IoT Low-Power Protocols

Protocols for IoT

Session		**MQTT**, **SMQTT**, **CoRE**, **DDS**, **AMQP** , **XMPP**, **CoAP**, …
Network	Encapsulation	**6LowPAN**, **6TiSCH**, **6Lo**, Thread, …
	Routing	**RPL**, **CORPL**, **CARP**, …
Datalink		WiFi, **Bluetooth Low Energy**, **Z-Wave**, **ZigBee Smart**, **DECT/ULE**, 3G/LTE, NFC, **Weightless**, **HomePlug GP**, **802.11ah**, **802.15.4e**, **G.9959**, **WirelessHART**, **DASH7**, ANT+, **LTE-A**, **LoRaWAN**, …

Security
TCG, Oath 2.0, SMACK, SASL, ISASecure, ace, DTLS, Dice, …

Management
IEEE 1905, **IEEE 1451**, …

Short range vs. long-range IoT

Local Area IoT

Source: Amazon

Source: LG

Wide Area IoT

Source: fiorentini.cn

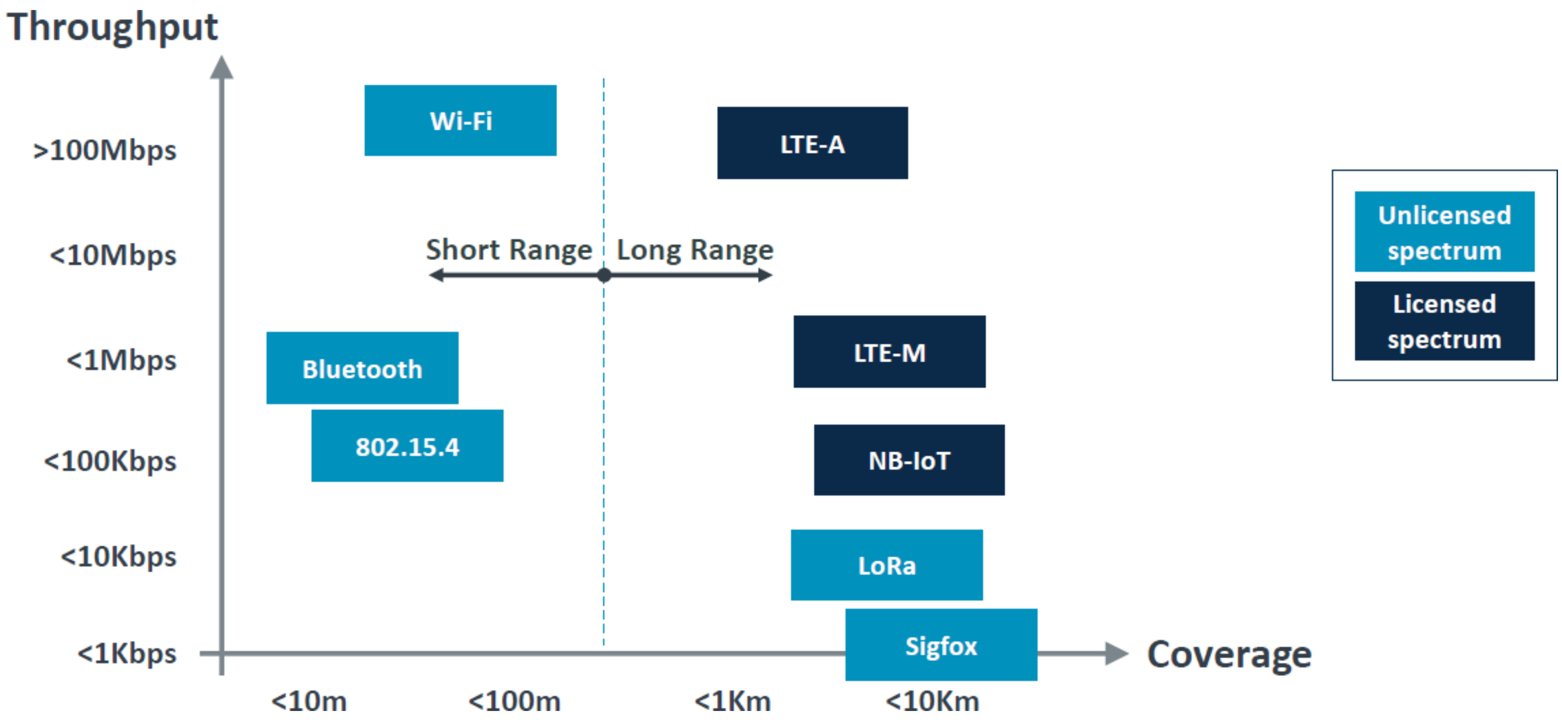
Source: ofo

Source: Max Pixel

Source: bdk

IoT-connectivity technologies

Multiple standards, different attributes



LPWA requirements

Low Power Wide Area wireless connects low bandwidth, low power devices and provides long-range coverage

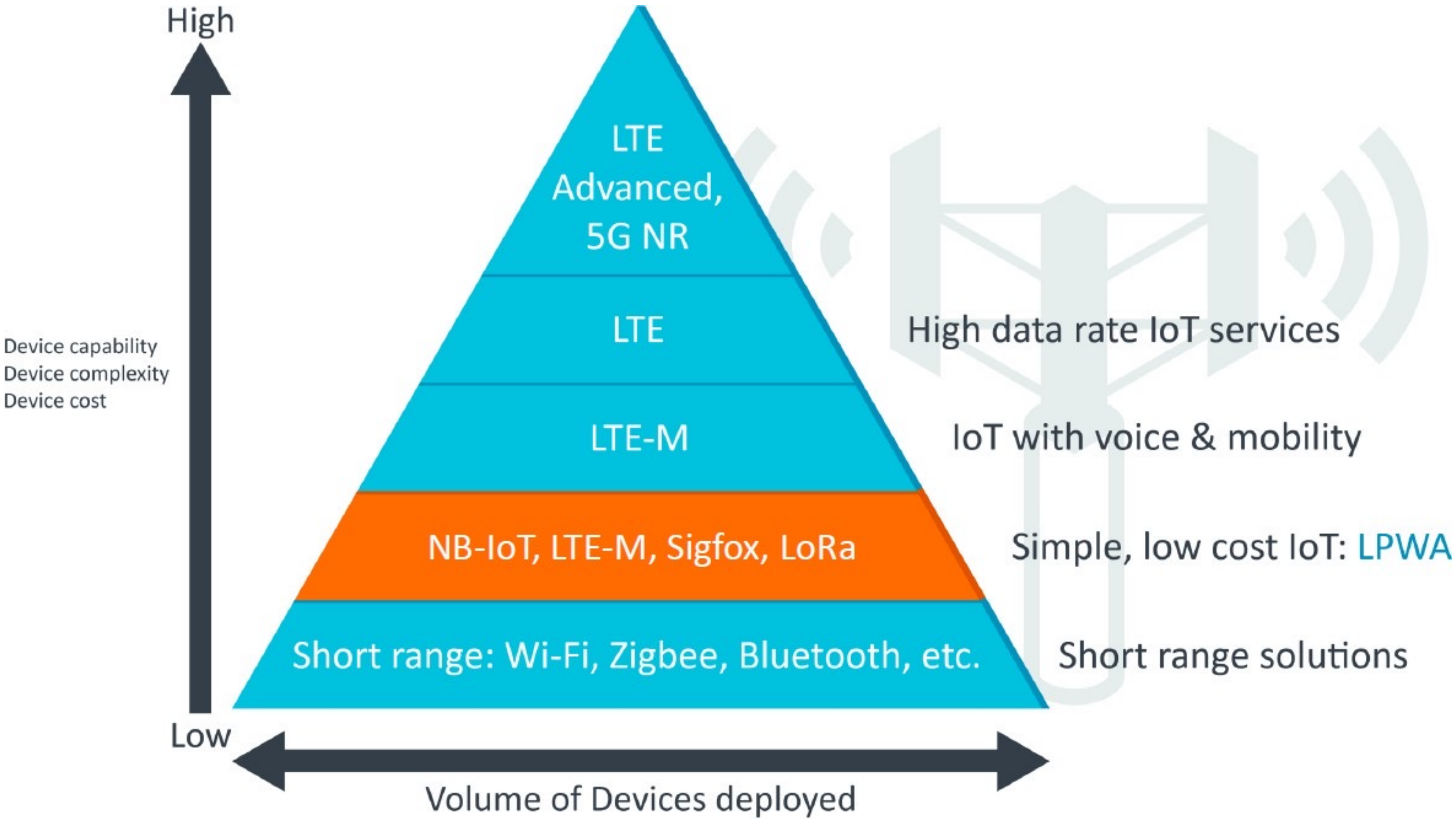
Includes cellular (NB-IoT, LTE-M/Cat-M1) *and* non-cellular (Sigfox, LoRa etc) technologies

LPWA requirements

The most critical factors in a LPWAN are:

- Network architecture
- Communication range
- Battery lifetime or low power
- Robustness to interference
- Network capacity (maximum number of nodes in a network)
- Network security
- One-way vs. two-way communication
- Variety of applications served

IoT -the connectivity pyramid



Bluetooth

- Started with Ericsson's Bluetooth Project in 1994 for radio-communication between cell phones over short distances
- Named after Danish king Herald Blatand (AD 940-981)
- Intel, IBM, Nokia, Toshiba, and Ericsson formed Bluetooth Special Interest Group (SIG) in May 1998
- Version 1.0A of the specification came out in late 1999
- IEEE 802.15.1 approved in early 2002 is based on Bluetooth. Later versions handled by Bluetooth SIG directly
- Key Features:
  - Lower Power: 10 mA in standby, 50 mA while transmitting
  - Cheap: $5 per device
  - Small: 9 mm^2 single chips

Bluetooth

- Radio band: 2.4-2.48 GHz
- Average 1Mbps - up to 3Mbps
- Supports point-to-point and point-to-multipoint
  - Creates personal area networks (PANs/Piconets)
  - Connects up to 8 devices simultaneously
- Minimal interference between devices
  - **Devices alter frequencies arbitrarily after packet exchanges -up to 1600 times/second - frequency hopping**
- 3 classes of Bluetooth transmit power

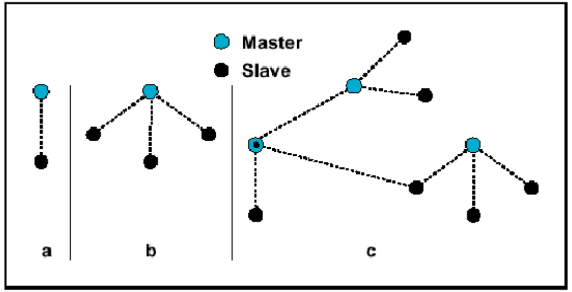


Figure 1.2: Piconets with a single slave operation (a), a multi-slave operation (b) and a scatternet operation (c).

Class	Maximum Power	Operating Range
Class 1	100mW (20dBm)	100 meters
Class 2	2.5mW (4dBm)	10 meters
Class 3	1mW (0dBm)	1 meter

Frequency hopping communication was invented by actress Hedy Lamar

UNITED STATES PATENT OFFICE

2,292,387

SECRET COMMUNICATION SYSTEM

Hedy Kiesler Markey, Los Angeles, and George Antheil, Manhattan Beach, Calif.

Application June 10, 1941, Serial No. 397,412

6 Claims. (Cl. 250—2)

This invention relates broadly to secret communication systems involving the use of carrier waves of different frequencies, and is especially useful in the remote control of dirigible craft.

Fig. 2 is a schematic diagram of the apparatus at a receiving station;

Fig. 3 is a schematic diagram illustrating a starting circuit for starting the motors at the

Bluetooth Versions

- **Bluetooth 1.1**: IEEE 802.15.1-2002
- **Bluetooth 1.2**: IEEE 802.15.1-2005. Completed Nov 2003. Extended SCO, Higher variable rate retransmission for SCO + Adaptive frequency hopping (avoid frequencies with interference)
- **Bluetooth 2.0** + Enhanced Data Rate (EDR) (Nov 2004): 3 Mbps using DPSK. For video applications. Reduced power due to reduced duty cycle
- **Bluetooth 2.1** + EDR (July 2007): Secure Simple Pairing to speed up pairing
- **Bluetooth 3.0**+ High Speed (HS) (April 2009): 24 Mbps using WiFi PHY + Bluetooth PHY for lower rates
- **Bluetooth 4.0** (June 2010): Low energy. Smaller devices requiring longer battery life (several years). New incompatible PHY. Bluetooth Smart or BLE
- **Bluetooth 4.1**: 4.0 + Core Specification Amendments (CSA) 1, 2, 3, 4
- **Bluetooth 4.2** (Dec 2014): Larger packets, security/privacy, IPv6 profile
- **Bluetooth 5** (2016): Improved energy consumption, increased range (200m)

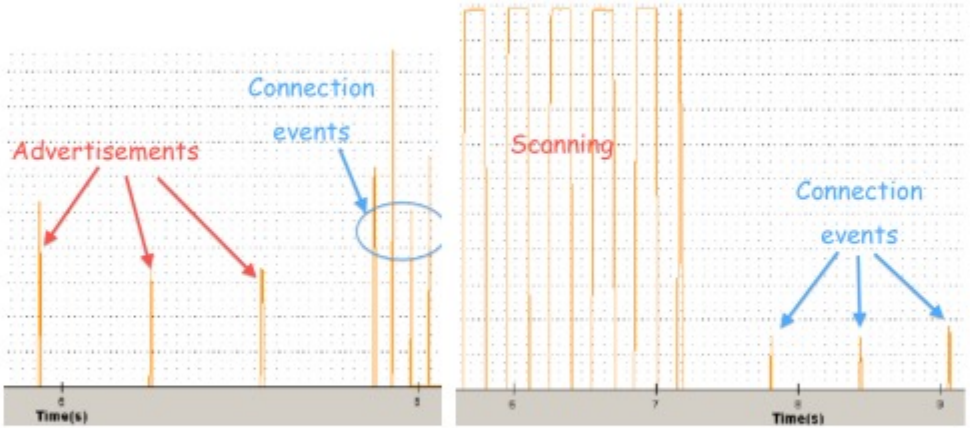
Bluetooth low energy

- **From 2001 – 2006 Nokia asked:**
- **How do we design a radio that can transmit short bursts of data for months or years *only being powered by a coin cell battery?***
- **The answer is: Keep the radio asleep mode most of the time!**

1. Advertise on only one of three channels
2. Transmit quickly at 1 Mbit/s
3. Make the minimum time to send data only 3 msec
4. Make a very predictable time when the device accepts connections
5. Limit the max transmit power to 10 mW
6. However, don't sacrifice security: AES 128-bit

What tradeoffs were made?

