IOT SYSTEM DESIGN

TECHNOLOGIES & PROTOCOLS FOR IOT

Dr. T. DEEPA ,
Associate Professor,
Department of Electronics and Communication Engineering,
SRM Institute of Science and Technology (SRM IST),
Kattankulathur- 603203 .
Chengalpattu District, Tamil Nadu.
https://www.srmist.edu.in/engineering/ece/faculty/dr-t-deepa

Topics :

- Communication Technologies & Protocols
  - Short range IoT Solutions
  - Long range IoT Solutions

Communication Protocols for IoT

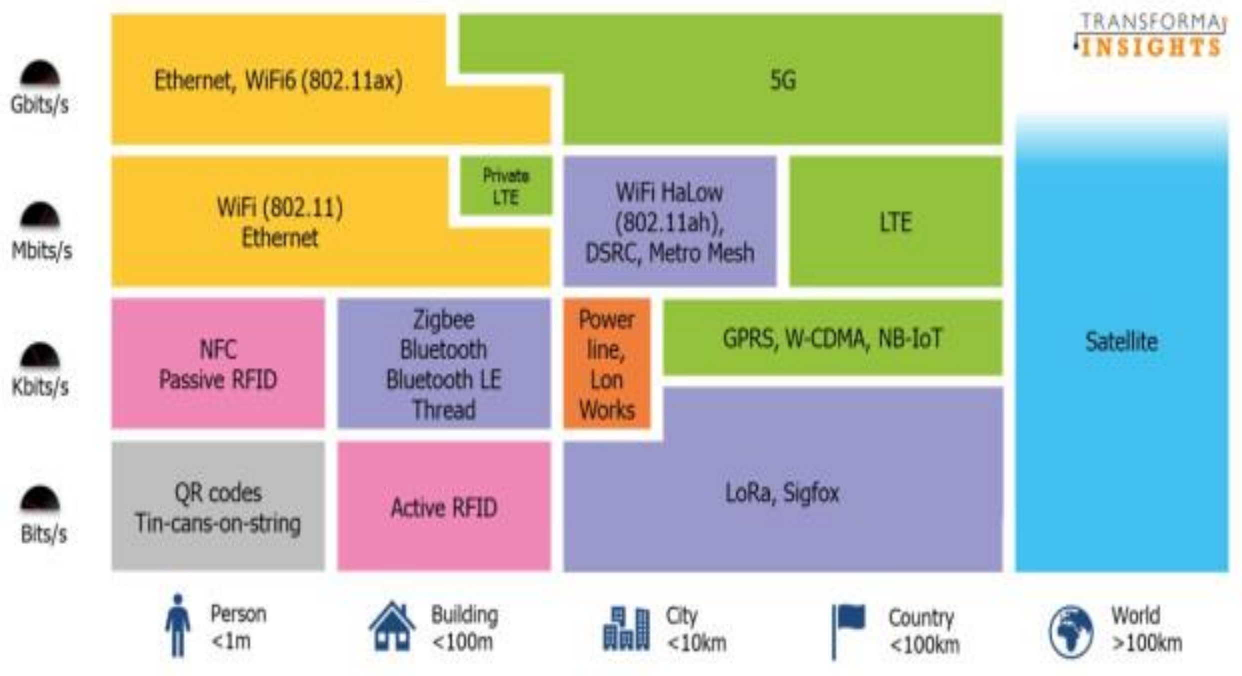
The following communication protocols have immediate importance to consumer and industrial IoTs:

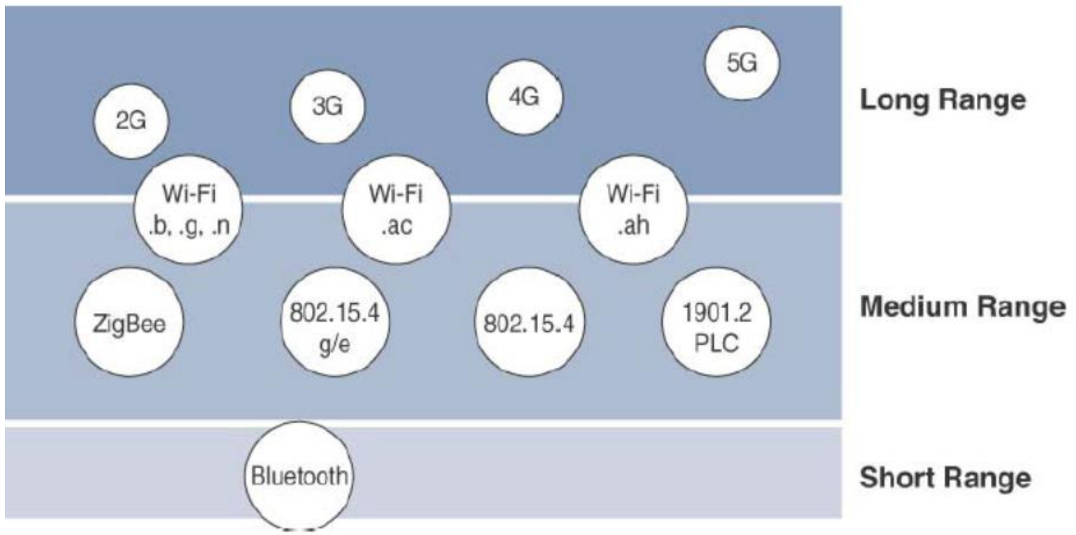
- IEEE 802.15.4
- Zigbee
- 6LoWPAN
- Wireless HART
- Z-Wave
- ISA 100
- Bluetooth
- NFC
- RFID

Outline

- The landscape technologies for IoT connectivity
- Standards for WSANs
  - IEEE 802.15.4
    - IEEE 802.15.4g/e
  - Zigbee
  - 6LoWPAN
  - RFID
  - Bluetooth
  - NFC,Z-wave
  - WI-FI
  - LoRa
  - Sigfox
  - LTE-M
  - Weightless

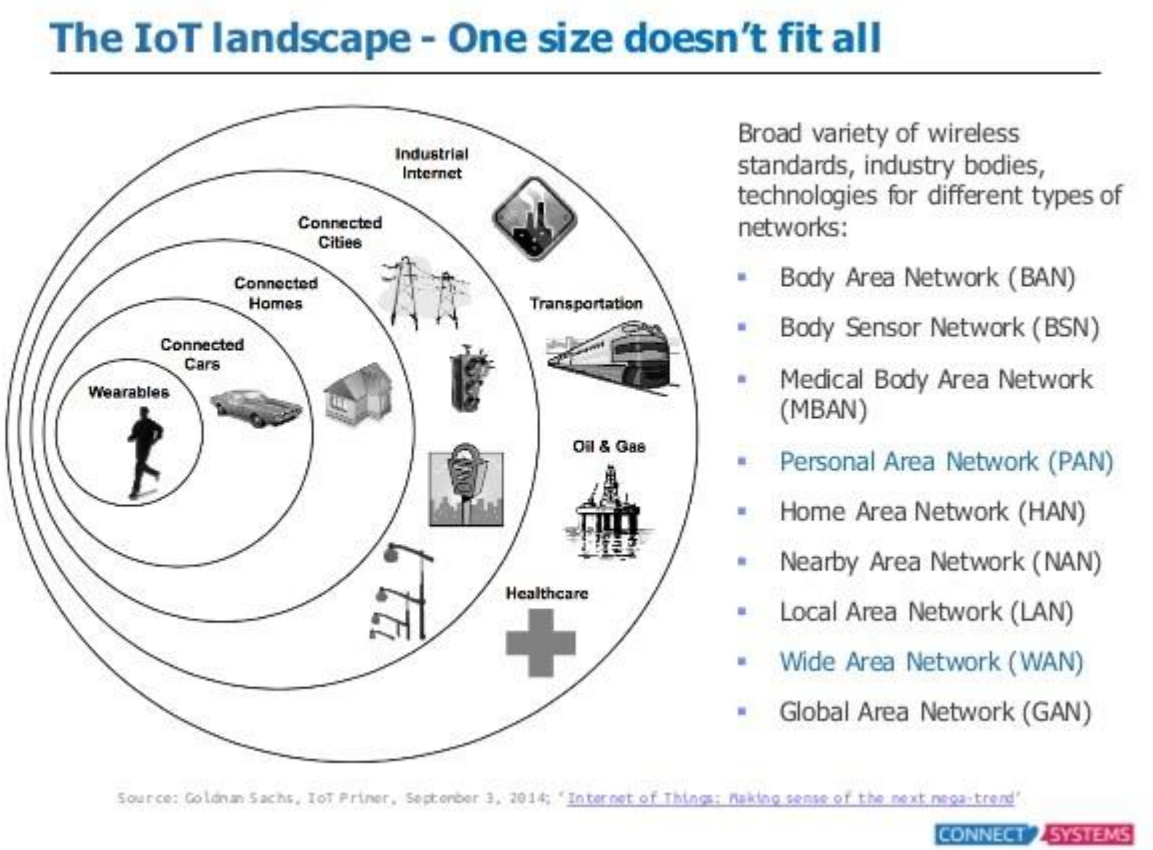
The landscape of technologies for wireless IoT connectivity





