Explosion of the Internet of Things: What does it mean for wireless devices?

June 2015

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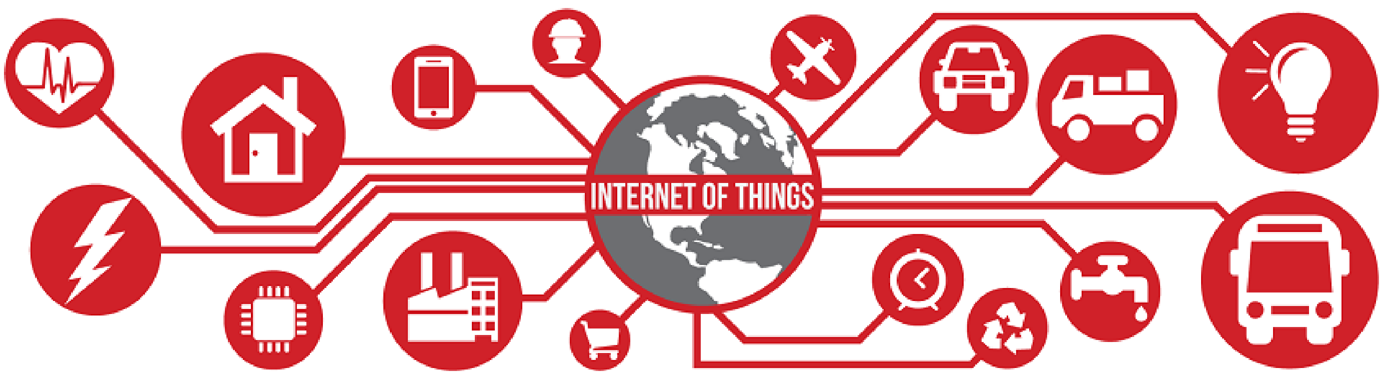
Keysight Technologies

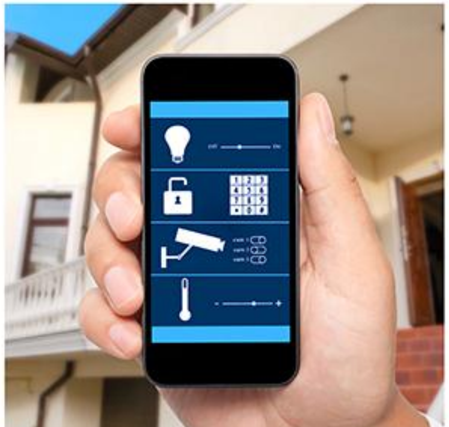


KEYSIGHT TECHNOLOGIES

Agenda

- IoT/M2M Introduction and Market Situation
- IoT/M2M Key Enabling Wireless Technologies
  - Bluetooth low energy (BLE)
  - IEEE 802.15.4 low range personal area network (LoWPAN)
  - IEEE 802.11 wireless local area network (WLAN)
  - Wide area networks (WAN)
    - Low power wide area network (LPWAN)
    - Cellular
- Summary

What is the Internet of Things (IoT)?

Connecting billions of devices to the internet



KEYSIGHT TECHNOLOGIES

IoT Market Predictions

50B devices will be connected by 2020
- Cisco

>30B Connected devices by 2020
- ABI Research

95.5B connected devices by 2025
- HIS Technology

Primary IoT Markets

Smart Home

- Security & alarm
- Light control
- HVAC control
- Remote control
- Door control
- Energy efficiency
- Entertainment
- Appliances

Wearables

- Health monitor
- Fitness trackers
- Smart watch
- Smart glasses
- Smart bands
- E-textiles
- Hearing-aid

Smart City

- Traffic management
- Water distribution
- Waste management
- Security
- Lighting
- Environmental monitoring
- Parking sensor

Industry Automation

- Smart machine
- Surveillance camera
- Factory automation
- Asset tracking
- Logistics and optimization of supply chain

Smart Energy

- Generation & trading
- Transmission
- Distribution & metering
- Storage
- Services

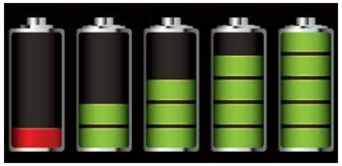
Connected Car

- V2V / V2X /V2I communications
- eCall
- Infotainment
- Traffic control
- Navigation
- Autonomous vehicles
- Maintenance

KEYSIGHT TECHNOLOGIES

What does IoT Mean for a Wireless Device?

– IoT devices are battery powered and are wireless like smartphones yet need to be very much different. How?
  - **Low energy consumption** – battery life of years not hours or days
  - **Connectivity** – must be optimized for low energy
    - Low power low data rate wireless connectivity standards are key for IoT
  - **Low cost** – allowing any object to be connected in high volumes (massive connectivity)
  - Simplicity
  - Lower maintenance



Wireless Connectivity for the Internet of Things

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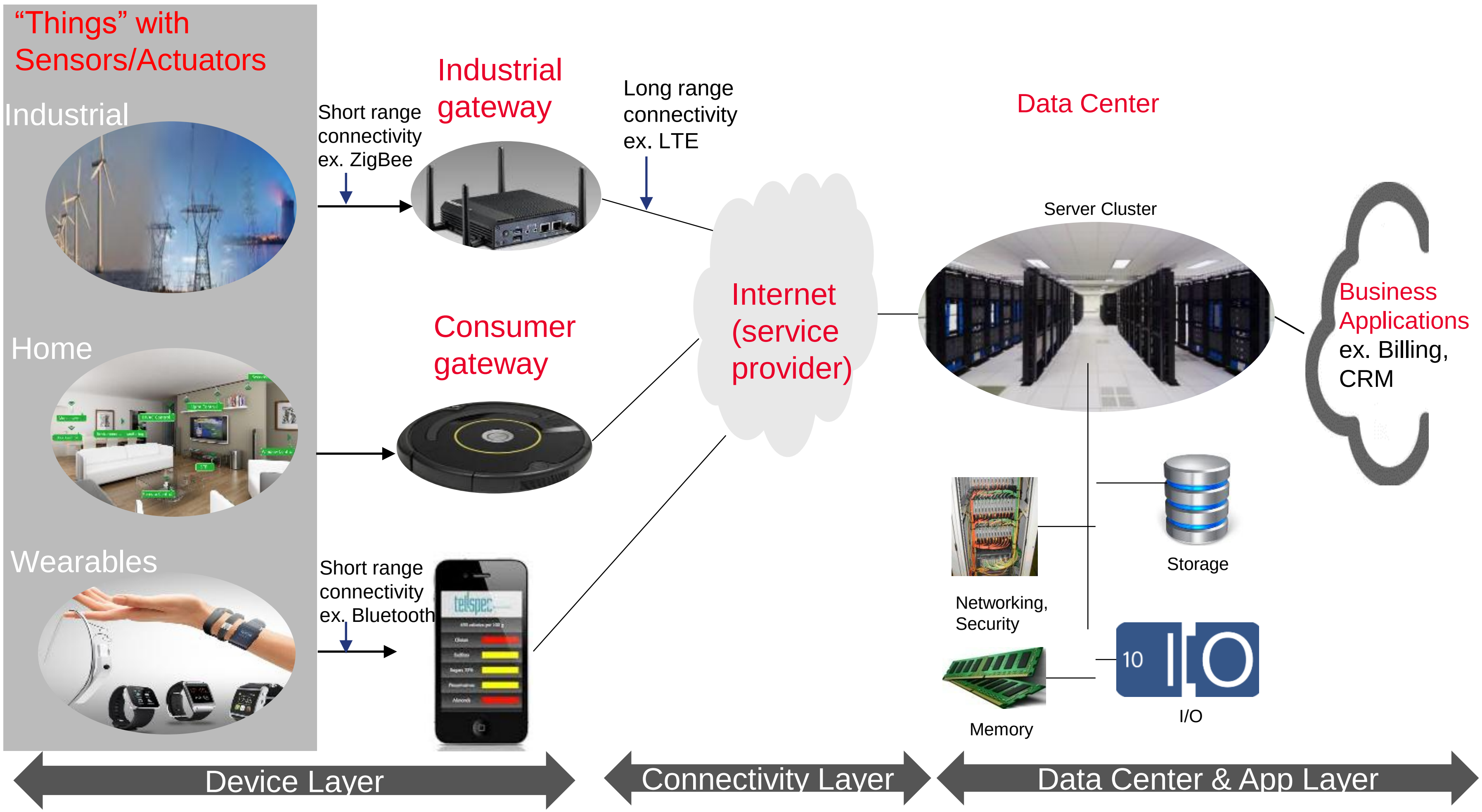
Wireless Connectivity

