



Changing the way the world connects

## Bluetooth 4.0: Low Energy

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**Joe Decuir, Standards Architect, CSR plc; IEEE Region 6 NW Area chair**





# Agenda

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Wireless Applications Perspective

What is Bluetooth?

What is Bluetooth Low Energy?

- How do the components work?
- How low is the energy?

Perspective: how does ZigBee & 802.15.4 work?

What is Bluetooth Low Energy good for?

Where can we learn more?

Backup: CSR, speaker, other wireless comparisons



## 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

**State** = low bandwidth, low latency data

**Low Power**



# Perspective: what is Bluetooth?

**Bluetooth is a set of specifications for common short range wireless applications**

- They are written, tested & maintained by the Bluetooth SIG (~13,000 members)

**The specifications include:**

- Core components - radios, protocols (we own everything, so we can optimize)
- Profiles (aka applications)
- **AND: we rigorously validate the specs before we Adopt them, like 3GPP**

**The ‘classic’ Bluetooth radio:**

- 2.4 GHz ISM band, 1 M symbols/s, GFSK, 4PSK or 8PSK
- 1 MHz channel spacing, with frequency hopping
- Adaptive Frequency Hopping, for co-existence with Wi-Fi, etc
- Up to 100 mW, for a lot more than 100m range

**Bluetooth 3.0 Generic Alternate MAC/PHY (AMP) can use additional radios:**

- IEEE 802.11g and WiMedia UWB (ECMA-368) have been tested
- IEEE 802.11g has been Adopted, 802.11n is in progress, to complete in 2011



## What is traditional Bluetooth used for?

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### Top uses by volume (>1B total/yr):

- Mobile phones, including ‘smart phones’
- Wireless controllers for video games
- Voice headsets and “Car kits”
- PCs
- M2M applications – credit card readers, industrial automation
- stereo headsets and speakers

Although Bluetooth is commonly used for human I/O, it already has a good penetration into high reliability M2M applications.



## How much energy does traditional Bluetooth use?

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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?

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A new radio, new protocol stack, new profile architecture and a new qualification regime.

It's designed to run from coin cells and support an Apps Store model

It is a radio standard for a new decade, enabling the **Internet of Things**

## Features:

- Mostly new PHY; some parts derived from the Basic Rate (BR) radio
- New advertising mechanism, for ease of discovery & connection
- Asynchronous connection-less MAC: used for low latency, fast transactions (e.g. 3ms from start to finish)
- New Generic Attribute Profile to simplify devices and the software that uses them.
- Asynchronous Client / Server architecture

Designed to be **LOWEST** cost and **EASY** to implement



# Bluetooth low energy factsheet

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Range:	~ 150 meters open field
Output Power:	~ 10mW (10dBm)
Max Current:	~ 15mA
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

*Specification*

*Implementation specific*



## Bluetooth low energy factsheet #2

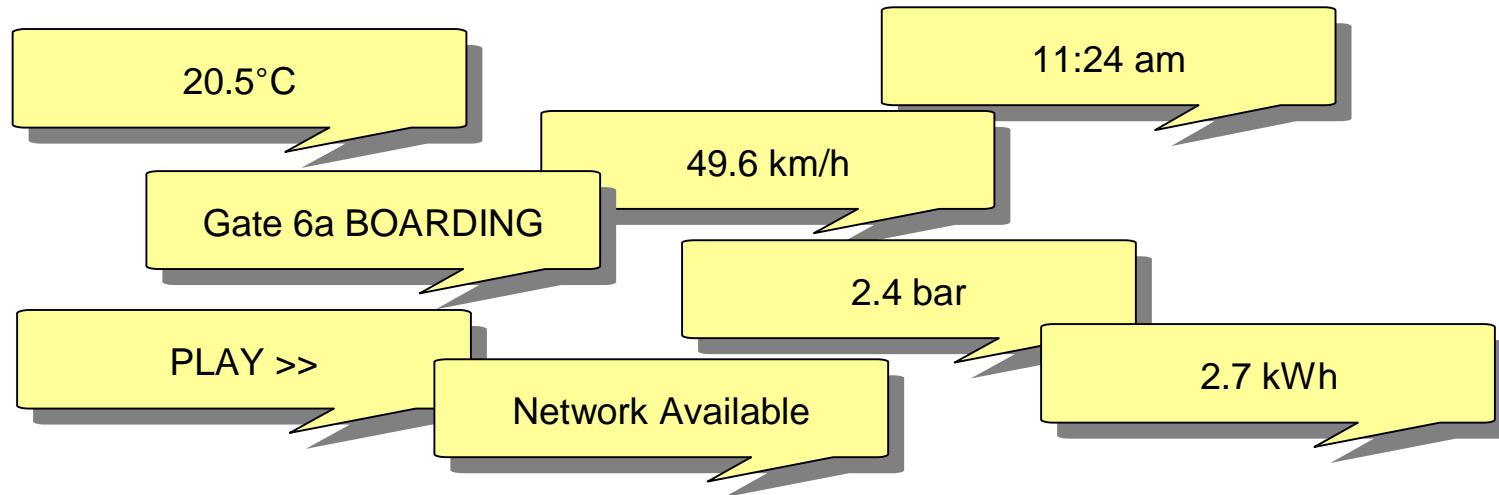
Did you notice something missing?

### 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 optimised 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 be triggered by local events.
- Data can be read at any time by a client.
- Interface model is very simple (GATT)



## It's about the Internet of Things

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Things have data  
&  
Web Services want this data

*Bluetooth low energy provides the technology to connect these two.*

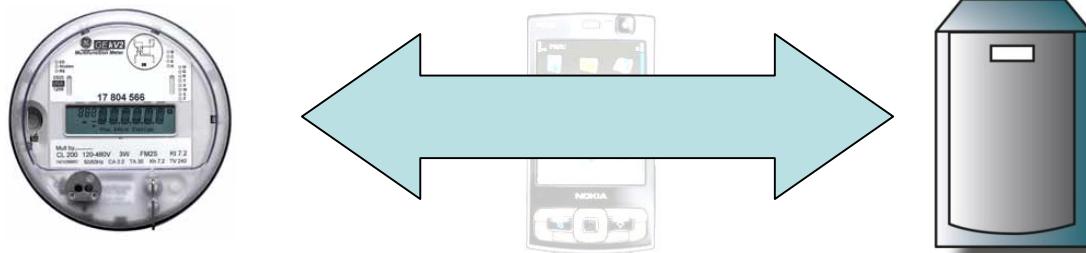


## Bluetooth Low Energy is about generic gateways

Devices that support *Bluetooth* low energy Gateway functionality provide a transparent pipe from a device to an IP address.

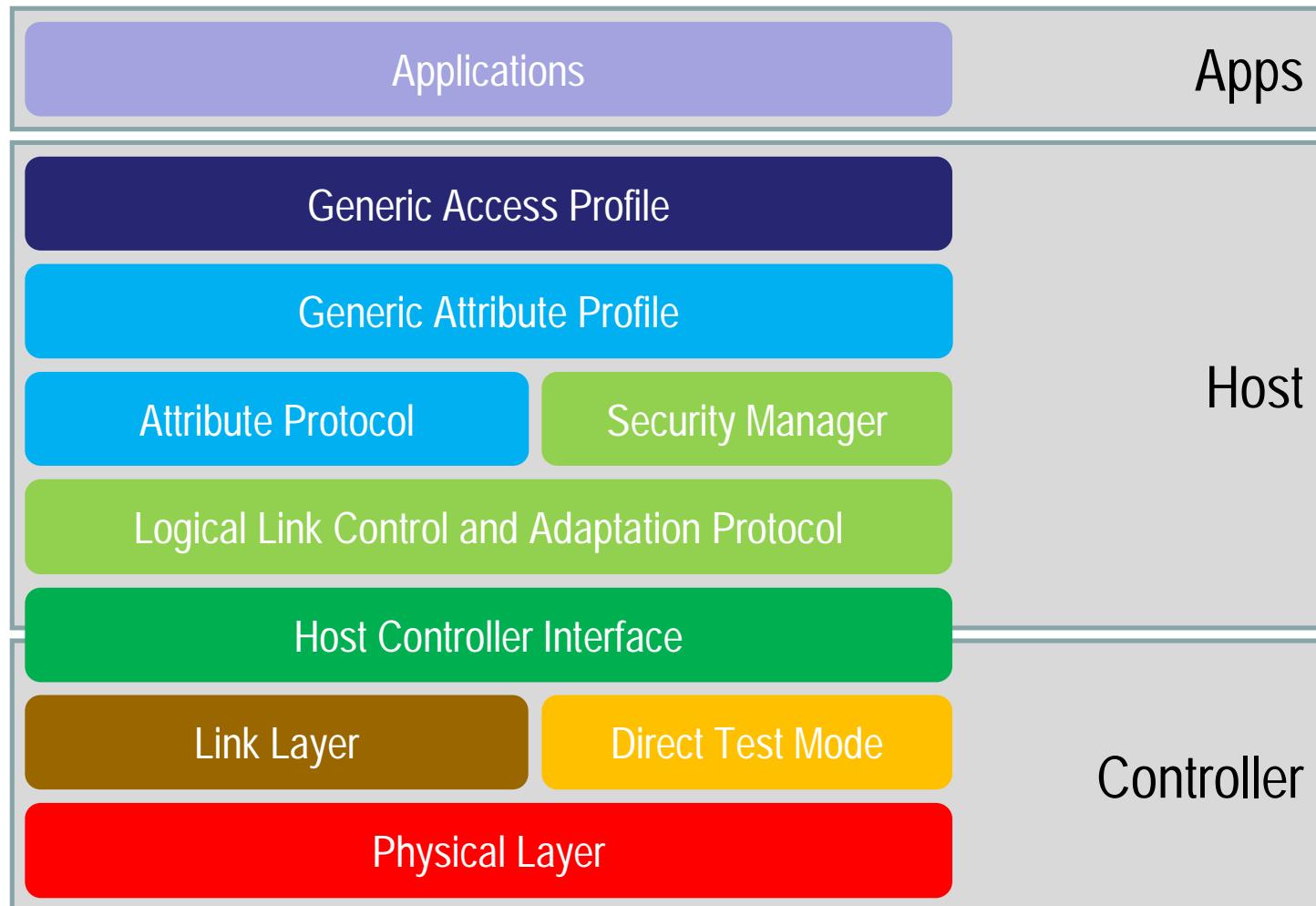
Middleware at the IP address can access the device directly as if it were a collector talking to it locally.

