COMMTECH knowledge

IoT-Internet of Things

5G Trends in Low Power Wireless Communication for IoT

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Technology map

- Short and medium range:
  - Bluetooth
  - WiFi (802.15.11ah)
  - ZigBee based on 802.15.4
  - Industrial standards based on 802.15.4
- Long range
  - LoRa
  - Sigfox
  - Other proprietary technologies
- Cellular 2G, 3G or 4G
  - eMTC (LTE)
  - EC-GSM
  - NB-IoT
- Other organizations
  - ETSI Low Throughput Network
  - IETF 6LPWALP-WAN
  - Weightless SIG
  - DASH7 Alliance

Low Power Wide Area (LPWA) Networks

LPWA technologies for IoT applications

- Complement cellular and short range wireless technologies in addressing diverse requirements.
- One fourth of overall 30 billion IoT/M2M devices require wide-area connectivity for low power and low data rate devices.
- Range of a few to tens of kilometers
- Battery life of ten years and beyond
- For those use cases that are delay tolerant, do not need high data rates, and typically require low power consumption and low cost.

Design Goals And Techniques

- *Long Range*
- *Ultra Low Power Operation*
- *Low Cost*
- *Scalability,* support for massive number of devices sending low traffic volumes, with increasing number and densities of connected devices.
- *Quality of Service,* LPWA technologies provide no or limited QoS.

Long Range

- *Use of Sub-1GHz Band,* compared to the 2.4 GHz band
  - Ø Less congested
  - Ø Less attenuation and multipath fading caused by obstacles and dense surfaces
- *Modulation Techniques,* designed to achieve a link budget of 150+/-10 dB
  - Ø Spread spectrum techniques spread a narrowband signal over a wider bandwidth, the transmission is a noise-like signal harder to detect by an eavesdropper, more resilient to interference, and robust to jamming attacks
    - § Chirp Spread Spectrum (CSS)
    - § Direct Sequence Spread Spectrum (DSSS)
  - Ø Narrowband modulation techniques with a low bandwidth signal, usually less than 25kHz. The noise level experienced inside a single narrowband is also minimal. No frequency de-spreading is required to decode the signal at the receiver, resulting in simple and inexpensive transceiver design. An *ultra* narrow band (UNB) of width as short as 100Hz, further reducing the experienced noise and increasing the number of supported end-devices per unit bandwidth. However, the effective data rate for individual end devices decreases as well, thus increasing the amount of time the radio needs to be kept ON. This low data rate in combination with spectrum regulations on sharing underlying bands may limit maximum size and transmission frequency of data packets, limiting number of business use cases.

Ultra Low Power Operation

A battery lifetime of 10 years or more with AA or coin cell batteries is desirable to bring the maintenance cost down.

Ø *Topology*

- Mesh topology - the traffic is forwarded over multiple hops towards a gateway, some nodes get more congested than others depending on their location or network traffic patterns. They deplete their batteries quickly, limiting overall network lifetime to only a few months to years.
- Star topology connects end devices *directly* to an always-on base station provides quick access when required by the end-devices.

Ø *Duty Cycling*

Allows LPWA end devices to turn off their transceivers, when not required. Only when the data is to be transmitted or received, the transceiver is turned on. If an application needs to transfer the data only over the uplink, the end devices may wakeup only when data is ready to be transmitted.
If downlink transmissions are required as well, the end devices may wakeup at a scheduled time agreed with the base station.

Ø *Lightweight Medium Access Control*

Carrier sense multiple access with collision avoidance (CSMA/CA) using Request to Send/Clear to Send (RTS/CTS) with extra communication
ALOHA is a random access MAC protocol in which end devices transmit without doing any carrier sensing. The simplicity of ALOHA is thought to keep design of transceiver simple and low cost.
TDMA based MAC protocols are also considered to allocate radio resources more efficiently at the expense of more complexity.

Ø *Offloading Complexity From End Devices*

Low Cost

- *Reduction in Hardware Complexity*
- *Minimum Infrastructure*
- *Using License-Free or Owned Licensed Bands*

Scalability

Support for massive number of devices sending low traffic volumes, technologies should work well with increasing number and densities of connected devices.

- *Diversity Techniques*
  multi-channel and multi-antenna communication and redundant transmissions.

- *Densification*
  dense deployments of base stations.

- *Adaptive Channel Selection and Data Rate*
  Adapting the modulation schemes, selecting better channels to reach distances reliably, or adaptive transmission power control require efficient monitoring of link qualities and coordination between end devices and network.

Proprietary Technologies

- SigFox
- LoRa
- Ingenu
- Telensa
- Qowisio
- Cohere

SIGFOX

- Base stations with cognitive software-defined radios.
  The end devices connect to these base stations using Binary Phase Shift Keying (BPSK) modulation in an ultra-narrow (100Hz) Sub-GHz ISM band carrier.

- Bidirectional technology, with a significant link asymmetry.
  The downlink communication precede uplink communication after which the end device should wait to listen for a response from the base station. The number and size of messages over the uplink are limited to 140 12-byte messages per day to conform to the regional regulations on use of license-free spectrum.
  Over the downlink transmission of maximum of only 4 8-bytes per day.

- Reliability of the uplink communication is improved by using time and frequency diversity as well as redundant transmissions
  In Europe, the band between 868.180-868.220MHz is divided into 400 100Hz channels, out of which 40 channels are reserved and not used.

LoRa and LoRaWAN

- Modulates the signals in Sub-GHz ISM band using a proprietary spread spectrum technique developed and commercialized by Semtech Corporation.

- A bidirectional communication is provided by a chirp spread spectrum (CSS) technique
  Multiple spreading factors (7-12) to decide the tradeoff between range and data rate. Higher spreading factors delivers long range at an expense of lower data rates and vice versa.
  Forward Error Correction (FEC) to further increase the receiver sensitivity.
  The data rate ranges from 300 bps to 37.5 kbps depending on spreading factor and channel bandwidth.
  Multiple transmissions using different spreading factors can be received simultaneously by a LoRa base station - provide a third degree of diversity after time and frequency.

- "Star-of-stars" topology:

- Multiple receptions of same message at different base stations are used for localization of the transmitting end device. A time difference of arrival (TDOA) based localization technique supported by very accurate time synchronization between multiple base station is used.

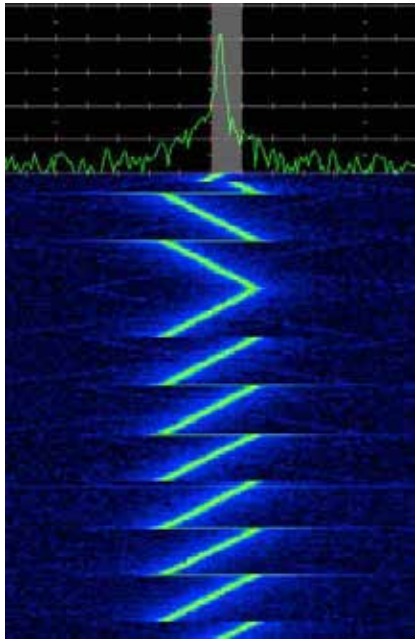
- LoRa™ Alliance proposed LoRaWAN, an open standard defining architecture and layers above the LoRa physical layer.

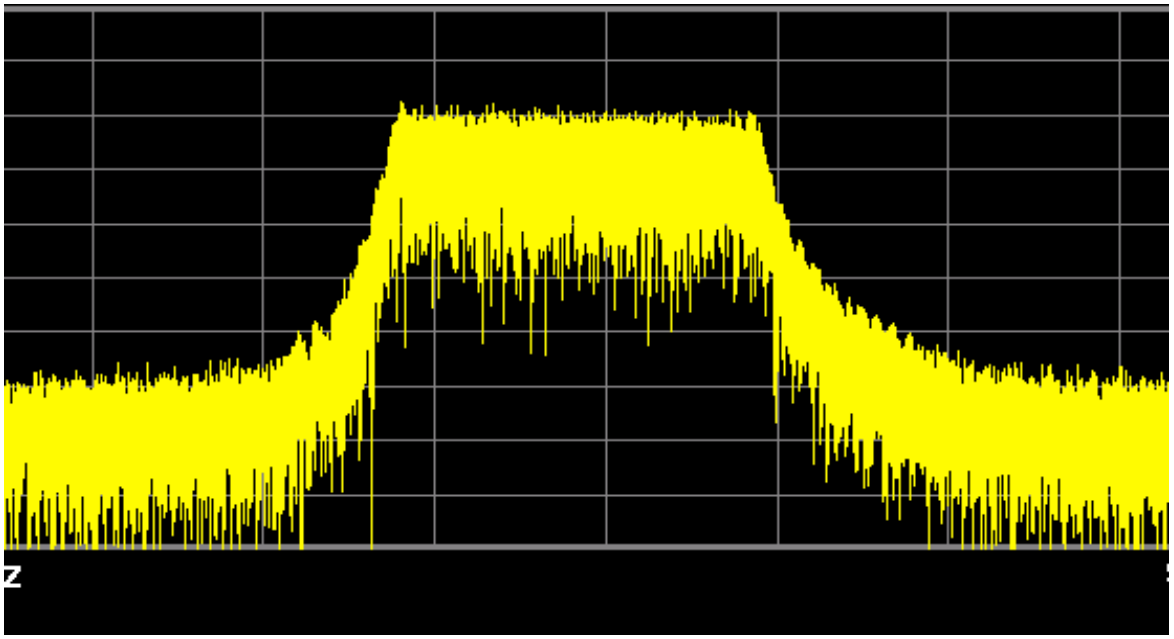
LoRaWAN™ Network Protocol
LoRa® Technology Modulation