A single wireless technology can not accommodate the diverse need of IoT markets

KEYSIGHT TECHNOLOGIES

Internet of Things Value Chain



IoT Key Enabling Wireless Technologies

Heterogeneous Mix of Technologies

Red text – emerging IoT technologies

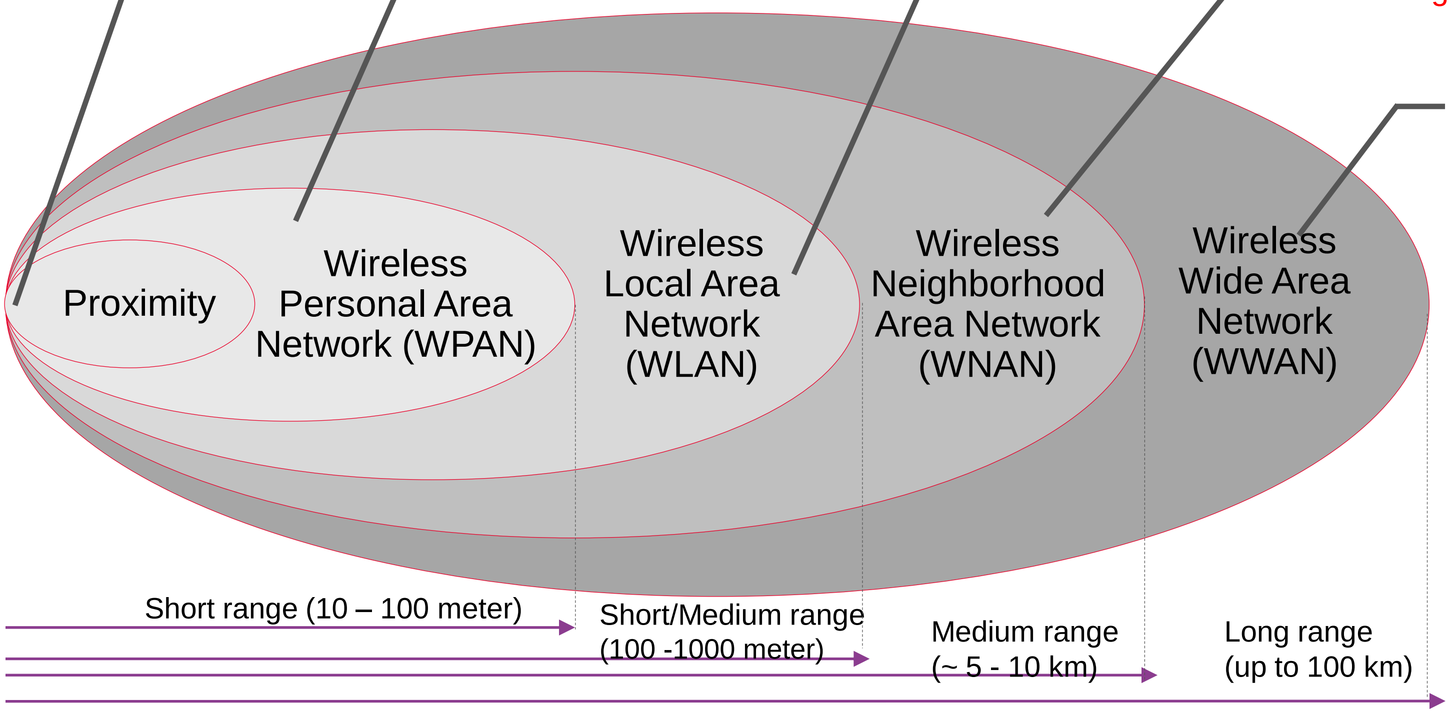
- NFC (EMV)
- RFID

- Bluetooth LE
- ZigBee
- Thread (6LoWPAN)
- Z-Wave
- ANT+
- WirelessHART
- ISA100.11a (6loWPAN)
- EnOcean
- Plus more

- 802.11a/b/g/n/ac
- 802.11af (white space)
- 802.11ah & 802.11p

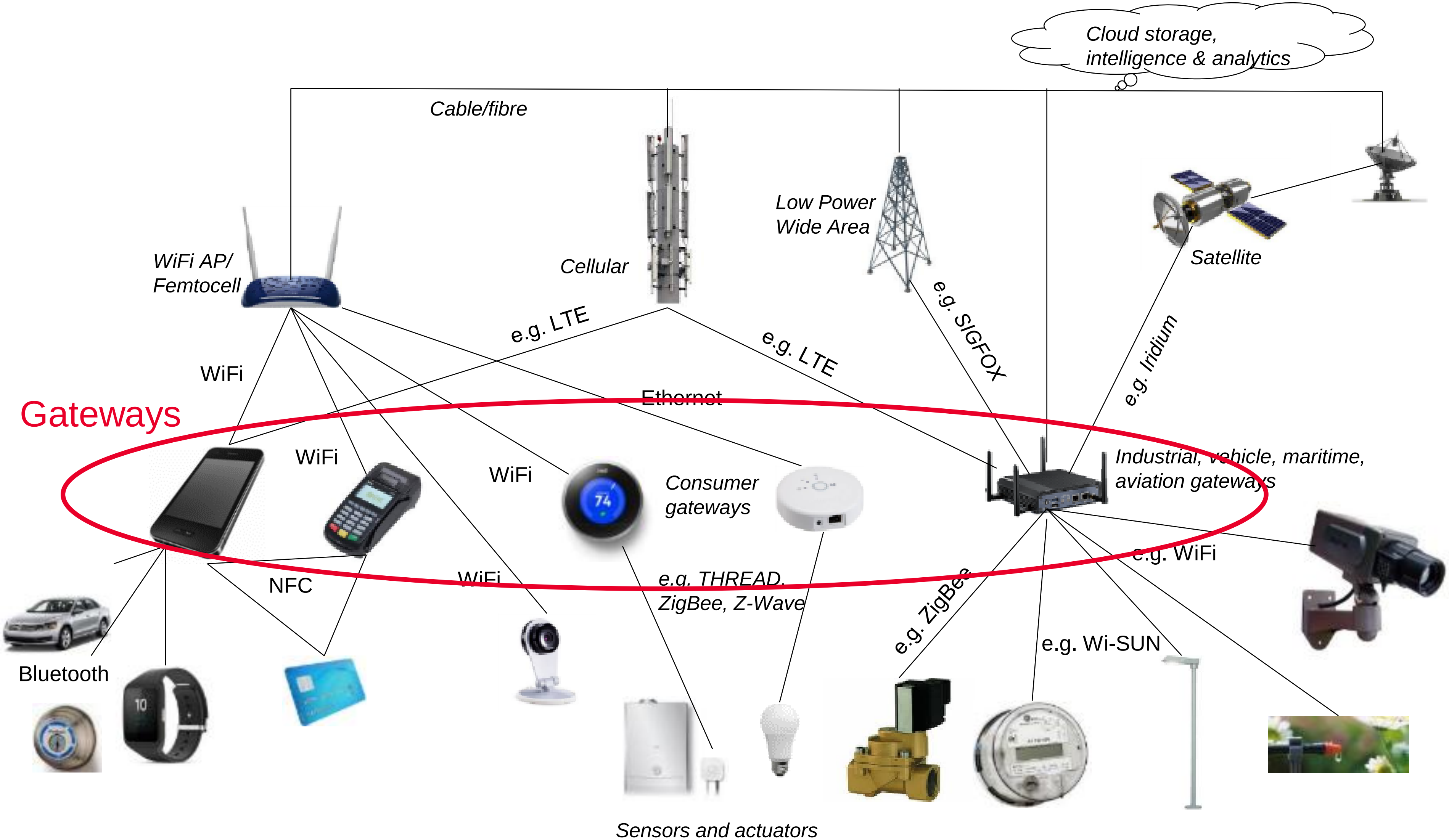
- Wi-SUN (6LoWPAN)
- ZigBee-NAN (6LoWPAN)

- Cellular
  - 2G/3G/4G
  - LTE-MTC
  - 5G in the future
- Low Power Wide Area (LPWAN)
  - SIGFOX
  - LoRa
  - Telensa
  - PTC
  - *Plus more*



Note 1: No stringent definition of what is considered WPAN, WLAN, WWAN.
Note 2: What is shown is not a complete list of radio formats

Connecting "Things" to the Cloud



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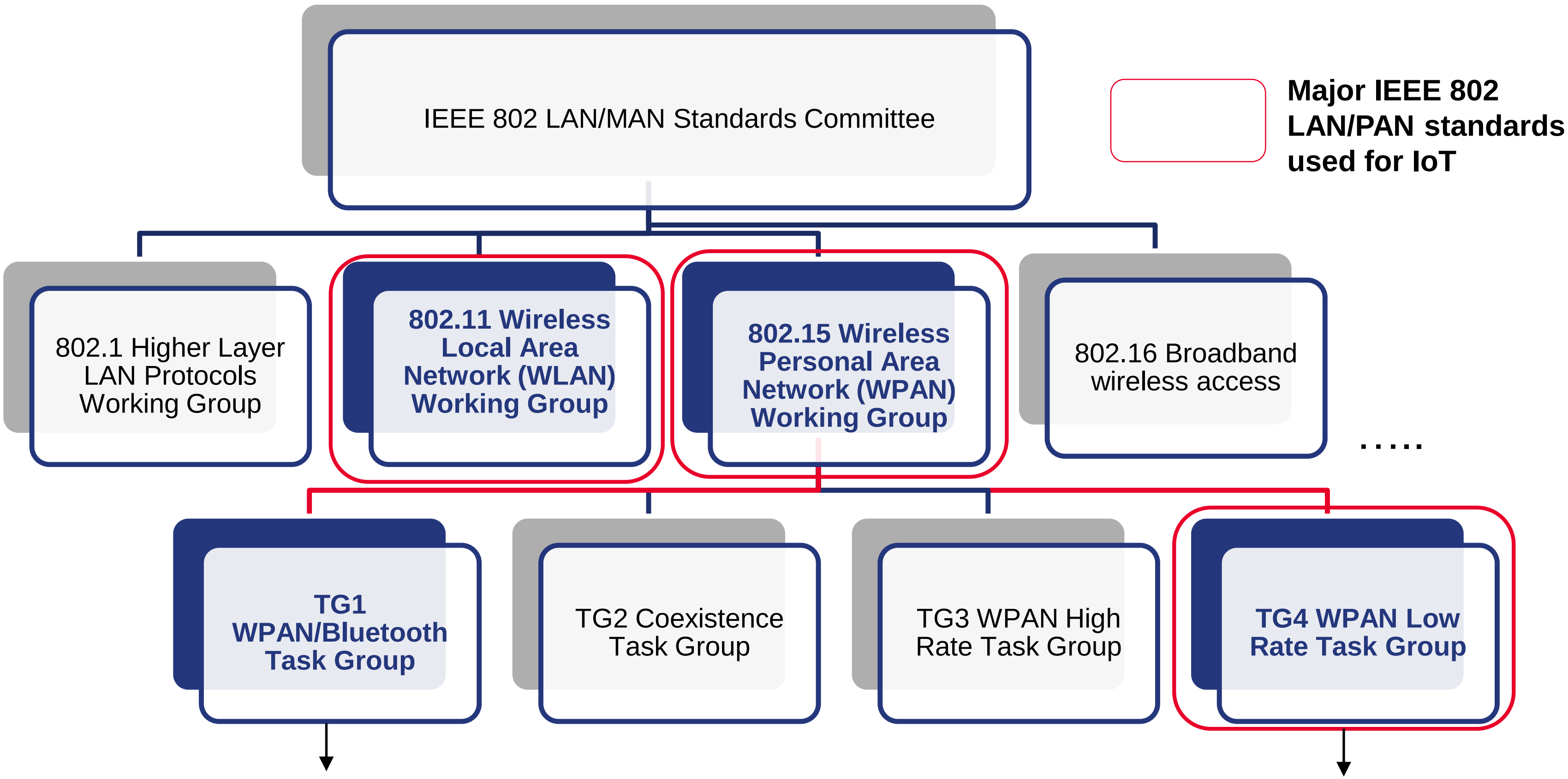
IEEE 802 LAN/MAN Working Group