The Gateway device plays no part other than in acting as a pipe.





# What are the pieces?





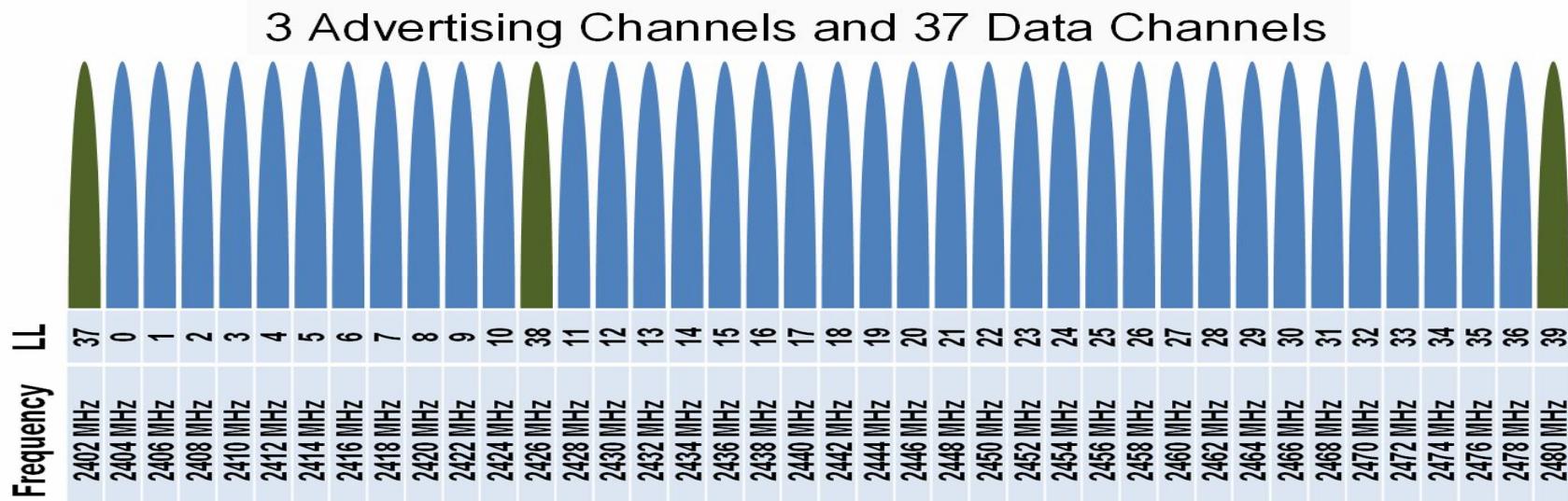
## How does it work: new radio

2.4 GHz ISM band

1 Mbps GFSK

- Larger modulation index than Bluetooth BR (which means better range)

40 Channels on 2 MHz spacing:





## How does it work: new Link Layer

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### Low Complexity

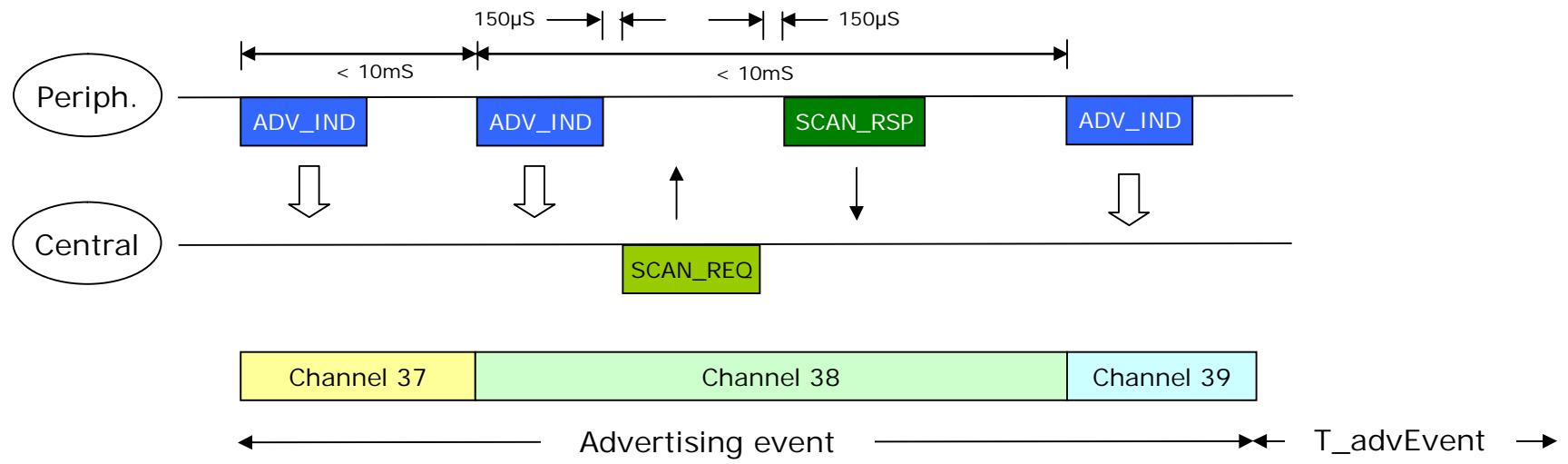
- 1 packet format
- 2 PDU types – depending on Advertising / Data Channel
- 7 Advertising PDU Types
- 7 Link Layer Control Procedures

### Useful Features

- Adaptive Frequency Hopping
- Low Power Acknowledgement
- Very Fast Connections



## How does it work: advertising

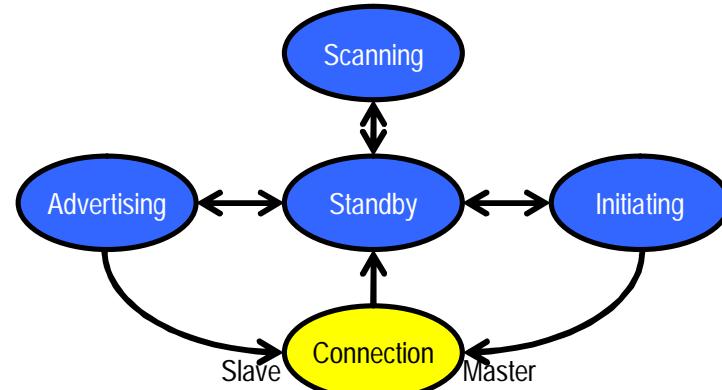
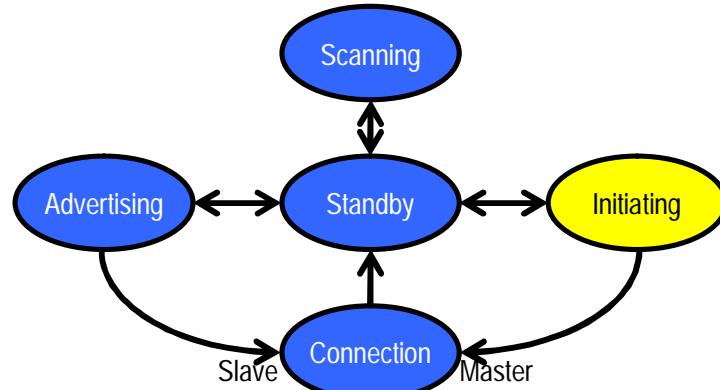
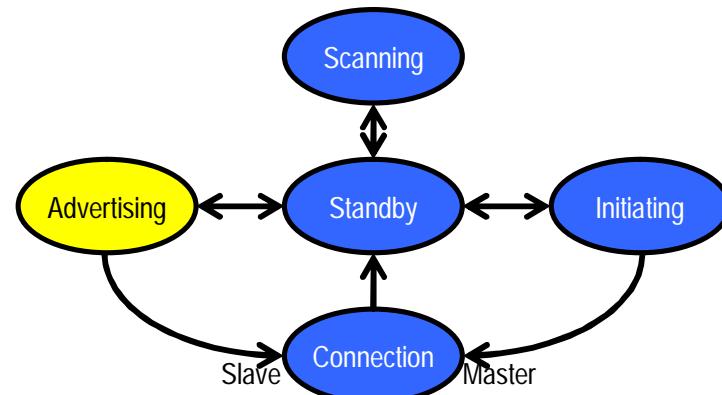
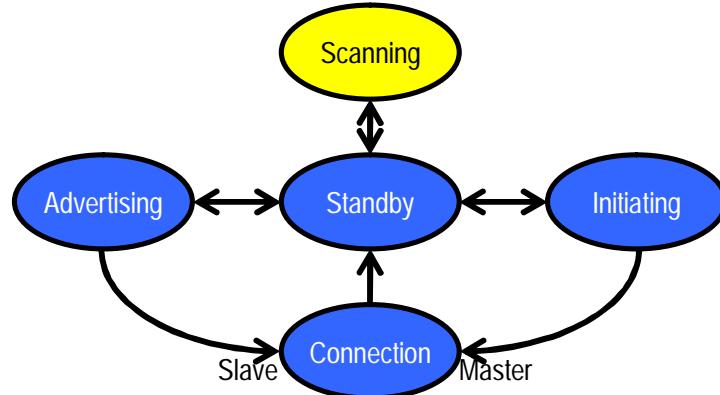


