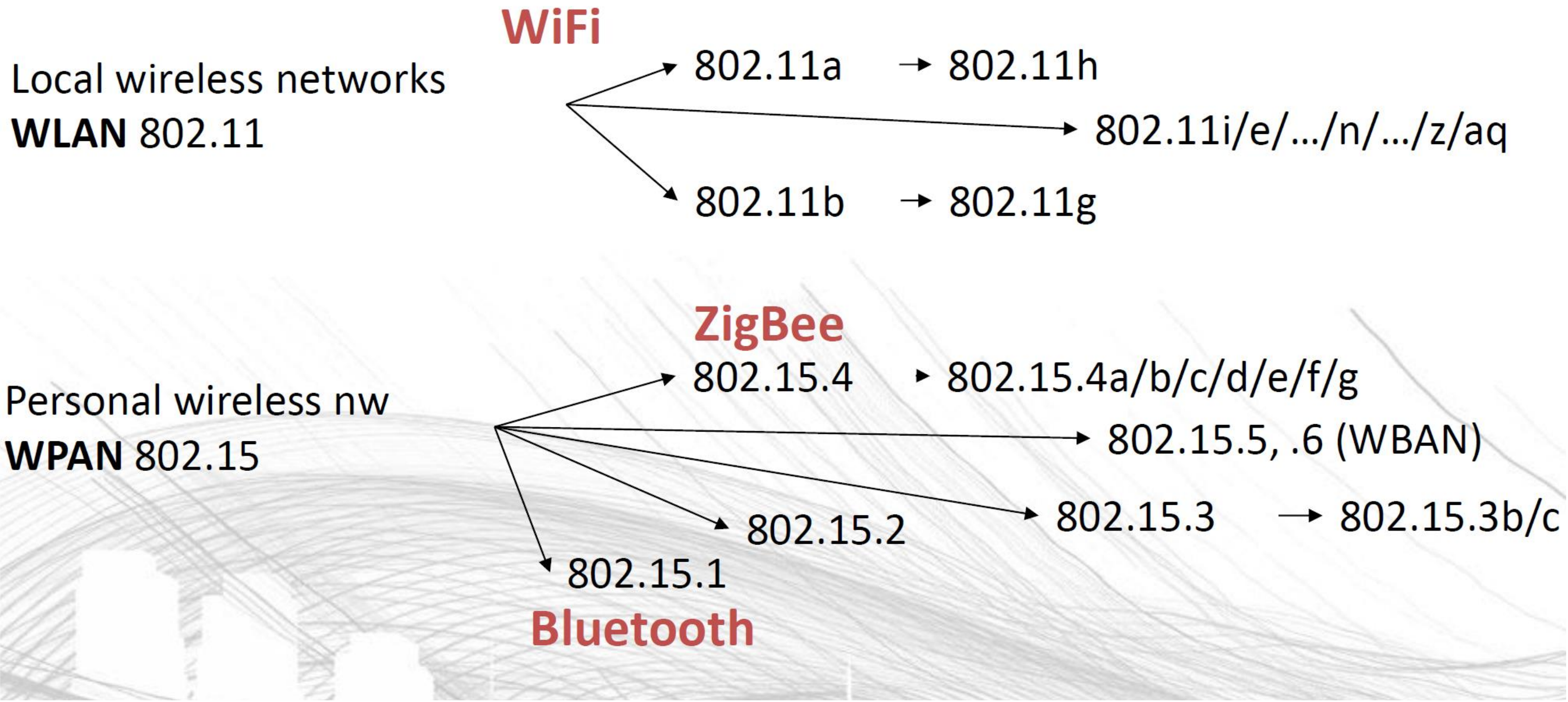
Physical and Link Layers Protocols- LP-WiFi