A Spread Spectrum Technology

- Developed by Semtech Corporation (http://www.semtech.com/)
- Chirped-FM modulation, symbols of ramping frequency
- Processing gain = increased receive sensitivity
- Enables longer range at expense of lower data rate

SEMTECH





LoRa® Technology Modulation

- **Spreading Factor (SF)**
  - Programmable SF:

    7, 8, 9, 10, 11, 12
  - The higher the SF the more information transmitted per bit; therefore higher processing gain
- **Bandwidth (BW)**
  - Programmable signal BW settings:

    125 kHz, 250 kHz, 500 kHz
  - For a given SF, a narrower BW = increased receive sensitivity; however, increased time on air
- **Forward Error Correction (FEC) Code Rate (CR)**
  - Additional coding rate provides more redundancy to detect errors and correct them

Modulation Settings for Europe

Longest Distance on LoRa® Modulation

- **Data Rate (DR) = 0**
  - LoRa® modulation
  - Spreading Factor (SF) = SF12
  - Bandwidth (BW) = 125 kHz
  - Coding Rate (CR) = 4/5
- **Bit Rate = 292 bps**
- **Max Application Payload Size = 51 bytes**
  - Time On Air = 2466 ms

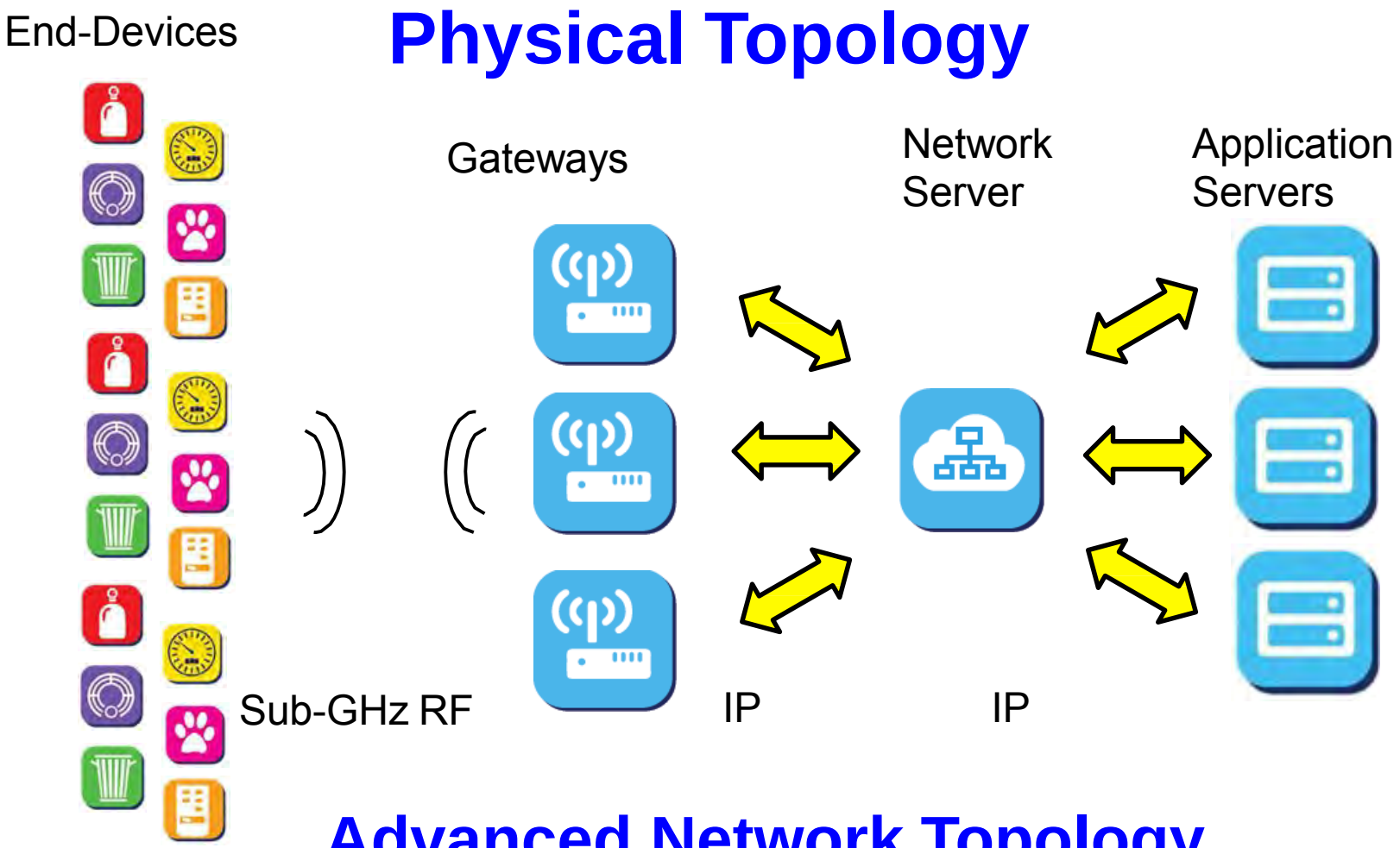
Modulation Settings for Europe

Highest Bit Rate on LoRa® Modulation

- **Data Rate (DR) = 6**
  - LoRa® modulation
  - Spreading Factor (SF) = SF7
  - Bandwidth (BW) = 250 kHz
  - Coding Rate (CR) = 4/5
- **Bit Rate = 10937 bps**
- **Max Application Payload Size = 222 bytes**
  - Time On Air = 185 ms

LoRaWAN™ Network Protocol

How Does LoRaWAN Protocol Work?



End-Device Classes

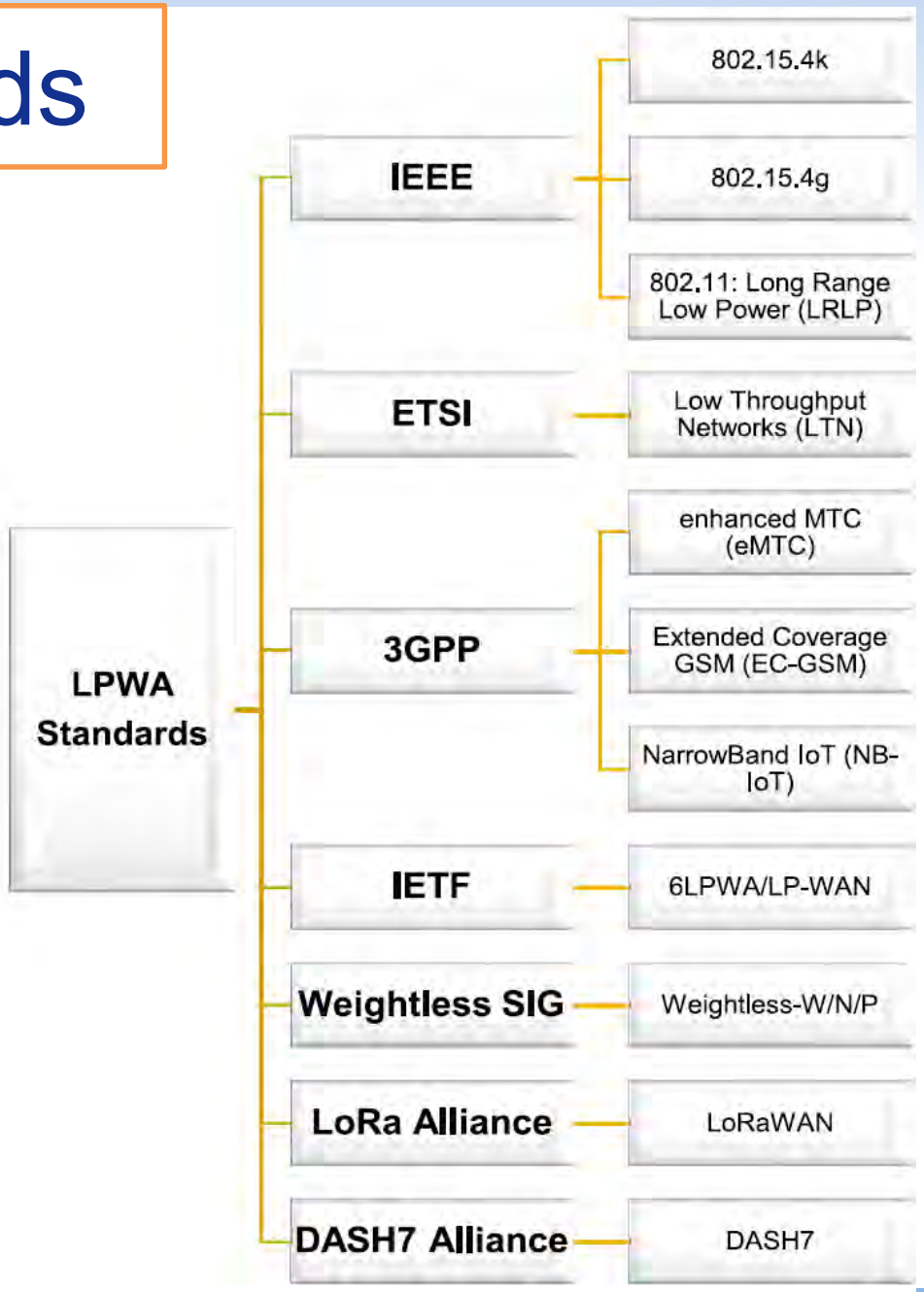
Each end-device class has different behavior depending on the choice of optimization:

- Battery Powered – Class A
- Low Latency – Class B
- No Latency – Class C

Technical Specifications of Various LPWA Technologies

	SIGFOX	LORAWAN	INGENU	TELENSA
Modulation	UNB DBPSK(UL), GFSK(DL)	CSS	RPMA-DSSS(UL), CDMA(DL)	UNB 2-FSK
Band	SUB-GHZ ISM:EU (868MHz), US(902MHz)	SUB-GHZ ISM:EU (433MHz 868MHz), US (915MHz), Asia (430MHz)	ISM 2.4GHz	SUB-GHZ bands including ISM:EU (868MHz), US (915MHz), Asia (430MHz)
Data rate	100 bps(UL), 600 bps(DL)	0.3-37.5 kbps (LORA), 50 kbps (FSK)	78kbps (UL), 19.5 kbps(DL) [39]	62.5 bps(UL), 500 bps(DL)
Range	10 km (URBAN), 50 km (RURAL)	5 km(URBAN), 15 km (RURAL)	15 km (URBAN)	1 km (URBAN)
Num. of channels / orthogonal signals	360 channels	10 in EU, 64+8(UL) and 8(DL) in US plus multiple SFs	40 1MHz channels, up to 1200 signals per channel	multiple channels
Link symmetry	×	✓	×	×
Forward error correction	×	✓	✓	✓
MAC	unslotted ALOHA	unslotted ALOHA	CDMA-like	?
Topology	star	star of stars	star, tree	star
Adaptive Data Rate	×	✓	✓	×
Payload length	12B(UL), 8B(DL)	up to 250B (depends on SF & region)	10KB	?
Handover	end devices do not join a single base station	end devices do not join a single base station	✓	?
Authentication & encryption	encryption not supported	AES 128b	16B hash, AES 256b	?
Over the air updates	×	✓	✓	✓
SLA support	×	×	×	×
Localization	×	✓	×	×

LPWA Standards



IEEE 802.15.4k

- *Low Energy, Critical Infrastructure Monitoring* (LECIM) *Networks*
- Operate in the ISM bands (Sub-GHz and 2.4 GHz)
- DSSS and FSK as two new PHY layers.
- Multiple discrete channel bandwidths ranging from 100kHz to 1MHz.
- The MAC layer specifications:
  CSMA/CA without priority channel access (PCA),
  CSMA, and ALOHA with PCA. to prioritize their traffic in accessing the medium, providing a notion of quality of service.
- Star topology exchanging asynchronous and scheduled messages.

IEEE 802.15.4g

- *Low-Data-Rate, Wireless, Smart Metering Utility Networks*
- Massive number of fixed end devices deployed across cities or countries.
- Three PHY layers:
  - FSK
  - Orthogonal Frequency- Division Multiple Access (OFDMA)
  - Offset Quaternary Phase Shift Keying (OQPSK)
- Multiple data rates from 40 kbps to 1 Mbps.
- Frames of size up to 1500 bytes so to avoid fragmenting Internet Protocol (IP) packets.

Wi-Fi HaLow

- *IEEE 802.11 - Wireless Local Area Networks* - WLAN technologies
- Efforts for extending range and decreasing power consumption for WLAN in IEEE 802.11 Task Group AH (TGah)
- PHY and MAC for long range Wi-Fi operation in Sub-GHz ISM band. New features to achieve 1 km range in outdoor environments and the data rate in excess of 100 kbps.
- PHY adopts OFDM that transmit at the rate 10 times slower than IEEE 802.11ac, an earlier standard, so to extend the communication range.
- At the MAC layer, over heads associated with frames, headers and beacons are reduced to prolong battery powered operation.
- MAC protocol is tailored to thousands (8191) of connected end devices so that it reduces the resulting collisions among them.
- End devices are enabled with mechanisms to save energy during the inactive periods but yet retain their connection/synchronization with the access points.
- Provides significantly longer range and lower energy consumption than other WLAN standards, ZigBee, and Bluetooth but not as much as the other LPWA technologies.

Technical Specifications of Various LPWA standards

Standard	IEEE		Weightless-SIG			Dash7 Alliance
	802.15.4k	802.15.4g	Weightless-W	Weightless-N	Weightless-P	Dash7
Modulation	DSSS, FSK	MR-(FSK, OFDMA, OQPSK)	16-QAM, BPSK, QPSK, DBPSK	UNB DBPSK	GMSK, offset-QPSK	GFSK
Band	ISM Sub-GHz & 2.4GHz	ISM Sub-GHz & 2.4GHz	TV white spaces 470-790MHz	ISM Sub-GHz EU (868MHz), US (915MHz)	Sub-GHz ISM or licensed	Sub-GHz 433MHz, 868MHz, 915MHz
Data rate	1.5 bps-128 kbps	4.8 kbps-800 kbps	1 kbps-10 Mbps	30 kbps-100 kbps	200 bps-100kbps	9.6,55.6,166.7 kbps
Range	5 km (urban)	up to several kms	5 km (urban)	3 km (urban)	2 km (urban)	0-5 km (urban)
Num. of channels / orthogonal signals	multiple channels Number depends on channel & modulation		16 or 24 channels(UL)	multiple 200 Hz channels	multiple 12.5 kHz channels	3 different channel types (number depends on type & region)
Forward error correction	✓	✓	✓	×	✓	✓
MAC	CSMA/CA, CSMA/CA or ALOHA with PCA	CSMA/CA	TDMA/FDMA	slotted ALOHA	TDMA/FDMA	CSMA/CA
Topology	star	star, mesh, peer-to-peer (depends on upper layers)	star	star	star	tree, star
Payload length	2047B	2047B	>10B	20B	>10B	256B
Authentication & encryption	AES 128b	AES 128b	AES 128b	AES 128b	AES 128/256b	AES 128b

3GPP

- 3GPP is evolving its existing cellular standards to strip complexity and cost, improve the range and signal penetration, and prolong the battery lifetime.
  - Ø Long Term Evolution (LTE) enhancements for Machine Type Communications (eMTC)
  - Ø Extended Coverage GSM (EC-GSM)
  - Ø Narrow- Band IoT (NB-IoT)
- Offer different trade-offs between cost, coverage, data rate, and power consumption to address diverse needs of IoT and M2M applications.

3GPP: eMTC

- *LTE Enhancements for Machine Type Communications (eMTC):*
- Conventional LTE end devices offer high data rate services at a cost and power consumption not acceptable for MTC use cases. To reduce the cost while being compliant to LTE system requirements, 3GPP reduces the peak data rate from LTE Category 1 to LTE Category 0 and then to LTE Category M1. Further cost reduction is achieved by supporting optional half duplex operation in Category 0.
- From Category 0 to Category M1 (eMTC), a pronounced drop in the receive bandwidth from 20 MHz to 1.4 MHz in combination with a reduced transmission power will result in more cost-efficient and low-power design.
- To extend the battery lifetime for eMTC, 3GPP adopts two features:
  - *Power Saving Mode (PSM)* and
  - *extended Discontinuous Reception (eDRx)*.