Devices can advertise for a variety of reasons:

- 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

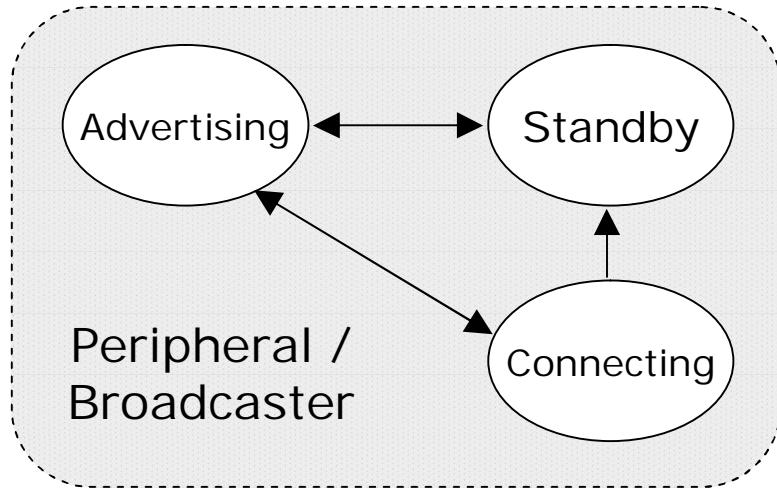


## How does it work: 4 active states

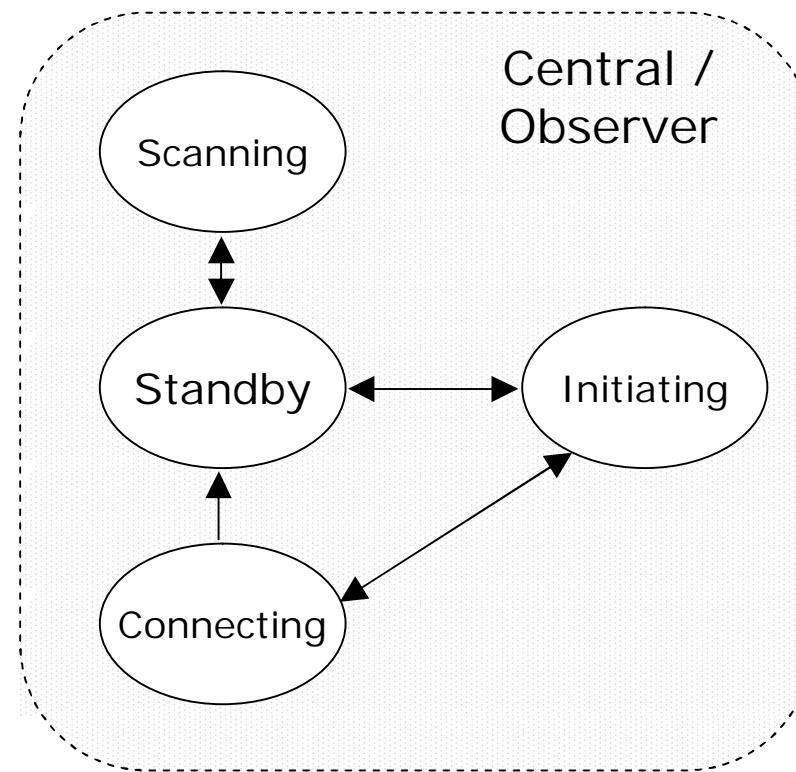




## How it works: peripheral states and central states



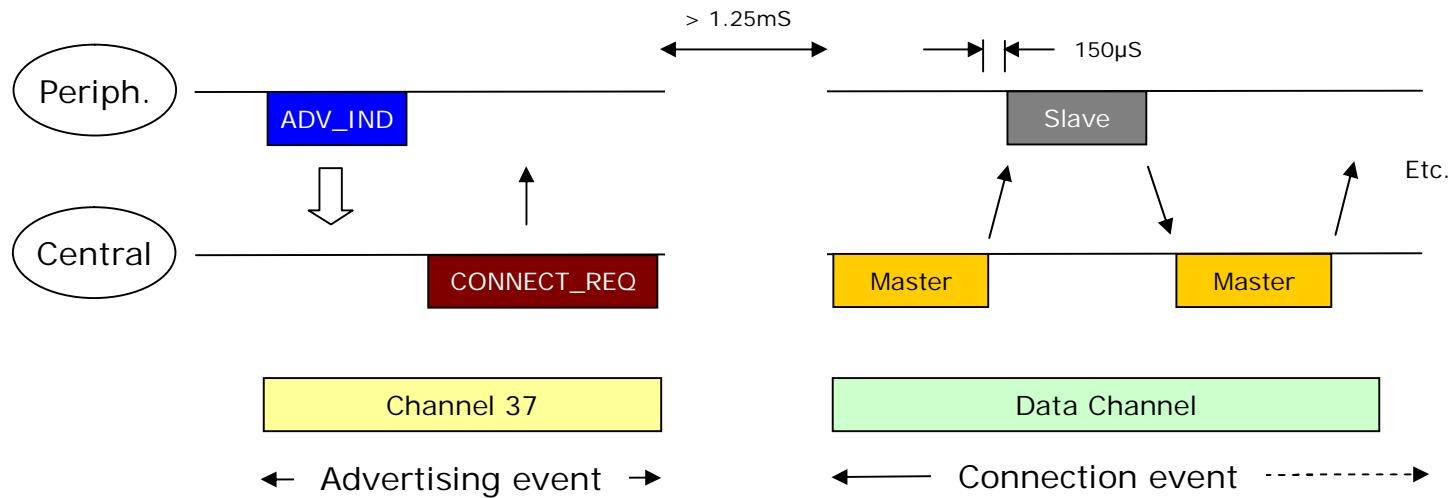
A Broadcaster cannot enter the Connecting state.



An Observer cannot enter the Initiating State.



## How does it work: data transactions



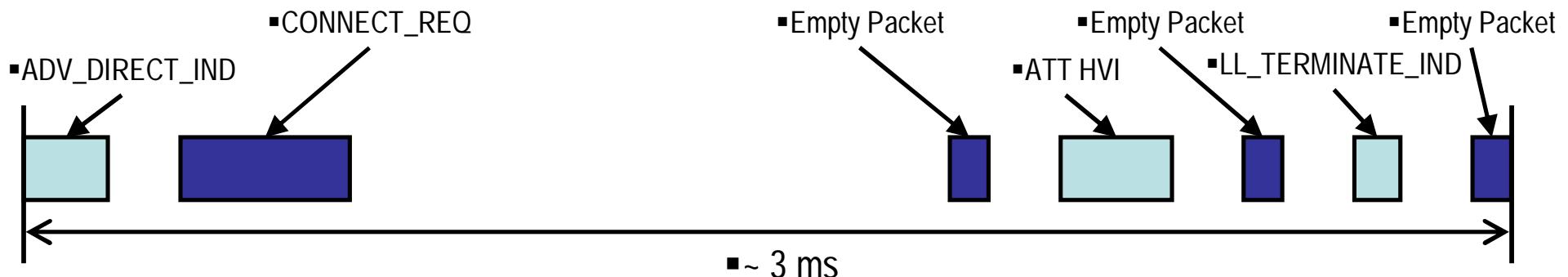
Once a connection is made:

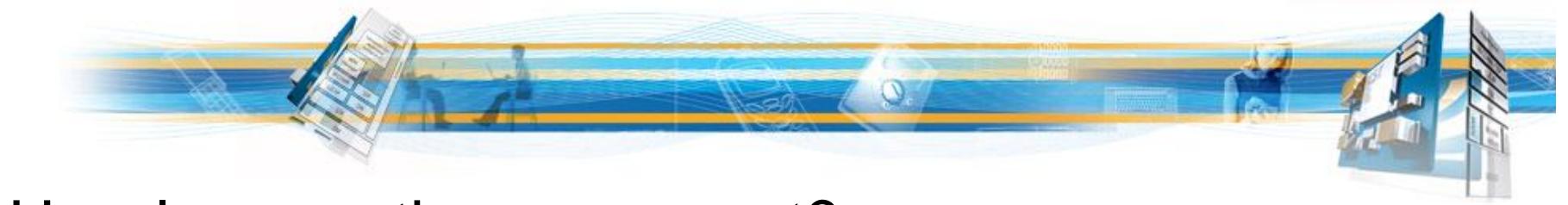
- Master informs slave of hopping sequence and when to wake
- All subsequent transactions are performed in the 37 data channels
- Transactions can be encrypted
- Both devices can go into deep sleep between transactions.