IEEE 802.15.1
(BT standard is no longer maintained by IEEE, it is controlled by Bluetooth SIG)

IEEE 802.15.4

Bluetooth® Standard Evolution

1999 — V1.0
- Many problems
- Difficult making products interoperable

2003 — V1.2
- Faster connection/ discovery
- Use AFH
- Up to 721 kbps

2004 — V2.0 + EDR
- Introduction of EDR
- EDR Up to 2.1 Mbps

2007 — V2.1 + EDR
- SSP, EIR
- power consumption optimization

2009 — V3.0 + HS
- Alternate MAC/PHY
- Unicast connectionless data
- Enhanced power control
- HS up to 24 Mbps

2010 — V4.0
- Adoption of Bluetooth LE
- LE up to 260 kbps
- Including classic, LE and HS

2013 — V4.1
- Coexist with 4G
- Smart connectivity
- Data transfer improvement

2014 — V4.2
- For IoT (Support IPv6/6LoWPAN)
- High privacy
- Data throughput increase (10x packet capacity increase)

Two New Trademarks for Certified BT Devices

- Bluetooth SMART READY — For dual-mode: LE + Legacy BT
- Bluetooth SMART — For single-mode: LE only

IoT Key Enabling Technologies
Bluetooth Smart – Powering IoT

Bluetooth Core 4.0/4.1/4.2 enables a world of sensors

– Bluetooth Low Energy (BLE) enables low cost sensors to send their data over the internet
    - Version 4.2 enables IPv6 to a BT device

– Very low duty cycle = low power consumption

– Ability to run for years (up to 5 years) on standard coin-cell batteries

– Target applications:
    - Health monitors such as heart rate monitor
    - Fitness devices, smart watches
    - Environmental sensing
    - Proximity applications and many others

Bluetooth® Low Energy Vs. Classic

Technical Specification	Bluetooth Low Energy	Classic Bluetooth (BR/EDR/HS)
Radio frequency	2400 – 2483.5 MHz	2400 – 2483.5 MHz
Modulation Technique	Frequency Hopping	Frequency Hopping
Modulation Scheme/Index	GFSK / 0.5	GFSK / (0.28- 0.35)
Number of Channels	40	79
Channel spacing	2 MHz	1 MHz
Range	~10 - 100m	~10 - 100m
Over the air data rate	1 Mbps	1/2/3 Mbps
Nodes/Active Slaves	Unlimited (10-20 is practical #)	7
Security	128 bit AES and application layer user defined	56 bit E0 (classic)/128 bit AES (AMP) and applications layer user defined
Robustness	Relaxed to save power and enable higher mod. index	Adaptive fast frequency hopping, FEC, fast ACK
Latency (from a non-connected state)	< 3 ms	100 ms
Network Topology	Star-bus (no mesh)	Piconet (with Scatternet)
Power consumption	0.01 to 0.5W(use case dependent)	1 W as the reference

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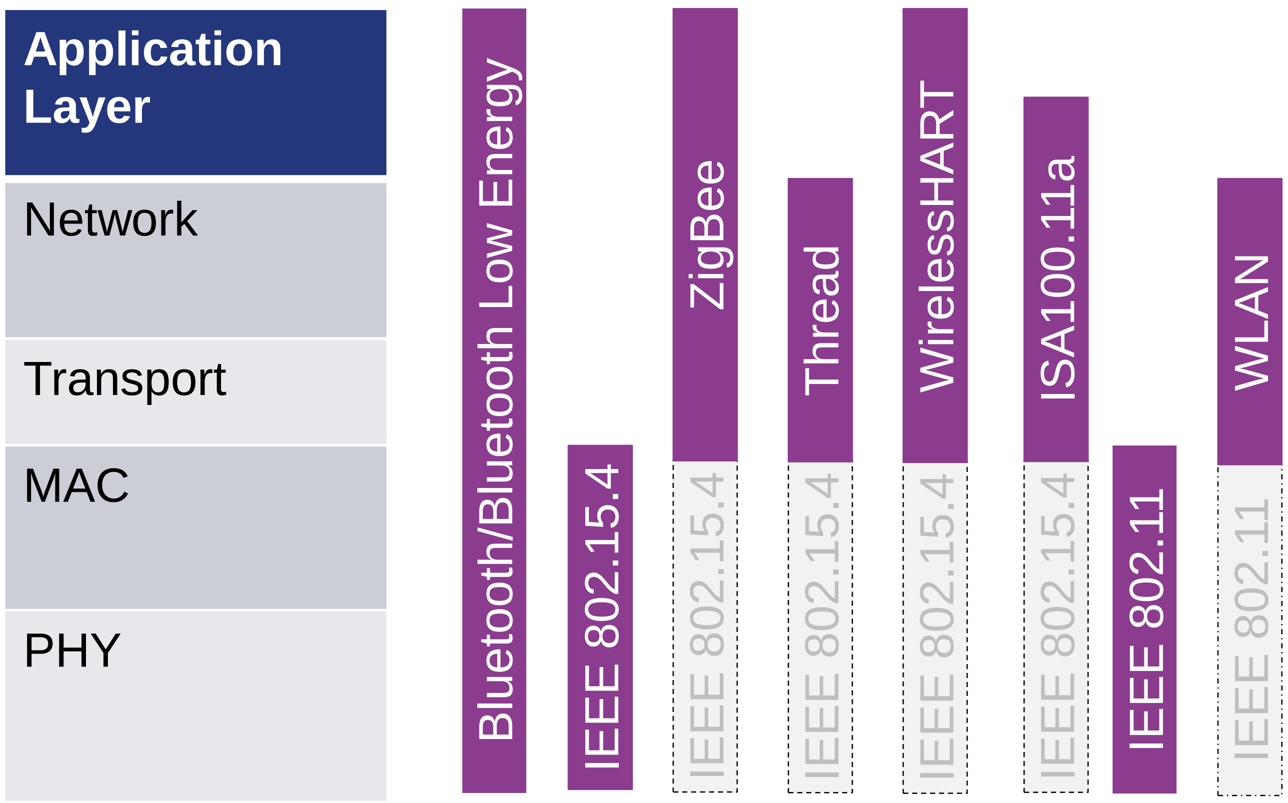
Wireless Standards



IEEE 802 defines standards, does not define a certification process or test plans, that is done by the individual standards/working groups

IEEE 802.15.4

Low Rate Wireless Personal Area Network (LoWPAN)

– Important standard for home networking, industrial control and building automation

– Deals with low data rate, long battery life (months or even years) and very low complexity

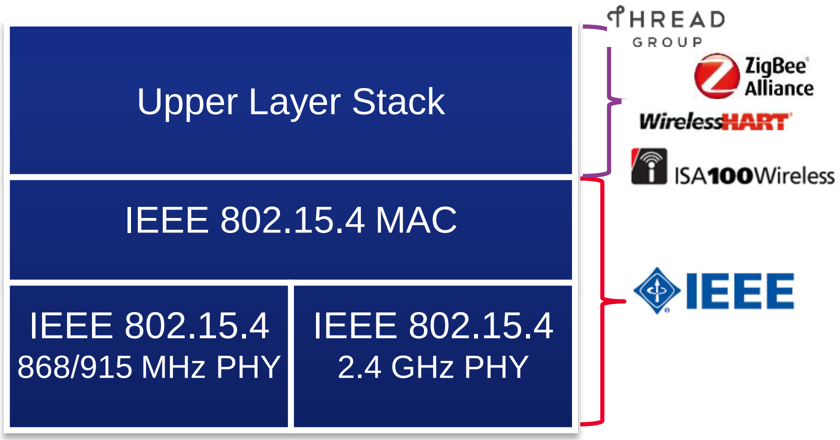
  • Data rates of 250 kbps, 40 kbps, and 20 kbps

– Specifies PHY and MAC layers for LoWPAN networks

  • Ex. ZigBee, THREAD, WirelessHART, ISA100.11a

– Upper layers for WPAN are not developed by IEEE 802.15 working group

  • Standards or working groups, such as ZigBee Alliance, implement upper layers to enable multi-vendor interoperable solutions



KEYSIGHT TECHNOLOGIES

IP-Based 802.15 Wireless Personal Area Network

IPv6 over Low Power Personal Area Networks (6LoWPAN)

- 6LoWPAN – working group name in the IETF
  - Defines how IP networking layers utilize the IEEE 802.15.4 link
- Enables wireless IPv6 communication over IEEE 802.15.4
  - PHY and MAC based on IEEE 802.15.4-2006
  - Network layer based on internet protocol

– Adds adaptation layer between MAC and network layer (IPv6) to handle interoperability between IEEE 802.15.4 and IPv6. Major functions include:
  - Header compression – IPv6 headers are too large for 802.15.4
  - Packet fragmentation and reassembling – to handle frame size mismatch between 802.15.4 and IPv6
- Example 6LoWPAN based formats:
  - THREAD, ISA100.11a, ZigBee IP, Wi-SUN