  They enable end devices to enter in a deep sleep mode for hours or even days without losing their network registration. The end devices avoid monitoring downlink control channel for prolonged periods of time to save energy.

3GPP: EC-GSM & NB-IoT

- EC-GSM extend the GSM coverage by +20dB using Sub-GHz band for better signal penetration in indoor environments. Exploits repetitive transmissions and signal processing techniques to improve coverage and capacity of legacy GPRS.
  Two modulations Gaussian Minimum Shift Keying (GMSK) and 8-ary Phase Shift Keying (8PSK) provide data rates up to 240 kbps with the latter technique.
  The standard supports 50k devices per base station and enhanced security and privacy features compared to conventional GSM based solutions.

- NB-IoT is a narrow-band technology that was made available as a part of Release-13 and enables deployment flexibility, long battery life, low device cost and signal coverage extension.
  - NB-IoT is not compatible with 3G but can coexist with GSM, GPRS and LTE. It can be deployed in a single GSM carrier of 200 kHz, inside a single LTE physical resource block (PRB) of 180 kHz or inside an LTE guard band. NB-IoT cuts the cost and energy consumption further by reducing the data rate and bandwidth requirements (needs only 180 kHz) and simplifying the protocol design and mobility support. - -
  - NB-IoT aims for a 164 dB coverage, serving up to 50k end devices per cell with the potential for scaling up the capacity by adding more NB-IoT carriers.
  - NB-IoT uses single-carrier Frequency Division Multiple Access (FDMA) in uplink (up to 20 kbps) and Orthogonal FDMA (OFDMA) in downlink (up to 250 kbps).
  - An NB-IoT based radio can achieve a battery life of 10 years when transmitting 200 bytes of data per day.

Short and Medium Range Networks

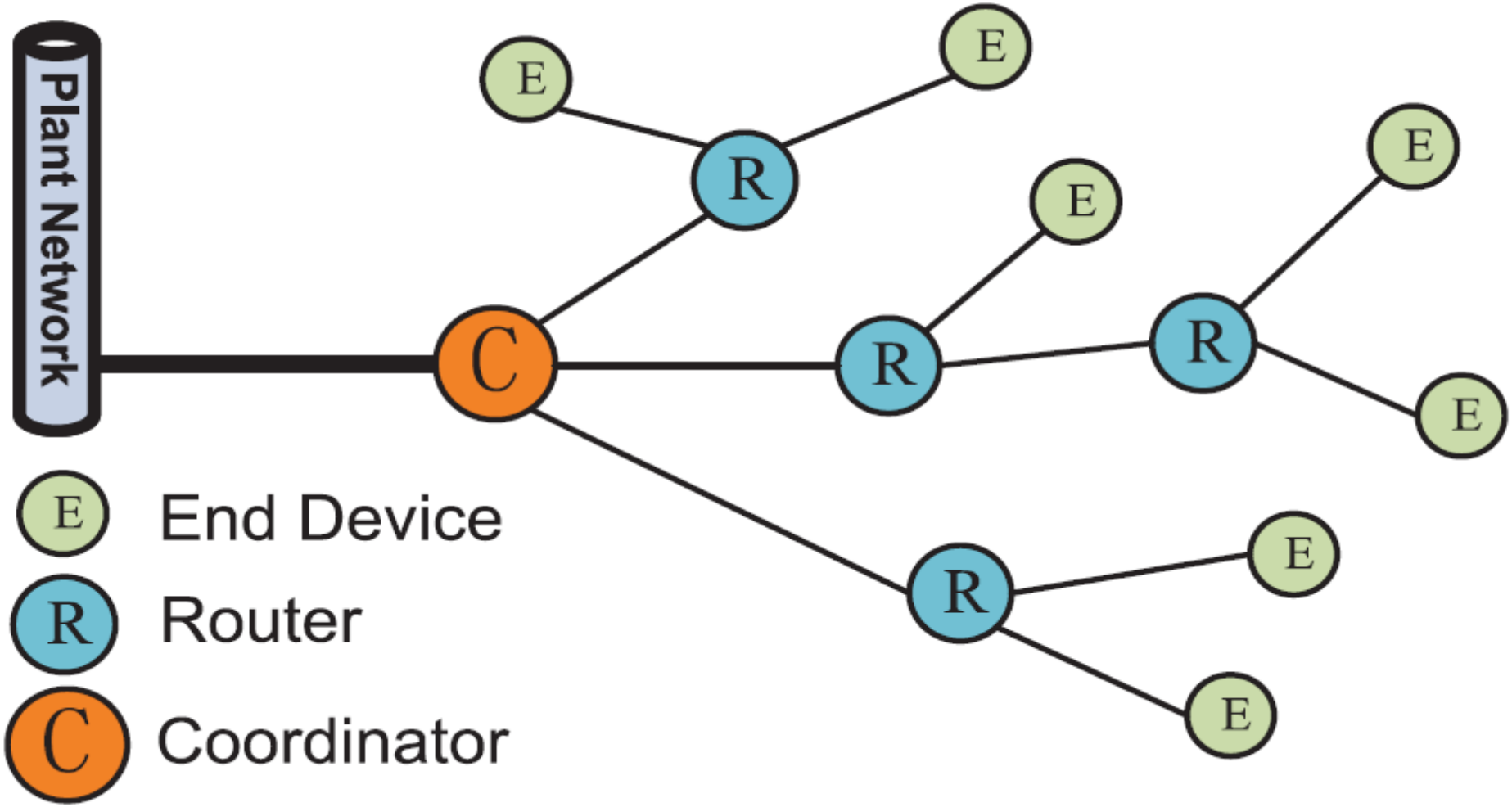
Bluetooth
WiFi (802.15.11ah)
ZigBee based on 802.15.4
Industrial standards based on 802.15.4

Industrial Wireless Sensor Network Standards

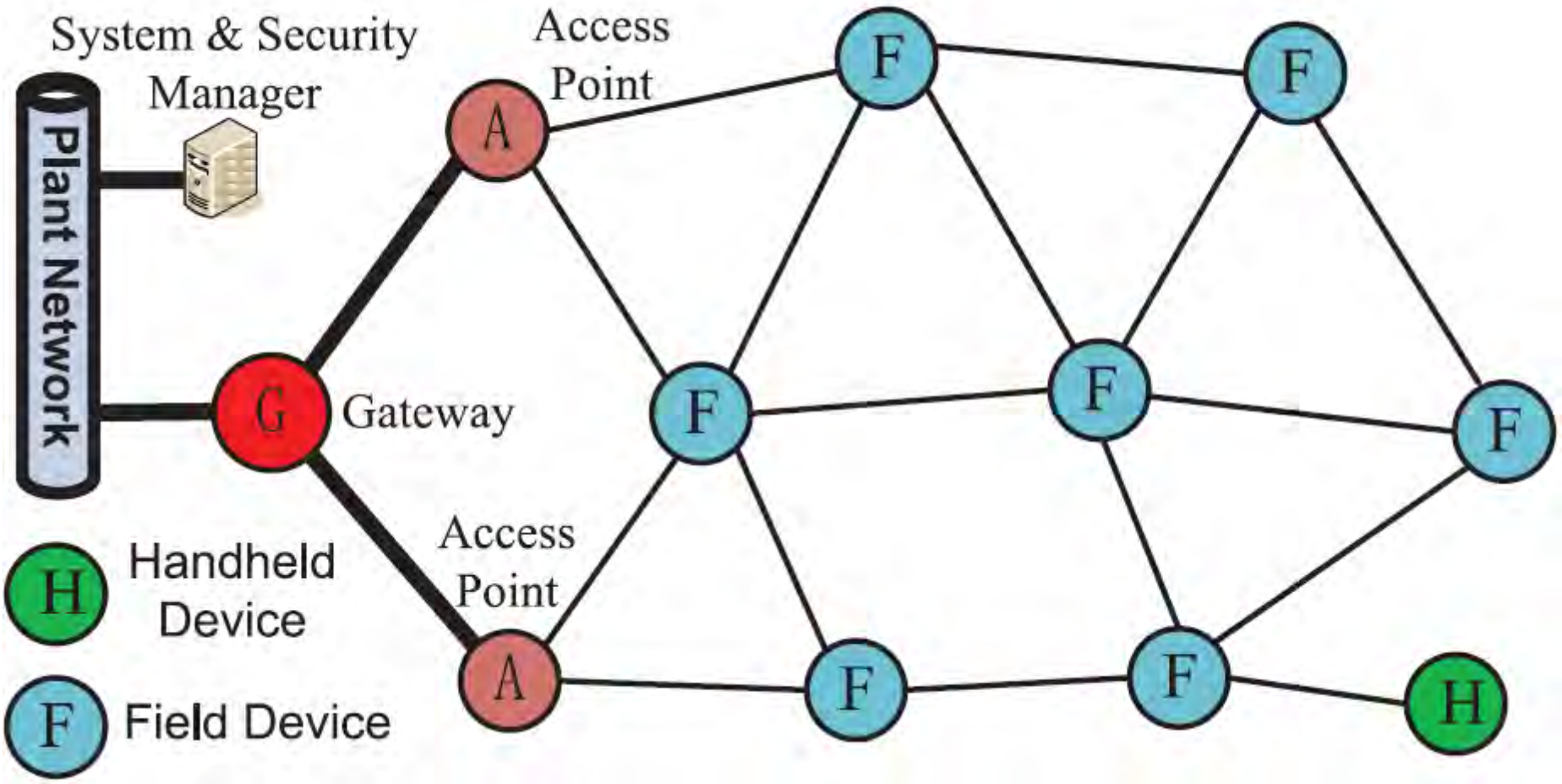
Four most popular industrial wireless sensor network standards:

- ZigBee
- WirelessHART
- ISA100.11a
- WIA-PA.