## Let's add it up, for a minimum transaction

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
- Est TX power is 15mW (mostly TX power amp for 65nm chips).
- For 1.5v battery, this is 10ma.  $0.015 \text{ W} \times .003 \text{ sec} = 45 \text{ micro Joule}$

How long could a sensor last on a battery?

- An example battery: Lenmar WC357, 1.55v, 180mAh, \$2-5.
- $180\text{mAh}/10\text{ma} = 18\text{Hr} = 64,800 \text{ seconds} = 21.6\text{M transactions}$
- Suppose this sensor sends a report every minute = 1440/day
- For just the BT LE transactions, this is 15,000 days, or >40 yr
- 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.



## How does it work: Attribute Protocol

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### Clients and Servers

- Servers expose Attributes
- Clients use them

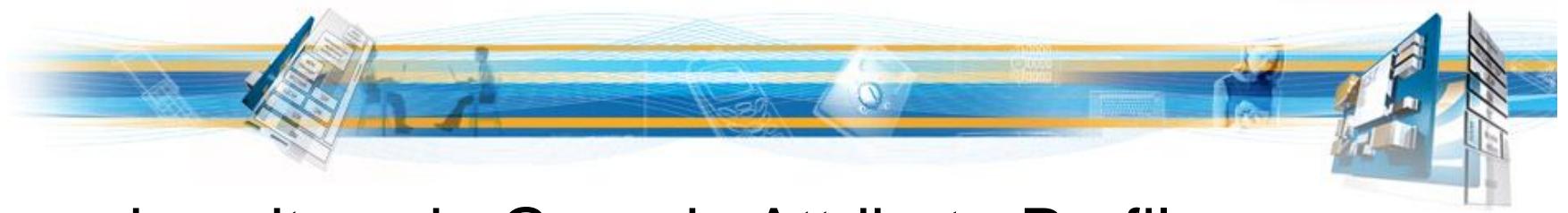
16 bit address space of handles – address within a device

Each attribute has a UUID – identify what it is

- 16-bit if standardized by the Bluetooth SIG
- 128-bit if invented by the manufacturer
- Note: that manufacturers can add value without waiting for the SIG

The protocol supports a handful of actions:

- By the Client: Discover/Find, Read, Write, Confirm an Indication
- By the Server: respond to Client actions, Notification and Indication



## How does it work: Generic Attribute Profile

### Simple Servers

Those servers provide:

- Characteristics
- Services: which can include characteristics and/or other services

Expose the state of the server.

Allows choice of security level

- Up to 128 bit AES

Interfaces with the Attribute Protocol

Defines Data Formats

Low Energy encapsulates all of the protocols and formats into the core.

This makes profile development much faster and easier.

The format is easy to encode in XML.



## Extension: gateways

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Any system that can connect to Low Energy devices AND to a wide area network can serve as gateways.

- Your home PC can see devices around your home
- Your smart phone can see all the devices around you

**The simplicity of GATT servers makes it easy to represent those devices over the web.**

Low Energy allows generic gateways (such as mobile phones)

- These allow devices to connect “out of the box”
- Enables any device to connect to the web via a handset.

With the longer range of Low Energy, a single device can be the home control gateway.



## Competitive perspective: how does ZigBee work?

You all have choices. The most significant of several in this space are ANT and the ZigBee Alliance

ZigBee is the older and better established of the two.

- ZigBee is based on the IEEE 802.15.4 MAC and PHY

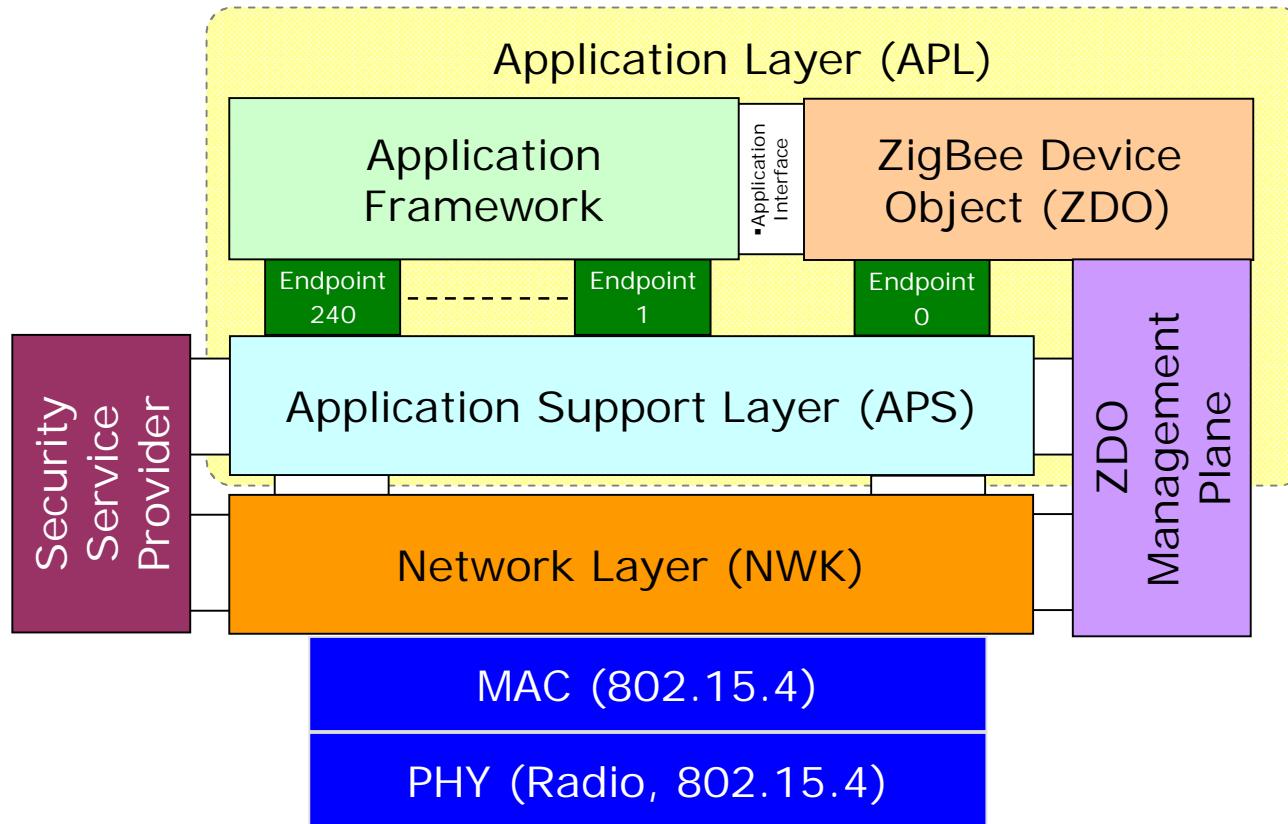
### Technical Description:

- PHY: 802.15.4
- MAC: 802.15.4
- Middle layers: NWK
- Upper layers: applications

### Administrative comparisons:

- Market presence
- Testing
- IP sharing

# The ZigBee stack





## 802.15.4 PHY

**IEEE 802.15.4 defines several PHY options:**

- 2450 MHz QPSK PHY
- 868/915 MHz: BPSK PHY; ASK PHY; O-QPSK PHY
- Note: 802.15.4a adds several more, including DS-UWB

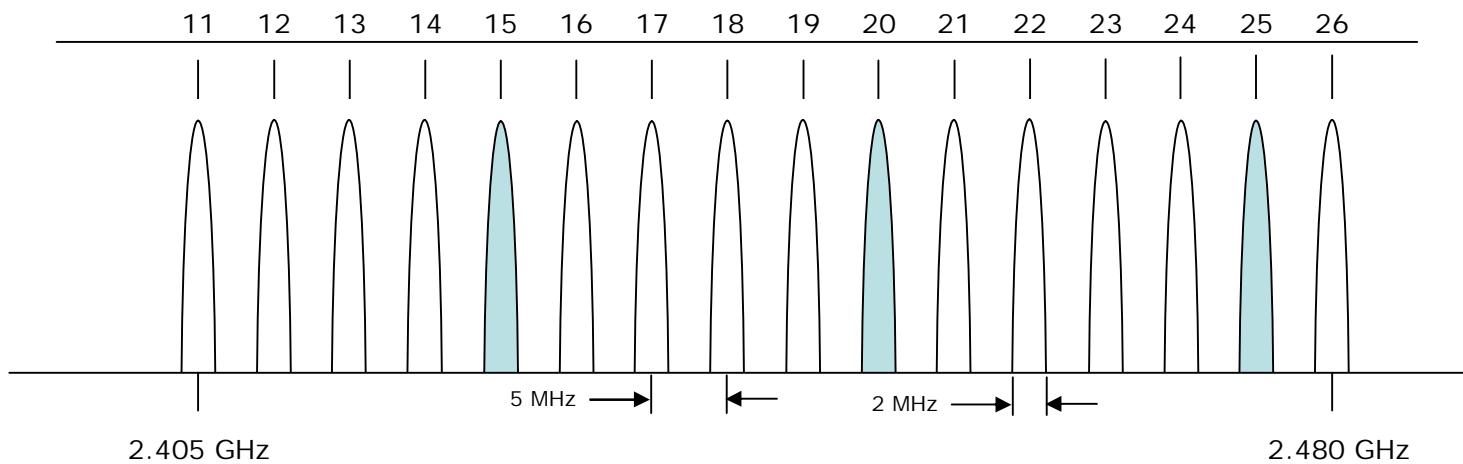
**ZigBee uses the ISM band (2450 MHz) PHY**