I E T F®

Internet Engineering Task Force

TCP/IP Protocol Stack		6LoWPAN Protocol Stack
HTTP, RTP	**Application**	Application
TCP, UDP, ICMP	**Transport**	UDP, ICMP
IP	**Network**	IPv6 with LoWPAN
Ethernet MAC	**Data Link**	IEEE 802.15.4 MAC
Ethernet PHY	**Physical**	IEEE 802.15.4 PHY

IEEE 802.15.4 PHY Layer
Frequency Bands and Data Rates

IEEE 802.15.4 - 2003

PHY (MHz)	Frequency Range (MHz)	Chip Rate (kcps)	Modulation Schemes	Data-rates (kbps)
868/ 915	868-868.6 (Europe)	300	BPSK	20
	902-928 (North America)	600	BPSK	40
2450	2400-2483.5 (Worldwide)	2000	O-QPSK	250

IEEE 802.15.4 - 2006

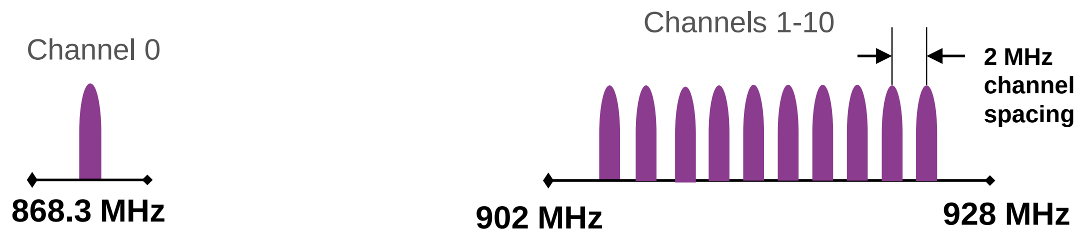
PHY (MHz)	Frequency Range (MHz)	Chip Rate (kcps)	Modulation Schemes	Data-rates (kbps)
868/ 915	868-868.6 (Europe)	300 (mandatory) 400/400 (optional)	BPSK (mandatory) O-QPSK/ASK (optional)	20 (mandatory) 100/250 (optional)
	902-928 (North America)	600 (mandatory) 1000/1600 (optional)	BPSK (mandatory) O-QPSK/ASK (optional)	40 (mandatory) 250/250 (optional)
2450	2400-2483.5 (Worldwide)	5	O-QPSK	250

IEEE 802.15.4 standard also provides support for Sub-1 GHz bands in China (779-787MHz) and Japan (915-930MHz) .

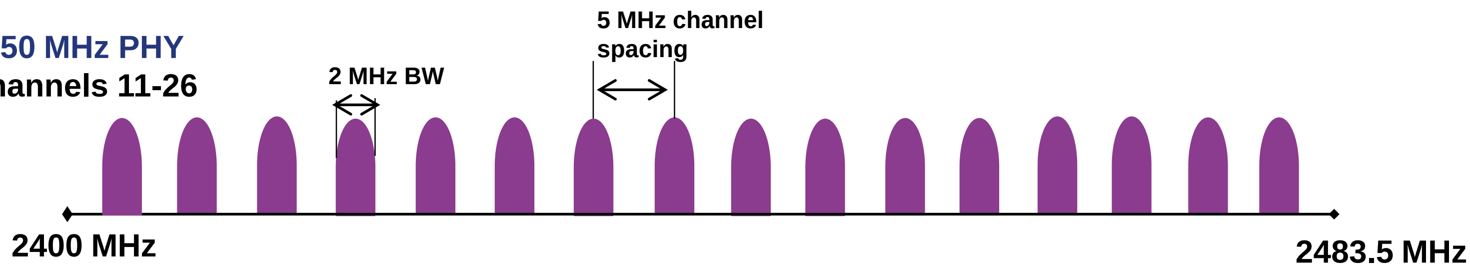
IEEE 802.15.4 PHY Layer

Number of Channels

868/915 MHz PHY
Channels 0 - 10



2450 MHz PHY
Channels 11-26



IEEE 802.15.4	Channel page	Channel number	Description
IEEE 802.15.4 - 2003 IEEE 802.15.4 - 2006	0	0	868 MHz PHY
		1-10	915 MHz PHY
		11-26	2400 MHz PHY
IEEE 802.15.4 - 2006	1	0	868 MHz PHY (ASK optional)
		1-10	915 MHz PHY (ASK Optional)
IEEE 802.15.4 - 2006	2	0	868 MHz PHY (O-QPSK optional)
		1-10	915 MHz PHY (O-QPSK optional)

KEYSIGHT TECHNOLOGIES

IoT Key Enabling Technologies
ZigBee

Low power, low data rate, mesh network

- Conceived in 1998, first standardized in 2003 and revised multiple times, latest in 2012 (ZigBee PRO)
- Based on IEEE 802.15.4 physical and MAC layers operating in sub-GHz and 2.4GHz frequency bands
- Transmission distances range from 10 to 100 meters - depending on power output and environmental characteristics

Upper Layer Stack		ZigBee Alliance
IEEE 802.15.4 MAC		IEEE
IEEE 802.15.4 868/915 MHz PHY	IEEE 802.15.4 2.4 GHz PHY	IEEE

Target Applications:

ZigBee Standards

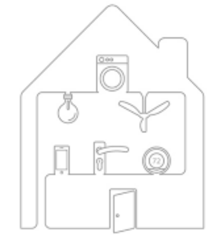
	ZigBee RF4CE (LoWPAN)		ZigBee PRO (LoWPAN)							ZigBee IP IPv6 based (6LoWPAN)
Application Standard	ZigBee Remote Control	ZigBee Input Device	ZigBee Building Automation	ZigBee Healthcare	ZigBee Home Automation	ZigBee Light Link	ZigBee Retail Services	ZigBee Smart Energy 1.x	ZigBee Telecom Services	ZigBee Smart Energy 2.0
Network	ZigBee RF4CE		ZigBee PRO							ZigBee IP
MAC	IEEE 802.15.4-MAC									IEEE 802.15.4 - MAC
PHY	IEEE 802.15.4 – 2003 Sub-GHz bands (region specific) 2.4 GHz (worldwide)									IEEE 802.15.4 - 2006 2.4 GHz

RF4CE (Radio Frequency for Consumer Electronics)

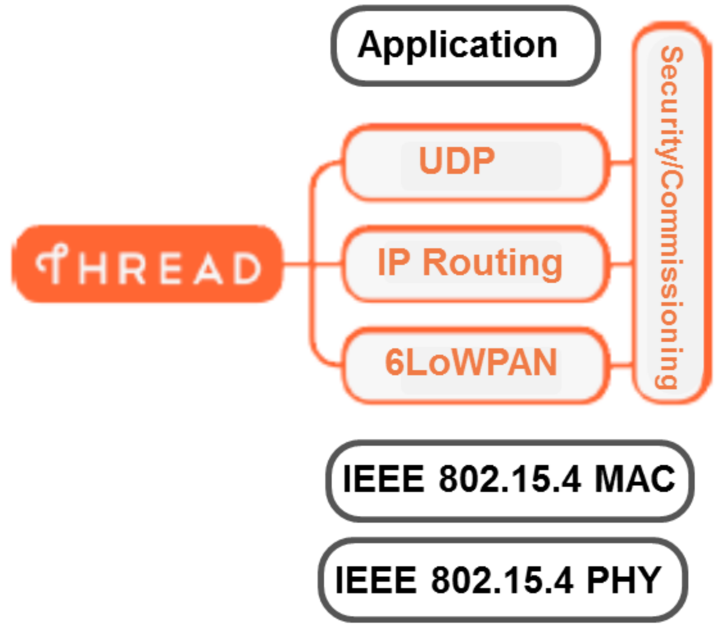
New ZigBee Standard Being Drafted:

- ZigBee Neighborhood Area Network (NAN) – used for smart utility
- ZigBee 3.0 - unification of ZigBee wireless standards into a single standard
  - Based on IEEE 802.15.4 MAC and PHY at 2.4 GHz frequency and
  - Based on ZigBee PRO networking
  - Currently undergoing testing – expected to be ratified in Q4, 2015

IoT Key Enabling Technologies
THREAD



- Thread Group launched in July 2014
- Main competitor to ZigBee for home automation
  - Appliances, access control, climate control, lighting, energy management etc..
- Collection of existing IEEE and IETF standards:
  - IEEE 802.15.4-2006 PHY/MAC operating in 2.4 GHz
  - 6LoWPAN (IPv6) based protocol
- Requires only software update to run on existing IEEE 802.15.4 based silicon such as 2.4 GHz version of ZigBee



Thread Protocol Stack

Ref:www.threadgroup.org

IoT for Home Automation

Technology Tradeoffs for Home Automation Application

Bluetooth SMART

Pros:

- Low energy
- Available on mobile devices *(Already supported on IOS and Android)*
- IPv6 based

Cons:

- Star network
- Short range
- New technology – not well established compared to ZigBee

WiFi™

Pros:

- Well established standards
- Available on mobile devices
- Good range
- IPv6 based

Cons:

- Star network
- Not low energy – new standard coming in 2016 (802.11ah)

ZigBee®

Pros:

- Low energy
- Well established standards
- Mesh network
- Good range

Cons:

- Not IP based for home automation *(ZigBee IP for Smart Energy 2.0 is IP based)*
- Not available on mobile phones/ tablets

THREAD

Pros:

- Low energy
- Mesh network
- Good range
- IPv6 based

Cons:

- Not well established compared to ZigBee
- Not available on mobile phones/ tablets