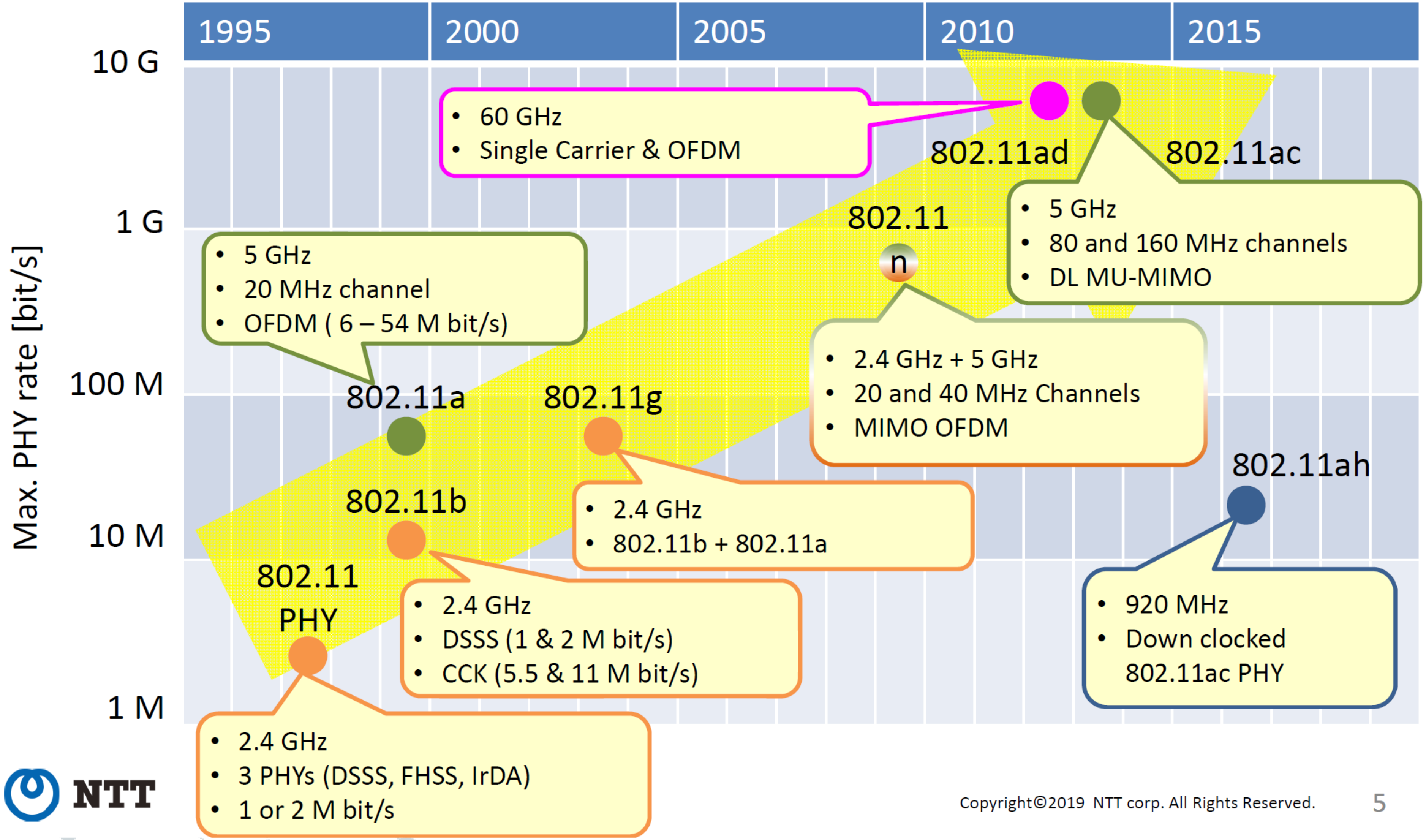
History of IEEE 802.11 Standardization

Standard	Date	Scope
IEEE 802.11	1997	Medium access control (MAC): One common MAC for WLAN applications
		Physical layer: Infrared at 1 and 2 Mbps
		Physical layer: 2.4-GHz FHSS at 1 and 2 Mbps
		Physical layer: 2.4-GHz DSSS at 1 and 2 Mbps
IEEE 802.11a	1999	Physical layer: 5-GHz OFDM at rates from 6 to 54 Mbps
IEEE 802.11b	1999	Physical layer: 2.4-GHz DSSS at 5.5 and 11 Mbps
IEEE 802.11c	2003	Bridge operation at 802.11 MAC layer
IEEE 802.11d	2001	Physical layer: Extend operation of 802.11 WLANs to new regulatory domains (countries)
IEEE 802.11e	2007	MAC: Enhance to improve quality of service and enhance security mechanisms
IEEE 802.11f	2003	Recommended practices for multivendor access point interoperability
IEEE 802.11g	2003	Physical layer: Extend 802.11b to data rates >20 Mbps
IEEE 802.11h	2003	Physical/MAC: Enhance IEEE 802.11a to add indoor and outdoor channel selection and to improve spectrum and transmit power management
IEEE 802.11i	2007	MAC: Enhance security and authentication mechanisms
IEEE 802.11j	2007	Physical: Enhance IEEE 802.11a to conform to Japanese requirements
IEEE 802.11k	2008	Radio Resource Measurement enhancements to provide interface to higher layers for radio and network measurements