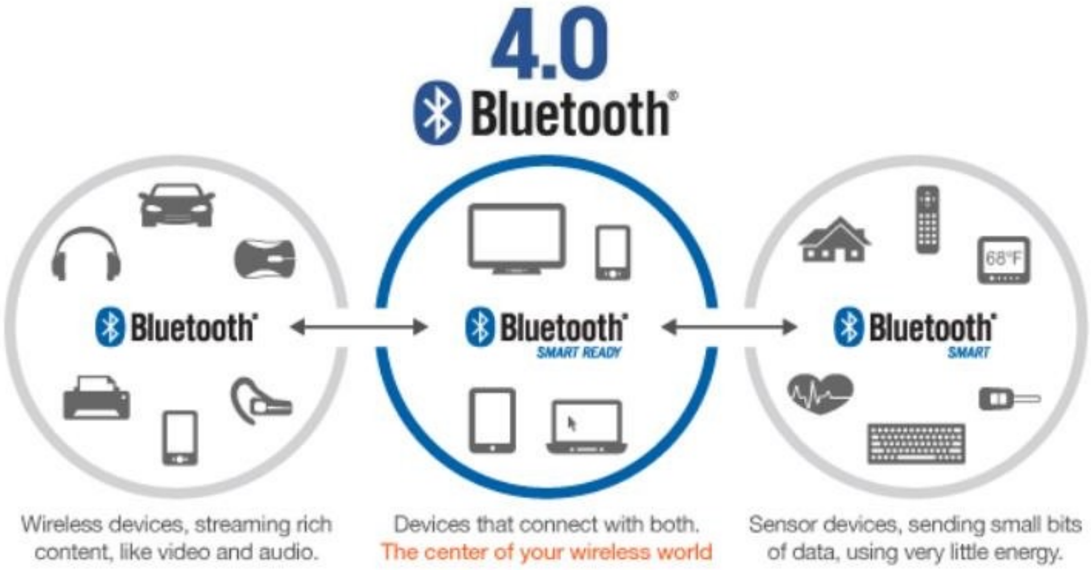
- The protocol is designed for transmitting tiny data
- 4 operations: Read, Write, Notify, Indicate
- Maximum of 20 bytes of data per packet



From: How Low Energy is Bluetooth Low Energy - Siekkinen et al.

Naming for Bluetooth 4.x

- Bluetooth 4.0
- Bluetooth Low Energy
  - BLE, BTLE, LE
- SIG Preferred
  - Bluetooth Smart
  - Bluetooth Smart Ready



Bluetooth Smart (BLE)

- **Low Energy**: 1% to 50% of Bluetooth classic
- **For short broadcast**: Your body temperature, Heart rate, Wearables, **sensors**, automotive, industrial

  Not for voice/video, file transfers, …
- **Small messages**: 1Mbps data rate but throughput not critical
- **Battery life**: In years from coin cells
- **Simple**: Star topology. No scatter nets, mesh, …
- **Lower cost** than Bluetooth classic
- New protocol design based on Nokia's **WiBree** technology Shares the same 2.4GHz radio as Bluetooth

  → Dual mode chips
- All new smart phones (iPhone, Android, …) have dual-mode chips

BLE Roles

Master

Client

Can read/write data to Slave/Server

Central

Peripheral

Slave

Server

Has read/write data

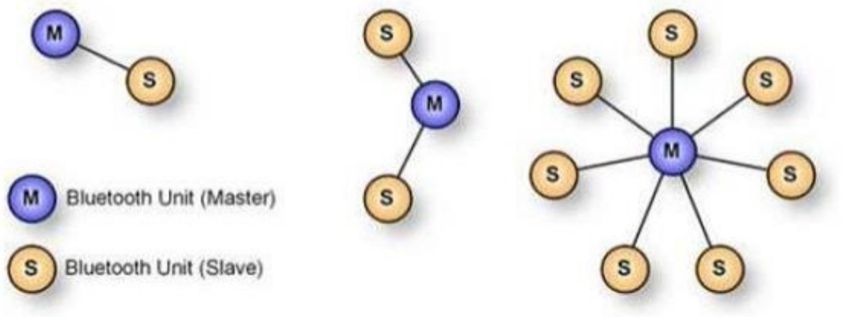
Can receive broadcast data

Observer

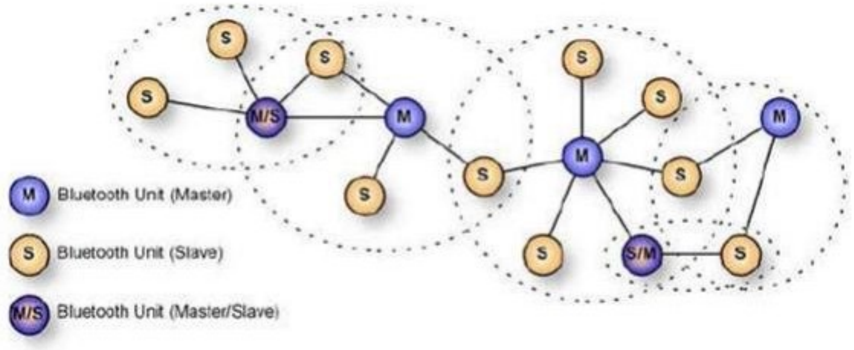
Broadcaster

Has read-only broadcast data

Topology

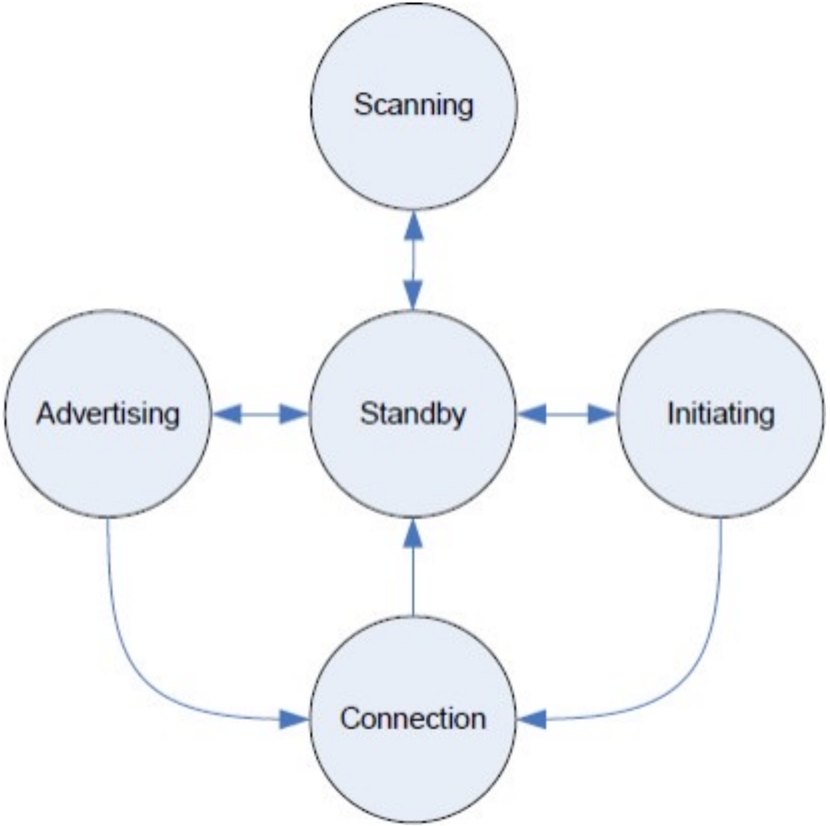


Piconet v4.0



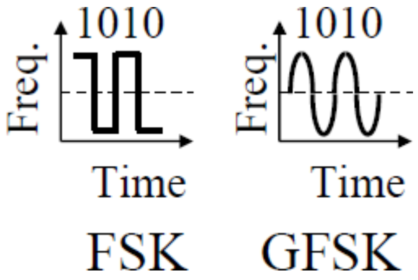
Scatter net v4.1

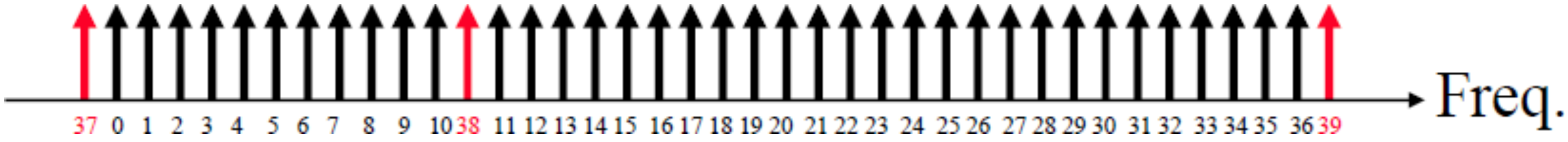
BLE Power Status



Bluetooth Smart PHY

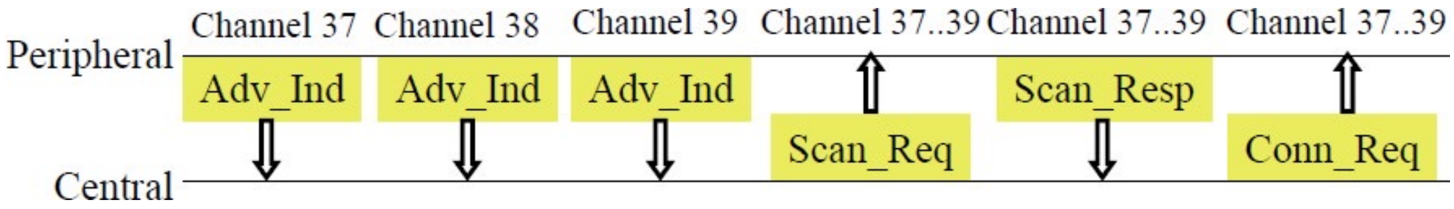
- 2.4 GHz. 150 m open field
- Star topology
- 1 Mbps Gaussian Frequency Shift Keying
  Better range than Bluetooth classic
- Adaptive Frequency hopping. 40 Channels
  with 2 MHz spacing
- 3 channels reserved for advertizing and 37 channels for data
- Advertising channels specially selected to avoid interference
  with WiFi channels