IoT Key Enabling Technologies

Wireless Industrial Automation

WirelessHART

HART= Highway Addressable Remote Transducer

- Wired HART is a global technology today
- WirelessHART enables industrial wireless sensor network communications based on wired HART principle
- **PHY/MAC:** IEEE 802.15.4-2006 2.4GHz
- **Data Link Layer** (DLL): optimized for collision- free and deterministic communications:
  - Frequency hopping, time slotted (10 ms) TDMA features
  - Optional collision avoidance - “clear channel assessment”(CCA) also known as “listen before talk” (LBT)
- **Network Layer:** Not IP based. Needs gateway to connect to the internet

ISA-100.11a

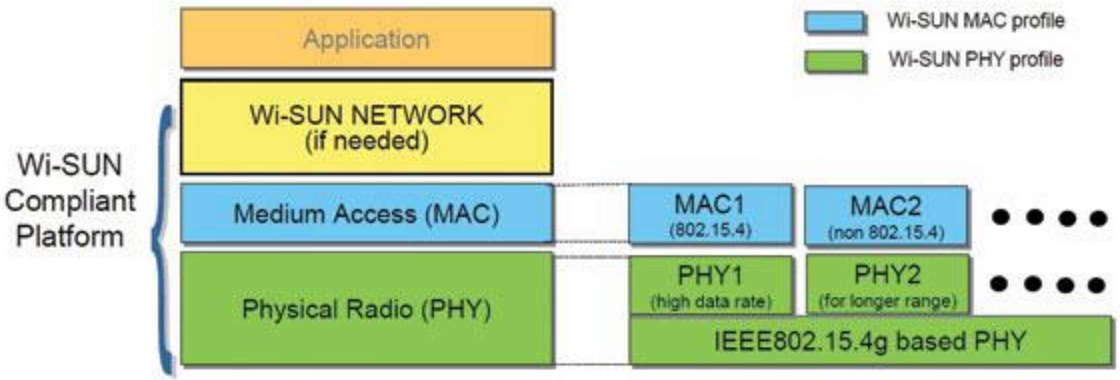
ISA= International Society of Automation

- ISA100.11a used for non-critical monitoring, alerting and control applications
- **PHY/MAC:** IEEE 802.15.4-2006 2.4 GHz
- **Data Link Layer (DLL):** optimized for collision- free and deterministic communications
  - Frequency hopping, time slotted (variable length)
  - Collision avoidance – uses “clear channel assessment”(CCA) also known as “listen before talk” (LBT)
- **Network Layer:** based on 6LoWPAN

IoT Key Enabling Technologies
Wi-SUN

- IPv6 based Wireless Smart Utility Network (Wi-SUN) based on IEEE 802.15.4g
  - IEEE 802.15.4g, also known as the Smart Utility Networks (SUN), was approved by IEEE in March, 2012
- Initially Japan focused, now expanding globally (US, South East Asia, India, Europe)
- Target smart utility use cases:
  - Gas metering; demand/response; distribution automation
- PHY layer based on IEEE 802.15.4g but the specification will be categorized based on use cases
  - Frequency: 868 MHz (EU), 915 MHz (USA), 2.4 GHz ISM bands (worldwide)
- MAC may be based on or not based on 802.15.4. Application dependent.

3 PHY formats supported:
- MR-FSK: 2FSK and 4FSK
- MR-OFDM: available but not popular
- MR-O-QPSK: DSSS and multiplexed DSSS



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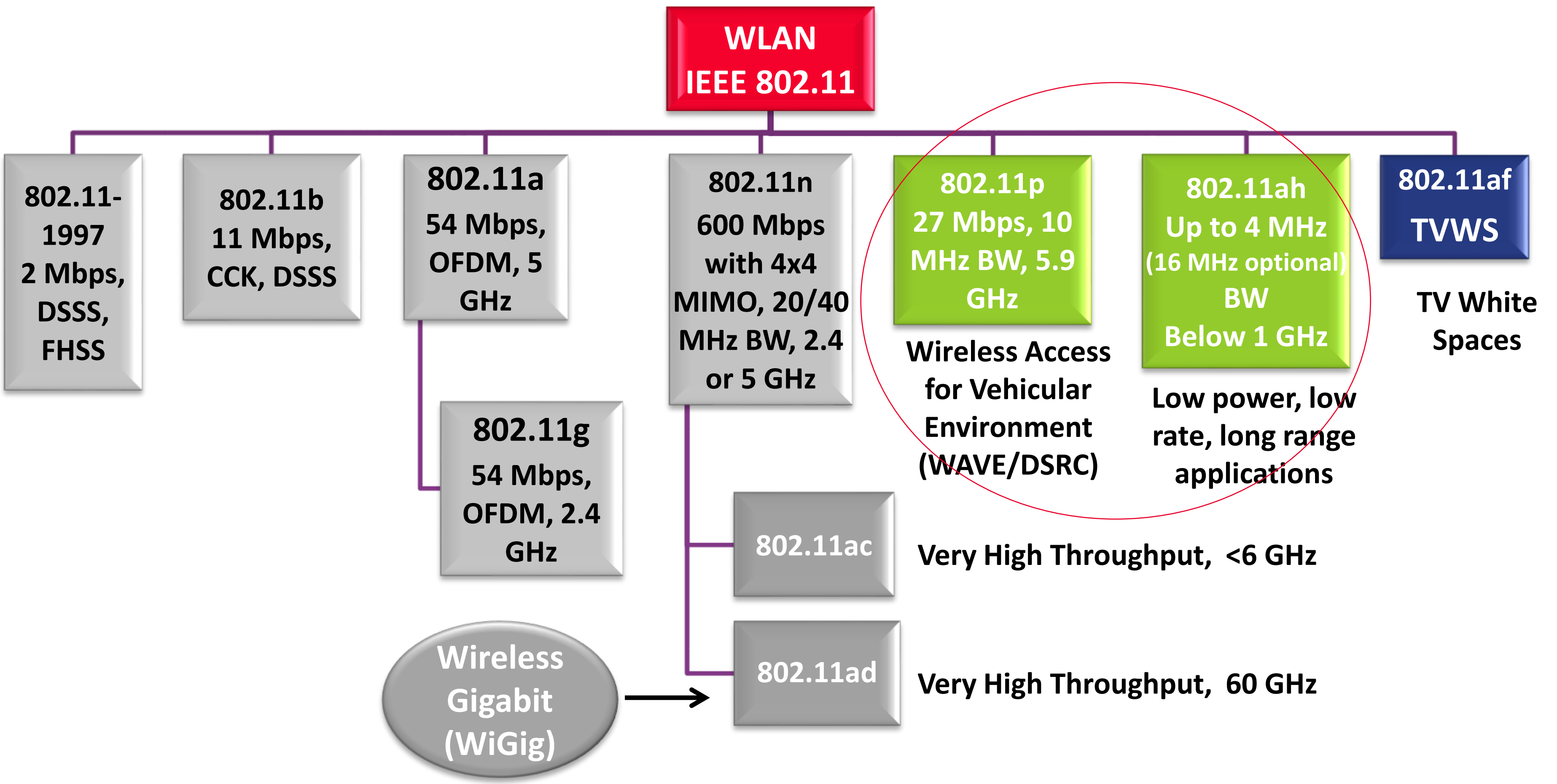
IEEE 802.11 Standards Evolution