History of IEEE 802.11 Standardization

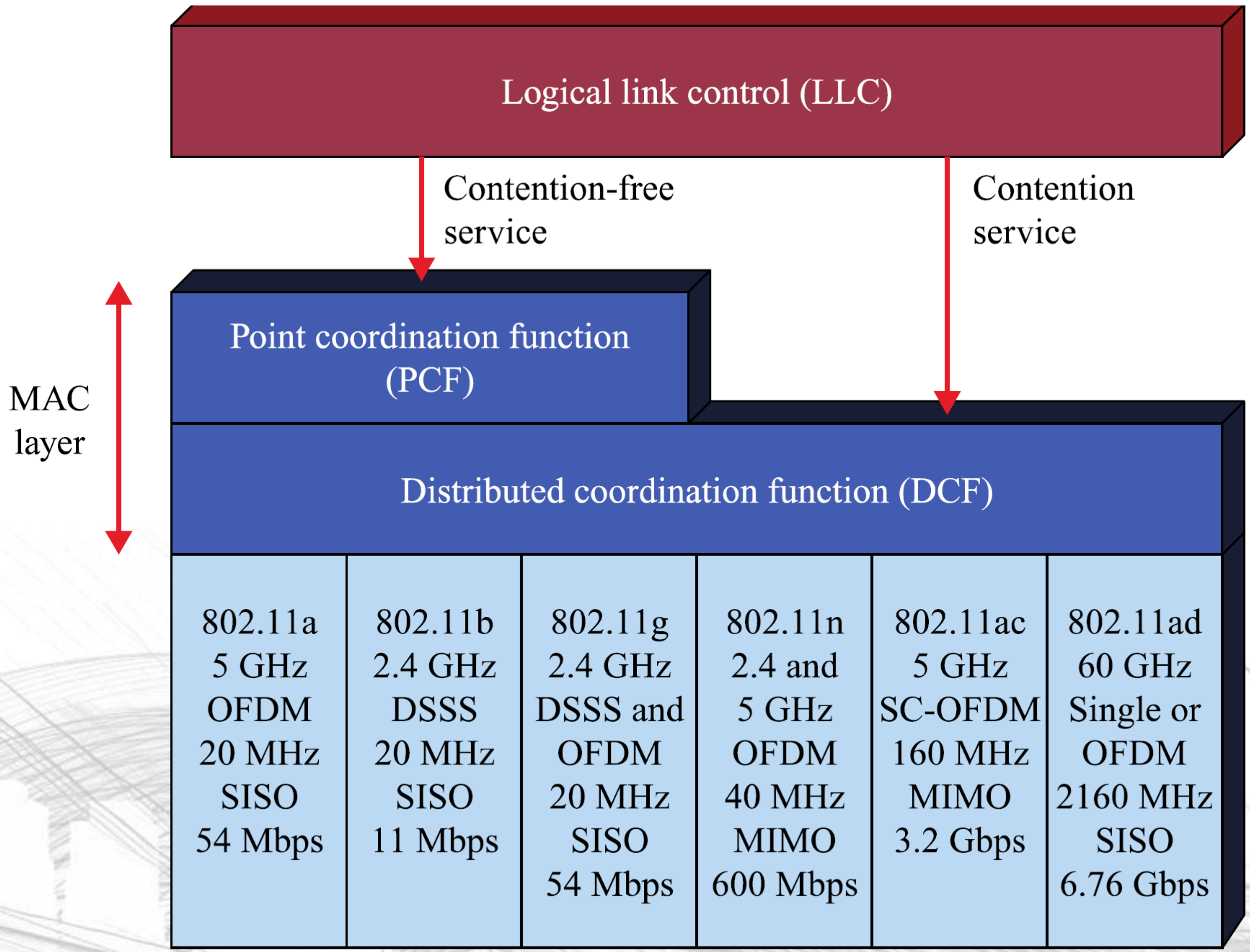
Standard	Date	Scope
IEEE 802.11m	Ongoing	This group provides maintenance of the IEEE 802.11 standard by rolling published amendments into revisions of the 802.11 standard.
IEEE 802.11n	2009	Physical/MAC: Enhancements to enable higher throughput
IEEE 802.11p	2010	Wireless Access in Vehicular Environments (WAVE)
IEEE 802.11r	2008	Fast Roaming/Fast BSS Transition
IEEE 802.11s	2011	Mesh Networking
IEEE 802.11T	Abandoned	Recommended Practice for Evaluation of 802.11 Wireless Performance
IEEE 802.11u	2011	Interworking with External Networks
IEEE 802.11v	2011	Wireless Network Management
IEEE 802.11w	2009	Protected Management Frames
IEEE 802.11y	2008	Contention Based Protocol
IEEE 802.11z	2010	Extensions to Direct Link Setup
IEEE 802.11aa	2012	Video Transport Stream
IEEE 802.11ac	Ongoing	Very High Throughput <6Ghz
IEEE 802.11ad	2012	Very High Throughput in 60 GHz
IEEE 802.11ae	2012	Prioritization of Management Frames
IEEE 802.11af	Ongoing	Wireless LAN in the TV White Space
IEEE 802.11ah	Ongoing	Sub 1GHz
IEEE 802.11ai	Ongoing	Fast Initial Link Set-up
IEEE 802.11aj	Ongoing	China Milli-Meter Wave (CMMW)
IEEE 802.11ak	Ongoing	Enhancements For Transit Links Within Bridged Networks
IEEE 802.11aq	Ongoing	Pre-Association Discovery (PAD)
IEEE 802.11ax	Ongoing	High Efficiency WLAN (HEW)

History of IEEE 802.11 Standardization



NTT

IEEE 802.11 Protocol Architecture



Physical and Link Layers Protocols- IEEE 802.11ah

- In unconstrained networks, IEEE 802.11 Wi-Fi is certainly the most successfully deployed wireless technology.
  - Either for connecting endpoints such as fog computing nodes, high-data-rate sensors, and audio or video analytics devices or for deploying Wi-Fi backhaul infrastructures, such as outdoor Wi-Fi mesh in smart cities, oil and mining, or other environments.
- Wi-Fi lacks sub-GHz support for
  - better signal penetration,
  - low power for battery-powered nodes,
  - the ability to support a large number of devices.
- For these reasons, the IEEE 802.11 working group launched a task group named IEEE 802.11ah to specify a sub-GHz version of Wi-Fi.

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

Physical and Link Layers Protocols- 802.11 ah

- The LP-WiFi also known as a new brand called Wi-Fi HaLow consumes lower power than a traditional WiFi device and also has a longer range.
  - This marketing name is based on a play on words between “11ah” in reverse and “low power.”
  - It is similar to the word “hello” but it is pronounced “hay-low.”

- The range of WiFi HaLow is nearly twice that of traditional WiFi.

- Like other WiFi devices, devices supporting WiFi HaLow also support IP connectivity, which is important for IoT applications.