- Worldwide spectrum (same as Bluetooth, Bluetooth LE, 802.11g, etc)
- Up to 250 kbps

**802.15.4 ISM modulation**

- 4 bits/symbol; 32 chip PN sequence/symbol; 2M chips/s => 250kbps
- Chips are QPSK on a selected carrier (next slide)

# Frequency usage for 802.15.4 / ZigBee



Note: RF4CE only uses channels 15, 20 & 25



## 802.15.4 MAC

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### Versatile:

- Supports multiple connection models: peer-to-peer, piconet and mesh
- Supports asynchronous and isochronous uses: contention-free in a managed superframe, contention within a superframe

### Frame types:

- Beacons, used by coordinators if Superframes used
- Data frames and acknowledgement frame
- MAC command frame



## ZigBee NWK layer functions

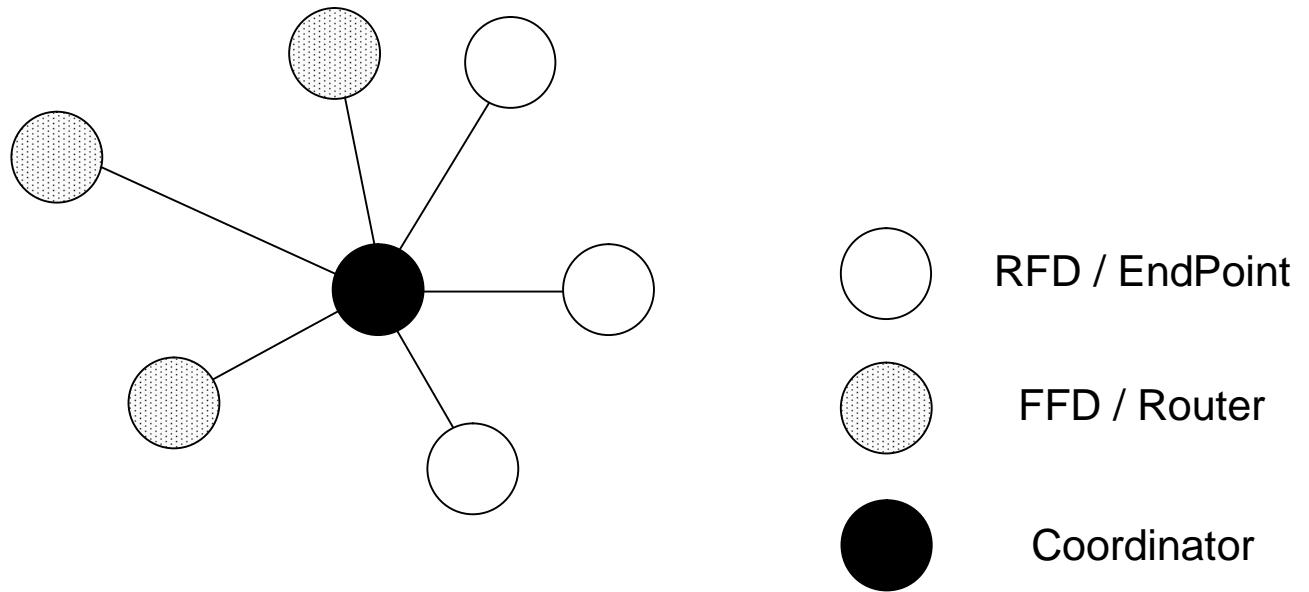
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1. Starting a network
2. Join and leave a network
3. **Configuring a new device:** configure the stack for operation as required.
4. **Addressing:** The ZigBee coordinator assigns addresses to devices joining the network.
5. **Synchronization within a network:** synchronize with another device either through tracking beacons or by polling.
6. **Security:** apply security to outgoing frames and removing security to terminating frames
7. **Routing:** route frames to their intended destinations, particularly through a mesh of bi-lateral connections.



# Basic topology of 802.15.4

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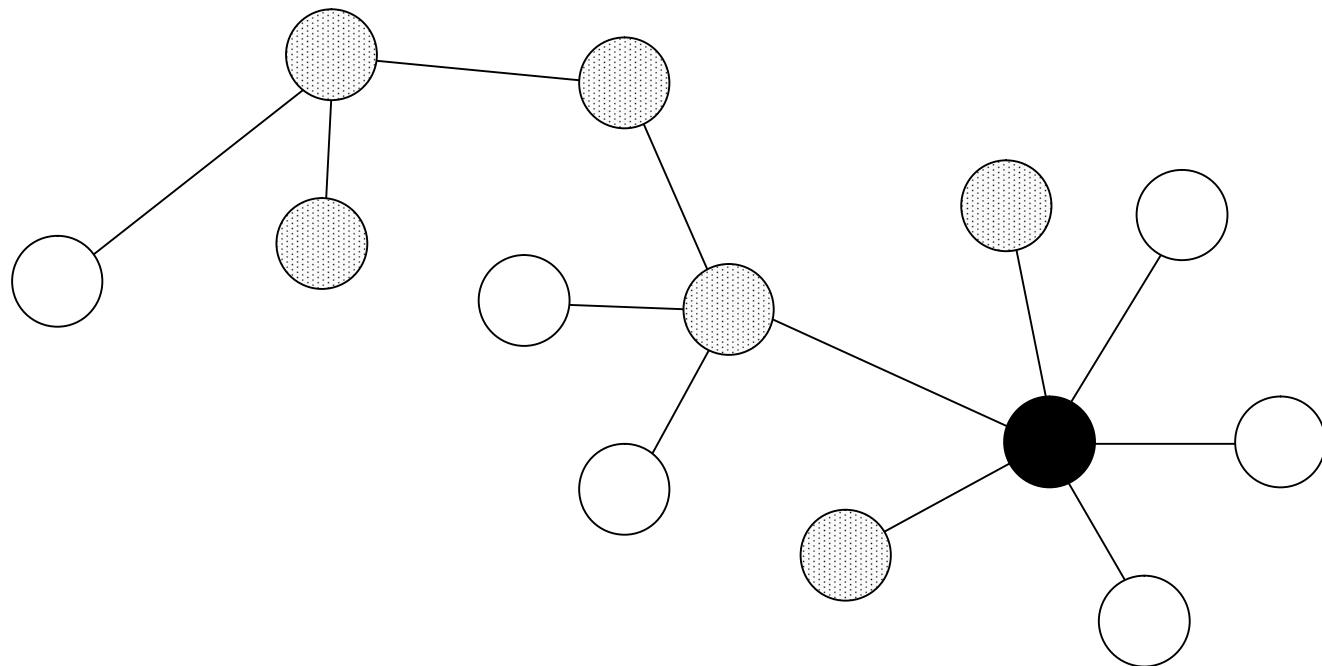