Source: https://www.embedded.com/the-internet-of-things-myth-the-search-for-a-connectivity-standard/

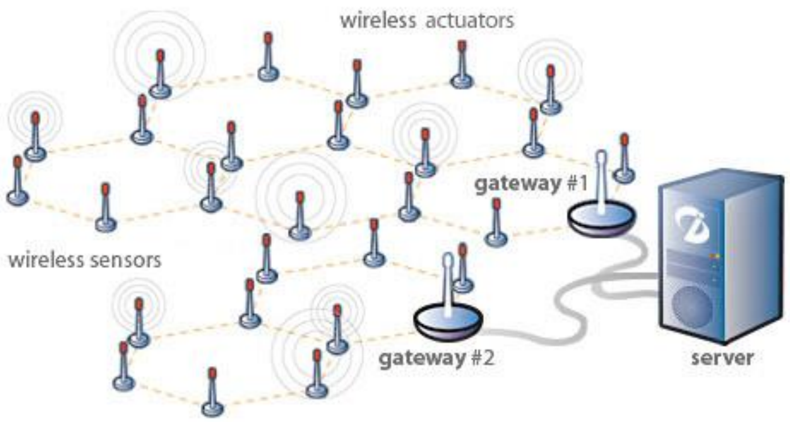
The IoT landscape



Source: https://www.gadgeon.com/blog/what-is-the-right-wireless-technology-for-your-iot-project/

Standards for Wireless sensors , actuators networks (WSANs)

- IEEE 802.15.4/802.15.4e
- ZigBee
- Bluetooth
- WirelessHART
- ISA-100.11a
- 6LoWPAN
  - *IPv6 over Low power WPAN*
- RPL
  - *Routing Protocol for Low power and Lossy networks*
- CoAP
  - *Constrained Application Protocol*



Introduction to IEEE 802.15.4

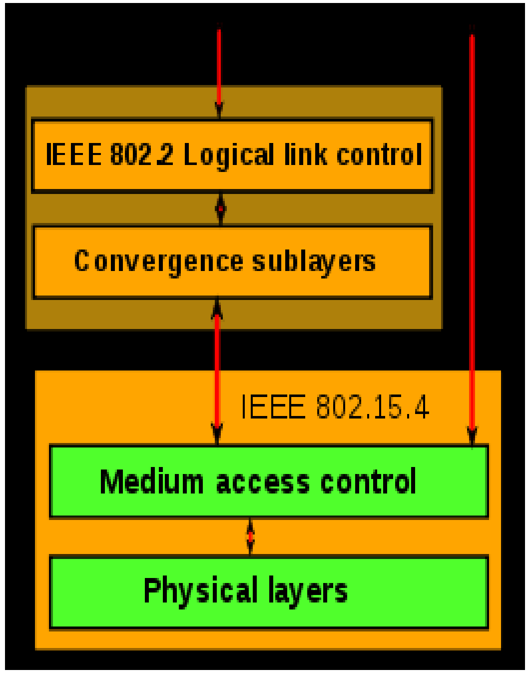
- This standard provides a framework meant for lower layers (MAC and PHY) for a wireless personal area network (WPAN).
  - PHY defines frequency band, transmission power, and modulation scheme of the link.
  - MAC defines issues such as medium access and flow control (frames).
- This standard is used for low power, low cost (manufacturing and operation), and low speedcommunication between neighboring devices (< ~75m).

Introduction to IEEE 802.15.4

- This standard utilizes direct sequence spread spectrum (DSSS) coding scheme to transmit information.
- DSSS uses phase shift keying modulation to encode information.
  - BPSK -868/915 MHz, data transmission rate 20/40 kbps respectively.
  - OQPSK -2.4 GHz, data transmission rate 250 kbps.
- DSSS scheme makes the standard highly tolerant to noise and interference and thereby improving link reliability.

Features – IEEE 802.15.4

- Well-known standard for low data-rate WPAN.
- Developed for low-data-rate monitoring and control applications and extended-life low-power-consumption uses.
- This standard uses only the first two layers (PHY, MAC) plus the logical link control (LLC) and service specific convergence sub-layer (SSCS) additions to communicate with all upper layers
- Operates in the ISM band.



Source: https://en.wikipedia.org/wiki/IEEE_802.15.4

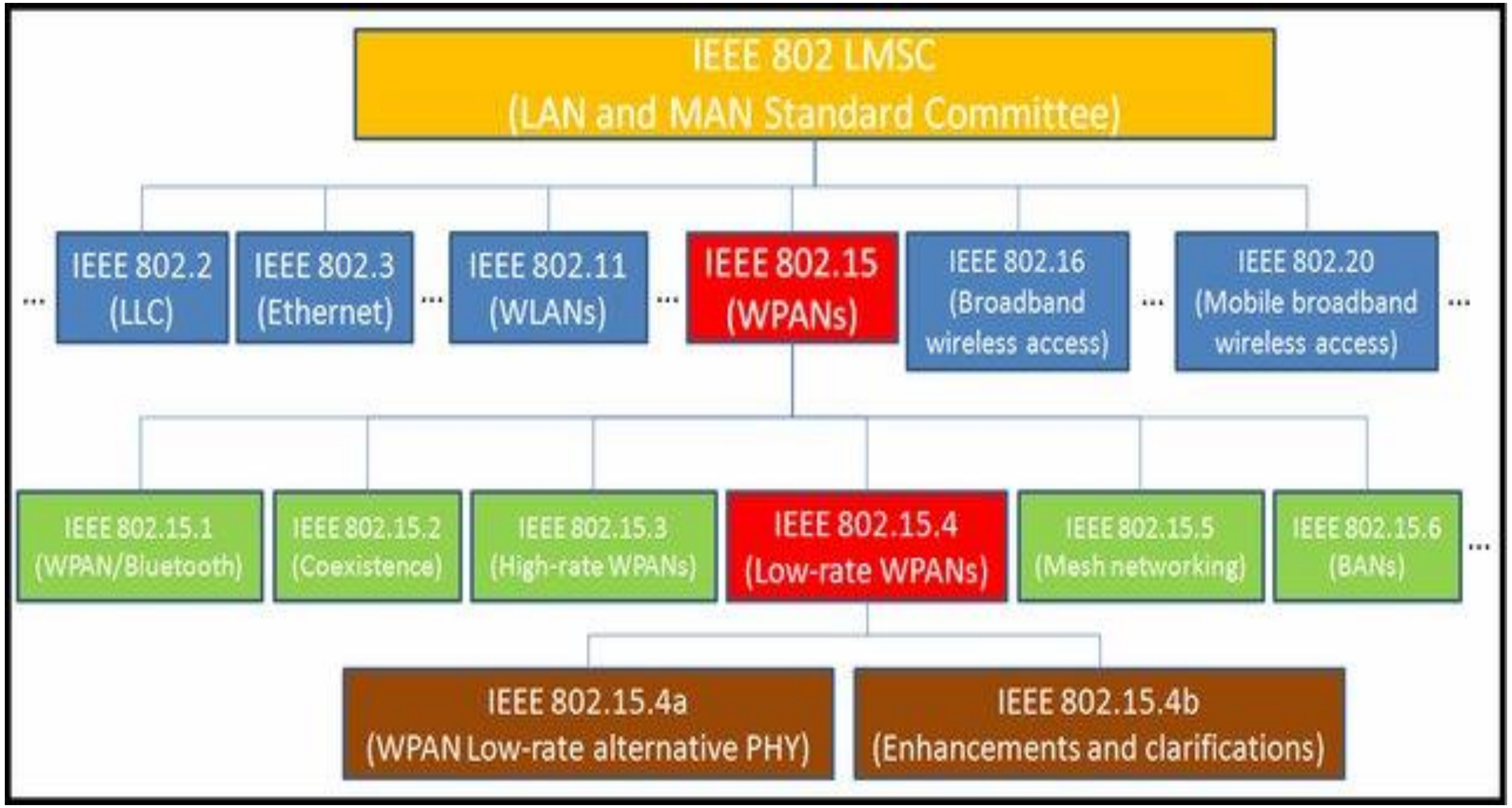
Features – IEEE 802.15.4(Contd)