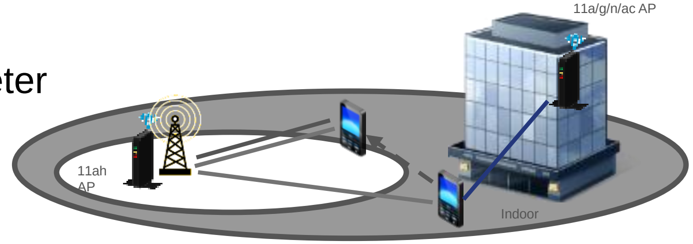


DSRC = Dedicated Short-Range Communications

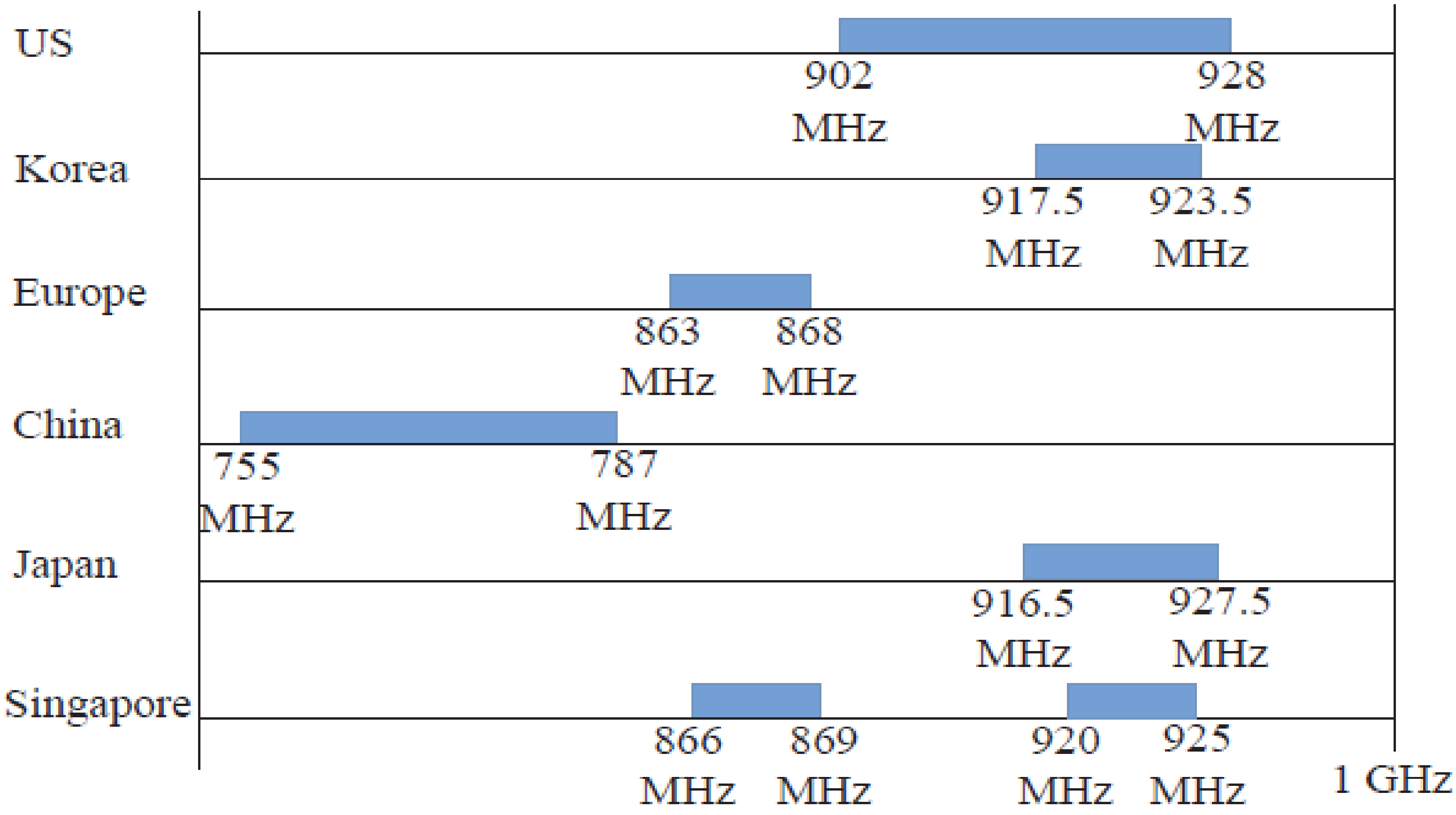
IoT Enabling Technologies

IEEE 802.11ah – Middle 2016

- Optimized for IoT applications
- PHY/MAC – *trade-off of power, range, rate*
  - PHY based on 802.11ac with data rates > 100 kbps
  - Optimizations for highly robust links and low power consumption required for battery operated devices
  - Sub-1 GHz unlicensed bands
  - Range up to 1 km – beyond 2.4 and 5 GHz range due to improved propagation characteristics of sub-GHz radio waves
- Target use cases
  - Large scale low power sensor networks and smart meter
  - Video surveillance, wearable consumer electronics
  - Backhaul for aggregated sensor and meter data
  - Outdoor Wi-Fi for cellular traffic offloading



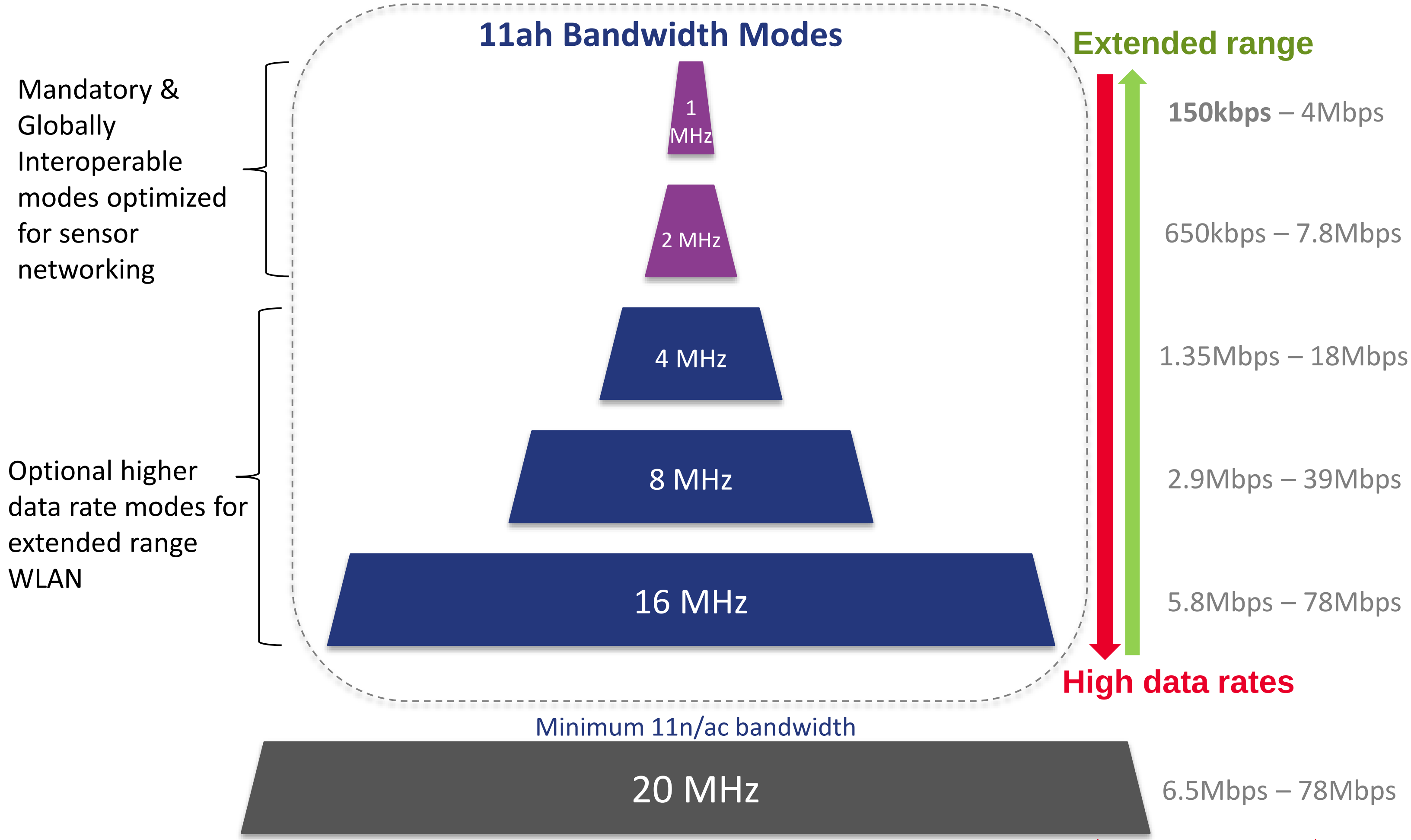
IEEE 802.11ah Global Channelization



Ref: IEEE 802.11ah draft standard

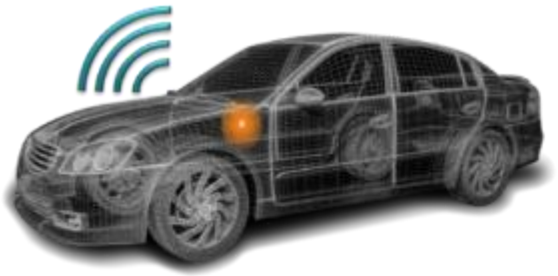
IoT Enabling Technologies

IEEE 802.11ah Bandwidth and Data Rates



IoT Key Enabling Technologies
IEEE 802.11p

- Adds a vehicular communication system to IEEE 802.11 WLAN standard -> Wireless Access in Vehicular Environment (WAVE)
- Supports low latency, Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2X) communication
  - Vehicle broadcasts its position and velocity and receives broadcasts of neighboring road users
  - Uses channels of 10MHz bandwidth in the 5.9GHz band (5.850-5.925 GHz)
  - Developed based on 802.11a but targets for reliable connection
- Main uses:
  - Vehicle safety services
  - Commerce transactions via cars
  - Toll collection
  - Traffic management



- USA, Europe, China, Japan, Korean and Singapore are working towards hard/soft mandate or MOU for dedicated short range communication (DSRC) installation.

IoT Enabling Technologies
IEEE 802.11p

- Frequency: 5.9 GHz (5.85-5.925 GHz)
- 1 control and 6 service channels with 10MHz bandwidth
- 802.11p vs. 802.11a : Targets the reliable connection rather than higher data rates

Physical parameters comparison between 802.11a and 802.11p standards

Parameters	802.11a	802.11p
Bit Rate (Mbps)	6, 9, 12, 18, 24, 36, 48, 54	3, 4.5, 6, 9, 12, 18, 24, 27
Modulation Type	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM
Code Rate	1/2, 2/3, 3/4	1/2, 2/3, 3/4
# of Subcarriers	52	52
Symbol duration	4 µs	8 µs
Guard Time	0.8 µs	1.6 µs
FFT period	3.2 µs	6.4 µs
Preamble duration	16 µs	32 µs
Subcarrier Spacing	312.5 kHz	156.25 kHz

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Low Power Wide Area Networks (LPWAN)

- **What is LPWAN?**
  - Typically star networks with up to100km coverage centred on a gateway with cellular backhaul
  - Optimized for machine type communication:
    - Very low data rates
    - Long battery life
    - Low duty cycle to co-exist in shared spectrum
  - Long support live for critical infrastructure that will outlive cellular technologies

- **Typical applications**
  - Street lighting (Telensa widely deployed)
  - Parking space occupancy sensors
  - Burglar alarm back-up (cellular jammers widely available)
  - Social housing use cases (e.g. smoke alarm and energy credit policing SIGFOX in UK)
  - Pet tracking
  - Garbage collection bin fill level for pick up route optimization (LoRa)
  - Agricultural sensors
  - Forest fire detection

IoT Key Enabling Technologies

LoRa™ (Long Range)