Star Network

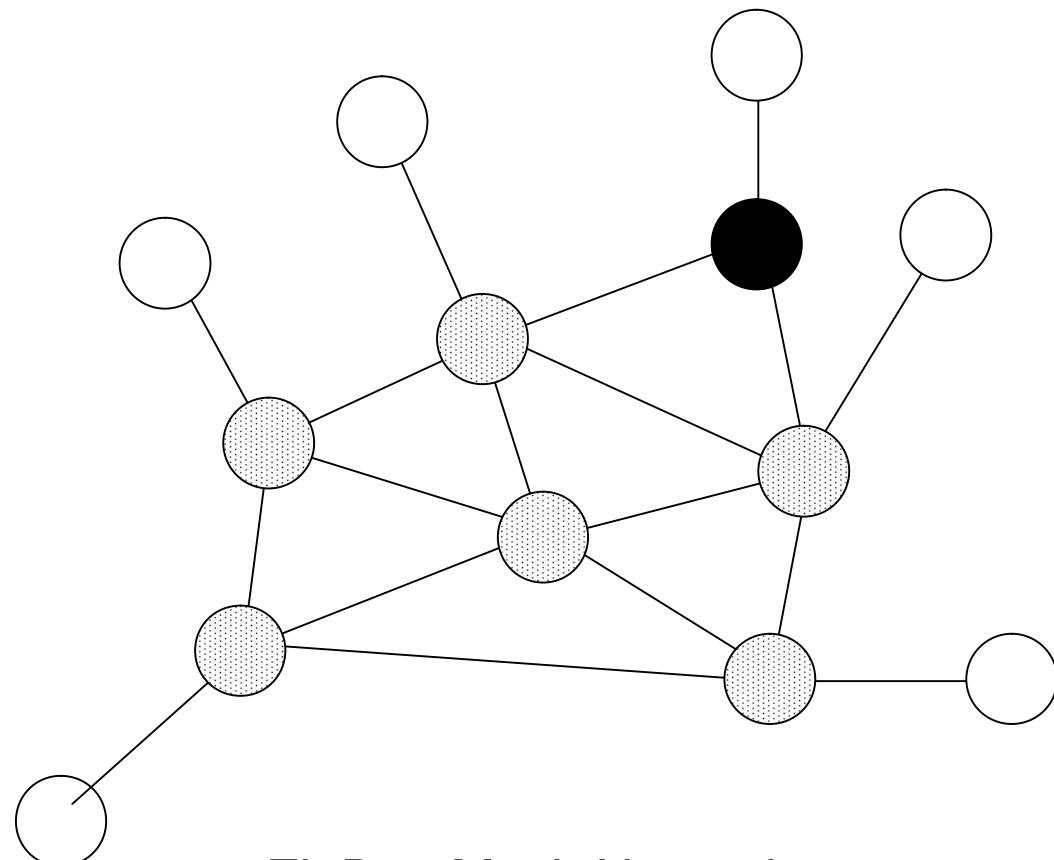


# ZigBee: Cluster tree network

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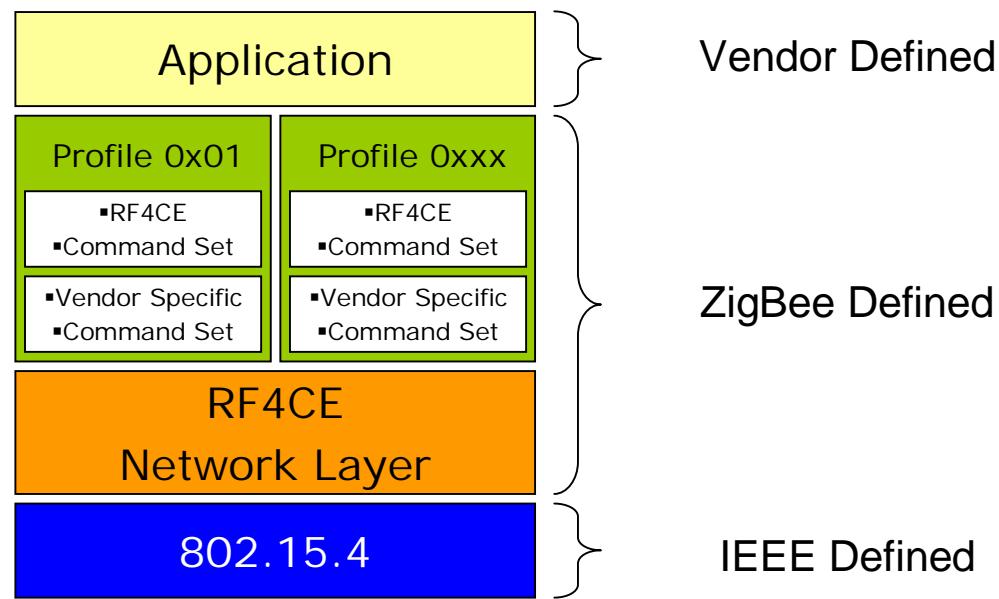


## ZigBee PRO: mesh



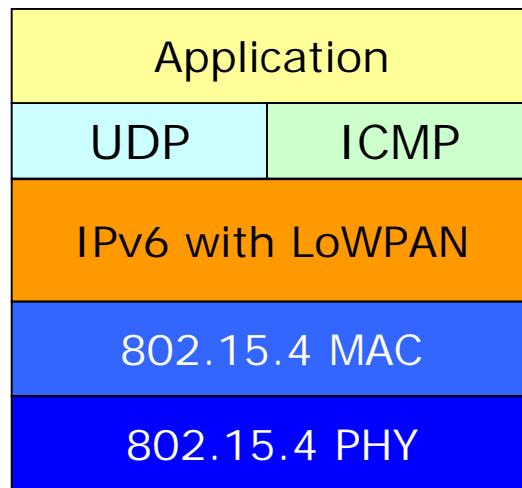
# ZigBee Mesh Network

# Future ZigBee 1: RF4CE



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

# Future ZigBee 2: 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

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## Business comparison:

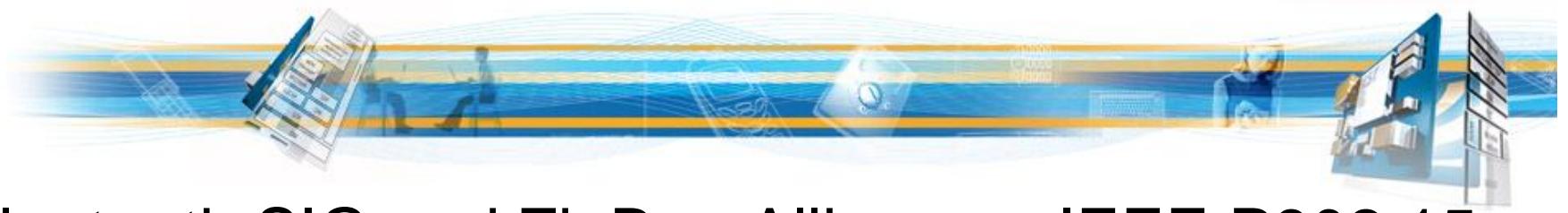
- ZigBee is older. It has gone through some iterations.
- ZigBee has market mindshare, but not a lot of shipments yet.
- Market barrier: connectivity – ZigBee is not in PCs or mobile phones yet.

## Technical comparison:

- Zigbee is low power; Bluetooth LE is even lower. Detailed analysis depends on specific applications and design detail, not 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.



## Bluetooth SIG and ZigBee Alliance + IEEE P802.15

### The IEEE 802.15.4 committees and the ZigBee Alliance collaborate

- P802.15.4 writes the PHY and MAC specs – no testing or IP sharing
- The Zigbee Alliance writes all the higher layers.
- The ZigBee Alliance does limited testing and IP sharing

### The Bluetooth SIG does all the essential administrative and technical work:

- Determine market needs
- Develop technical specification confidentially – the entire stack
- Perform design Q/A on al the stack specification components by IOP testing, before they are Adopted (ISO 9646, like 3GPP)
- Perform Qualification Q/A testing on the entire stack in each product – earning RANDZ IP rights



# What is Bluetooth Low Energy Good for?

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## Connecting the things we carry with us:

- Watches: remote display from other devices
- Tags: locate objects or keep track of them (e.g. warning if you walk away)
- Health/fitness sensors (e.g. pedometer in your shoes)
- Body sensors (e.g. blood pressure, pulse rate, etc)

## Accessing the things around us:

- Fobs: use proximity as a security/access control means
- Home and office automation

## Low duty cycle M2M communication:

- Sensors and controls in homes, offices and factories

## Communication within a system

- Car to car wheels/tires

## Connecting anything that has intrinsic data to the Internet



## Opportunities

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### New classes of gadgets

- Around a person
- Around a house
- In your car

### New applications on PCs and smart phones

- Use those devices

### New web services

- Anything can connect to the Web

### New Social Applications

- Your beer glass can talk to your Facebook page



## The billion unit markets for wireless.

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	TAM*
Phone accessories (internet / apps centric devices)	> 10 billion
Smart Energy (meters & displays). <i>Which will drive:</i>	~ 1 billion
Home Automation (white goods and HVAC)	> 5 billion
Health, Wellness, Sports & Fitness	> 10 billion
Assisted Living	> 5 billion
Animal Tagging (food assurance)	~ 3 billion
Intelligent Transport Systems	> 1 billion
M2M (Internet connected devices)	> 10 billion

\* TAM – Total Addressable Market



## What are the USE CASES planned for BT 4.0?

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- 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

And that's just the starting point...