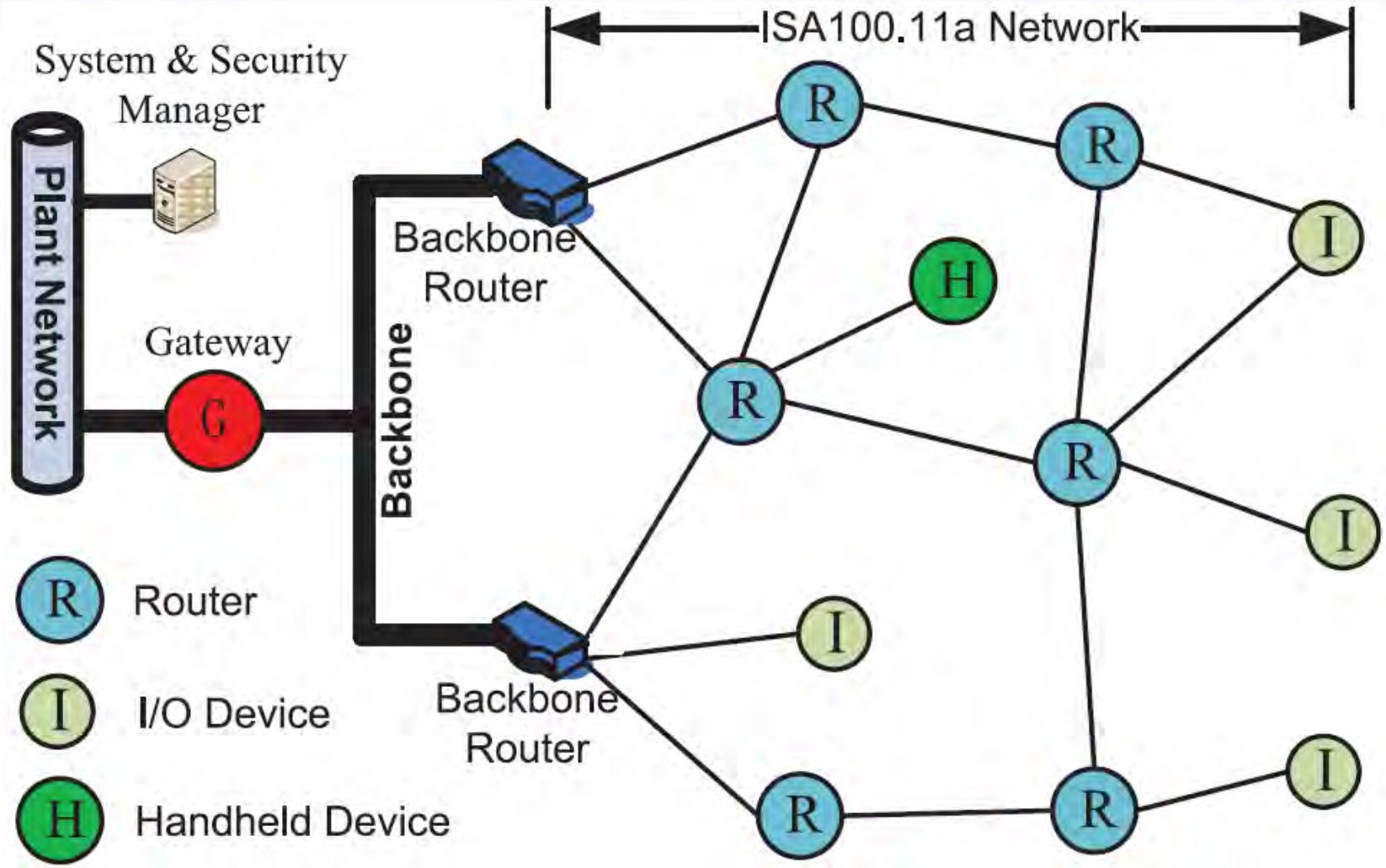
Typical Structure of the ZigBee Networks



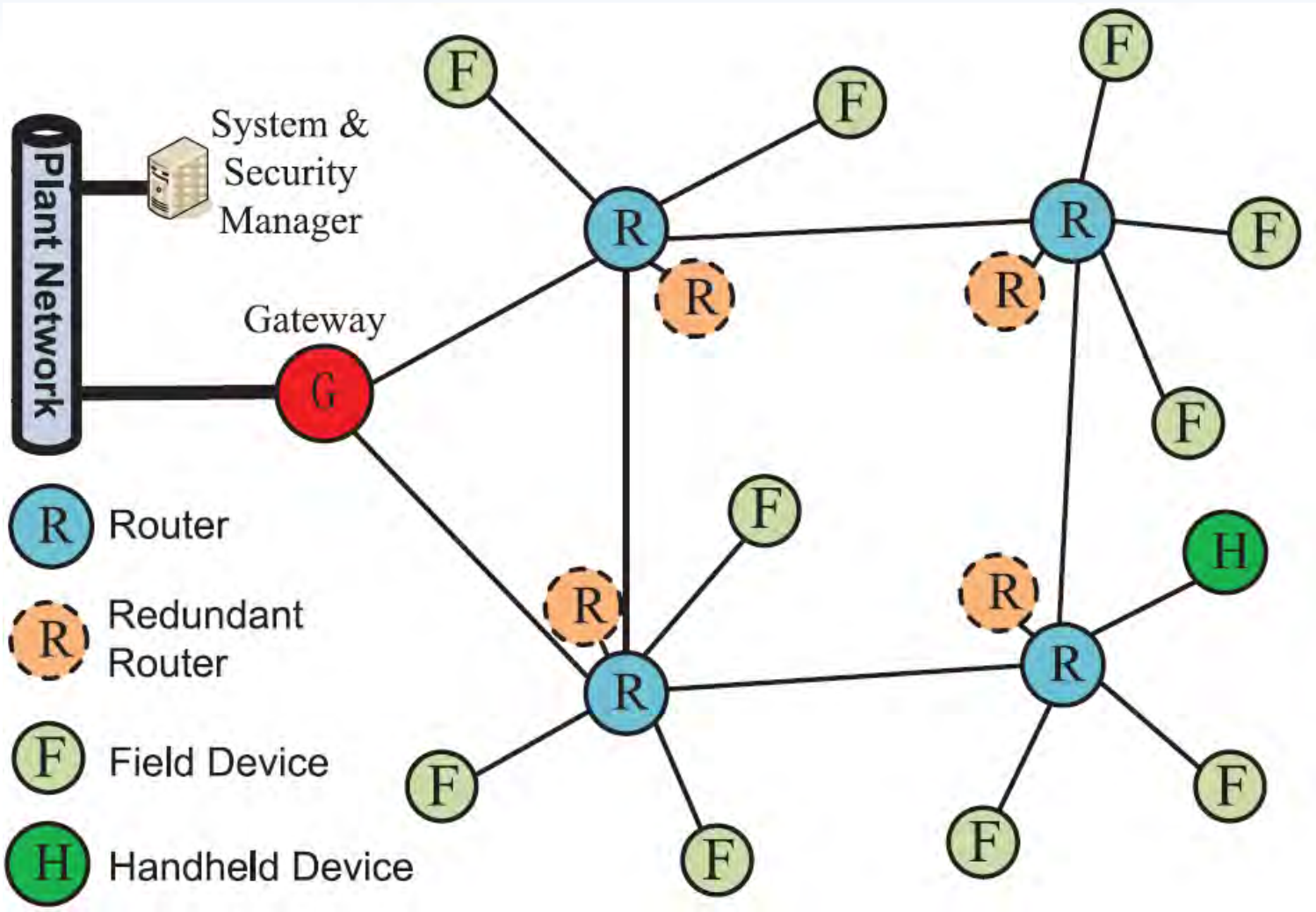
Typical Structure of the WirelessHART Networks