* Internet of Things: Architectures, Protocols, and Applications, Hindawi, 2017

Physical and Link Layers Protocols- IEEE 802.11ah

- Three main use cases are identified for IEEE 802.11ah:
  - –Sensors and meters covering a smart grid
    - Meter to pole, environmental/agricultural monitoring, industrial process sensors, indoor healthcare system and fitness sensors, home and building automation sensors
  - –Backhaul aggregation of industrial sensors and meter data
    - Potentially connecting IEEE 802.15.4g subnetworks
  - –Extended range Wi-Fi
    - For outdoor extended-range hotspot or cellular traffic offloading when distances already covered by IEEE 802.11a/b/g/n/ac are not good enough

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

IEEE 802.11ah-Physical Layer

- IEEE 802.11ah essentially provides an additional 802.11 physical layer operating in unlicensed sub-GHz bands.
  - 868–868.6 MHz for EMEAR,
  - 902–928 MHz and associated subsets for North America and Asia-Pacific regions
  - 314–316 MHz, 430–434 MHz, 470–510 MHz, and 779–787 MHz for China.

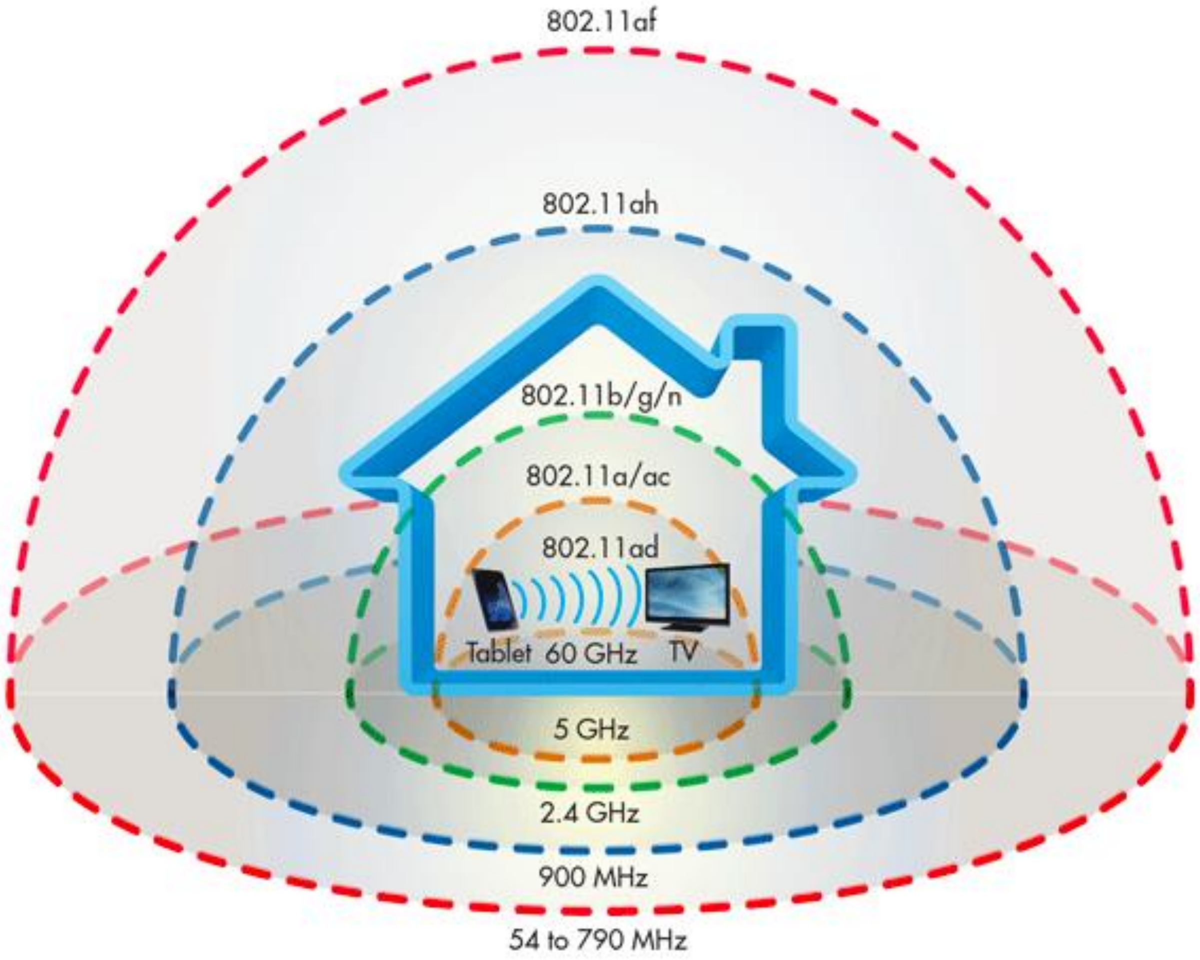
* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

IEEE 802.11ah-Physical Layer

- Based on OFDM modulation, IEEE 802.11ah uses channels of 2, 4, 8, or 16 MHz (and also 1 MHz for low-bandwidth transmission).
  - This is one-tenth of the IEEE 802.11ac channels, resulting in
    - one-tenth of the corresponding data rates of IEEE 802.11ac (The IEEE 802.11ac standard is a high-speed wireless LAN protocol at the 5 GHz band that is capable of speeds up to 1 Gbps)
  - While 802.11ah does not approach this transmission speed (as it uses one tenth of 802.11ac channel width, it reaches one-tenth of 802.11ac speed), it does provide an extended range for its lower speed data.
  - For example, at a data rate of 100 kbps, the outdoor transmission range for IEEE 802.11ah is expected to be 1 km.