- Power consumption is minimized due to infrequently occurring very short packet transmissions with low duty cycle (<1%).
- The minimum power level defined is –3 dBm or 0.5 mW.
- Transmission, for most cases, is Line of Sight (LOS).
- Standard transmission range varies between 10m to 75m.
- Best case transmission range achieved outdoors can be upto 1000m.
- Networking topologies defined are -- Star, and Mesh.

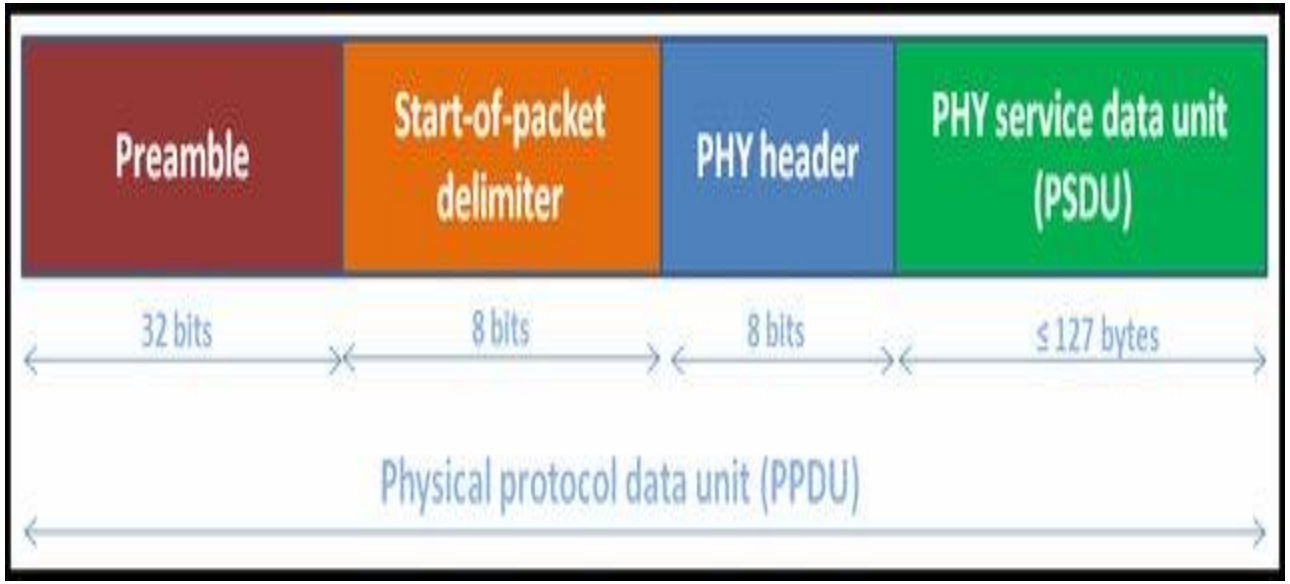
Features – IEEE 802.15.4

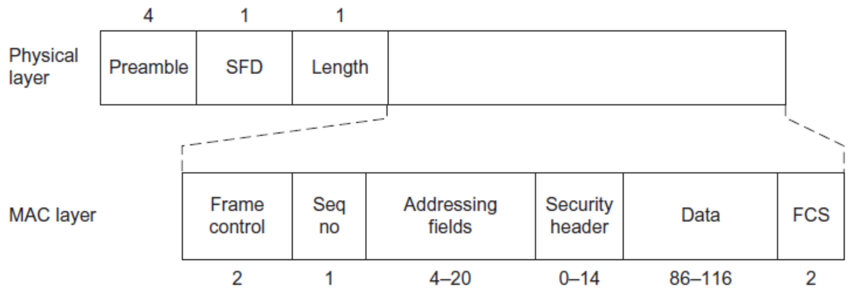
- Uses direct sequence spread spectrum (DSSS) modulation.
- Highly tolerant of noise and interference and offers link reliability improvement mechanisms.
- Low-speed versions use Binary Phase Shift Keying (BPSK).
- High data-rate versions use offset-quadrature phase-shift keying (O-QPSK).
- Uses carrier sense multiple access with collision avoidance (CSMA-CA) for channel access.
- Multiplexing allows multiple users or nodes interference-free access to the same channel at different times.