Typical Structure of the ISA 100.11a Networks



Typical Structure of the WIA-PA Networks



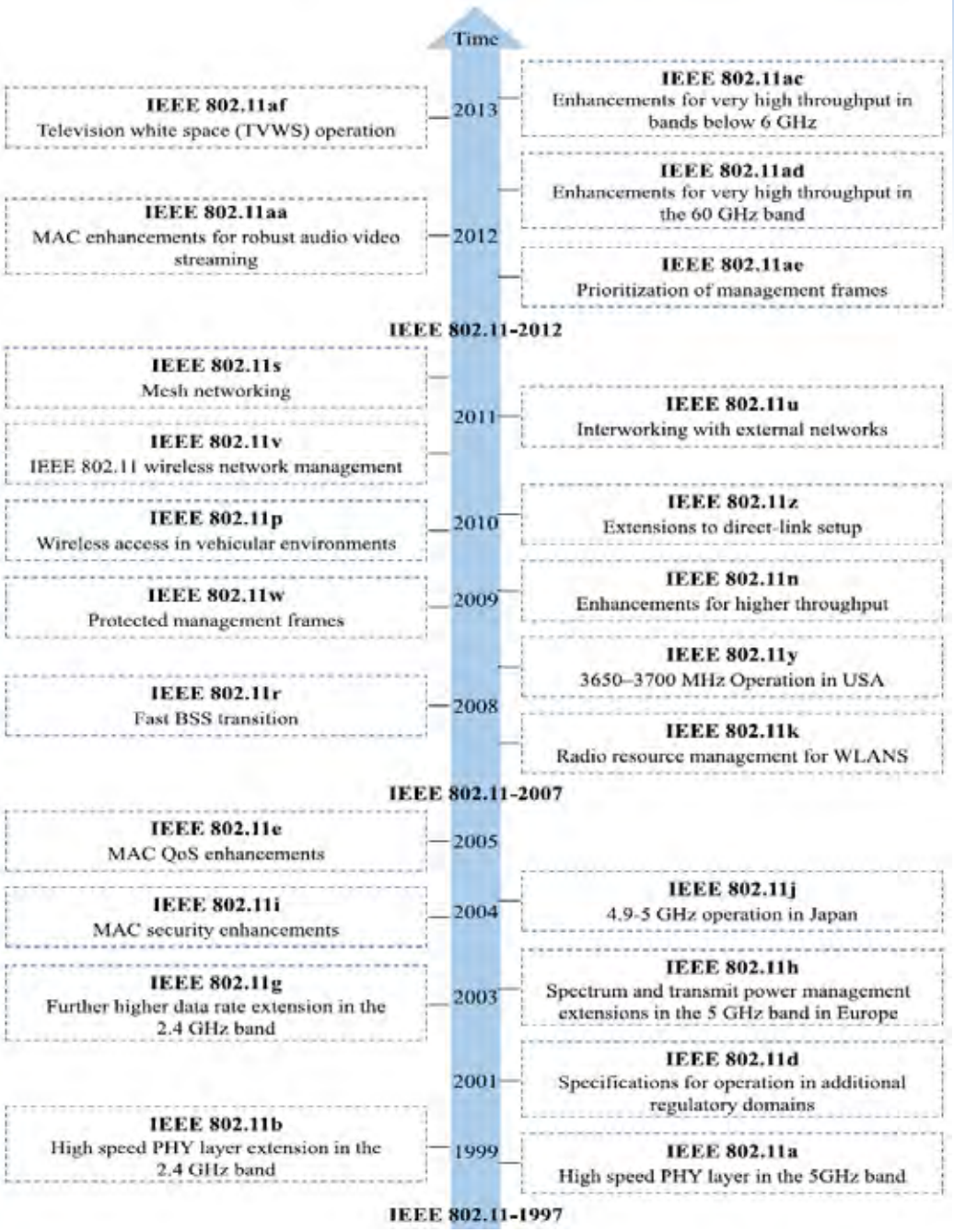
Frequency Bands of the Physical Layer in IEEE 802.15.4

Band	Geographical	Frequency band	Number of Channels	Bit rate	Channel bandwidth	Channel Number
868 MHz	Europe	868 to 868.6 MHz	1	20 kbits/s	600 kHz	0
915 MHz	America	902 to 928 MHz	10	40 kbits/s	2 MHz	1 – 10
2.4 GHz	Worldwide	2.4 to 2.4835 GHz	16	250 kbits/s	5 MHz	11 – 26

Comparison of Technical Features

Layer	Element	ZigBee	WirelessHART	ISA100.11a	WIA-PA
PHY	Number of channel	27 (All Bands)	15 (2.4GHz Band)	16 (2.4GHz Band)	16 (2.4GHz Band)
MAC /DLL	Beaconing	Yes/No	No	No	Yes
	Superframe Structure	IEEE802.15.4 Superframe	Collection of Timeslots	Collection of Timeslots	IEEE802.15.4 Superframe
	Access Method	Slotted and Unslotted CSMA	TDMA/CSMA	TDMA/CSMA	TDMA/CSMA
	Frequency Hopping	No (Frequency agility)	Slotted Hopping	Slotted /Slow /Hybrid hopping	Slotted/Adaptive hopping /Adaptive Frequency Switch
	Timeslot Duration	Configurable	10ms	Flexible and configurable	Configurable
	Time Standard	Undefined	UTC	TAI	Optional UTC
	Cast Method	Unicast/Multicast /Broadcast	Unicast/Broadcast	Unicast/Broadcast /DuoCast / n-cast	Unicast/Multicast /Broadcast
DLL /NET	Routing	Tree/Z-AODV	Superframe/Source and Graph Routing	Superframe/Source and Graph Routing	Static Routing
NET	Network topology	Tree, Star, Mesh	Star, Mesh	Star, Mesh	Mesh + Star
APP	Native APP layer	ZigBee Profile	HART	ISA100.11a	Profibus/FF/HART
SYS	Clock Tolerance	Loose Requirement	10 ppm	10 ppm or Loose requirement	Loose Requirement
	Time Synchronization Mechanism	Beacon Frame	Advertisement + Pairwise communication	Advertisement / Pairwise communication	Beacon Frame; Time synchronization Frame
	Route Ability of Device	RFD without Routing Ability	All devices can operate as router	Non-routing field devices are allowed	Field device without route ability
	Handheld device	No	Yes	Yes	Yes
	Peer to Peer Communications	Full/Limited	Full	Full/Limited	Limited
	Resource allocation	Centralized + Distributed	Centralized	Centralize	Centralized + Distributed

Evolution of the IEEE 802.11 standard



High Data Rate LPWA Solution: IEEE 802.11ah

- Wi-Fi solution for high data rate and long range M2M networks. Can support a wide range of data rates from 150 kbps to 8 Mbps Highest maximum data rate among the low power and long range M2M communication solutions.
- Defines the Sub GHz license-exempt operation to support sensors and IoT applications to provide better support for wireless sensors and metering network, backhaul network for sensors and meters, and the extended range Wi-Fi.
- IEEE 802.11ac can achieve more than 500 Mbps using 80 MHz channels for local area coverage. In field tests, IEEE 802.11n achieved with MIMO, a maximum throughput of 148 Mbps and 40.8 Mbps at a range of 800 m and 1,800 m, respectively.

IEEE 802.11ah PHY

- *Sub GHz License-Exempt Band:* In North America, the IEEE 802.11ah frequency spectrum is available at the 915 MHz ISM band, and it has totally 26 MHz available bandwidth from 902 MHz to 928 MHz.

- The orthogonal frequency-division multiplexing (OFDM) scheme is supported.