## 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
- Turns the alarm off if I'm already awake



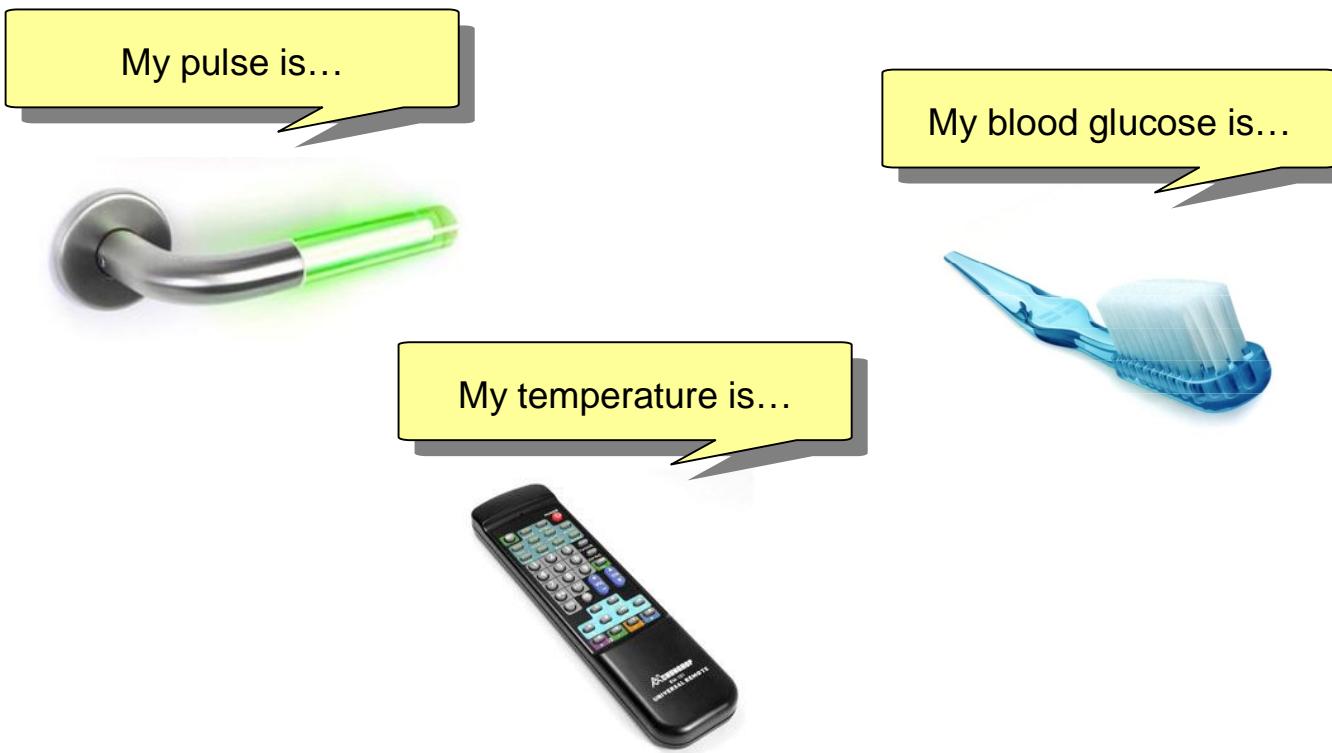


## Proximity demonstration



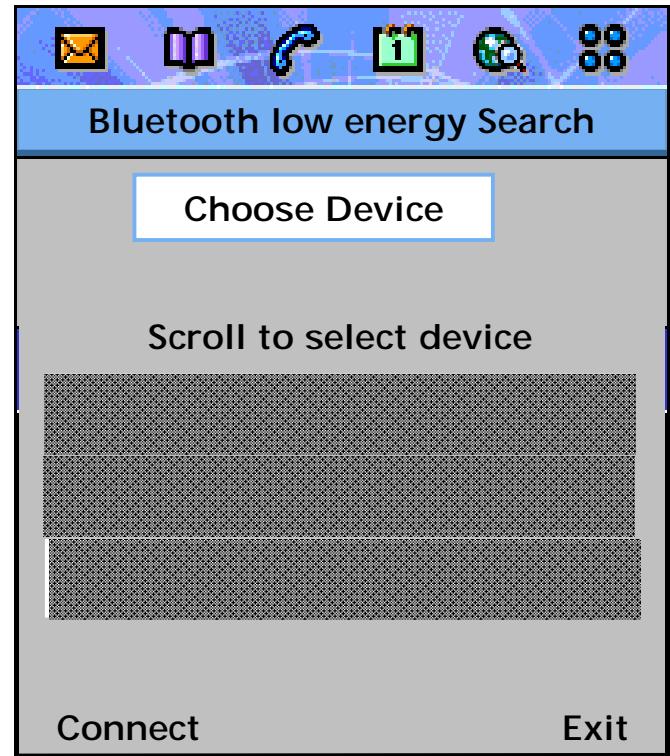


# Everyday objects can become sensors



...and monitor things unobtrusively

# Connection works: start with a phone





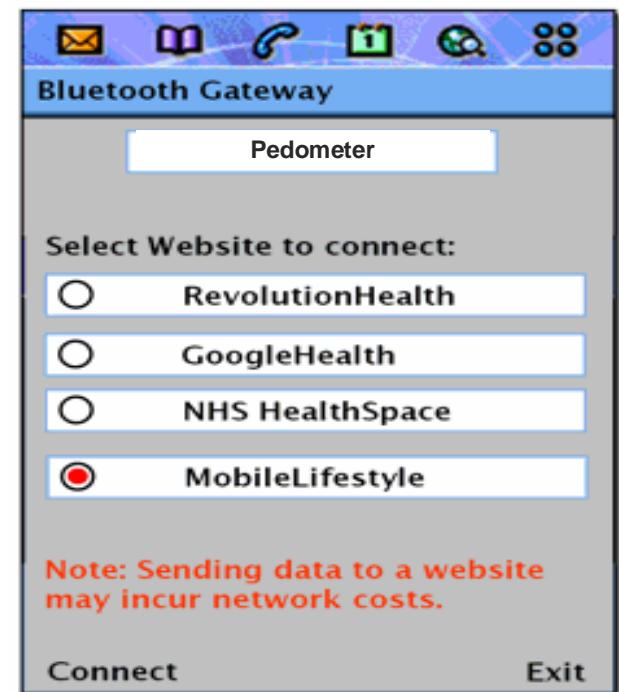
# Devices ship with a web address...

[www.patientslikeme.com](http://www.patientslikeme.com)





# ...using a generic app on your phone...





which connects them to the web app...

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# then automatically sends your data...

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# Or, tell the phone what they can do...

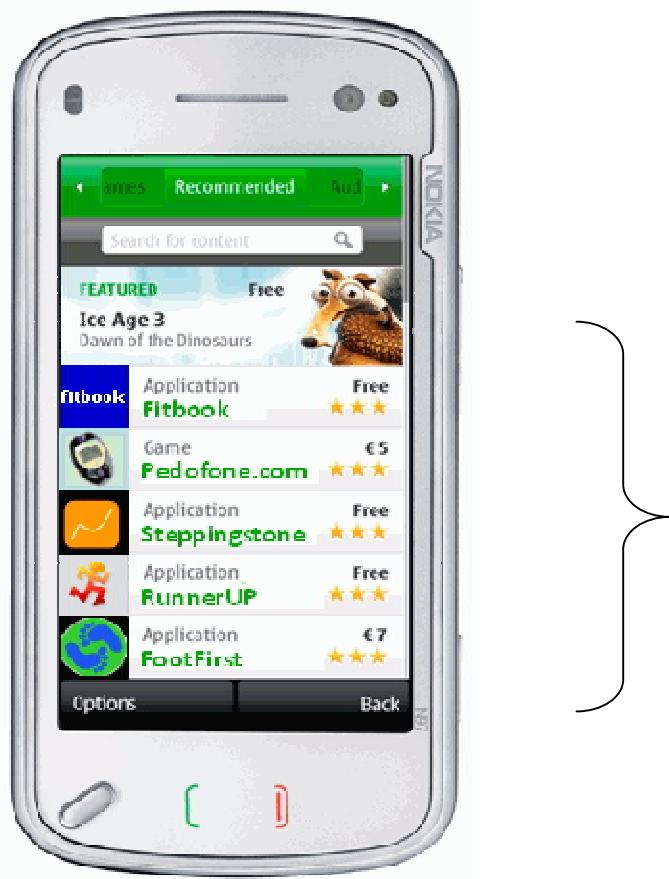


**Pedometer**  
**Acme Model XYZ**  
**Steps per Minute**  
**Total Steps**  
**Calories Used**  
**Find me an APP...**



and the phone gets a tailored set of Apps

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Easy to buy

=

More revenue



## Simplified Administrative Process

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We've made the standard much easier to use, as the complexity is inside the core.

We've made profiles much easier to write, as they just define data and behavior.

This make profile development faster. We have a streamlined process which can reduce Adoption time to just 3 months.

We have a simpler qualification system which removes qualification fees for designers using pre-qualified module, even when they add new profiles.

Bluetooth low energy is a new standard designed for a new decade of connected products. We've not just designed a standard – we've enabled an ecosystem for the future.



## Predictions

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**ZigBee will gain some traction where connectivity to PCs or mobile phones isn't necessary**

- This requires something to provide user control
- This requires something to provide the network gateway

**Bluetooth Low Energy will become a free add-on to mobile phones, PCs and some other devices that use classic Bluetooth now – they will switch to dual mode devices**

**The Bluetooth ecosystem will define two tools:**

- Internet gateways
- APIs for use in PC host OSs and in Smartphone OSs

**The Bluetooth ecosystem will define several dozen Profiles**

- Entrepreneurs will also define dozens of proprietary profiles



## Calls to Action

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### Learn about Bluetooth Low Energy

- Ask questions, today or later (see contact info)
- See resources on a later slide

### Think about how to use it to satisfy market needs

- The list of use cases above is just a start

### Find partners to deliver value

- There were dozens of companies who did IOP testing to validate the specification
- CSR is one of at least a half dozen chip makers



## Questions?

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## Resources:

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SIG site: <http://www.bluetooth.com/lowenergy>

The Bluetooth 4.0 specification:

[http://www.bluetooth.com/Specification%20Documents/Core\\_V40.zip](http://www.bluetooth.com/Specification%20Documents/Core_V40.zip)

Bluetooth Low Energy Training from 2010 All Hands Meeting:

[https://www.bluetooth.org/DocMan/handlers/DownloadDoc.ashx?doc\\_id=228441](https://www.bluetooth.org/DocMan/handlers/DownloadDoc.ashx?doc_id=228441)

For articles on Bluetooth Low Energy: [www.nickhunn.com](http://www.nickhunn.com)

Forthcoming book on Bluetooth Low Energy by Robin Heydon.