Standards – IEEE 802.15.4



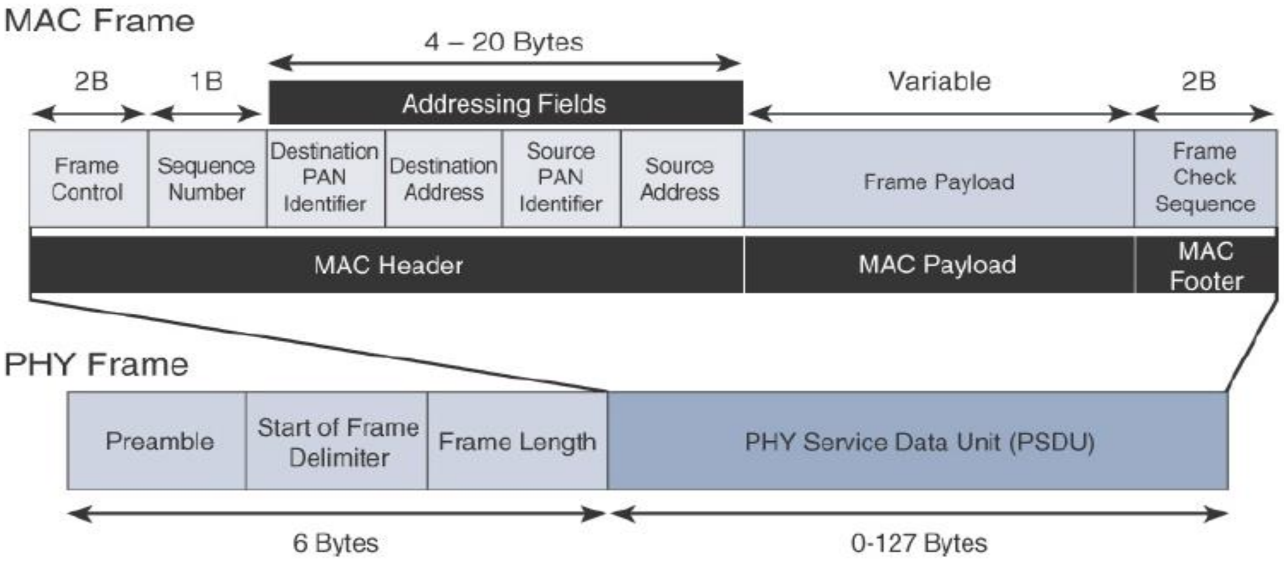
IEEE 802.15.4 PPDU format



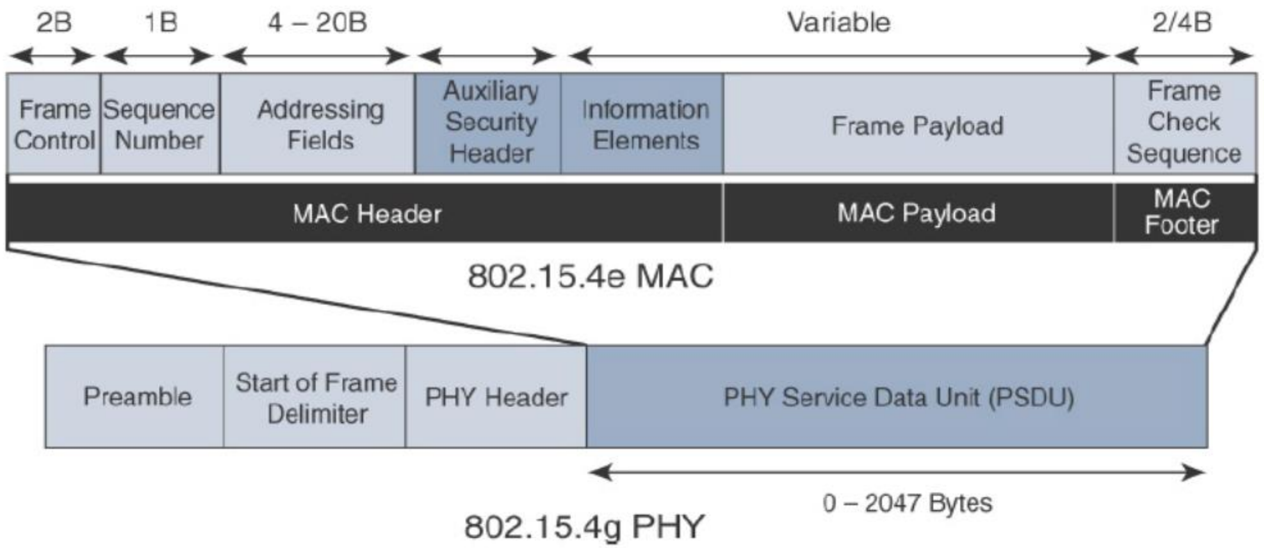


IEEE 802.15.4 FRAME FORMAT

- IEEE 802.15.4

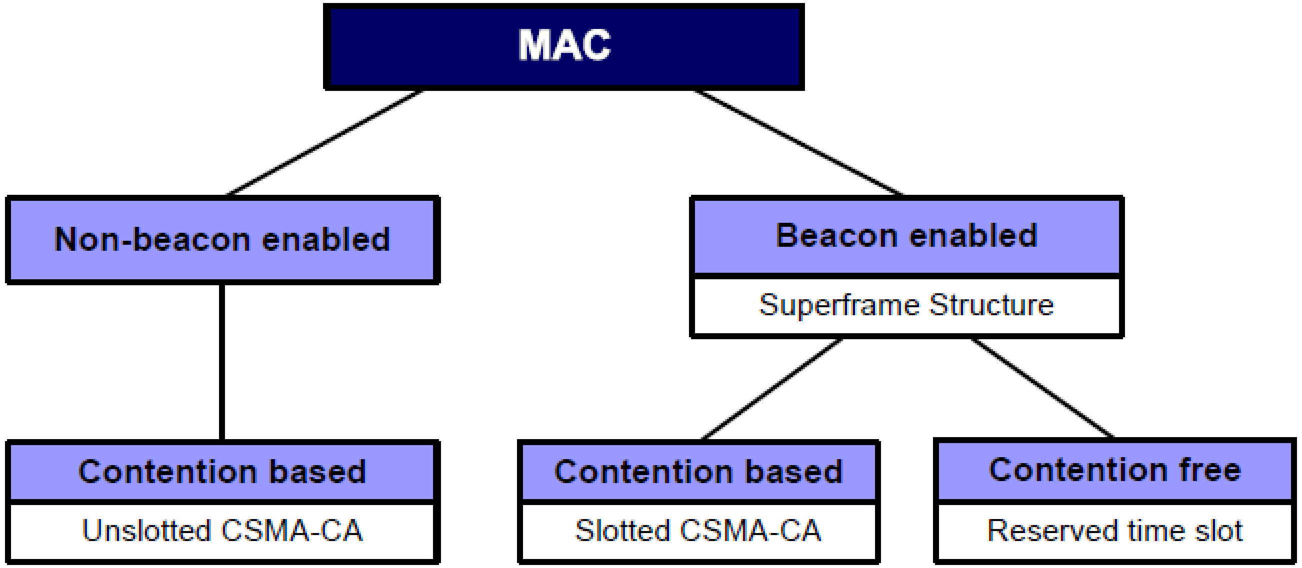


IEEE 802.15.4g/e



IEEE 802.15 MAC Protocols

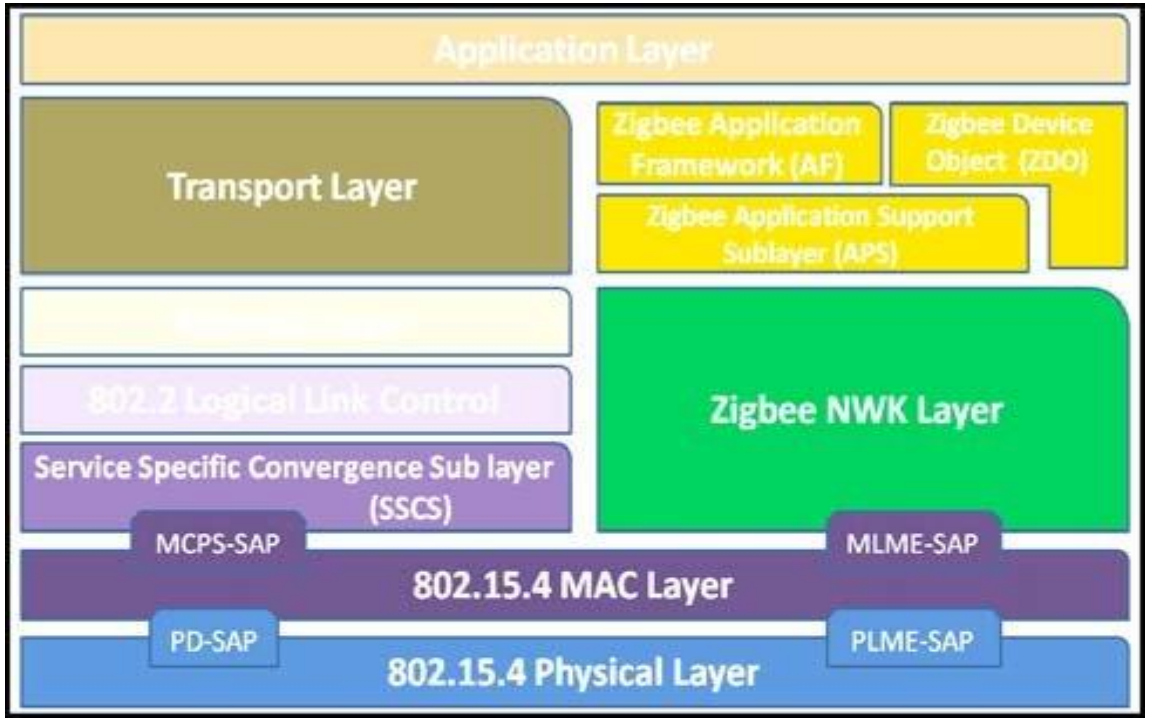
- Two different channel access methods
  - Beacon-Enabled duty-cycled mode
  - Non-Beacon Enabled mode (aka Beacon Disabled mode)