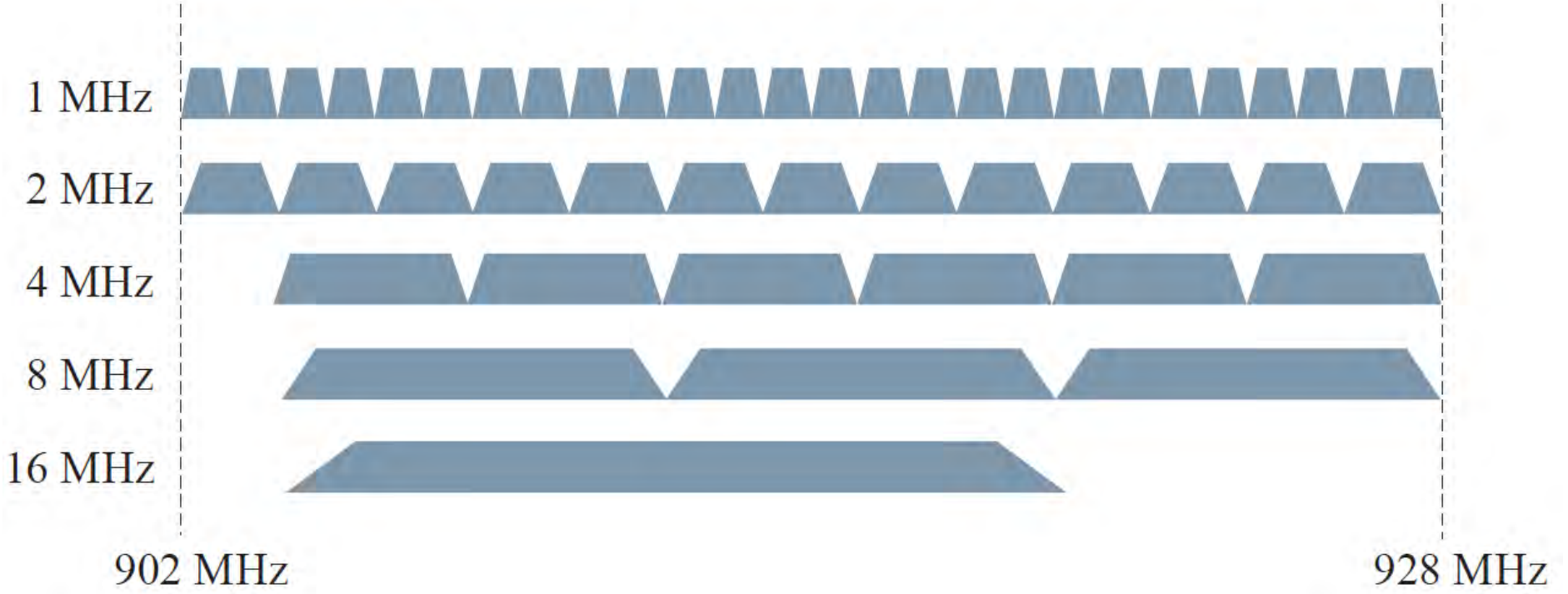
- Unlike the IEEE 802.11ac that has maximum 160 MHz bandwidth, the bandwidth of the IEEE 802.11ah ranges from 1 MHz to 16 MHz. Only the 1 and 2 MHz bandwidths are mandatory.
  For the 1 MHz bandwidth, 2 pilot sub-carriers and 24 data sub-carriers per OFDM symbol are defined, while for the 16 MHz bandwidth, 16 pilot sub-carriers and 468 data sub-carriers are assigned for each OFDM symbol.
  Utilizes multiple sets of Modulation and Coding Schemes (MCSs), number of spatial streams (NSS) and duration of the guard interval (GI). Coding schemes, the binary convolutional coding (BCC) and low-density parity check (LDPC).

IEEE 802.11ah MCS Setting vs. Data Rate

MCS Index	Modulation	Coding rate	Data rate (kbps)	
			1 MHz	2 MHz
0	BPSK	1/2	300	650
1	QPSK	1/2	600	1300
2	QPSK	3/4	900	1,950
3	16-QAM	1/2	1,200	2,600
4	16-QAM	3/4	1,800	3,900
5	64-QAM	2/3	2,400	5,200
6	64-QAM	3/4	2,700	5,850
7	64-QAM	5/6	300	6,500
8	256-QAM	3/4	3,600	7,800
9	256-QAM	5/6	400	Not valid
10	BPSK	1/2 with 2x repetition	150	Not valid

Modulation and coding scheme (MCS)
Bandwidth1, 2 MHz,
Number of spatial streams NSS =1
Duration of the (normal) guard interval GI = 8 μsec

IEEE 802.11ah channelization for the US



Bluetooth 4.0: Low Energy

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
  - Ø Blank sheet of paper design
  - Ø Different to Bluetooth classic (BR/EDR)
  - Ø Optimized for ultra low power
  - Ø 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

Bluetooth low energy factsheet (1)

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
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)