ZigBee Technology: [www.zigbee.org](http://www.zigbee.org)

“ZigBee Techology: Wireless Control that Simply works”

<http://intranet.da-iict.org/~ranjan/sn/papers/Zigbee.pdf>

IEEE 802.15: <http://ieee802.org/15/>

IEEE 802.15 working documents: <https://mentor.ieee.org/802.15>



## Backup: CSR role in Bluetooth Low Energy

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CSR plc (Cambridge Silicon Radio) sells more Bluetooth chips than any other company – [www.csr.com](http://www.csr.com)

- CSR people play major leadership positions within the Bluetooth Special Interest Group.

CSR people champion Bluetooth Low Energy:

- Co-chair the technical group that wrote the Core specification
- Co-chair technical groups writing Profile (Application) specifications
- Chair the group that wrote the test specifications &leads IOP testing
- Lead evangelism for Bluetooth Low Energy, and liaison to target organizations like the Continua Health Alliance
- Started the Smart Energy Study Group



## Backup: Speaker background

### 24 years in networking and communications standards:

- Bluetooth 3.0 + HS, Bluetooth 4.0
- Modems: ITU T.31, T.32, V.32bis, V.34, V.80, V.90, V.250, V.251, V.253
- 2G digital cellular access: GSM 07.07, TIA IS-99, TIA IS-135
- USB: Communications Device Class, with several subclasses; InterChip & High Speed InterChip USB; Wireless USB 1.1
- UWB: WiMedia UWB PHY 1.2, MAC 1.2, WLP 1.1, IEEE 802.15.4a

### Other work:

- Networking components in Windows: 95, 98, NT 4.0, 2000, XP
- Dozens of modems and fax modems
- Atari 2600, Atari 800, Amiga 1000

**IEEE:** Region 6 NW Area chair, Seattle Section officer, Seattle Com-19 chair, C-16/Comm-19 presentations in many Chapters in BC, CA, OR, NY and WA.

Contact: [jdecuir@ieee.org](mailto:jdecuir@ieee.org) or [joe.decuir@csr.com](mailto:joe.decuir@csr.com), M: +1-469-835-9058



## Backup: wireless Topologies

	Peer-peer	Piconet	Cluster Tree	Infra-structure	Mesh
Bluetooth BR/EDR/HS	Y	Y	(scatternet)	X	X
Bluetooth low energy	Y	Y	X	X	X
Wi-Fi	(802.11)*	(802.11)*	X	Y	X
Wi-Fi Direct	Y	Y	X	X	X
ZigBee	Y*	Y	Y	X	Y
ANT	Y*	Y	Y	X	X

\* Limited security in this topology

*Most applications are still cable replacement (peer-peer) or infrastructure.*



## Backup: Backwards compatibility and lifetime

	<b>Availability</b>	<b>Backwards Compatibility</b>
Bluetooth	11 years	Compatible with all previous versions at base 1Mbps
Bluetooth low energy	New	Will be compatible with Dual mode chips introduced in 2011
802.11	13 years	Security is compromised in mixed versions more than 3 years old
Wi-Fi	10 years	Security is compromised in mixed versions more than 3 years old. Two incompatible frequencies of operation – 2.4GHz and 5.1GHz
ZigBee	6 years	Three version – all with compatibility issues
ZigBee PRO	3 years	Incompatible with ZigBee
ZigBee PRO SEP2.0	New	Incompatible with other ZigBee stacks
ZigBee RF4CE	2 years	Incompatible with other ZigBee stacks
ANT	3 years	Only one version available.

### **Average years of compatibility**

Bluetooth	11 years and still compatible
Wi-Fi	3 - 5 years (at which point security is compromised)
ZigBee	2 years



## Backup: Licensing and qualification

	<b>Bluetooth</b>	<b>Wi-Fi</b>	<b>ZigBee</b>	<b>ANT</b>
License	RANDZ	RAND	RAND	No IP license
Annual Membership <sup>1</sup>	Free	\$5k / \$15k <sup>2</sup>	\$3.5k <sup>3</sup>	\$500 (5 yr)
Qualification Cost (per product)	~ \$7.5k	~ \$5 k	~ \$3 k	\$750 (5 yr)
Ownership of MAC/ PHY	Bluetooth	IEEE (802.11)	IEEE (802.15.4)	Dynastream

▪ 1 Minimum level of membership fee for use of trademark

▪ 2 To certify a Wi-Fi product, the minimum membership level is Regular.

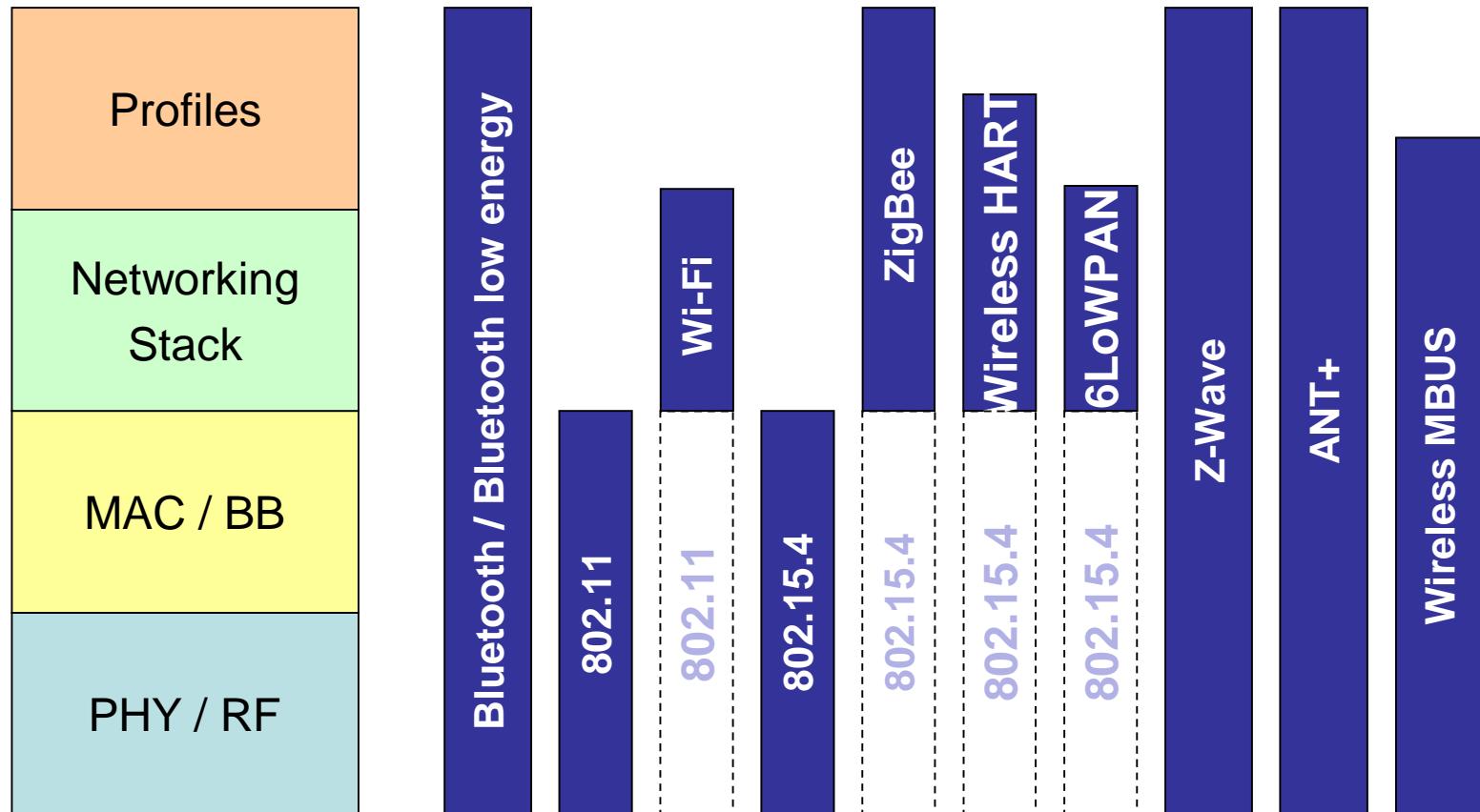
▪ 3 Non commercial users may use the ZigBee standard without payment.

▪ (Qualification costs can vary depending on membership level and use of prequalified components)

Plus CE, FCC, ICES, TELEC, CNCA, etc

Don't forget you need to perform R&TTE notification if your output power is greater than 10mW.

## Backup: Scope of wireless standards



A standard can only offer IP protection for the parts it own.