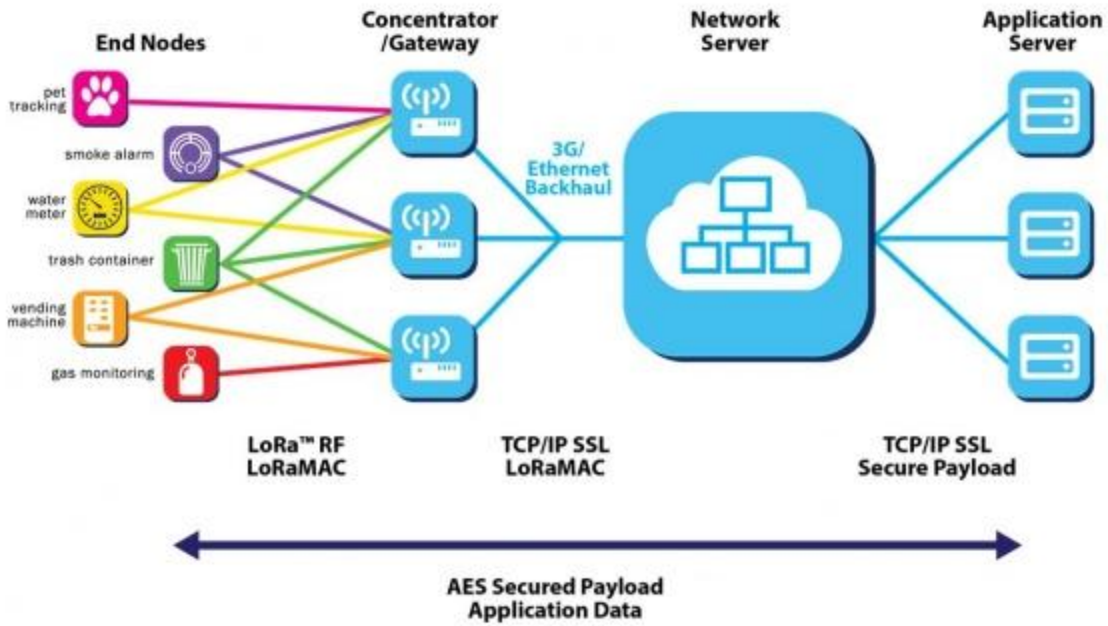
LoRa Alliance
Wide Area Networks for IoT

- LoRa is a Semtech technology for IoT
- Provides long range and low power wireless technology to connect low-cost, battery-operated sensors over long distances (10 miles range and > 10 years battery life)
- The LoRa Alliance was formed in February 2015. Release 1.0 of LoRaWAN specification was released to public on June 16, 2015
- **Applications:** smart city, sensor networks, industrial automation application

Frequency (MHz) ISM Band	Bandwidth	Modulation Schemes	Range
433 (Europe)	125 kHz & 250 kHz	**LoRa*** (Chirp Spread Spectrum or CSS) **GFSK**	>15 km (9 miles) in a suburban environment and up to 5 km (3 miles) in a dense urban environment
853-870 (Europe)	125 kHz & 250 kHz	**LoRa*** (Chirp Spread Spectrum or CSS) **GFSK**	
779-787 (China)	125 kHz & 250 kHz	**LoRa*** (Chirp Spread Spectrum or CSS) **GFSK**	
902-928 (North America)	125 kHz & 500 kHz	**LoRa*** (Chirp Spread Spectrum or CSS)	

* LoRa, Semtech's proprietary modulation, is a spread spectrum modulation scheme that is derivative of Chirp Spread Spectrum modulation (CSS) and which trades data rate for sensitivity within a fixed channel bandwidth.

LoRaWAN Network Architecture



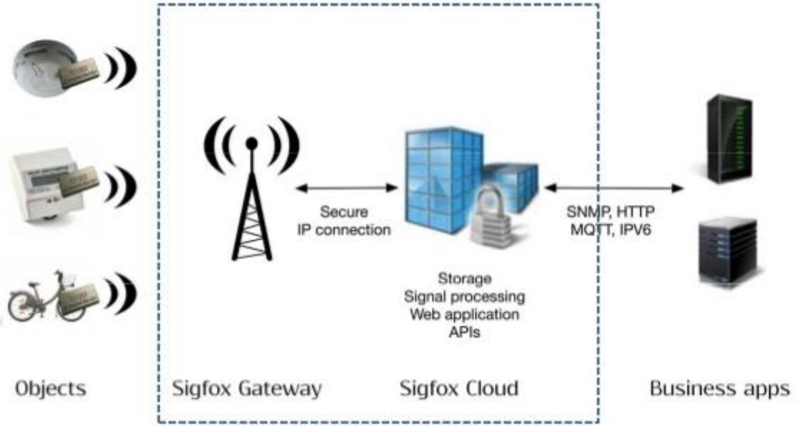
– LoRa **gateways** are a bridge relaying messages between **end-nodes** and a central **network server**

- End-nodes use single-hop wireless communication to one or more gateways
- Gateways are connected to the network server via standard IP connections such as 3G/4G cellular network
- A LoRa gateway deployed on a building or tower can connect to sensors more than ten miles away

IoT Key Enabling Technologies
SIGFOX

- SIGFOX is a startup in France building a low cost network dedicated for IoT (low throughput)
- Uses unlicensed spectrum – mostly sub-GHz band and patented ultra narrow band (UNB) communication
  - Ultra low throughput - ~100 bps
    - Device can send between 0 and 140 messages per day, each message is up to 12 bytes
  - Up to 20 years of battery life
  - Long range – up to 30 miles in rural area and 2-6 miles in urban area
- Devices require a SIGFOX modem to connect to SIGFOX network
- **Target applications:** smart meter, pet tracking, smoke detector, agriculture etc…
- Have networks deployed in France, Netherlands, Russia and Spain; Launching 902 MHz network in San Francisco

Topology



Wide area networks

Technology Trade-offs

SIGFOX

Pros:

- Long range
- Long battery life (up to 20 years)
- Low cost

Cons:

- New standard
- Unlicensed band - interference
- Can't run on existing cellular network – needs a dedicated SIGFOX network
- Very low data rate - can only be used for IoT

LoRa Alliance – Wide Area Networks for IoT

Pros:

- Long range
- Long battery life (>10 years)
- Low cost
- Uses cellular network as backhaul

Cons:

- New standard
- Unlicensed band - interference
- Very low data rate – can only be used for IoT

3GPP

Pros:

- Well established standards
- Long rage
- High data rate
- Very wide coverage
- Licensed band (except LTE-U)

Cons:

- Not optimized for IoT
  - Battery life
  - Cost

IoT Key Enabling Technologies
Cellular - LTE Machine Type Communication (LTE-MTC)

3GPP RAN Group

3GPP Rel 12 – Introduction to LTE-MTC (UE Cat-0)

Low device cost:	Long battery life
• DL peak data rate – 1 Mbps (vs. 10 Mbps in Cat-1) • LTE BW – 20 MHz • # of UE receive chains – 1 (vs. 2 in Cat-1) • Optional Half Duplex (vs. full duplex in Cat-1)	• Added new UE power saving mode (PSM)

3GPP Rel 13 further improvements planned to LTE-MTC (scheduled for completion in 2016)

Low device cost:	Long battery life: Further battery life improvements planned	Enhanced coverage: up to 15 dB better link budget over existing LTE
• Peak data rate ~ 200 kbps • 1.4 MHz narrowband operation • Simplified PHY/MAC		

Evaluation of brand new radio optimized for low end IoT market

Focus on very low data rates applications with limited mobility support

- 200 kHz narrowband operation (~100s bps), allowing smooth reframing of GERAN channels
- Long range (20 dB better link budget over existing GPRS)
- Very low cost & power consumption

KEYSIGHT TECHNOLOGIES

GERAN Cellular IoT - CIoT

Candidate Clean Slate Solutions for Massive Connectivity

	NB M2M & NB OFDMA	NBM2M	NB-OFDMA	C-UNB	NB-CSS
	Qualcomm , Neul-Huawei, u-blox	Neul-Hauwei, u-blox, Ericsson, Samsung	Qualcomm	SIGFOX	Semtech
	Downlink	***Downlink***	***Downlink***	***Downlink***	***Downlink***
Multiple access	OFDMA	FDMA	NB-OFDMA		FDMA & CSS
Sub-channel symbol rate	3.75 kHz				
Sub-channel spacing	3.75 kHz	15 kHz	2.5 kHz		3.2-12.8 kHz
Number of sub-channels	48				
Maximum transmit power	43 dBm				
Modulation mandatory	BPSK, QPSK	½ & ¾ conv-code: π/2-BPSK, π/4-QPSK			½ Viterbi 0.3GMSK
Modulation optional	16QAM	16-QAM			
Pulse shaping	Wideband spectral				
	shaping				
FFT size	64				
Budget					163 dB
	Uplink	***Uplink***	***Uplink***	***Uplink***	***Uplink***
Multiple access	FDMA	FDMA	SC-FDMA		FDMA & CSS
Sub-channel symbol rate	3.75 kHz				
Sub-channel spacing	5 kHz	5kHz			400 Hz-12.8 kHz
Number of sub-channels	36				
Maximum transmit power	23 dBm				
Modulation mandatory	GMSK	1/3 & 2/3 Turb-code; GMSK,			½ Viterbi 0.3GMSK
Modulation optional	BPSK, QPSK, 8PSK	π/2-BPSK, π/4-QPSK , π/8-8PSK, single carrier, sub-channel bonding			
Pulse shaping	Symbol rate shaping				
	GMSK: BT=0.3				
	PSK: root-raised cosine				
FFT size	-				
Budget					164 dB

- Narrow Band M2M **(NB M2M)**
- Narrow Band OFDMA **(NB-OFDMA)**
- Cooperative Ultra Narrow Band **(C-UNB)**
- Combined Narrowband & Chirp Spread Spectrum **(NB-CSS)**
- Converged **(NB M2M and NB OFDMA)**

IoT Key Enabling Wireless Technologies

What will 5G bring to IoT Market?

Massive Connectivity Use Case

Example: Home automation, remote patient monitoring, fleet management etc..