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

Physical and Link Layers Protocols- IEEE 802.11ah



IEEE 802.11ah-MAC Layer

- More efficient to deal with errors at the MAC level than higher layer (such as TCP)

- Frame exchange protocol
  - Source station transmits data
  - Destination responds with acknowledgment (ACK)
  - If source doesn't receive ACK, it retransmits frame

- Four frame exchange
  - Source issues request to send (RTS)
  - Destination responds with clear to send (CTS)
  - Source transmits data
  - Destination responds with ACK

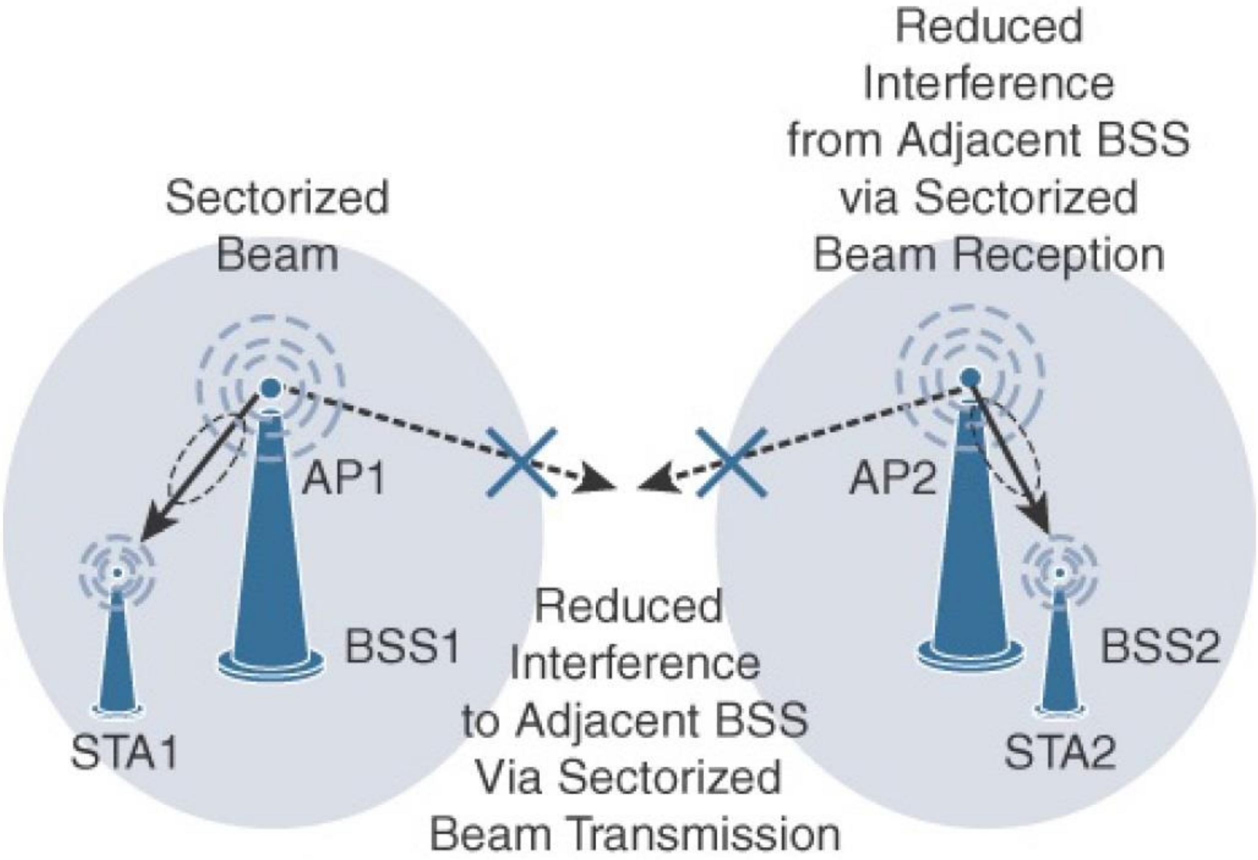
IEEE 802.11ah-MAC Layer

- The 802.11ah MAC layer is focused on
  - power consumption and mechanisms to allow low-power Wi-Fi stations to wake up less often and operate more efficiently.
  - providing low power consumption and the ability to support a larger number of endpoints.
  - This sort of MAC layer is ideal for IoT devices that often produce short, low-bit-rate transmissions.

* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

Physical and Link Layers Protocols- IEEE 802.11ah

- IEEE 802.11ah
  - Topology
    - Star
    - Mesh (relay networks)



* IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

Contents

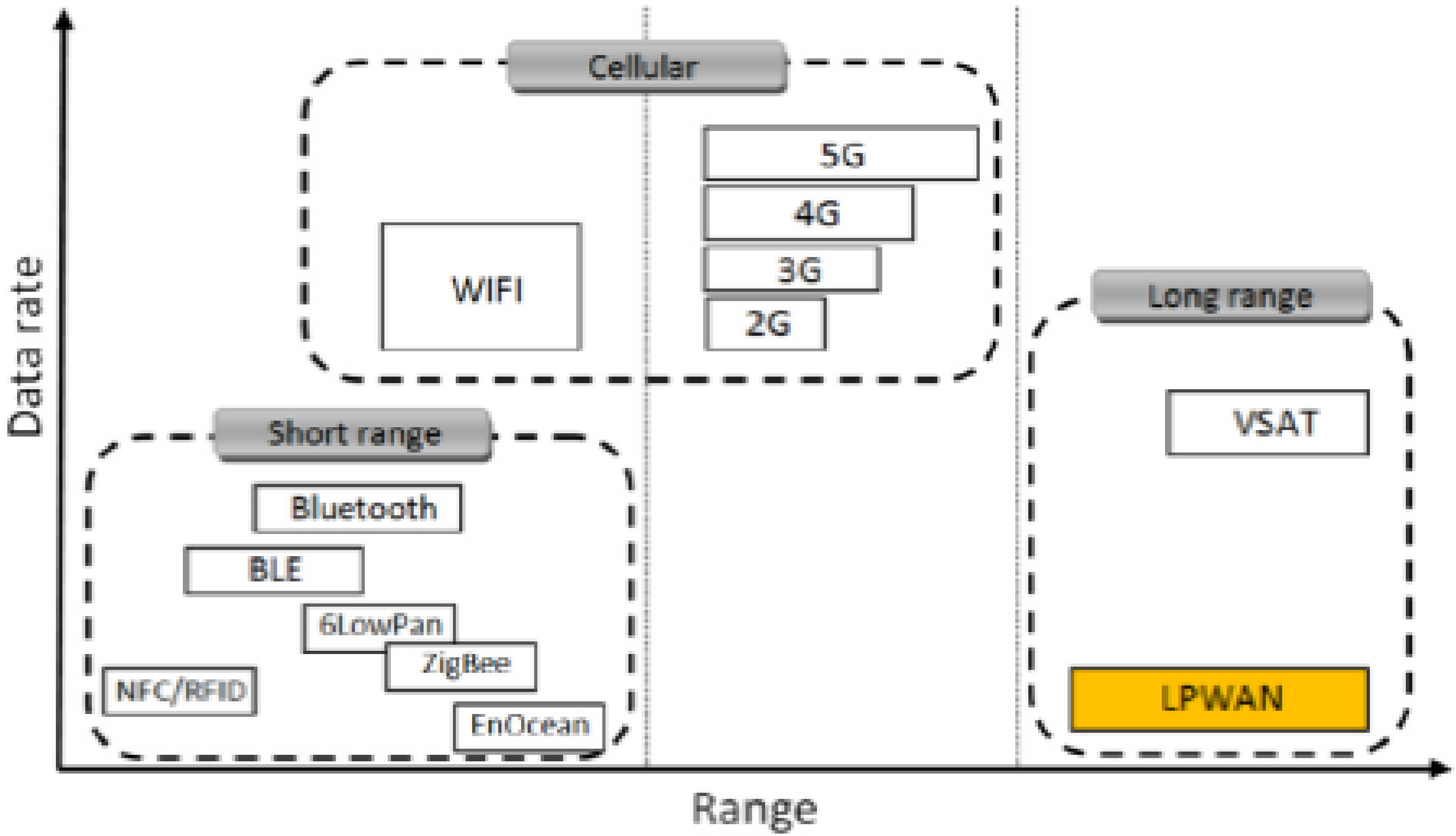
- Introduction
- Physical and Link Layers Protocols (IoT Access Technologies)
- Network Layer Protocols (IP as the IoT Network Layer)
- Transport Layer Protocols
- Application Layer Protocols

Mostly adopted from Chapters 4, 5, and 6 of **IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing**, Cisco press, 2017

Contents

Mostly adopted from Chapters 4, 5, and 6 of IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Thing, Cisco press, 2017

IoT Protocol Stack- Physical and Link Layers Protocols



Low Power Wide Area Network (LPWAN)

- Long-Range
  - Long Range Communications (WAN)
  - Low Number of Required BSs

- Low data rate
  - Less than 10 Kb/s
- Low-Power
  - Batteries last up to 10 years