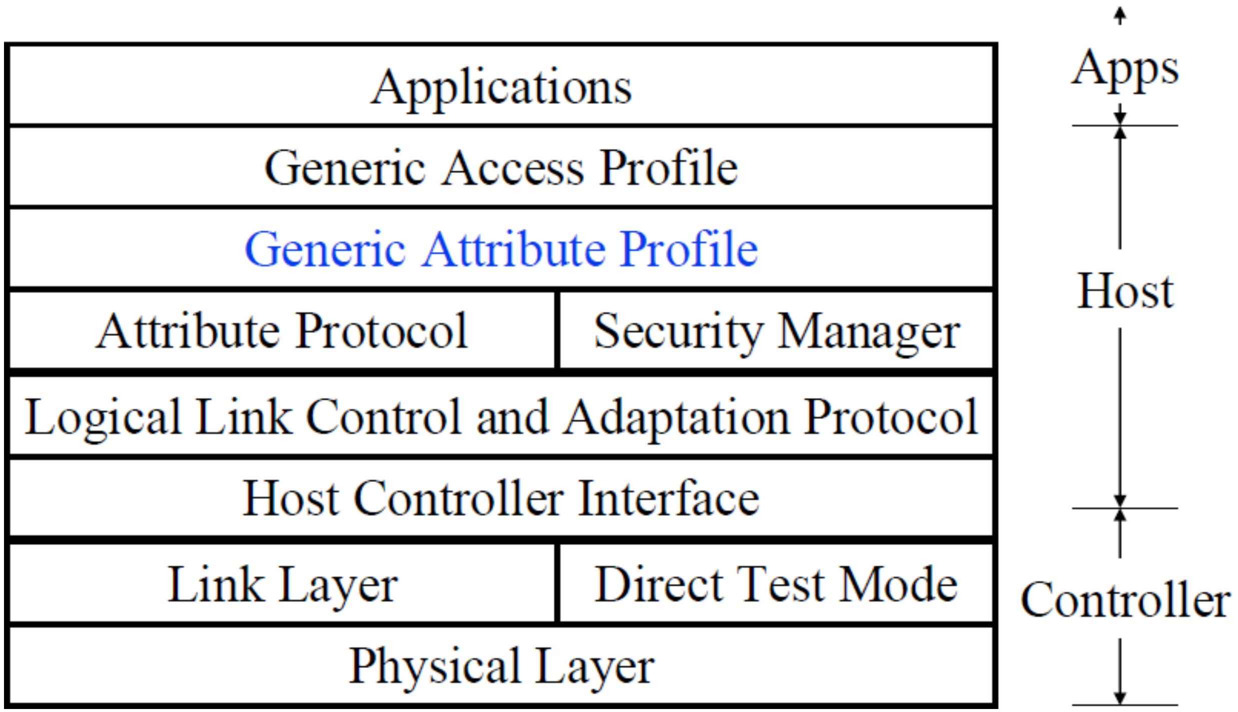


Bluetooth Smart MAC

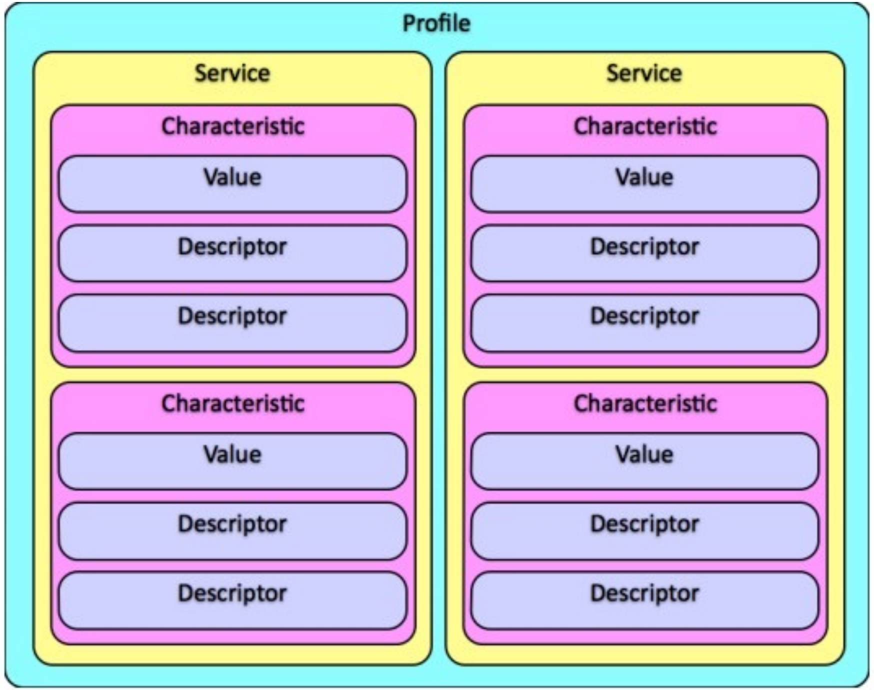
- Two Device Types: "**Peripherals**" simpler than "**central**"
- Two PDU Types: Advertising, Data
- **Non-Connectable Advertising**: Broadcast data in clear
- **Discoverable Advertising**: Central may request more information. Peripheral can send data without connection
- **General Advertising**: Broadcast presence wanting to connect. Central may request a short connection.
- **Directed Advertising**: Transmit signed data to a previously connected master

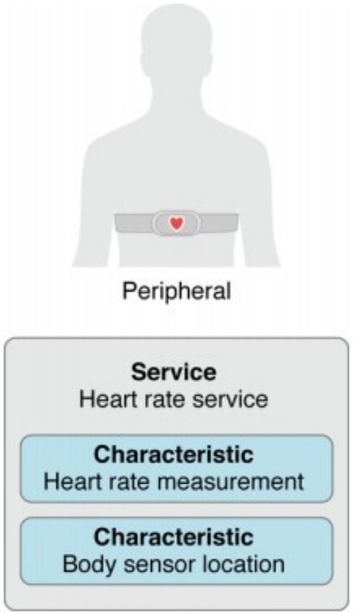


Bluetooth Smart Protocol Stack



Generic Attribute Profile - GATT





Services, characteristics, and descriptors are collectively referred to as *attributes*, and identified by UUIDs.
16 bits (e.g. "**180A**") or 128 bits (e.g. "**6BCF0ED3-68E3-4804-96D5-5AB8765FB9BC** ")

GATT Operations

- Central can
  - Discover UUIDs for all primary services
  - Find a service with a given UUID
  - Find secondary services for a given primary service
  - Discover all characteristics for a given service
  - Find characteristics matching a given UUID
  - Read all descriptors for a particular characteristic
  - Can do read, write, long read, long write values etc.
- Peripheral
  - Notify or indicate central of changes

Security

- Encryption (128 bit AES)
- Pairing (without key, with a shared key, out of band pairing)
- Passive eavesdropping during key exchange (but fixed in Bluetooth 4.2)
- Many products are building their own security on top of BLE

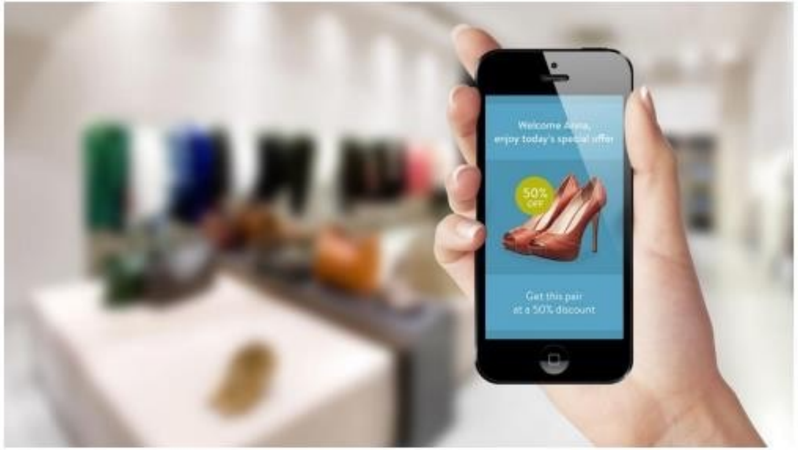
Bluetooth Smart Applications

- Proximity: In car, In room 404, In the mall
- Locator: keys, watches, animals
- Health devices: Heart rate monitors, physical activities monitors, thermometers
- Sensors: Temperature, Battery Status, tire pressure
- Remote control: Open/close locks, turn on lights

Use Cases – Physical Security

Use Cases – Home Automation

Use Cases – Geo-fencing/ Positioning

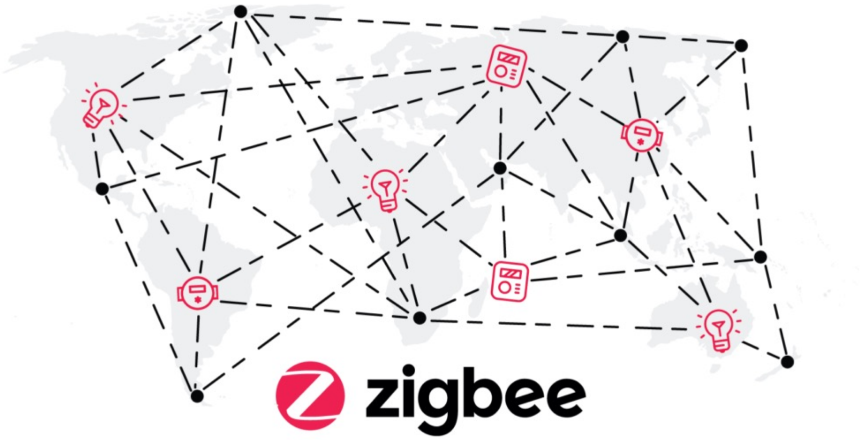


Use Cases - Fun

Development Kits/Boards

ZigBee

- Technological standard created for the control and sensor networks
- Suited for low-cost, low-power wireless IoT networks
- Based on IEEE 802.15.4 standard
- Created by ZigBee Alliance – Philips, Motorola, HP, Intel etc.
- Conceived in 1998, standardized in 2003, and revised in 2006

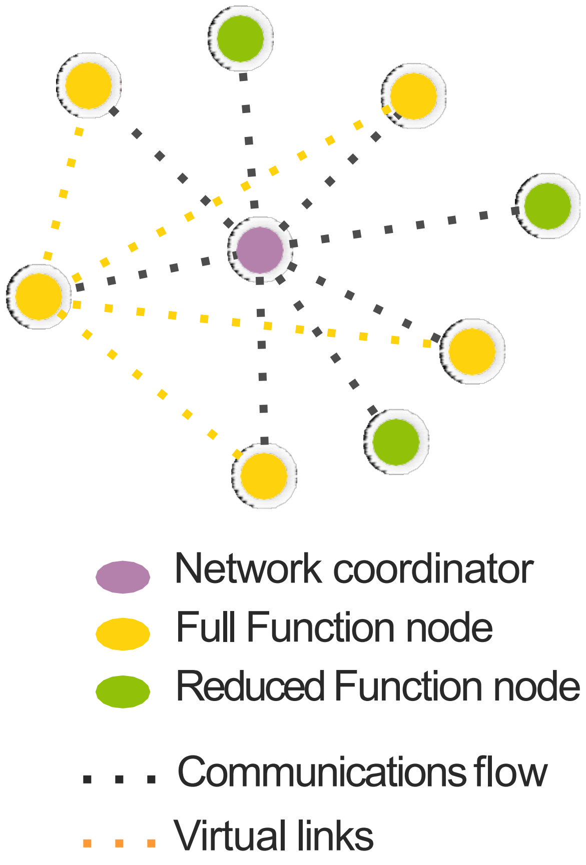


ZigBee Technology-Performance

- Proven excellent in-building coverage
  - Inherently robust radio link
  - Mesh networking
  - Acknowledge oriented protocol
  - Now proven in major deployments in Australia, Sweden, & USA
- Proven tolerance to interference
  - Trade shows like CES-works when WiFi and Bluetooth fail
  - Montage Hotels and MGM City Center deployments
  - Products which implement multiple radio technologies
- Proven coexistence
  - Many multi-radio products and multi-radio deployments
- Proven scalability
  - City Center at 70,000 plus radios
  - Montage Hotels at 4000 plus radios per property

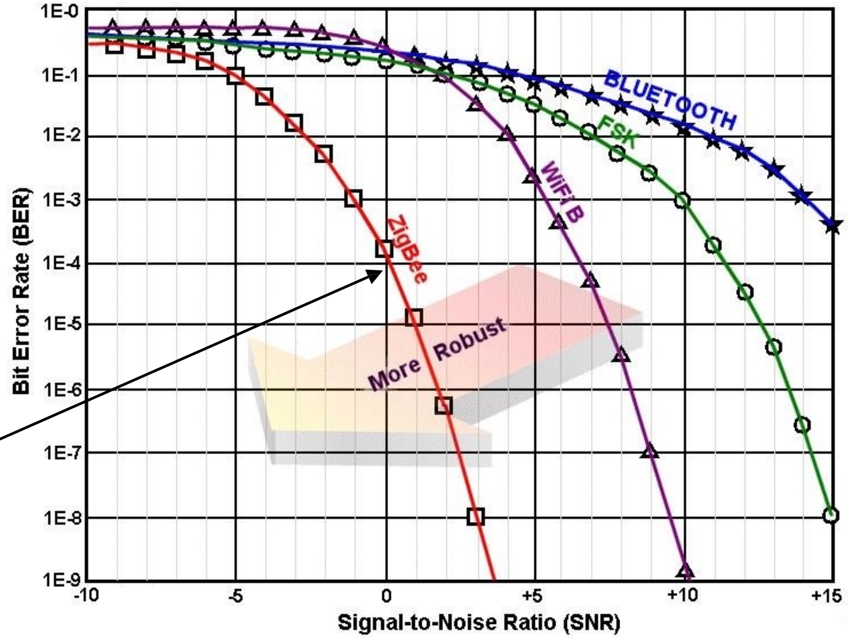
Basic Network Characteristics

- 65,536 network (client) nodes
- 27 channels over 2 bands
- 250Kbps data rate
- Optimized for timing-critical applications and power management
- Full Mesh Networking Support