Limitations- IEEE 802.15.4 MAC Protocols

- Reliability and scalability issues
- Unbounded latency
- Due to contention-based CSMA-CA algorithm
- No guaranteed bandwidth
- Unless GTS is used
- GTS only provides a limited service (7 slots)
- No built-in frequency hopping technique
- Prone to failures due to interferences and multi-path fading

OSI layers with IEEE 802.15.4 and Zigbee Standards



https://www.researchgate.net/publication/41392302_Interconnection_between_802154_Devices_and_IPv6_Implications_and_Existing_Approaches/figures?lo=1

Some Real Life Scenarios : Requirements

- For smart cities, smart buildings, etc.,
- Energy Efficiency
  - Target battery lifetime: 5 years, or more
- Scalability
  - Large network sizes
- Timeliness
  - Alert applications, process monitoring, ...
- Reliability
  - Wire-like reliability may be required, e.g., 99.9% or better

Other IoT Access Technologies

- IEEE 802.15.4: foundational wireless protocol for connecting smart objects.
- IEEE 802.15.4g and IEEE 80fi.15.4e: Improvements to 802.15.4 that are targeted to utilities and smart cities deployments.
- IEEE 802.11ah: This section discusses IEEE 802.11ah, a technology built on the well-known 802.11 Wi-Fi standards that is specifically for smart objects.
- LoRaWAN: a scalable technology designed for longer distances with low power requirements in the unlicensed spectrum.
- •NB-IoT and Other LTE Variations: NB-IoT and other LTE variations, which are often the choice of mobile service providers looking to connect smart objects over longer distances in the licensed spectrum.

IEEE 802.15 Task Group 4e

- chartered to define a MAC amendment to the existing standard 802.15.4-2006.
- The intent of this amendment was to enhance and add functionalities to the 802.15.4-2006 MAC

    better support the industrial markets

    increase robustness against external interference

- On February 6, 2012 the IEEE Standards Association
- Board approved the IEEE 802.15.4e MAC Enhancement Standard document for publication.
- http://www.ieee802.org/15/pub/TG4e.html

IEEE 802.15 Task Group 4e

- Major Changes
- General functional improvements
  - not tied to any specific application domain
- MAC Behaviour Modes
- support of specific application domains
- Remarks:
  - Many ideas borrowed from previous industrial standards
    - Wireless HART and ISA 100.11.a
    - *slotted access*, *shared and dedicated slots*, *multi-channel* communication, and *frequency hopping*.

IEEE 802.15.4e- Applications

- Target Application Domains
  - Industrial applications
  - Commercial applications
  - Healthcare applications
- Provides
  - Flexibility
  - Robustness
  - High reliability
  - Deterministic latency
  - Scalability
  - Efficiency

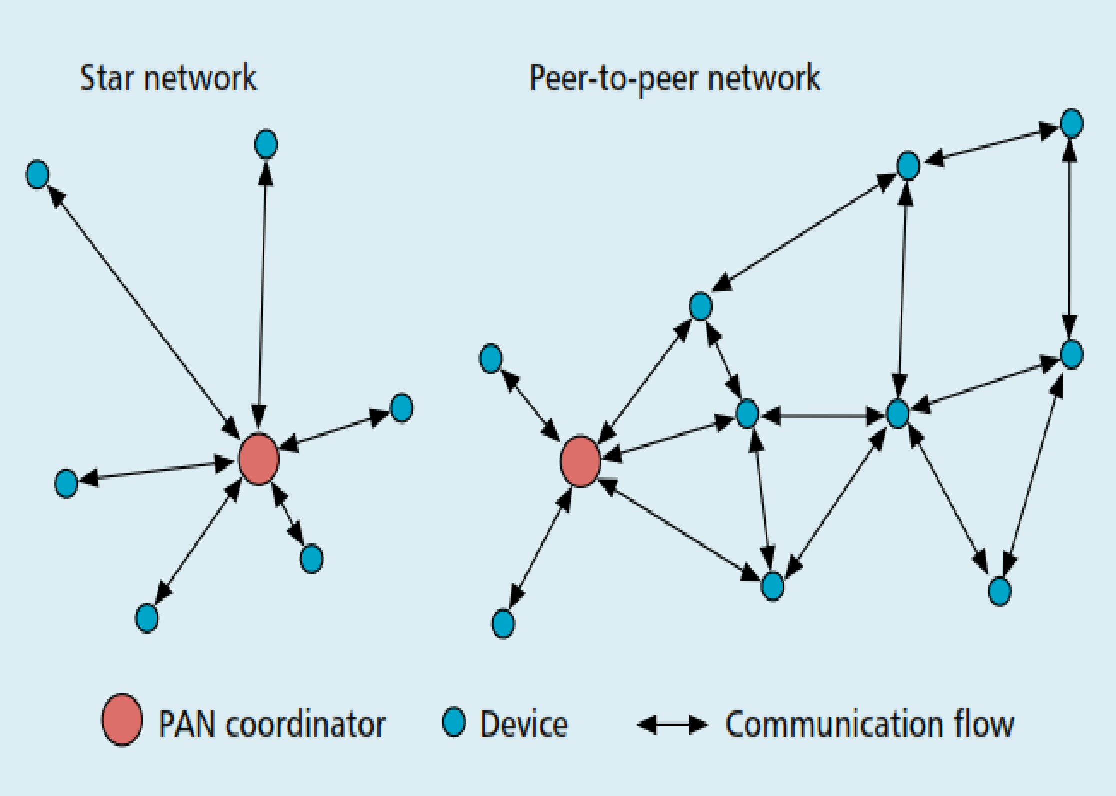
Main Features

- Multi-channel, multi-superframe
- Mesh extension to GTS
- Two channel diversity modes
  - channel adaptation
  - channel hopping
- Distributed beacon scheduling
- Distributed slot allocation
- Group acknowledgments
- Many topologies
  - Star, cluster-tree and peer-to-peer

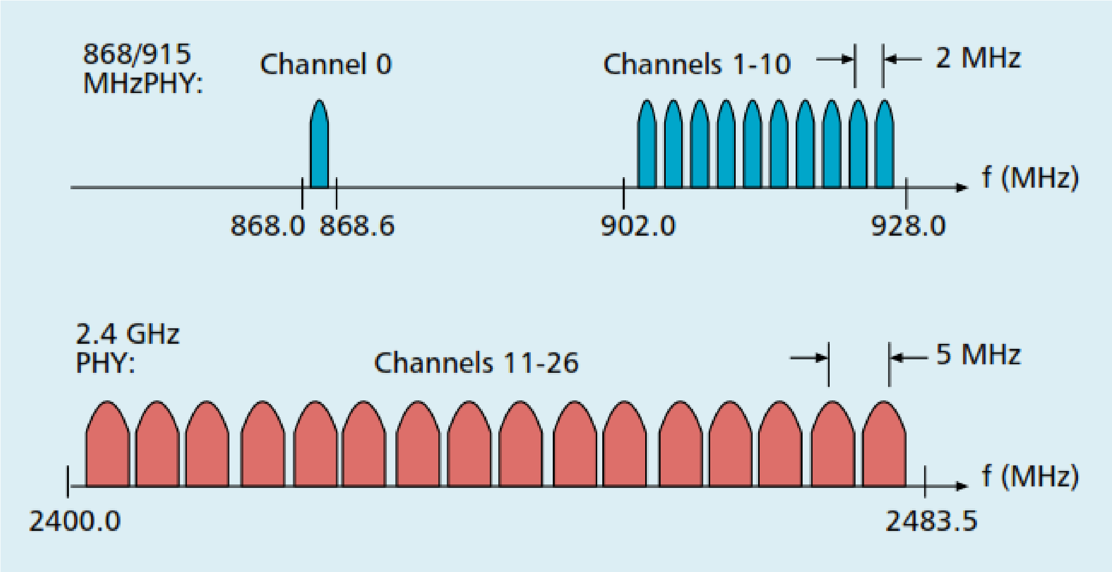
IEEE 802.15.4g and 802.15.4e

- 802.15.4e-2012 and 802.15.4g-2012, both of which are especially relevant to the subject of IoT.
- The IEEE 802.15.4e amendment of 802.15.4-2011 expands the MAC layer feature set to remedy the disadvantages associated with 802.15.4, including MAC reliability, unbounded latency, and multipath fading.
- In addition to making general enhancements to the MAC layer, IEEE 802.15.4e also made improvements to better cope with certain application domains, such as **factory and process automation and smart grid.**
- **Smart grid is associated with the modernization of the power grid and utilities infrastructure by connecting intelligent devices and communications**.
- •IEEE 802.15.4g-2012 is also an amendment to the IEEE 802.15.4-2011 standard, and just like 802.15.4e- 2012, it has been **fully integrated into the core IEEE 802.15.4-2015 specification.**
- •The focus of this **specification is the smart grid or, more specifically, smart utility network communication. 802.15.4g seeks to optimize large outdoor wireless mesh networks for field area networks (FANs).**