- Low-Subscription Cost

Low Power Wide Area Network (LPWAN)- Review

- Long-Range
  - Long Range Communications (WAN)
  - Low Number of Required BSs

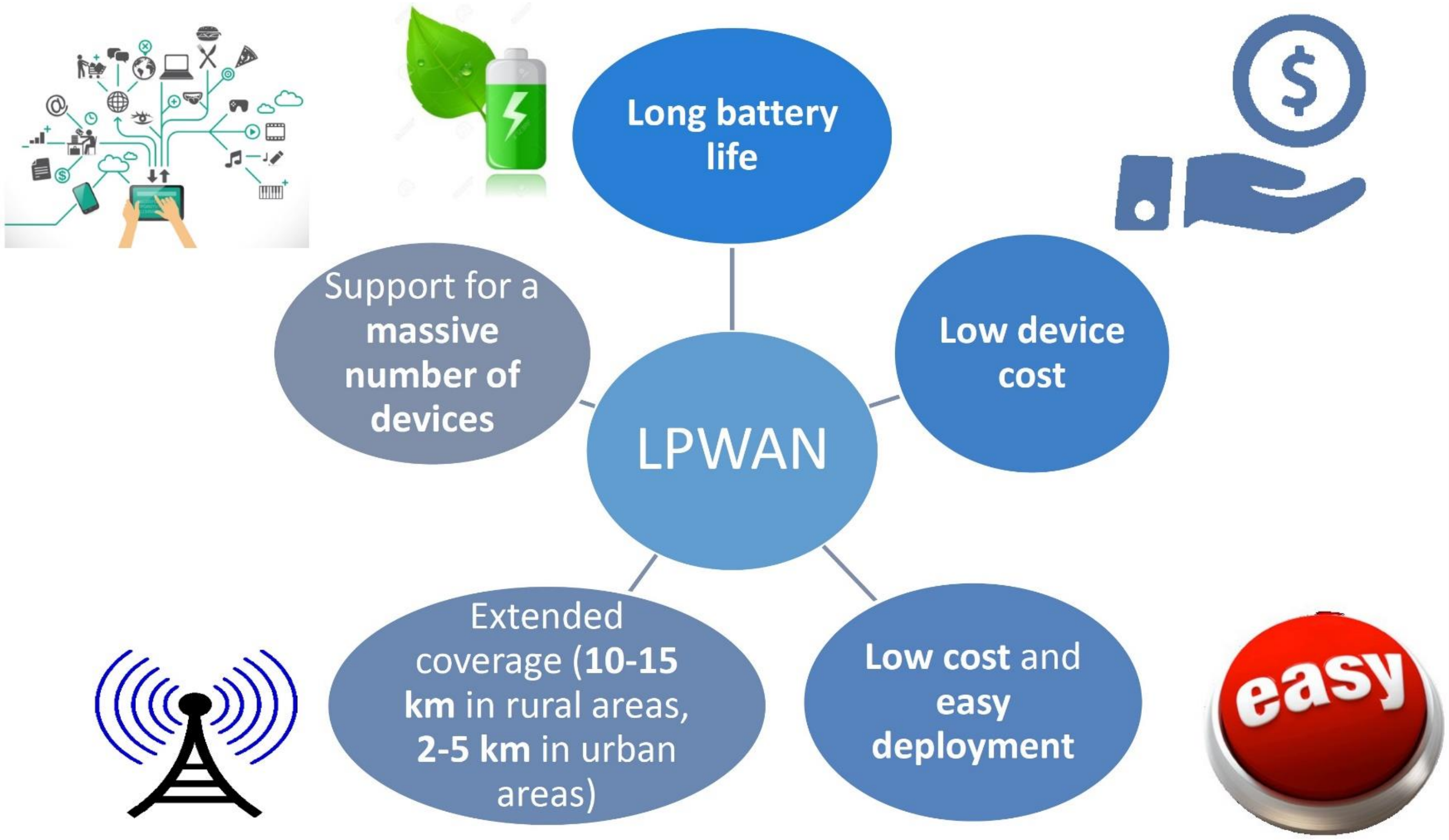
- Low data rate
  - Less than 10 Kb/s
- Low-Power
  - Batteries last up to 10 years

- Low-Subscription Cost

LPWAN- Design Goals

- The success of LPWA technologies lies in their ability to offer low-power connectivity to massive number of devices distributed over large geographical areas at an unprecedented low-cost
- The key objective of LPWA technologies to achieve
  - a long range
  - with low power consumption and
  - low cost
  - Scalability (massive number of devices)
  - Low-rate
- This is unlike that of the other technologies for which achieving higher data rate, lower latency and higher reliability may be more important.

LPWAN- Design Goals



IoT Long Range Technologies: Standards, ITU, 2017

LPWAN- Design Goals

- Why are existing LAN and WAN Technologies not appropriate for IoT applications?
  - Are they Long rage?
    - Existing WAN technologies are not very long range!
    - They mostly operate on GHz bands.
    - They need many BSs for good coverage
  - Are they Low-rate
    - They have been designed for high-rate applications
  - Are they Low Cost:
    - Their technologies are complex and the corresponding hardwares are costive and are with high-power consumptions
  - Are they low power?
  - Are they Scalable
    - Increasing scalability needs BSs densifications

Techniques for Achieving Design Goals in LPWAN

- Long-ranges
  - LPWA technologies are designed for a wide area coverage and an excellent signal propagation to hard-to-reach indoor places such as basements.
  - This allows the end-devices to connect to the base stations at a distance ranging from a few to tens of kilometers depending on their deployment environment (rural, urban, etc.).
  - Sub-GHz band and special modulation schemes, discussed next, are exploited to achieve this goal

Techniques for Achieving Design Goals in LPWAN

- Techniques for achieving Long-ranges
  - Use of Sub-1GHz band
    - Firstly, compared to the 2.4 GHz band, the lower frequency signals experience less attenuation and multipath fading caused by obstacles and dense surfaces like concrete walls.
    - Secondly, sub-GHz is less congested than 2.4 GHz, a band used by mostpopular wireless technologies e.g., Wi-Fi, cordless phones, Bluetooth, ZigBee
  - Modulation Techniques:
    - Narrowband
    - Spread Spectrum

Techniques for Achieving Design Goals in LPWAN

- Low Power
  - Topology
  - Duty Cycling
  - Lightweight Medium Access Control
  - Offloading complexity from end devices