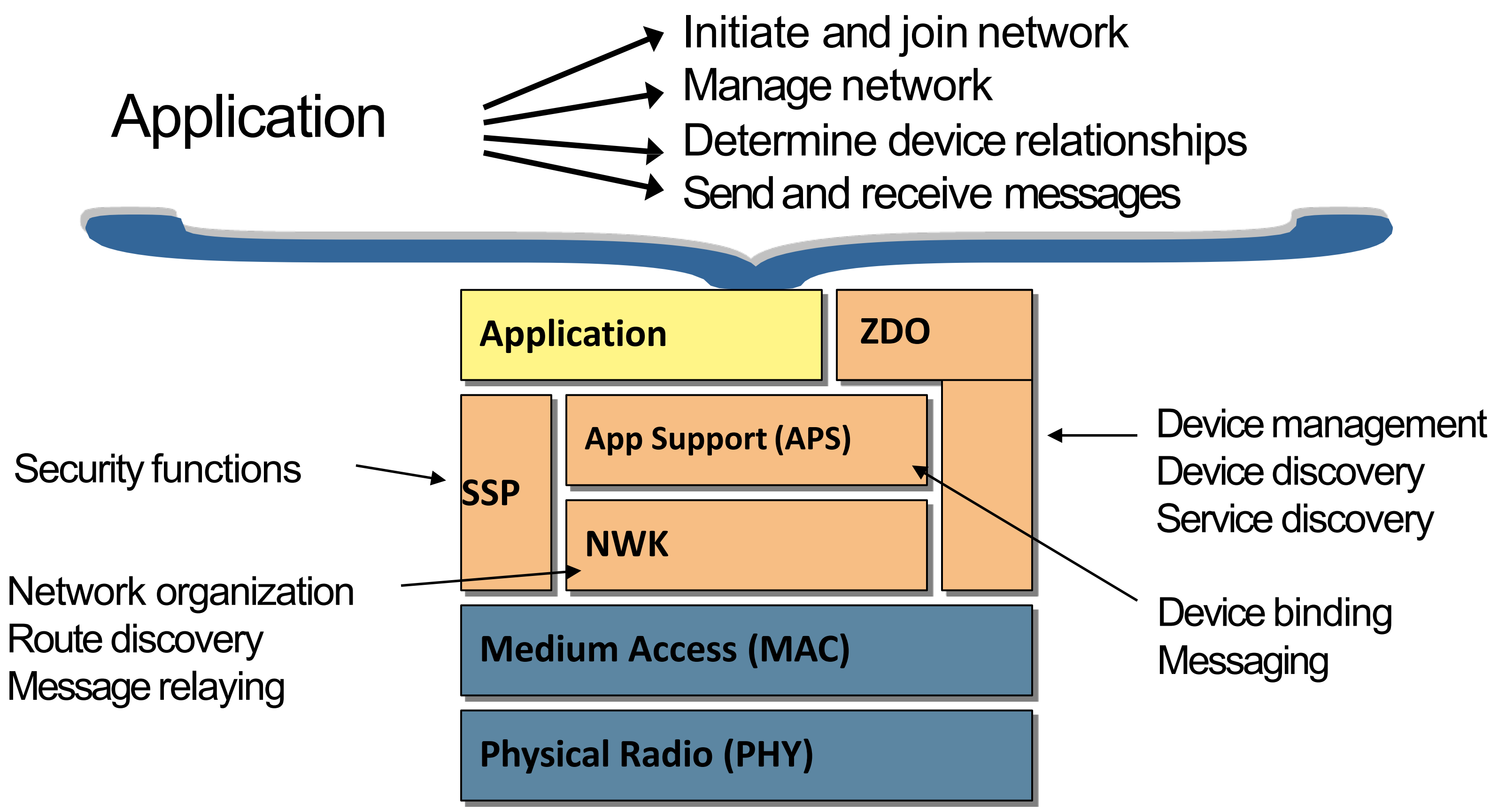
Basic Radio Characteristics

ZigBee technology relies upon IEEE 802.15.4, which has excellent performance in low SNR environments



Frequency Band	License Required?	Geographic Region	Data Rate	Channel Number(s)
868.3 MHz	No	Europe	20kbps	0
902-928 MHz	No	Americas	40kbps	1-10
2405-2480 MHz	No	Worldwide	250kbps	11-26

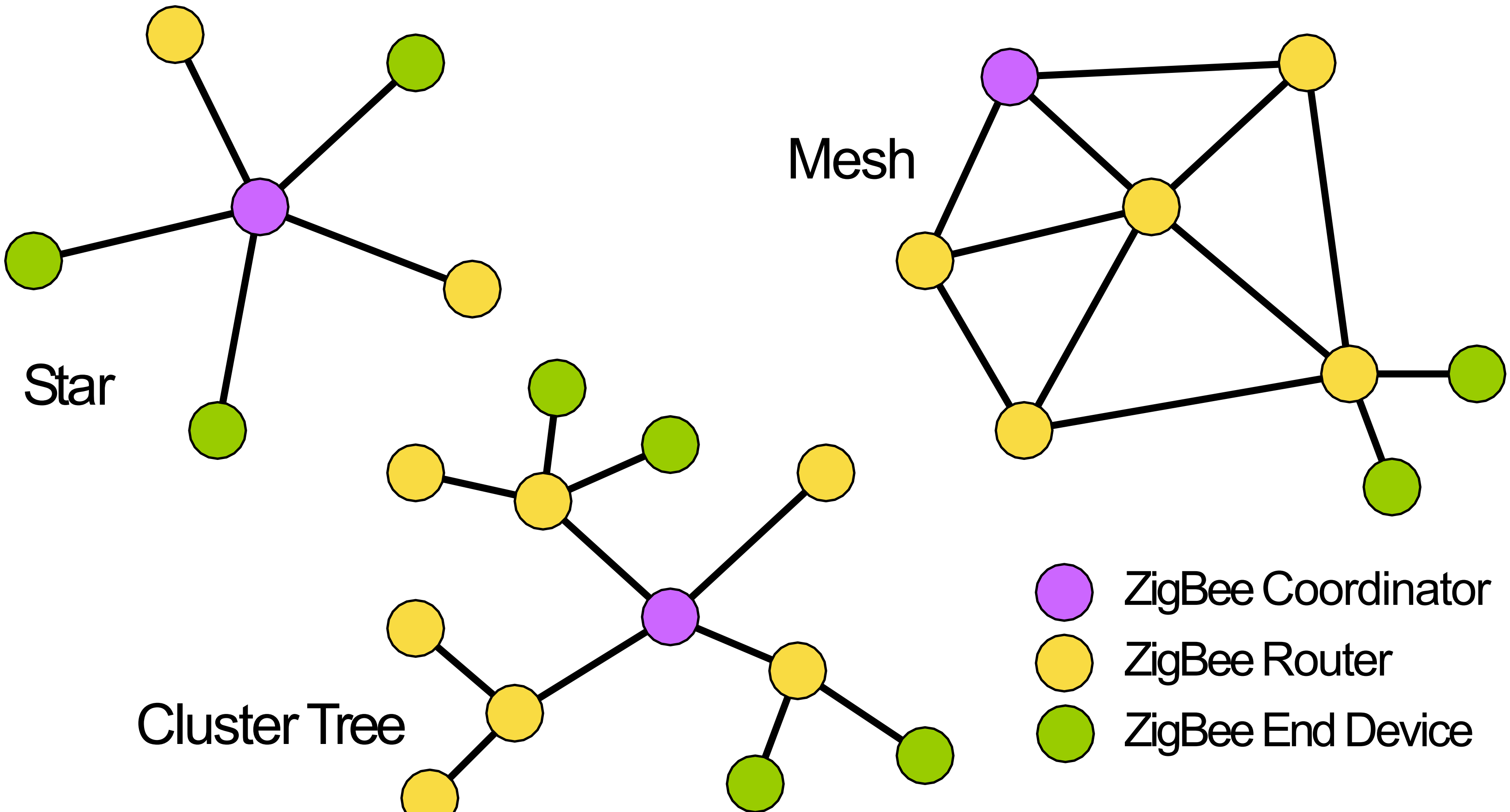
ZigBee Stack Architecture



ZigBee Device Types

- ZigBee Coordinator (ZC)
  - – One required for each ZB network.
  - – Initiates network formation.
- ZigBee Router (ZR)
  - – Participates in multihop routing of messages.
- ZigBee End Device (ZED)
  - – Does not allow association or routing.
  - – Enables very low cost solutions

ZigBee Network Topologies



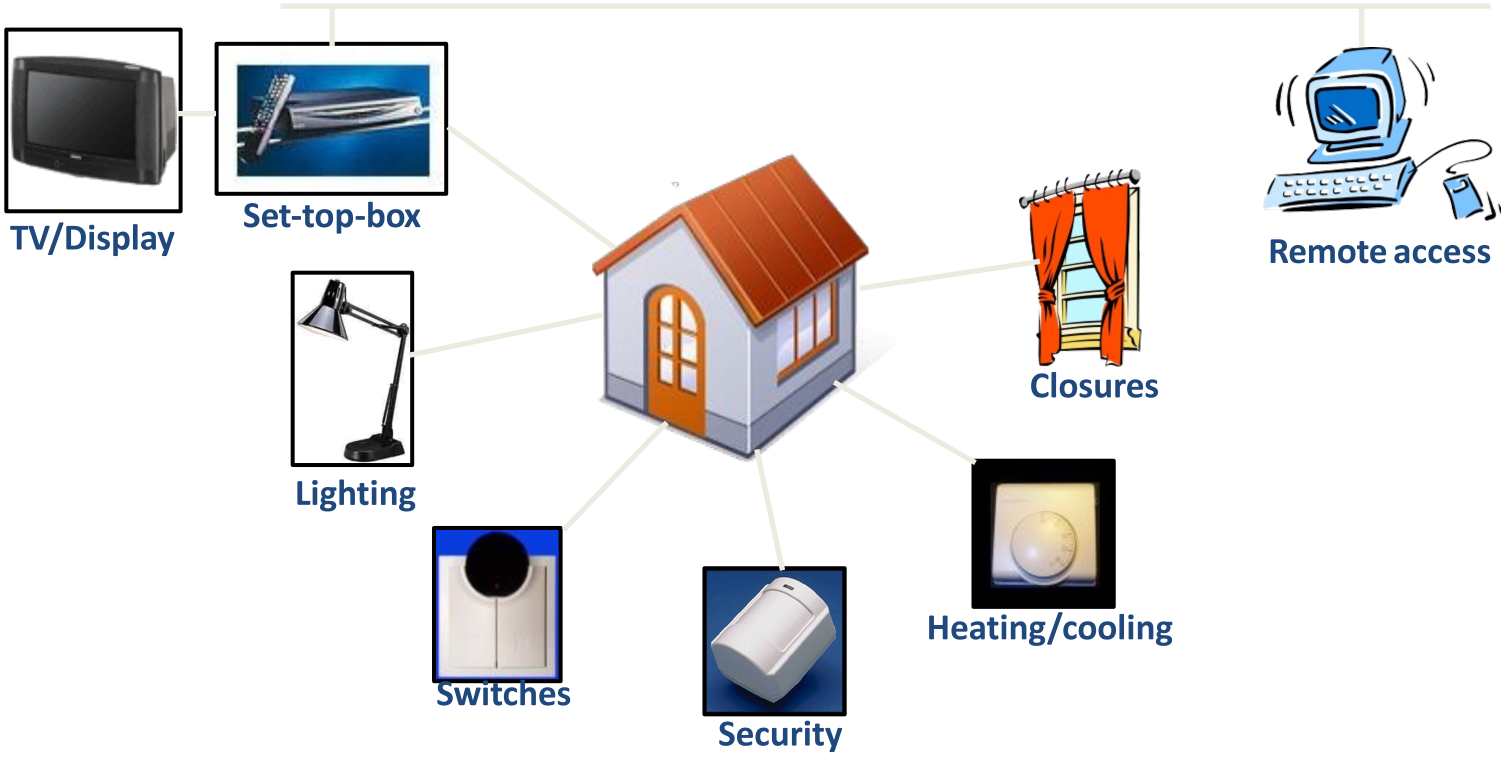
ZigBee Public Profiles

- Home Automation (HA)
- Smart Energy (SE)
- Commercial Building Automation (CBA)
- ZigBee Health Care (ZHC)
- Telecom Applications (TA)

- ZigBee RF4CE Remote Control

- +Future profiles proposed by member companies…

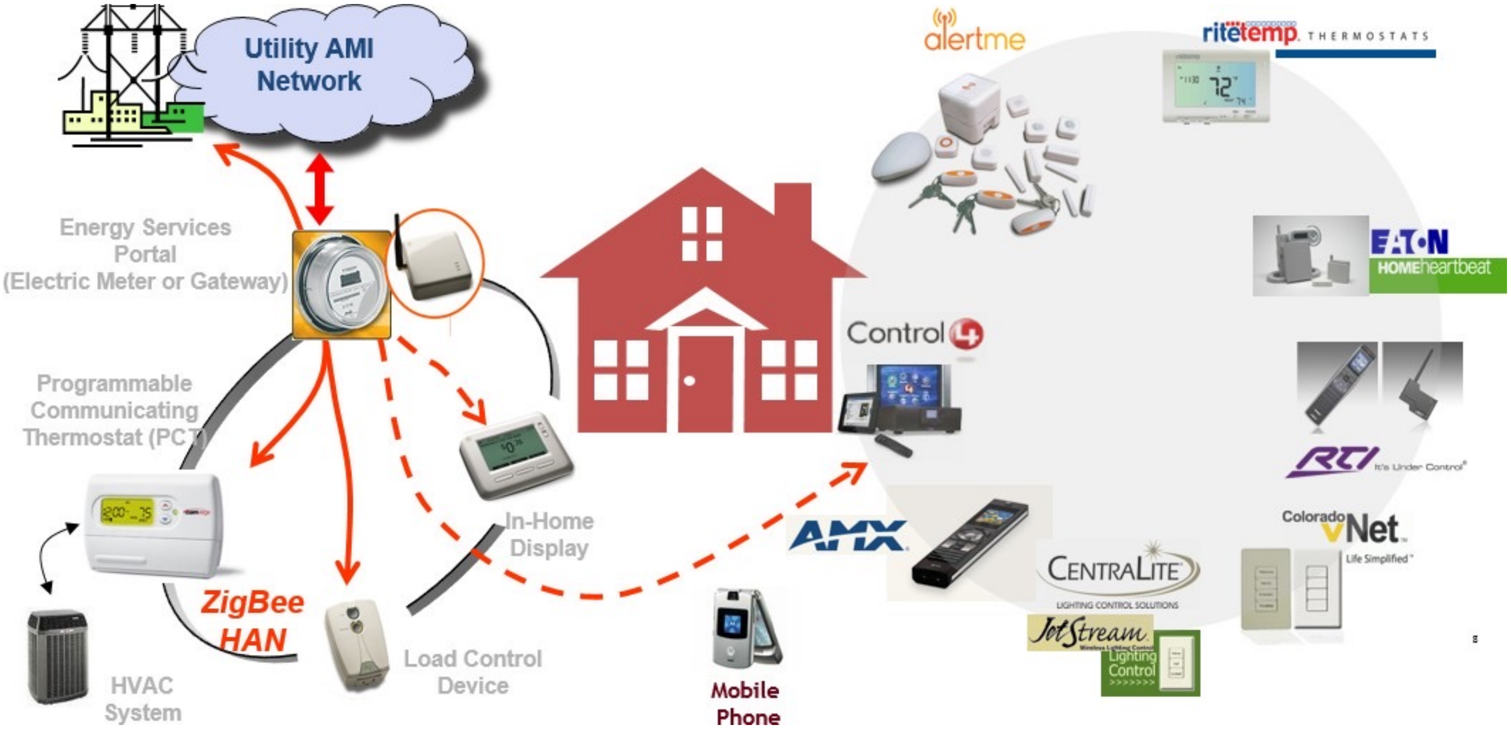
ZigBee Home Automation: for Home Control



