Temperature Sensor
- Humidity Sensor
- HVAC
- Generic I/O (automation)
- Battery status
- Heart rate monitor
- Physical activity monitor
- Blood glucose monitor
- Cycling sensors
- Pulse Oximeter
- Body thermometer

Example use: proximity

- It can enable proximity detection
  - I’m in the car
  - I’m in the office
  - I’m in the meeting room
  - I’m in the movie theater

- It can enable presence detection
  - Turn the lights on when I walk around the house
  - Automatically locks the door when I leave home
  - Turn the alarm off if I’m already awake

Everyday objects can become sensors

My pulse is …

My blood glucose is …

My temperature is …

… and monitor things unobtrusively