WSAN - Network Topologies



Channel Frequencies



Source: Ed Callaway, Paul Gorday, Lance Hester, Jose A. Gutierrez, Marco Naeve, Bob Heile, **Home Networking with IEEE 802.15.4: Developing Standard for Low-RateWireless Personal Area Networks,** *IEEE Communications Magazine*, August 2002.

Introduction -Zigbee

- Provides a framework for medium-range communication in IoT connectivity.
- Defines PHY (Physical) and MAC (Media Access Control) layers enabling interoperability between multiple devices at low-datarates.
- Operates at 3 frequencies –
  - 868 MHz (1 channel using data transmission rate up to 20 kbps)
  - 902-928MHz (10 channels using data transmission rate of 40 kbps)
  - 2.4 GHz (16 channels using data transmission rate of 250 kbps).

Features - Zigbee

- Most widely deployed enhancement of IEEE 802.15.4.
- The ZigBee protocol is defined by **layer 3 and above**. It works with the 802.15.4 layers 1 and 2.
- The standard uses layers 3 and 4 to define additional communication enhancements.
- These enhancements include authentication with valid nodes, encryption for security, and a data routing and forwarding capability that enables mesh networking.
- The most popular use of ZigBee is wireless sensor networks using the mesh topology.

Features – Zigbee(Contd.)

- The lower frequency bands use BPSK.
- For the 2.4 GHz band, OQPSK is used.
- The data transfer takes place in 128 bytes packet size.
- The maximum allowed payload is 104 bytes.
- The nature of transmission is line of sight (LOS).
- Standard range of transmission –upto70m.

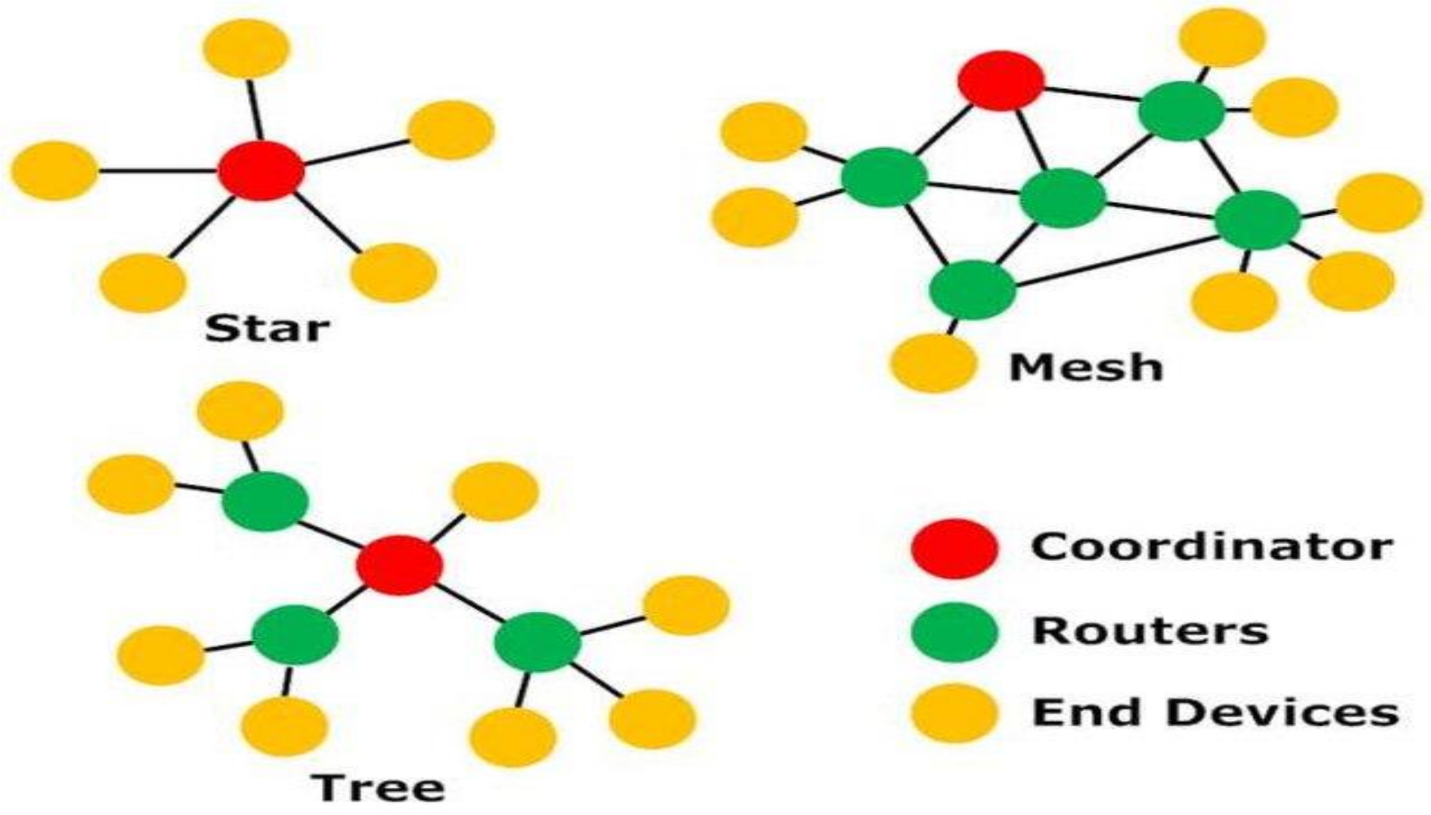
Features – Zigbee(Contd.)

- Relaying of packets allow transmission over greater distances.
- Provides low power consumption (around 1mW per Zigbee module) and better efficiency due to
  - adaptable duty cycle
  - low data rates (20 -250 kbit/s)
  - low coverage radio (10 -100 m)
- Networking topologies include star, peer-to-peer, or cluster-tree (hybrid), mesh being the popular.

Zigbee Topologies

- The Zigbee protocol defines three types of nodes:
  - **Coordinators**-Initializing, maintaining and controlling the network. There is one and only one per network.
  - **Routers**-Connected to the coordinator or other routers. Have zero or more children nodes. Contribute in multi hop routing.
  - **End devices** -Do not contribute in routing.
- **Star topology** has no router, one coordinator, and zero or more end devices.
- In **mesh** and **tree** topologies, one coordinator maintains several routers and end devices.