ZigBee Home Area Network (HAN)

Smart Energy & Home Automation

Urgent demand for Smart Energy + compatibility with mainstream Home Automation systems enables customer choice

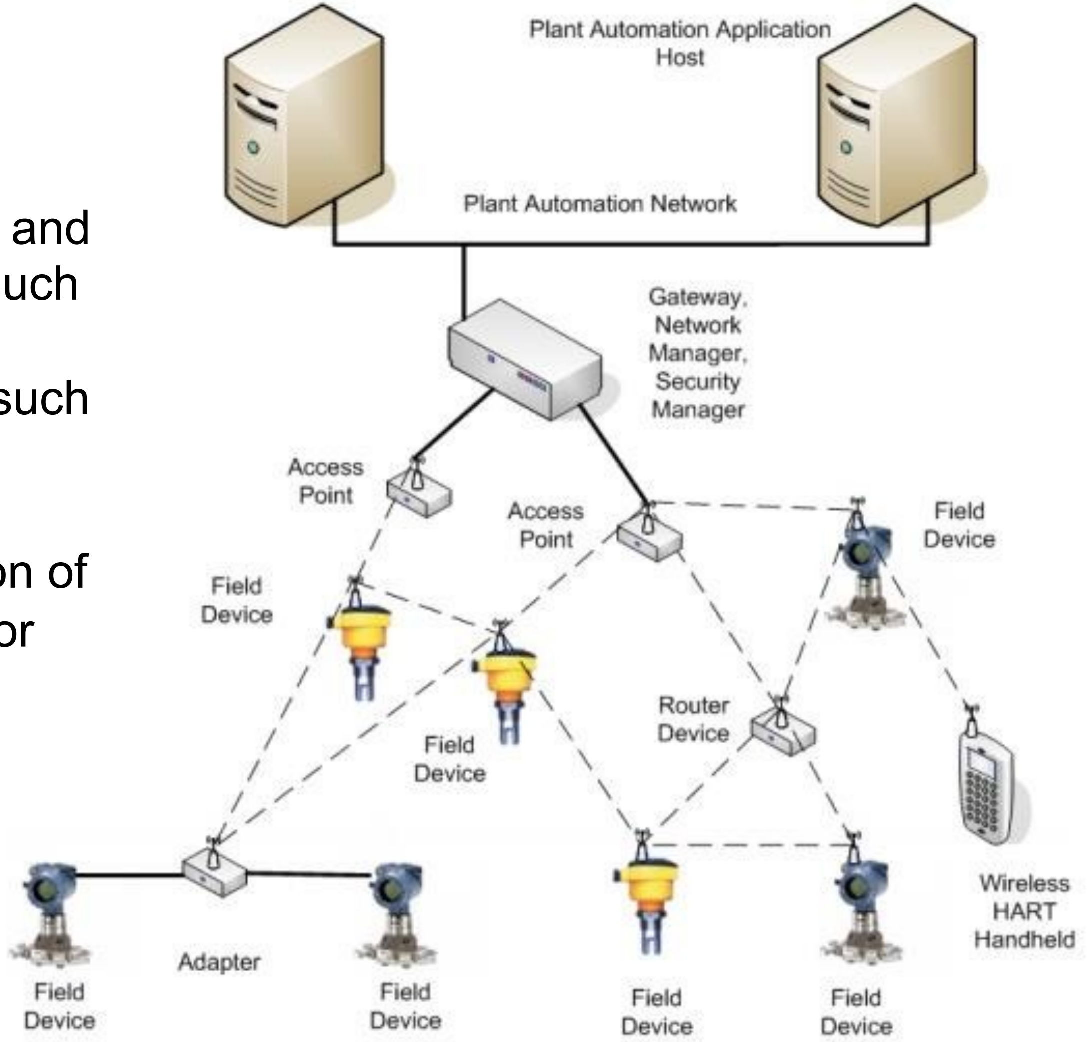


WirelessHART

- The HART (Highway Addressable Remote Transducer Protocol) communication protocol is designed to add diagnostic information to process devices compatible with legacy 4-20mA analog instrumentation
- The overall performance has been designed to satisfy process automation needs. It is able to work on distances up to 1500m
- WirelessHART is an extension of HART, its functions include
  - Implements an RF self-healing mesh network
  - Allows for network-wide time synchronization
  - Enhances the publish/subscribe messaging
  - Adds network and transport layers
  - Adds a fast pipe for time critical traffic and ciphering

Overview

- WirelessHART targets sensors and actuators, rotating equipment such as kiln dryers, environmental health and safety applications such as safety showers, condition monitoring, and flexible manufacturing in which a portion of the plant can be reconfigured for specific products.



WirelessHART

- WirelessHART main characteristics
  - Low power consumption and low-cost devices
  - Data rate of 250 kbps per channel in 2.4GHz ISM band with 15 channels
  - Based on IEEE 802.15.4-2006 PHY layer
  - Based on a proprietary data link layer with TDMA and CSMA/CA
  - Supporting *channel hopping* and *channel blacklisting*
  - Network layer implementing self-healing mesh network
  - Application layer fully compatible with HART

WirelessHART

Comparison between HART, wirelessHART and ZigBee

TABLE 31.1 ISO/OSI 7 Layer Model: Comparison among HART, WirelessHART, and ZigBee

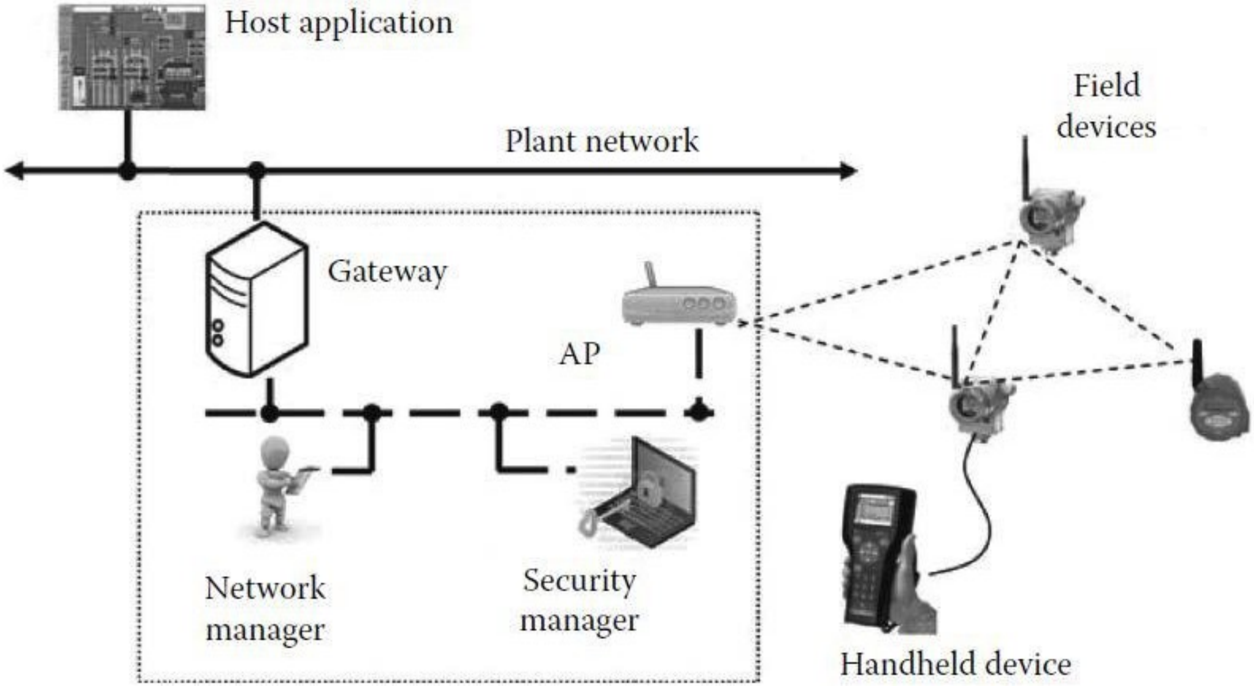
Layer \ Standard	HART	WirelessHART	ZigBee
Application	Command oriented, predefined data types and application procedures		Application and security
Presentation	—	—	—
Session	—	—	—
Transport	Auto-segmented transfer of large amount of data, reliable stream transport, and negotiated segment sizes		—
Network	—	Power Optimized redundant path mesh network	Ad-hoc routing, mesh networks
Data link	Token passing master/slave	Time synchronized channel hopping	IEEE 802.15.4-2006
Physical	Simultaneous analog and digital signaling (4–20 mA wire)	IEEE 802.15.4-2006 at 2.4 GHz	IEEE 802.15.4-2006

The Network Architecture

- Each wirelessHART network includes four main elements
  - **Field devices**. They include wirelessHART process transmitters and wireless adapters
  - **Gateway**. Gateway bridges the wirelessHART network with wired infrastructures
  - **Network manager** (*only one*). It is responsible for network configuration, communication among devices, management of routing messages and monitor network conditions
  - **Security manager**. Security manager deals with security and encryption, setting up session keys and their periodic change
  - Handheld devices for maintaining purposes are optional

The Network Architecture

Example wirelessHART network



Z-Wave

- Z-Wave is a low-power MAC protocol designed for home automation and has been used for IoT communication, especially for smart home and small commercial domains
- It covers about 30-meter point-to-point communication and is suitable for small messages in IoT applications, like light control, energy control, wearable healthcare control and others
- It uses CSMA/CA for collision detection and ACK messages for reliable transmission
- It follows a master/slave architecture in which the master control the slaves, send them commands, and handling scheduling of the whole network

Z-Wave Vs. Zigbee: What do they have in common?

- Both technologies are mesh networks
    - Each node in the system acts as both a wireless data source and a repeater. Information from a single sensor node hops from node to node until the transmission reaches the gateway
- Both technologies use the IEEE 802.15.4 low-rate personal area network (LR-PAN) protocol
    - for the unified physical layer (OSI layer 1), structuring packets, and creating MAC (Medium Access Control) schemes
- Both are widely used in local area sensor data networks
    - like in security systems, urban smart grid controllers, HVAC control systems, home automation, and lighting controls

Z-Wave Vs. Zigbee: How are they different?

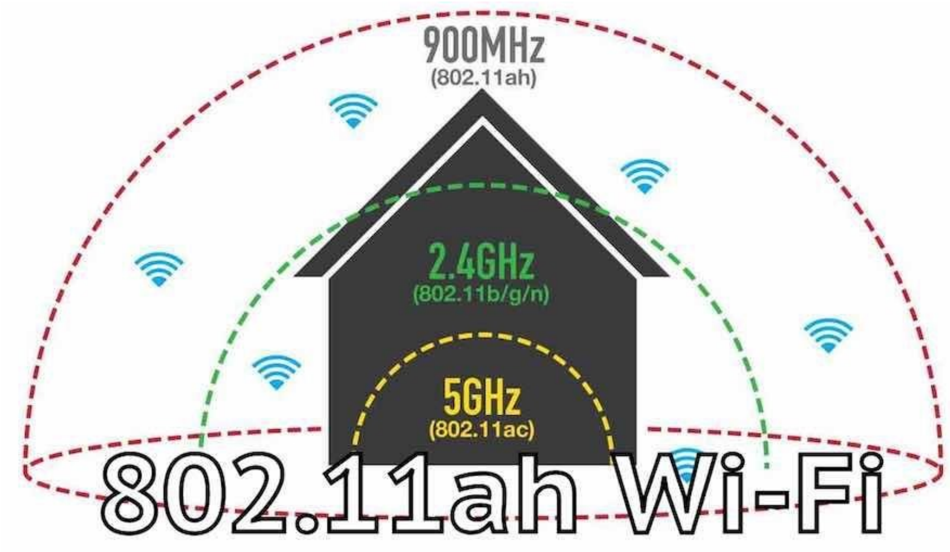
- Z-wave has a tightly controlled product ecosystem that caters to the smart home and smart building space, whereas Zigbee can be used for a number of applications
  - There's no expectation that two Zigbee devices are interoperable unless the interoperability is preplanned. A Z-Wave application, on the other hand, will almost always integrate with another Z-Wave device
- Zigbee uses the global standard 2.4GHz ISM frequency band, whereas Z-Wave uses the 915 MHz ISM band (in the U.S.) and the 868 MHz RFID band (in Europe).
- 2.4 GHz band can be subject to intense interference from WiFi and Bluetooth systems,
  whereas the sub-GHz bands Z-Wave uses do not face the same interference issues
- Lots of providers make Zigbee radios, but Z-Wave uses a proprietary radio system from Sigma designs
- Z-Wave uses frequency-shift keyed modulation (FSK), whereas Zigbee modulation is carried out through direct sequence spread spectrum (DSSS)