Techniques for Achieving Design Goals in LPWAN

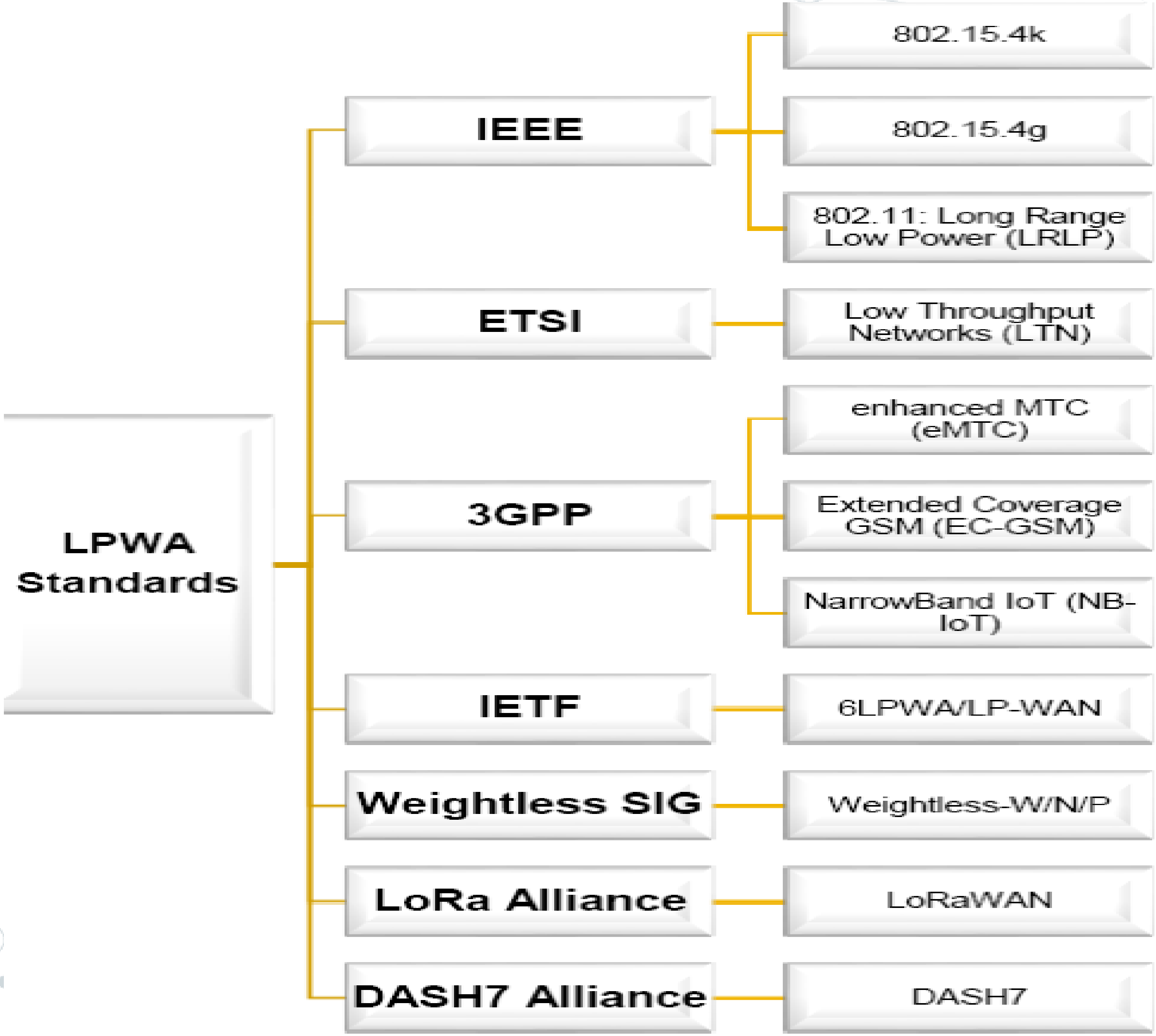
- Low Cost
  - The commercial success of LPWA networks is tied to connecting a large number of end devices, while keeping the cost of hardware below $5 and the connectivity subscription per unit as low as $1.
  - LPWA technologies adopt several ways to reduce the capital expenses (CAPEX) and operating expenses (OPEX) for both the end-users and network operators.

Techniques for Achieving Design Goals in LPWAN

- Low Cost
  - Use of star-type (instead of mesh) connectivity,
  - Simple MAC protocols,
  - Techniques to offload complexity from end devices enables manufacturers to design simple and therefore low-cost end devices.
  - Reduction in hardware complexity
  - Minimum infrastructure
  - Using license-free or owned licensed bands

Techniques for Achieving Design Goals in LPWAN

- Scalability



LPWA Standards
IEEE
802.15.4k
802.15.4g
802.11: Long Range Low Power (LRLP)
ETSI
Low Throughput Networks (LTN)
3GPP
enhanced MTC (eMTC)
Extended Coverage GSM (EC-GSM)
NarrowBand IoT (NB-IoT)
IETF
6LPWA/LP-WAN
Weightless SIG
Weightless-W/N/P
LoRa Alliance
LoRaWAN
DASH7 Alliance
DASH7

LPWANs

- SigFox:
  - Developed in 2010 by the startup Sigfox (in France)
  - Operates and commercializes its own IoT solution in 31 countries

- LoRaWAN
  - First developed by the start-up Cycleo in 2009 (in France) and was purchased three years later by Semtech (USA)
  - In 2015, LoRa was standardized by LoRa-Alliance and is deployed in 42 countries
  - Investment of various mobile operators (e.g., Bouygues and Orange in France, KPN in Netherlands, and Fastnet in South Africa)

- NB-IoT
  - Based on narrow band radio technology and is standardized by the 3GPP (Release 13 on June 2016)
  - In December 2016, Vodafone and Huawei integrated NB-IoT into the Spanish Vodafone network.