Zigbee based Network Topologies



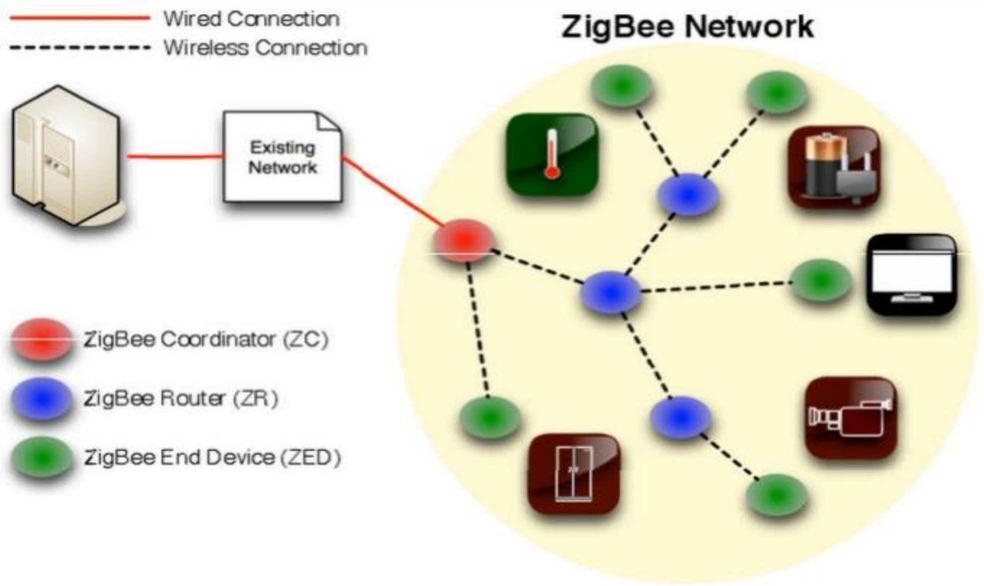
Source:
https://www.researchgate.net/publication/269517670_Design_and_Performance_Analysis_of_Building_Monitoring_System_with_Wireless_Sensor_Networks/figures?lo=1

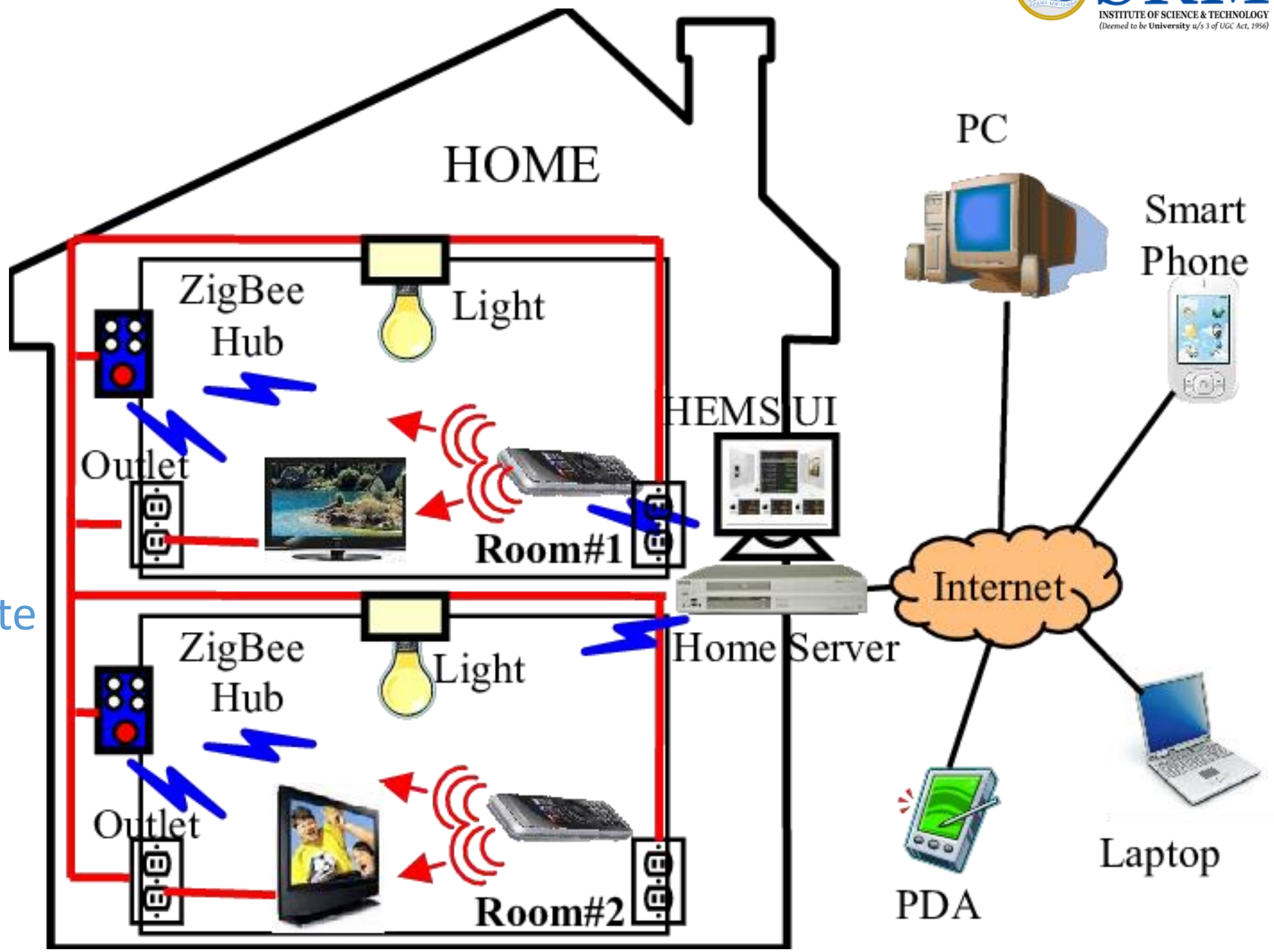
Zigbee Variants :

- Each cluster in a cluster-tree network involves a coordinator through several leaf nodes.
- Coordinators are linked to parent coordinator that initiates the entire network.
- ZigBee standard comes in two variants:
  - **ZigBee**
  - **ZigBee Pro** -offers scalability, security, and improved performance utilizing many-to-one routing scheme.

ZigBee

- **Operations:**
  - **Coordinator**: acts as a root and bridge of the network
  - **Router**: intermediary device that permit data to pass to and through them to other devices
  - **End Device:** limited functionality to communicate with the parent nodes





Low cost and available

Zigbee Types

- *ZigBee Coordinator (ZC)*:
- The Coordinator forms the root of the ZigBee network tree and might act as a bridge between networks.
- There is a single ZigBee Coordinator in each network, which originally initiates the network.
- It stores information about the network under it and outside it.
- It acts as a Trust Center & repository for security keys.

Zigbee Types

- *ZigBee Router (ZR)*:

  Capable of running applications, as well as relaying information between nodes connected to it.

- *ZigBee End Device (ZED)*:
  - It contains just enough functionality to talk to the parent node, and it cannot relay data from other devices.
  - This allows the node to be asleep a significant amount of the time thereby enhancing battery life.
- Memory requirements and cost of ZEDs are quite low, as compared to ZR or ZC.

Zigbee Network Layer

- The network layer uses Ad Hoc On-Demand Distance Vector (AODV) routing.
  - To find the final destination, the AODV broadcasts a route request to all its immediate neighbors.
- The neighbors relay the same information to their neighbors, eventually spreading the request throughout the network.
- Upon discovery of the destination, a low-cost path is calculated and informed to the requesting device via unicast messaging.

Zigbee Applications

- Building automation
- Remote control (RF4CE or RF for consumer electronics)
- Smart energy for home energy monitoring
- Health care for medical and fitness monitoring
- Home automation for control of smart homes
- Light Link for control of LED lighting
- Telecom services

Introduction - 6LOWPAN

- 6LoWPAN is IPv6 over Low-Power Wireless Personal Area Networks.
- It optimizes IPv6 packet transmission in low power and lossy network (LLN) such as IEEE 802.15.4.
- Operates at 2 frequencies:
  - 2400–2483.5 MHz (worldwide)
  - 902–929 MHz (North America)
- It uses 802.15.4 standard in unslotted CSMA/CA mode.