IEEE 802.11ah

sub 1GHz WLAN for IoT

- Defines operation of license-exempt (ISM) IEEE 802.11 wireless networks in frequency bands below 1 GHz
  - excluding the TV White Space bands (802.11af)
- IEEE 802.11 WLAN user experience for fixed, outdoor, point to multi point applications

What lies beneath Wi-Fi HaLow

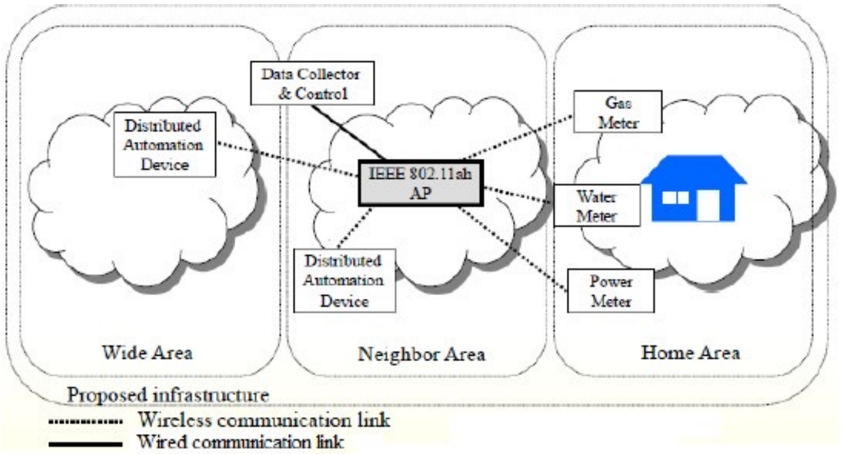


IEEE 802.11ah: scope

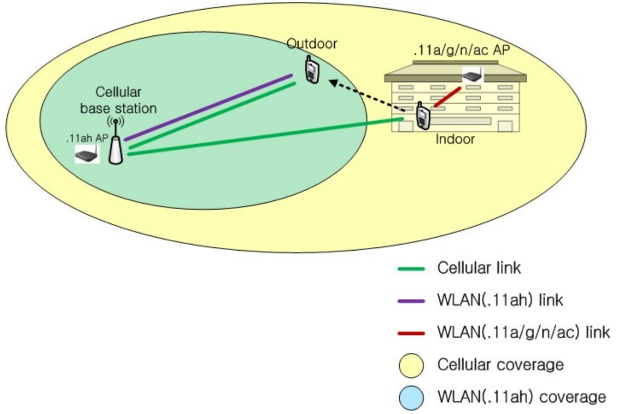
- Defines an OFDM PHY operating in the license-exempt bands below
  1 GHz
  - and enhancements to the IEEE 802.11 MAC to support this PHY, and to provide mechanisms that enable coexistence with other systems in the bands (e.g. IEEE 802.15.4 P802.15.4g)
- The PHY is meant to optimize the ***rate vs. range*** performance of the specific channelization in a given band
  - transmission range up to 1 km
  - data rates > 100 kbit/s
- The MAC is designed to support thousands of connected devices

IEEE 802.11ah: use cases

- Use Case 1 : Sensors and meters
  - Smart Grid -meter to pole
  - Environmental monitoring
  - Industrial process sensors
  - Healthcare
  - Home/Building automation
  - Smart city



- Use Case 2 : Backhaul sensor and meter data
  - Backhaul aggregation of sensor networks
  - Long point-to-point wireless links
- Use Case 3 : Extended range Wi-Fi
  - Outdoor extended range hotspot
  - Outdoor Wi-Fi for cellular traffic offloading



IEEE 802.11ah: PHY (1)

- Advantages of transmitting in sub 1 GHz:
  - Spectrum characteristics
    - good propagation and penetration
    - large coverage area and one-hop reach
    - license-exempt, light licensing
  - Reliability:
    - less congested frequency band
    - high sensitivity and link margin
    - available diversity –(frequency, time, space)
  - Battery operation
    - long battery life
    - short data transmissions

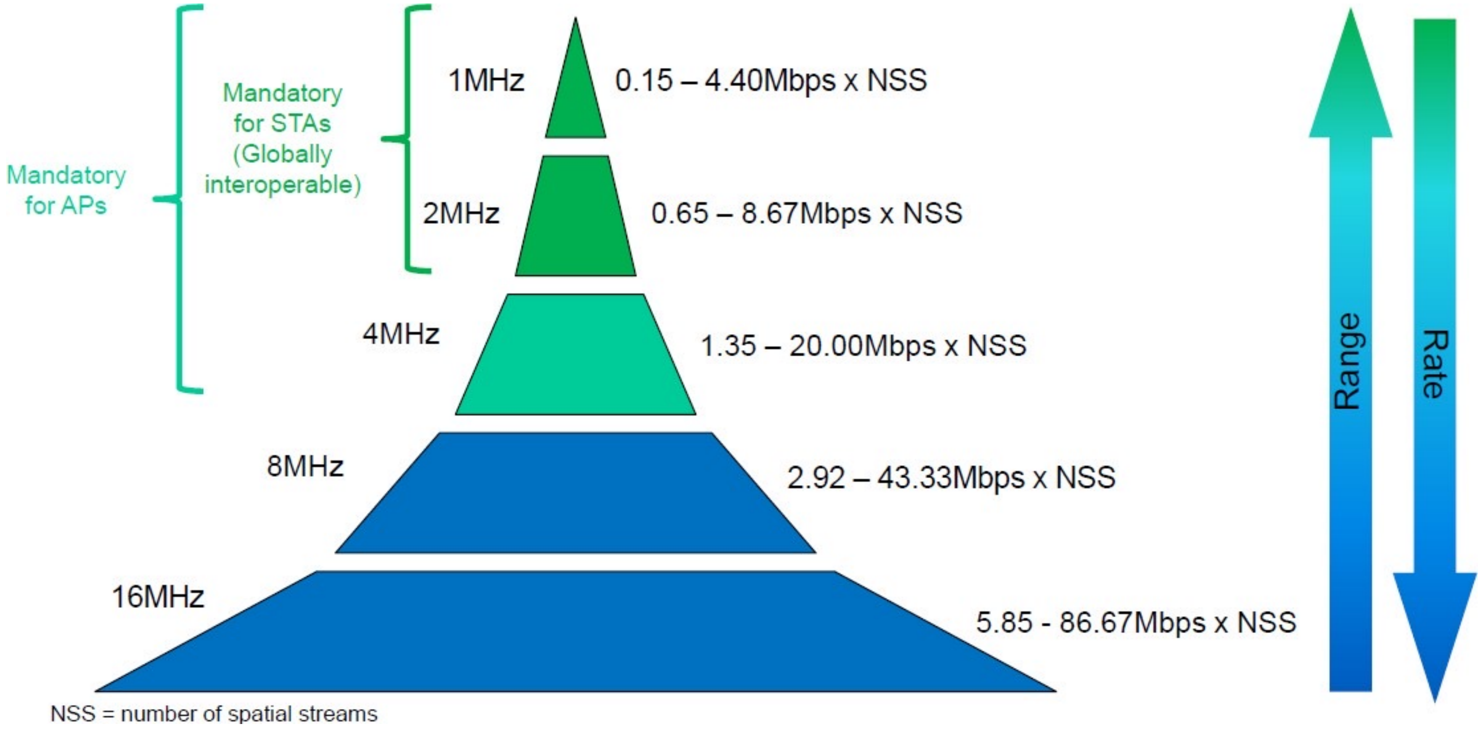
IEEE 802.11ah: PHY (2)

- Channelization:
  - Configurable bandwidth (*channel bonding*) of: **1**, **2**, 4, 8 and 16MHz

- Inherited from IEEE 802.11ac (adapted to S1G)
  - OFDM
  - MIMO + MU-MIMO
  - PHY rates ranging from 150kbps to 347Mbps

IEEE 802.11ah: PHY (3)

Expected throughput vs. coverage

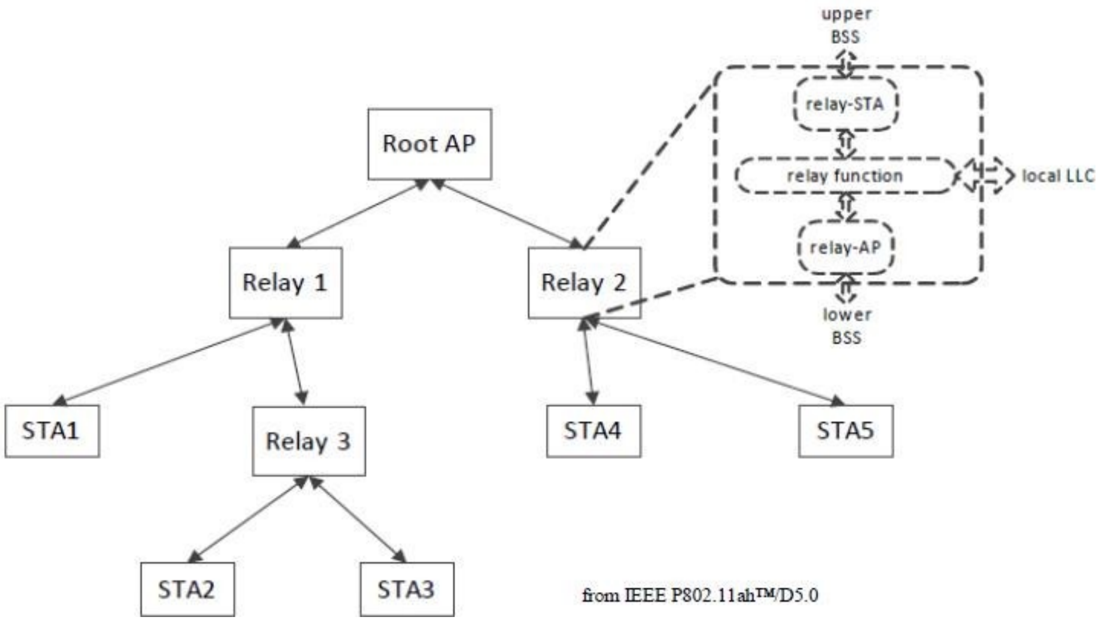


IEEE 802.11ah: MAC

- Need to reduce overhead: low data rates + short frames (typical in some use cases)
  - Short MAC headers and Beacons
  - Implicit acknowledgement (no ACK needed)
- Need to support thousands of associated devices (increases coverage
  → increases reachable STAs)
  - Thousands of STAs → huge collision probability!
  - Restricted Access Window (RAW): regular RAW
    - Divide STAs into groups (AID)
    - Split channel access into time slots
    - Assign slots to groups (AP indicates RAW allocation and slot assignments in its Beacons)
    - Different *backoff* rules apply during RAW (due to different contention conditions)

Multihop Relay Operation

- Extend (root) AP coverage
- STAs will require lower tx power
- STAs may use faster MCS (less tx time)



from IEEE P802.11ah™/D5.0

IEEE 802.11ah: Summary

LONG RANGE

- Lower frequency band
- Longer OFDM symbols
- Robust modulation and coding schemes

SCALABILITY

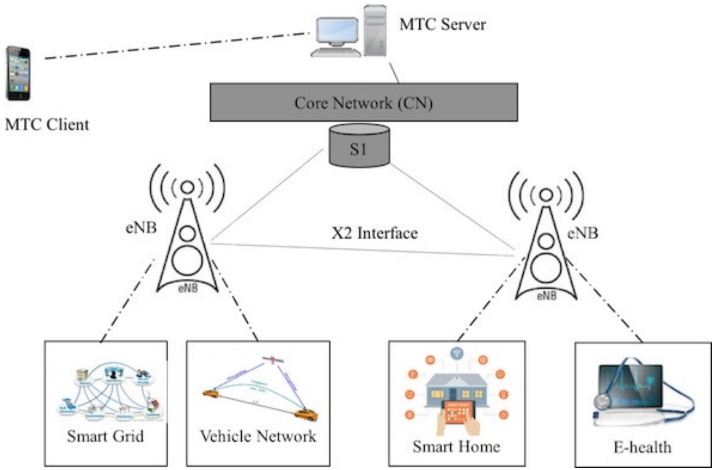
- Support for >8000 nodes
- Grouping
- RAW access

EFFICIENCY

- Reduced frame formats
- Efficient frame exchanges
- Enhanced power saving mechanisms

LTE-A

- Long-Term Evolution Advanced (LTE-A) is a set of standards designed to fit M2M communication and IoT applications in cellular networks