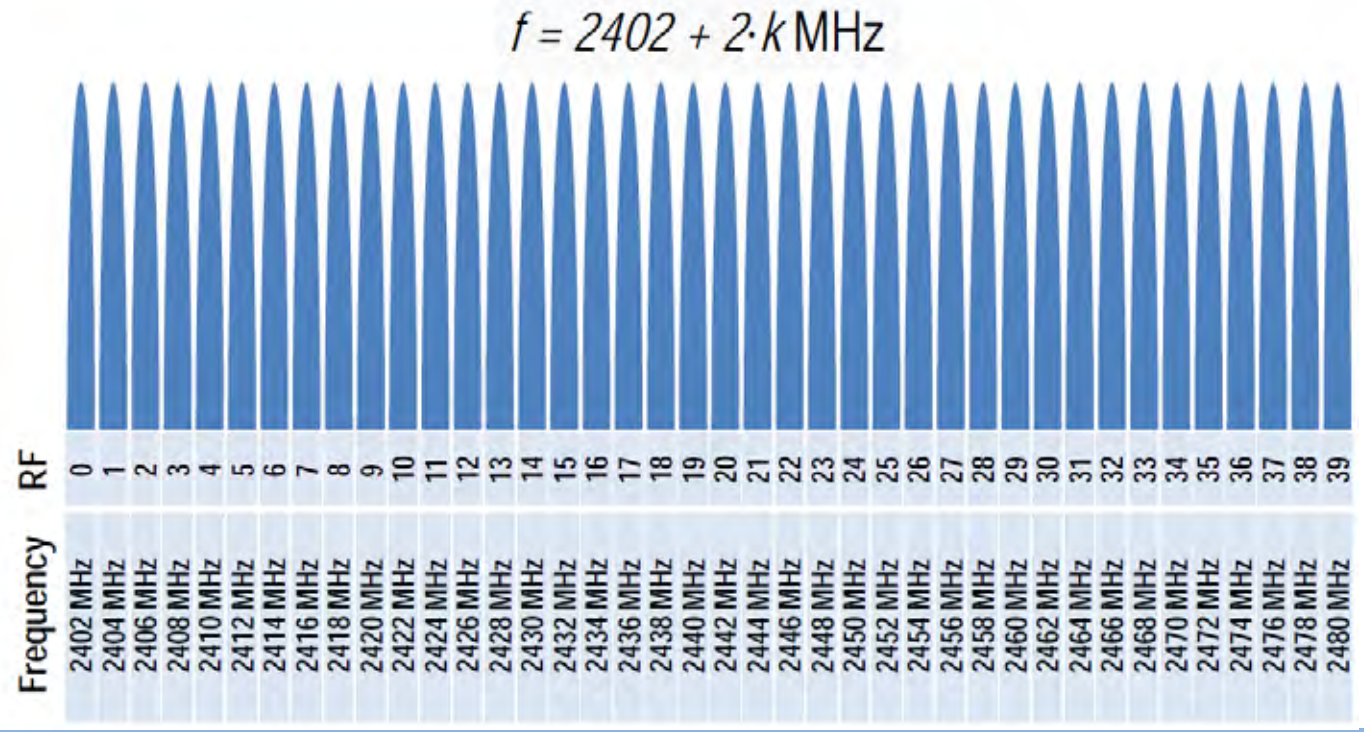
Device Modes

- 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

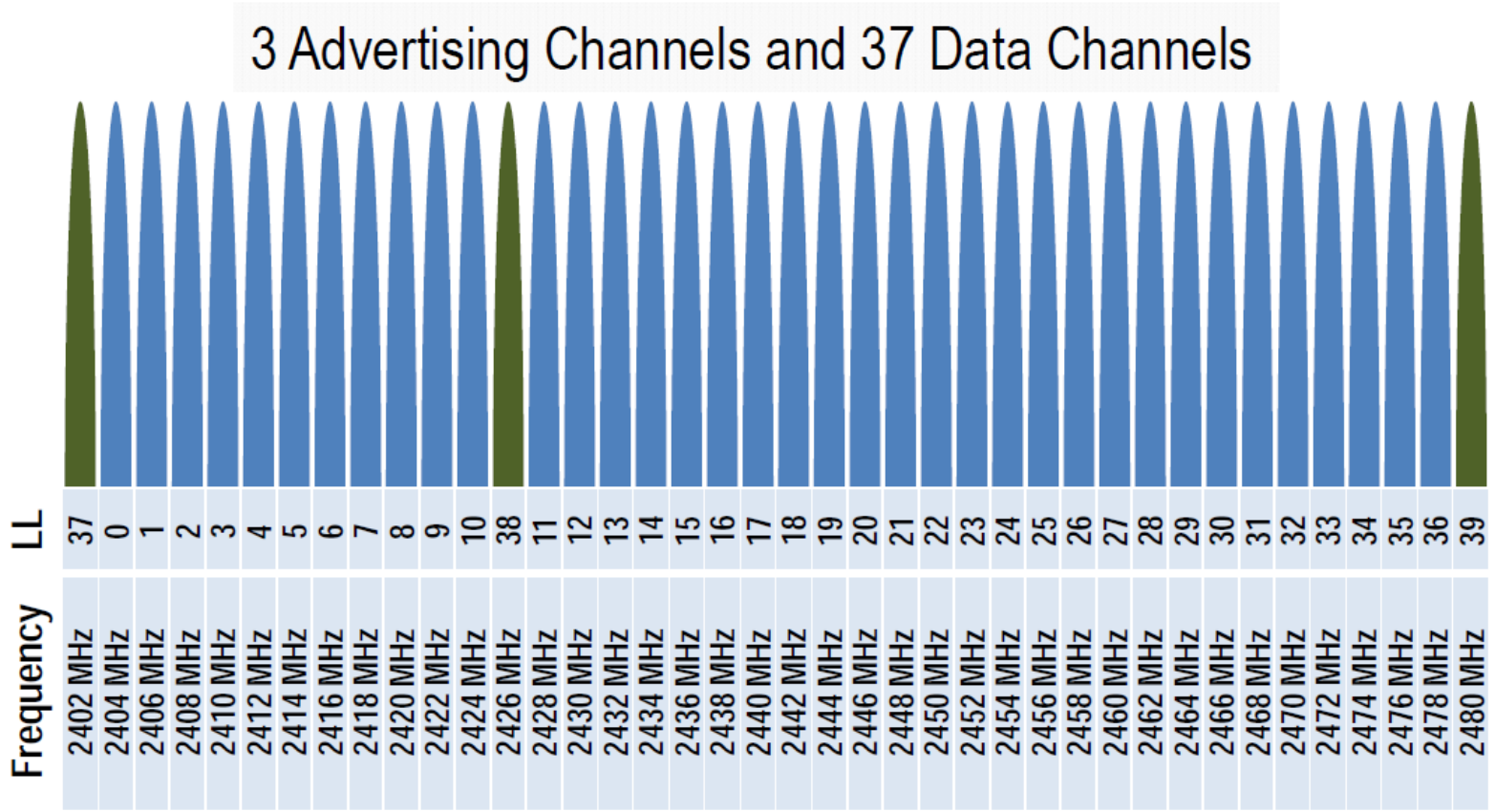
Physical Layer

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

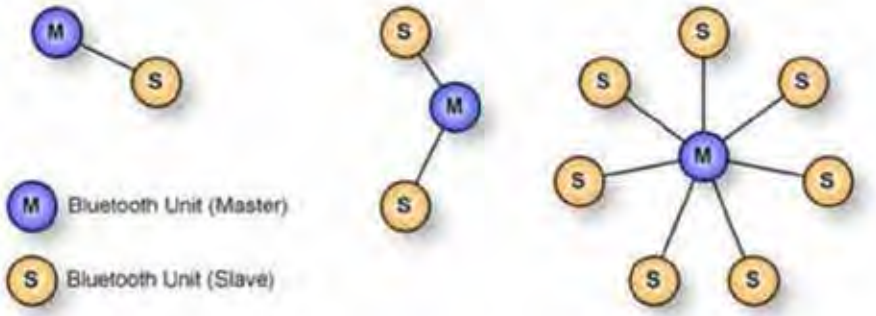


Physical Channels

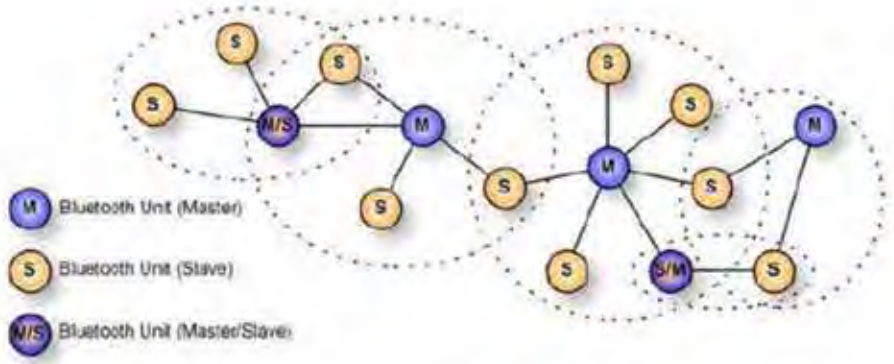
- Two types of channels



BL Topology



Piconet v4.0

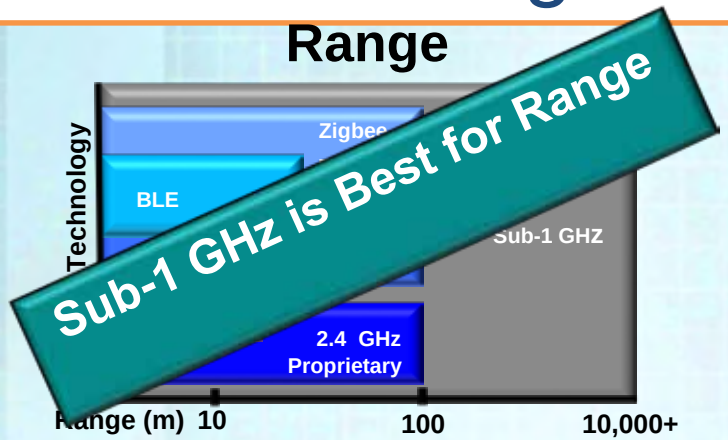


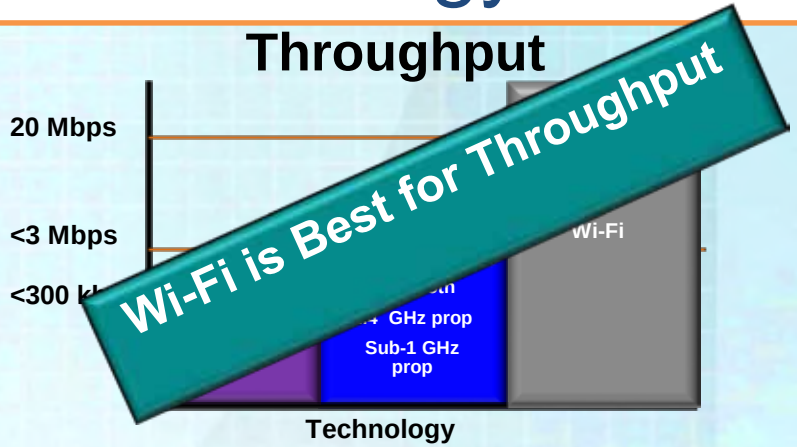
Scatter net v4.1

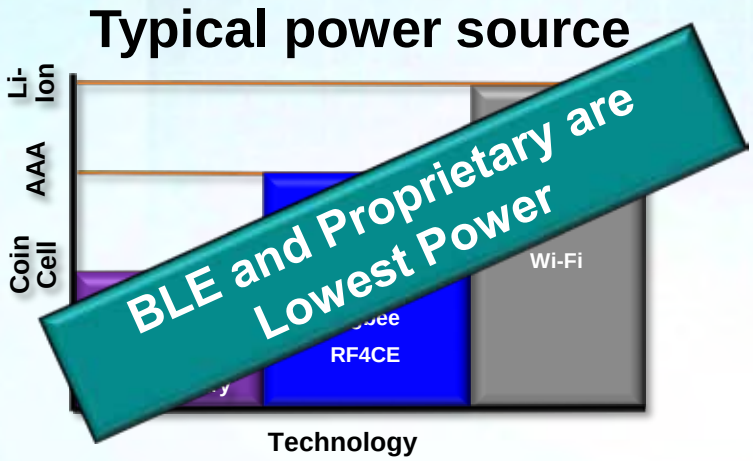
Conclusions

- Short and medium range:
  - Bluetooth
  - WiFi (802.15.11ah)
  - ZigBee based on 802.15.4
  - Industrial standards based on 802.15.4
- Long range
  - LoRa
  - Sigfox
  - Other proprietary technologies
- Cellular 2G, 3G or 4G
  - eMTC (LTE)
  - EC-GSM
  - NB-IoT
- Other organizations
  - ETSI Low Throughput Network
  - IETF 6LPWALP-WAN
  - Weightless SIG
  - DASH7 Alliance

Choosing the Right Technology







Conclusions

The LPWA networks use:

- Sub-GHz operation
- Star or multi-star topography
- Time, frequency and space diversity for best performance
- Sleep mode and low rate to save power