Requirements:

- Low cost
- Low energy
- Massive numbers
- Long range

5G will bring – ultra-low cost, ultra-low energy, wide coverage

Mission Critical Connectivity Use Case

Example: Autonomous vehicle, remote control in mfg, medicine (remote surgery) etc…

Requirements:

- Ultra high reliable
- Ultra low latency
- Ultra high availability

5G will bring: Ultra-high reliability, ultra-low latency, high security network. **Combination of ultra low latency and high reliability is not achievable with current wireless technologies.**

Summary

- IoT is not a particular technology nor a particular device – it is about embedding connectivity - via sensors and actuators - into devices and sharing data across them
- Energy efficiency and wireless connectivity are key in making IoT work
- Heterogeneous mix of wireless technologies are used, some are competing, and others to cover a wide variety of use cases serving diverse requirements in various environments
- Low power, low rate personal area network technologies - such as those based on IEEE 802.15.4 - have proven instrumental in driving sensor implementations
- Cellular, WiFi and low power wide area communication technologies serve as a backbone for transferring the collected data to the cloud

Q and A Session

Thank You!

KEYSIGHT TECHNOLOGIES

Backup

IoT Key Enabling Wireless Technologies Summary

Standards	Freq(s)	Max BW	Data rate	Mod	Range	Network	Applications
LTE-M Category 0/1 (LTE Rel12/13)	LTE band	1.4 MHz	200 kbps ~ 1 Mbps	OFDM	1000 m	WMAN	lower speed and power versions of the LTE standard defined in Rel12/13
802.11ah (IEEE 802.11)	Sub GHz	1 to 16 MHz	150 kbps to 78 Mbps	OFDM	1000 m	WLAN	Target for IoT, wearable devices or extend range
802.11p (IEEE 802.11)	5.8~5.9 GHz	5/10/20 MHz	1.5 Mbps to 54 Mbps	OFDM	1000 m	WLAN	Wireless access in vehicle environment (WAVE)
Bluetooth Low Energy	2.4 GHz	1 MHz	1 Mbps	GFSK	50 m	WPAN	automotive, healthcare, security, home entertainment
Z-Wave (ITU G.9959)	868.42 MHz 908.42 MHz	200 kHz	9.6 kbps ~100 kbps	BFSK GFSK	100 m	WPAN	Remote controls, smoke alarm, security sensors Owned by Denmark Zensys
ZigBee (802.15.4)	ISM < 2.4 GHz	2 MHz	40 kbps to 250 kbps	BPSK OQPSK	10 m	WPAN	Home automation, smart grid, remote control
Thread (802.15.4)	ISM < 2.4 GHz	2 MHz	40 kbps to 250 kbps	BPSK, FSK OQPSK	10 m	WPAN	Mesh network for home and support 6LoWPAN
Wi-Sun (802.15.4g)	ISM < 2.4 GHz	200 kHz to 1.2 MHz	50 kbps to 1 Mbps	FSK ,OFDM, OQPSK	1000 m	WNAN	FAN and HAN Smart Utility Networks, Smart Grid, Smart Metering
NFC (ISO/IEC18092)	13.56 MHz	1 MHz	848 kbps	FSK, ASK	20 cm	P2P	Contactless payment, easy other connection (Wi-Fi, BT), identity and access

KEYSIGHT TECHNOLOGIES

NFC Technologies

NFC-A, B or F

NFC device may support one or more technologies (NFC-A, B or F)

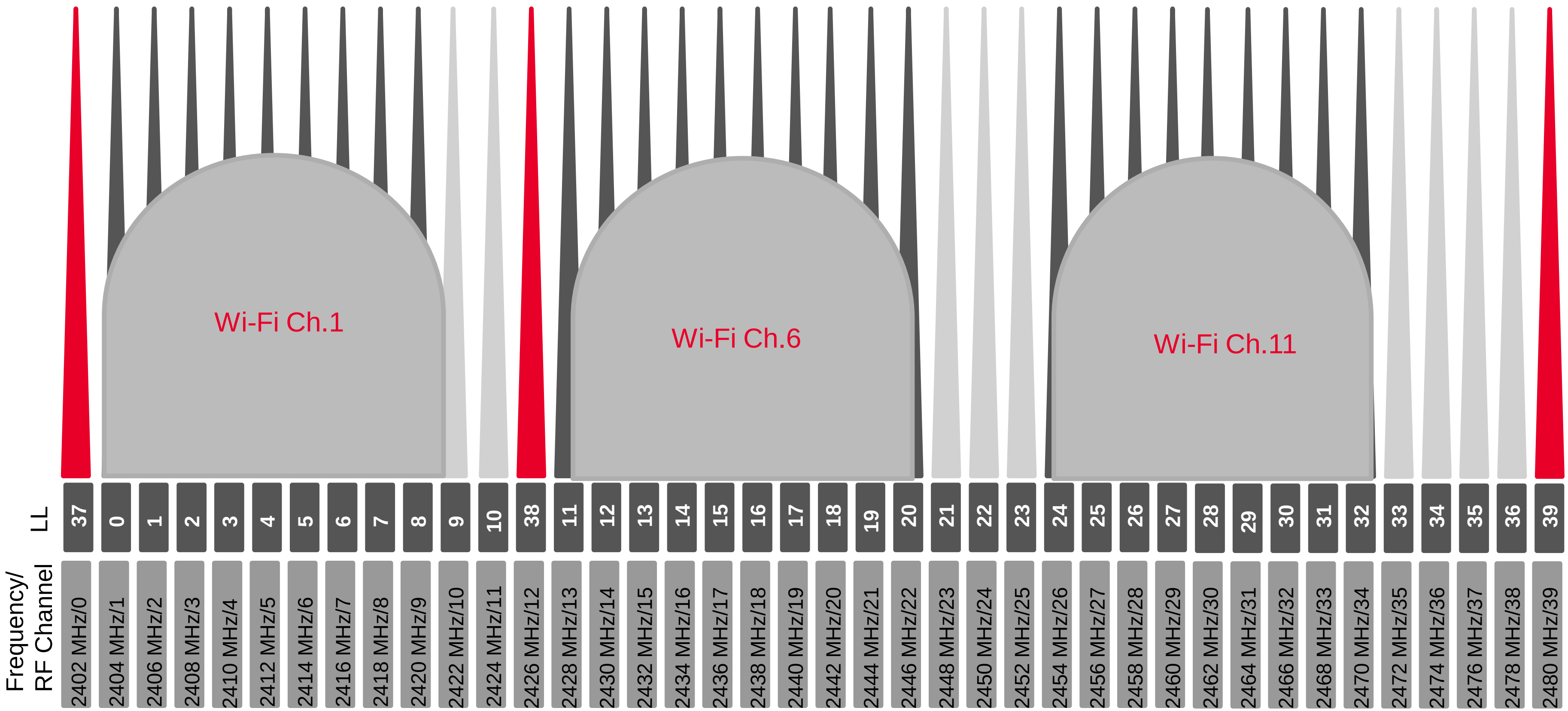
Technology	Poller/ Listener	Data Rate (kbit/s)	Coding	Modulation	Carrier frequency (MHz)
NFC-A Based on ISO 18092	Poller	106	Modified Miller	ASK 100%	13.56
	Listener	106	Manchester	Load Modulation (ASK)	13.56 (+/- 848 kHz)
NFC-B Based on ISO 14443B	Poller	106	NRZ-L	ASK 10%	13.56
	Listener	106	NRZ-L	Load modulation (BPSK)	13.56 (+/- 848 kHz)
NFC-F Based on ISO 18092	Poller	212/424	Manchester	ASK 10%	13.56
	Listener	212/424	Manchester	Load modulation (ASK)	13.56 (+/- 848 kHz)

IoT Key Enabling Technologies
NFC - Now

NFC uses magnetic induction between two loop antennas located within each other's near field effectively forming an air-core transformer.

– Based on RFID technology at 13.56 MHz
– Operating distance typically up to 10 cm
– Data exchange rate typically used today up to 848 kbps
– Compatible with today's contactless RFID technologies
– NFC is complementary to Bluetooth and Wi-Fi technologies
– Three modes of operation:
  - Peer Mode (P2P)
  - Reader/Writer (R/W)
  - Card Emulation (CE)

Bluetooth Low Energy Channel Allocations



Bluetooth Low Energy:

- 3 advertising channels (37, 38, 39)
- 37 data channels
- 0.6-1.2 ms for scanning

< 10 – 20 times less power

Classic Bluetooth:

- 32 hop frequencies for same task
- 22.5 ms

KEYSIGHT TECHNOLOGIES

PHY Differences between 802.11ac and 802.11ah

Feature	802.11ac	802.11ah
Channel bandwidth	20/40/80/160 MHz	1/2/4/8/16 MHz
FFT size	64/128/256/512	32/64/128/256/512
Data subcarriers /	52/108/234/468	24/52/108/234/468
Pilot Sub-carriers	4/6/8/16	2/4/6/8/16
Pilot Type	Fixed pilot	Fixed pilot or traveling pilot
Subcarrier spacing	312.5 kHz	31.25 kHz
OFDM symbol duration	4.0/3.6 us	40/36 us
Guard interval (short/normal/long)	0.4/0.8/1.6 us	4/8/16 us
Preamble duration	16 us	320 us(1M BW)/160 us
Modulation types	BPSK/QPSK/16QAM/64QAM/256QAM	BPSK/QPSK/16QAM/64QAM/256QAM
Coding rates	1/2, 2/3, 3/4, 5/6	1/2 rep2, 1/2, 2/3, 3/4, 5/6
MCS	0-9	MCS0-9, 10
Transmission Mode	VHT mode, non-HT duplicate mode	Normal mode S1G, 1 MHz duplicate mode, 2 MHz duplicate mode
Duplicated PPDU	Non-HT PPDU	S1G_DUP_1M, S1G_DUP_2M
MIMO	Up to 8	Up to 4
Multi-user	Up to 4	Up to 4, only available in S1G_LONG PPDU
Beamforming	Support	Support

Source: Draft Amendment Proposed by 802.11 TGah Working Group