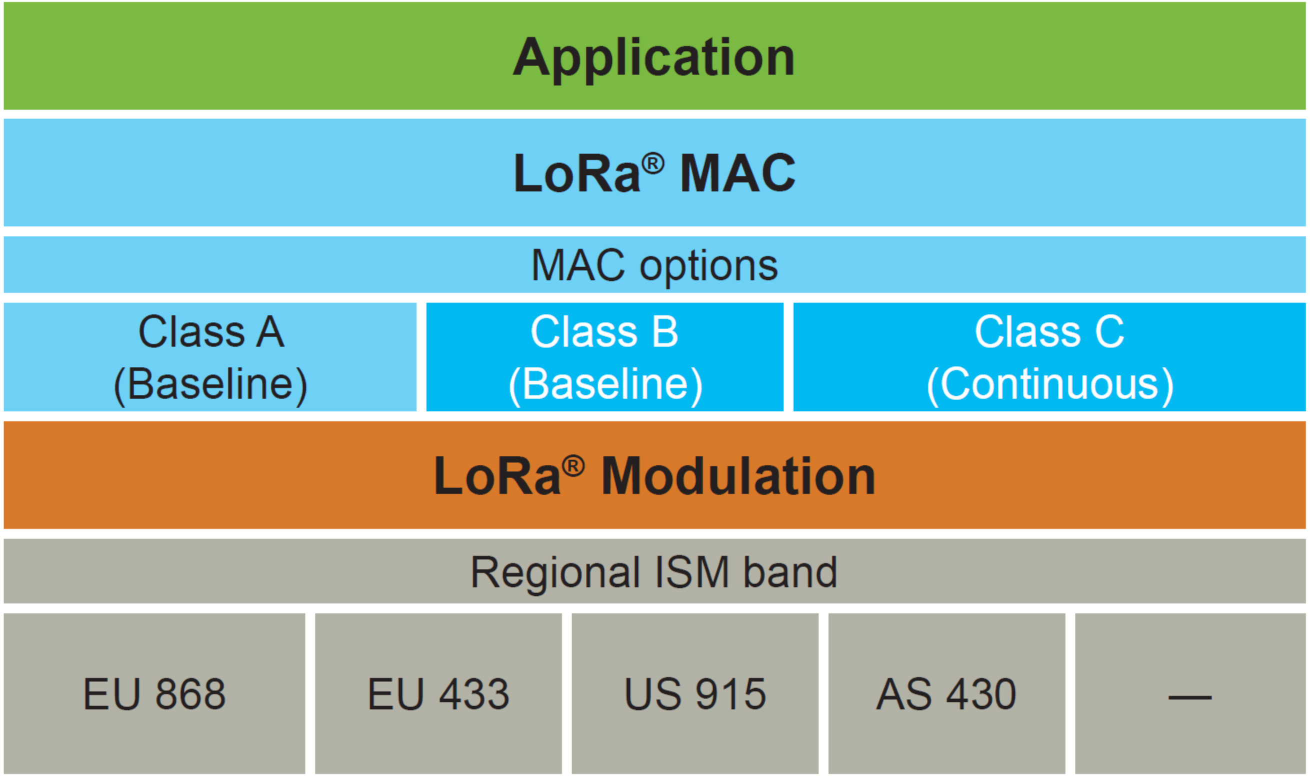
- LTE-A is a scalable, lower-cost protocol compared to other cellular protocols
- LTE-A uses OFDMA (Orthogonal Frequency Division Multiple Access) as a MAC layer access technology, which divides the frequency into multiple bands and each one can be used separately
- The architecture of LTE-A consists of a core network (CN), a radio access network (RAN), and the mobile nodes
  - The CN is responsible for controlling mobile devices and to keep track of their IPs
  - RAN is responsible for establishing the control and data planes and handling the wireless connectivity and radio-access control

LoRaWAN

- LoRaWAN is a wireless technology designed for low-power WAN networks with low cost, mobility, security, and bidirectional communication for IoT applications
- It is a low-power consumption optimized protocol designed for scalable wireless networks with millions of devices
- It supports redundant operation, location free, low cost, low power and energy harvesting technologies to support the future needs of IoT while enabling mobility and ease of use features

WHAT IS LoRaWAN™?

LoRaWAN™ defines the communication protocol and system architecture for the network while the LoRa physical layer enables the long-range communication link.



LoRa

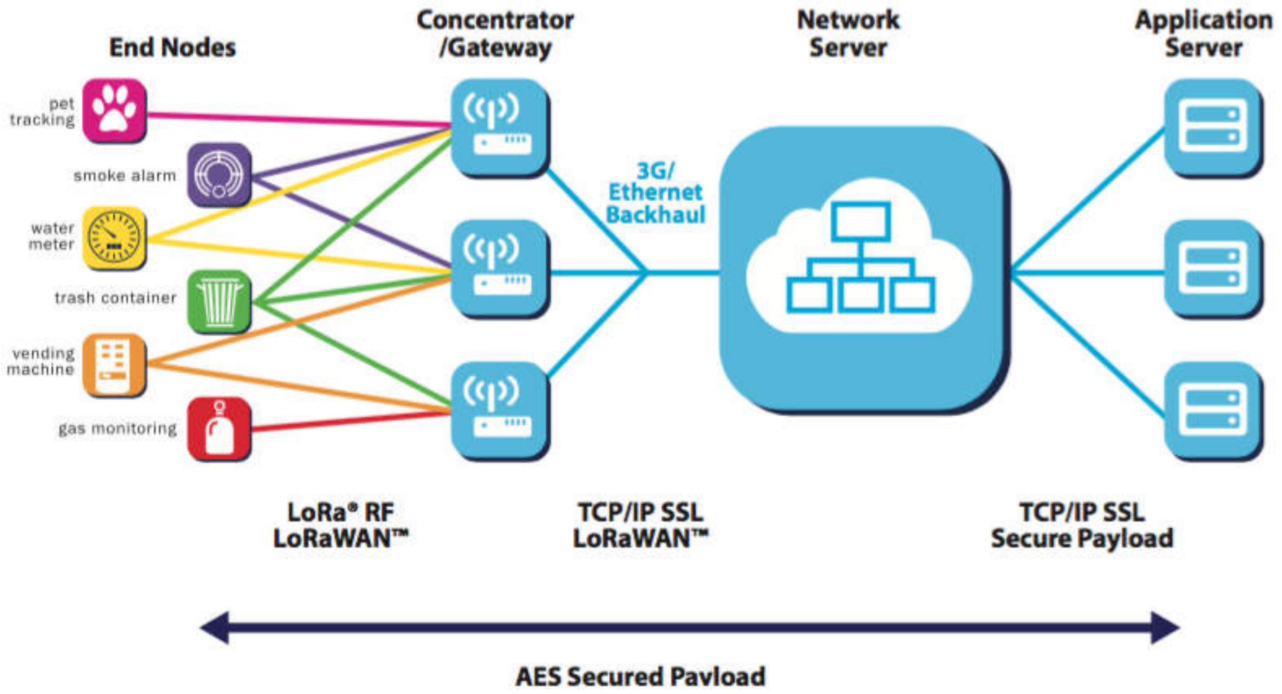
What is it?

- LoRa technology was originally developed by a French company, Cycleo (founded in 2009 as an IP and design solution provider), a patented spread spectrum wireless modulation technology that was acquired by SemTech in 2012 for $5 million
- In April 2013, SemTech released the SX1272 chip, which was equipped with
  LoRa technology
  - At that time, FSK modulated European smart meter transceivers were used, with a maximum transmission distance of 1 to 2 kilometers
  - LoRa operated under the same conditions, and the transmission distance could be more

LoRa Technology

Two major components

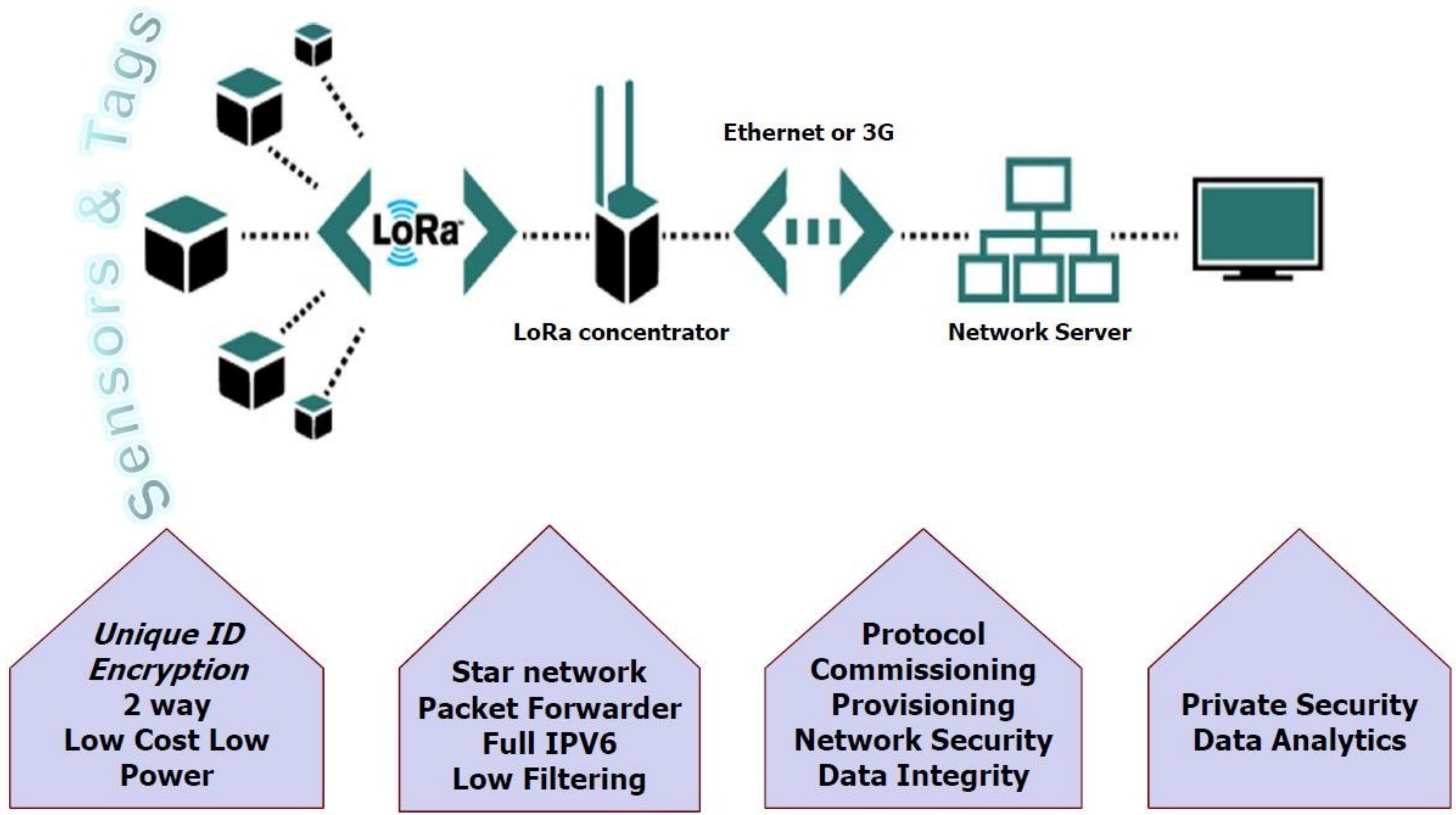
- End device: ED
- Base Station: BS



LoRaWAN network protocol

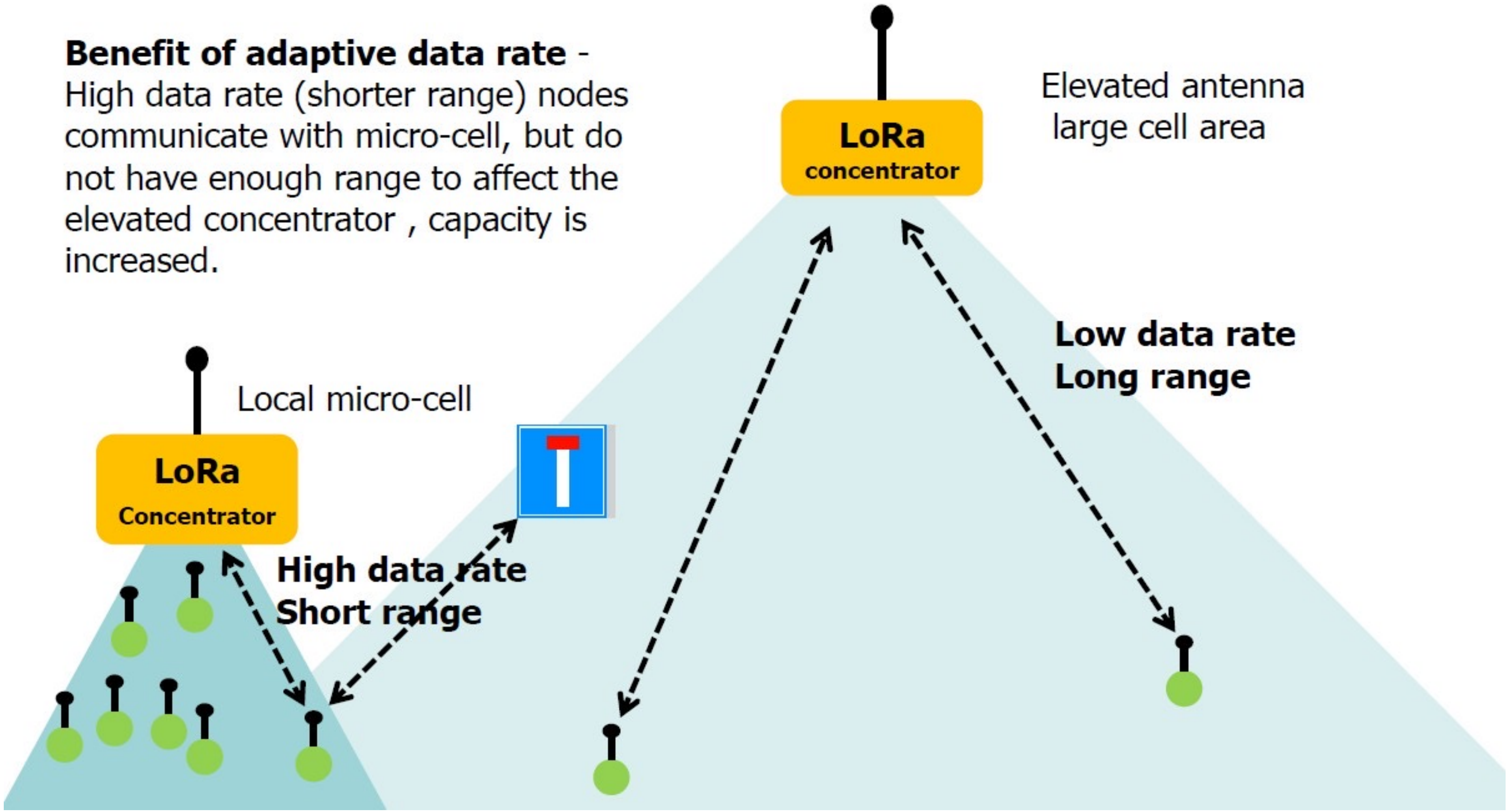
- LoRaWAN network protocol is optimized specifically for energy limited EDs
- LPWAN typically has star topology and consists of BSs relaying data messages between the EDs and an application server
- The BSs can be connected to the central server via backbone internet protocol (IP) based link, and the wireless communication based on LoRa or GFSK modulation is used to move the data between EDs and the BSs

Network Architecture

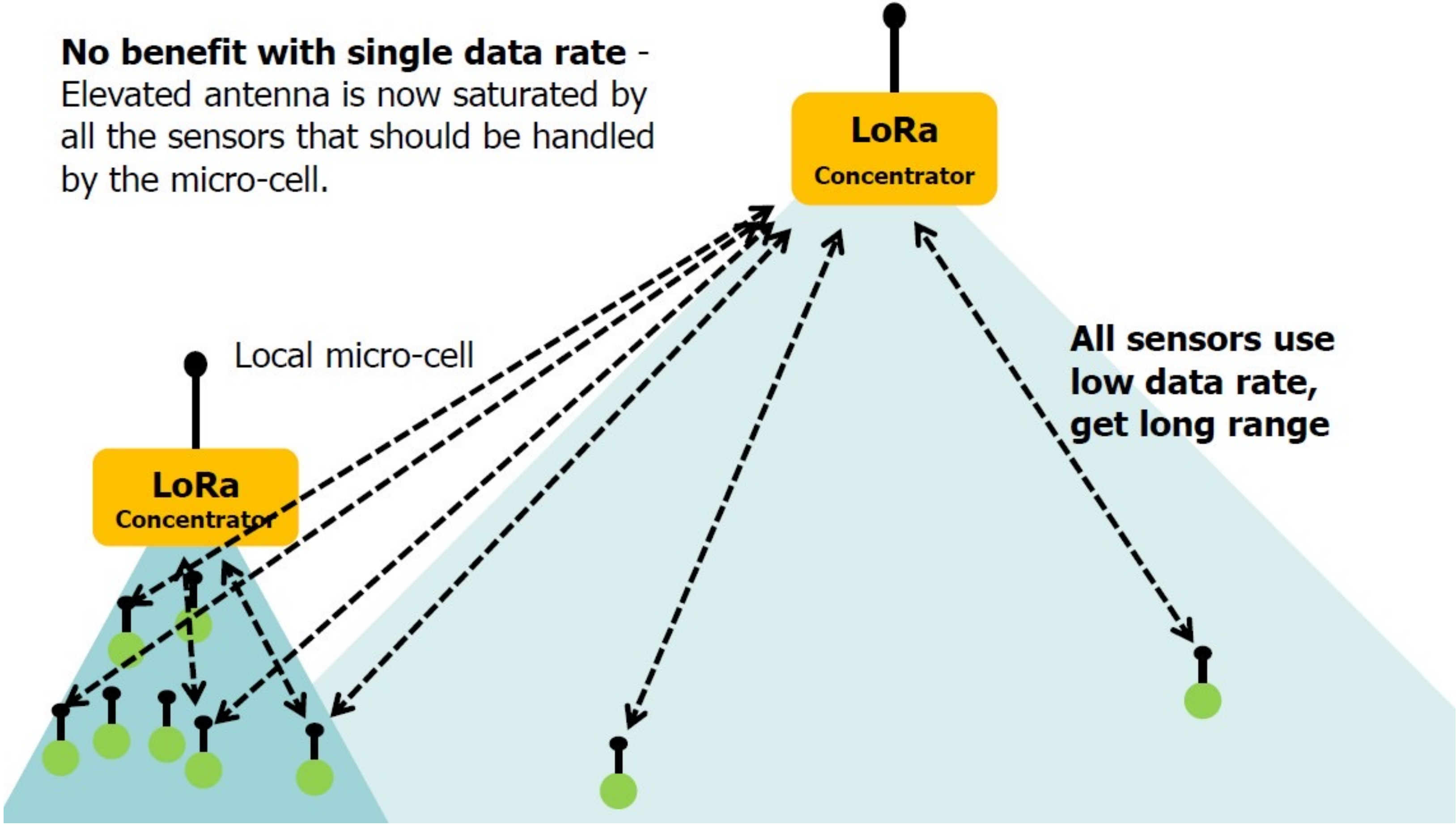


Network Capacity: Adaptive Data Rate

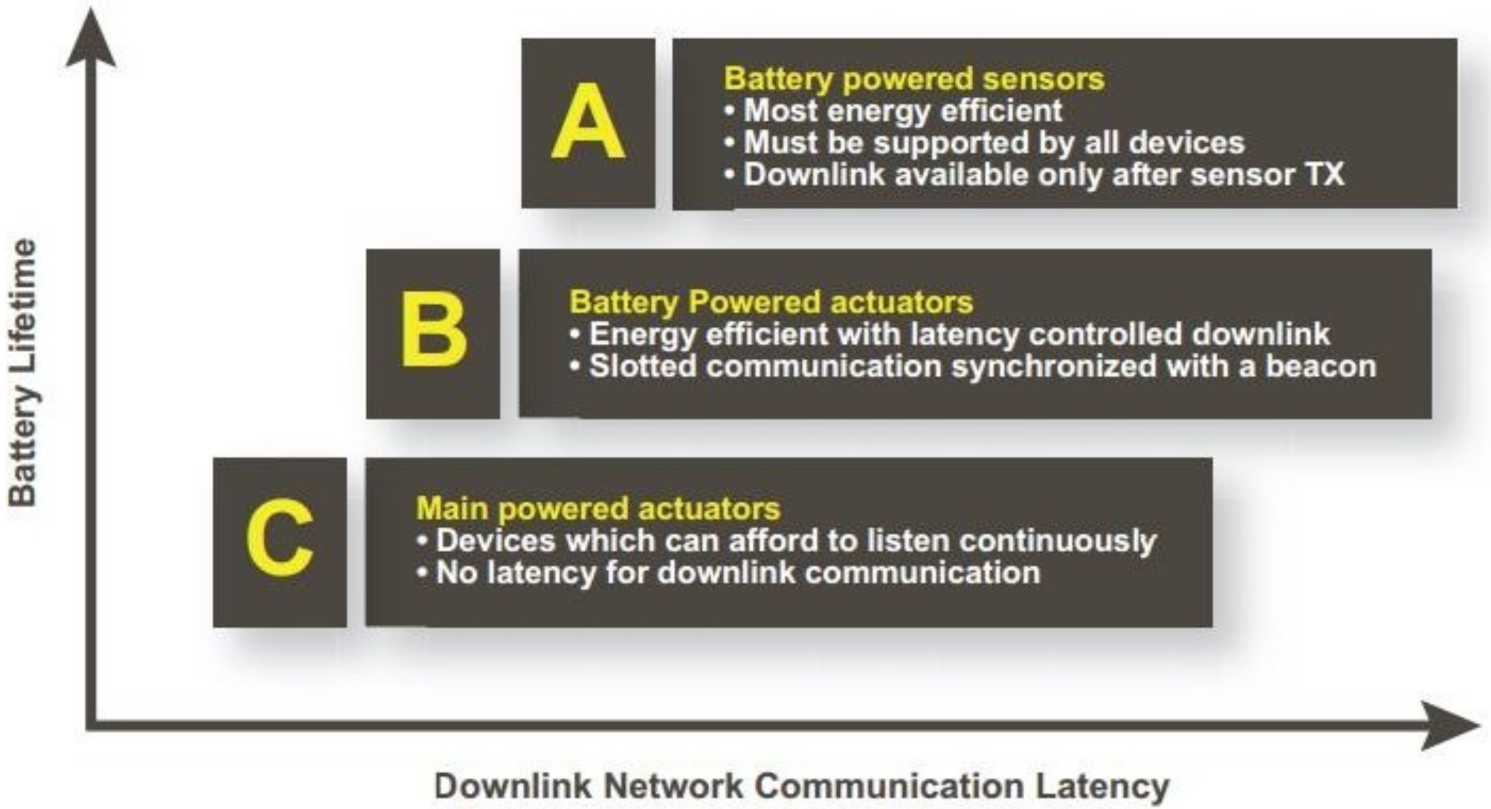
Benefit of adaptive data rate - High data rate (shorter range) nodes communicate with micro-cell, but do not have enough range to affect the elevated concentrator , capacity is increased.



Network Capacity: Single Data Rate



Three classes of EDs



LoRaWAN Performance

Data rates settings and frames characteristics

Table I. LoRaWAN data rates settings and frames characteristics

Data rate (DR)	SF	Band width, kHz	Modu-lation	maximum MACPayload size, bytes	Maximum FRMPayload size[1], bytes	Shortest downlink frame ToA, s	Longest downlink frame ToA, s	Shortest uplink frame ToA, s	Longest uplink frame ToA, s
0	12	125	LoRa	59	51	0.991	2.793	1.155	2.793
1	11	125	LoRa	59	51	0.578	1.479	0.578	1.561
2	10	125	LoRa	59	51	0.289	0.698	0.289	0.698
3	9	125	LoRa	123	115	0.144	0.677	0.144	0.677
4	8	125	LoRa	250	242	0.072	0.697	0.082	0.707
5	7	125	LoRa	250	242	0.041	0.394	0.041	0.400
6	7	250	LoRa	250	242	0.021	0.197	0.021	0.200
7	n/a	150	GFSK	250	242	0.0032	0.0421	0.0035	0.0424

[1] - given that $FHDR_{OPTS}$=0

LoRaWAN Performance

Maximum throughput per LoRaWAN channel and ED

Table IV. Maximum throughput per LoRaWAN channel and ED

Data rate (DR)	Bandwidth, kHz	Maximum APP throughput per channel, bit/s	Maximum APP throughput per ED per channel, bit/s		
			10% duty cycle	1% duty cycle	0.1% duty cycle
0	125	146.1	14.61	1.46	0.15
1	125	261.4	26.14	2.61	0.26
2	125	584.2	58.42	5.84	0.58
3	125	1 359.2	135.92	13.59	1.36
4	125	2 738.1	273.81	27.38	2.74
5	125	4 844.7	484.47	48.45	4.84
0-5 cumulative[1]	125	9 933.6	n/a	n/a	n/a
6	250	9 689.3	968.93	96.89	9.69
7	150	45 660.4	1 851.6[2]	456.6	45.66

[1]- given that the spreading factors for DR0-DR5 are orthogonal, the transmissions with different SF may coexist in the same channel at the same time
[2]- due to the need for opening RX windows after each frame, the maximum possible duty cycle is 4.1% (see Table II, acknowledged transmission)

COMPARING LPWAN TECHNOLOGY OPTIONS

Feature	LoRaWAN	Narrow-Band	LTE Cat-1 2016 (Rel12)	LTE Cat-M 2018 (Rel13)	NB-LTE 2019(Rel13+)
Modulation	SS Chirp	UNB / GFSK/BPSK	OFDMA	OFDMA	OFDMA
Rx bandwidth	500 - 125 KHz	100 Hz	20 MHz	20 - 1.4 MHz	200 KHz
Data Rate	290bps - 50Kbps	100 bit/sec 12 / 8 bytes Max	10 Mbit/sec	200kbps – 1Mbps	~20K bit/sec
Max. # Msgs/day	Unlimited	UL: 140 msgs/day	Unlimited	Unlimited	Unlimited
Max Output Power	20 dBm	20 dBm	23 - 46 dBm	23/30 dBm	20 dBm
Link Budget	154 dB	151 dB	130 dB+	146 dB	150 dB
Batery lifetime - 2000mAh	105 months	90 months		18 months	
Power Efficiency	Very High	Very High	Low	Medium	Med high
Interference immunity	Very high	Low	Medium	Medium	Low
Coexistence	Yes	No	Yes	Yes	No
Security	Yes	No	Yes	Yes	Yes
Mobility / localization	Yes	Limited mobility, No loc	Mobility	Mobility	Limited Mobility No Loc

Conclusion

- LoRaWAN technology, like any other, has its own strengths and weaknesses
  - The high coverage and satisfactory scalability under low uplink traffic
  - The most critical drawbacks are low reliability and potentially poor performance in terms of downlink traffic
- LoRa can be effectively utilized for the moderately dense networks of very low traffic devices which do not impose strict latency or reliability requirements