Introduction - 6LOWPAN

- Low-power Wireless Personal Area Networks over IPv6.
- Allows for the smallest devices with limited processing ability to transmit information wirelessly using an Internet protocol.
- Allows low-power devices to connect to the Internet.
- Created by the Internet Engineering Task Force (IETF) - RFC5933 and RFC 4919.

Features - 6LOWPAN

- Allows IEEE 802.15.4 radios to carry 128-bit addresses of
- Internet Protocol version 6 (IPv6).
- Header compression and address translation techniques allow the IEEE 802.15.4 radios to access the Internet.
- IPv6 packets compressed and reformatted to fit the IEEE 802.15.4 packet format.
- Uses include IoT, Smart grid, and M2M applications.

LoRaWAN

- The LoRaWAN wireless technology was developed for LPWANs that are critical for implementing many new devices on IoT networks.
- The term LoRa refers to the PHV layer, and LoRaWAN focuses on the architecture, the MAC layer, and a unified, single standard for seamless interoperability. LoRaWAN is managed by the LoRa Alliance, an industry organization.
- The PHV and MAC layers allow LoRaWAN to cover longer distances with a data rate that can change depending on various factors. The LoRaWAN architecture depends on gateways to bridge endpoints to network servers. From a security perspective, LoRaWAN offers AES authentication and encryption at two separate layers.

LoRaWAN (Contd)

- Unlicensed LPWA technologies represent new opportunities for implementing IoT infrastructures, solutions, and use cases for private enterprise networks, broadcasters, and mobile and non-mobile service providers.
- The ecosystem of endpoints is rapidly growing and will certainly be the tie-breaker between the various LPWA technologies and solutions, including LoRaWAN.
- Smart cities operators, broadcasters, and mobile and non-mobile services providers, which are particularly crucial to enabling use cases for the consumers' markets, are addressing the need for regional or national IoT infrastructures.
- As private enterprises look at developing LPWA networks, they will benefit from roaming capabilities between private and public infrastructures. These can be deployed similarly to Wi-Fi infrastructures and can coexist with licensed-band LPWA options.
- Overall, LoRaWAN and other LPWA technologies answer a definite need in the IoT space and are expected to continue to grow as more and more "things" need to be interconnected.

Short Range IoT Solutions

Introduction - RFID

- RFID is an acronym for "radio-frequency identification"
- Data digitally encoded in RFID tags, which can be read by a
- reader.
- Somewhat similar to barcodes.
- Data read from tags are stored in a database by the reader.
- As compared to traditional barcodes and QR codes, RFID tag data can be read outside the line-of-sight.

Features of RFID

- RFID tag consists of an integrated circuit and an antenna.
- The tag is covered by a protective material which also acts as a shield against various environmental effects.
- Tags may be passive or active.
- Passive RFID tags are the most widely used.
- Passive tags have to be powered by a reader inductively before they can transmit information, whereas active tags have their own power supply.

Working Principle – RFID

- Derived from Automatic Identification and Data Capture (AIDC) technology.
- AIDC performs object identification, object data collection and mapping of the collected data to computer systems with little or no human intervention.
- AIDC uses wired communication
- RFID uses radio waves to perform AIDC functions.
- The main components of an RFID system include an RFID tag or smart label, an RFID reader, and an antenna.

RFID - Applications

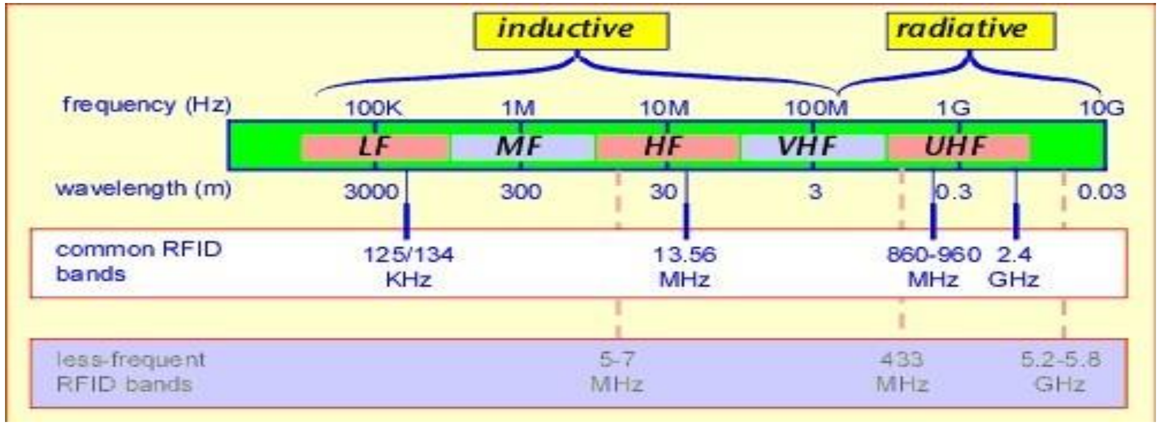
- Inventory management
- Asset tracking
- Personnel tracking
- Controlling access to restricted areas
- ID badging
- Supply chain management
- Counterfeit prevention (e.g. in the pharmaceutical industry)

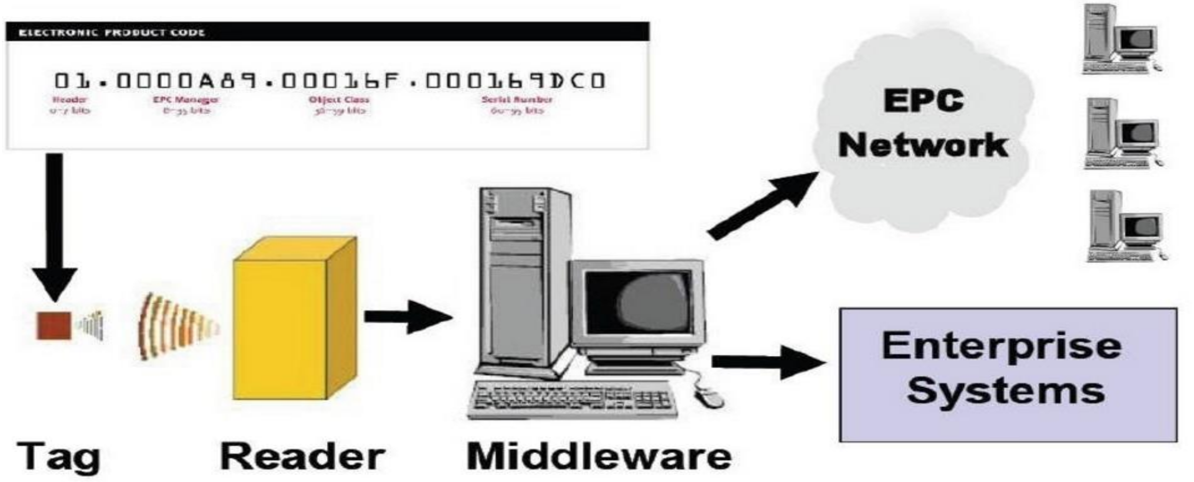
Functionality based IoT Protocol Organization

- **Connectivity** (6LowPAN, RPL)
- **Identification** (EPC, uCode, IPv6, URIs)
- **Communication / Transport** (WiFi, Bluetooth, LPWAN)
- **Discovery** (Physical Web, mDNS, DNS-SD)
- **Data Protocols** (MQTT, CoAP, AMQP, Websocket, Node)
- **Device Management** (TR-069, OMA-DM)
- **Semantic** (JSON-LD, Web Thing Model)
- **Multi-layer Frameworks** (Alljoyn, IoTivity, Weave, Homekit)

RFID: Radio Frequency Identification

- **Appeared first in 1945**
- **Features:**
  - Identify objects, record metadata or control individual target
  - More complex devices (e.g., readers, interrogators, beacons) usually connected to a host computer or network
  - Radio frequencies from 100 kHz to 10 GHz
- **Operations:**
  - Reading Device called Reader (connected to banckend network and communicates with tags using RF)
  - One or more tags (embedded antenna connected to chip based and attached to object)





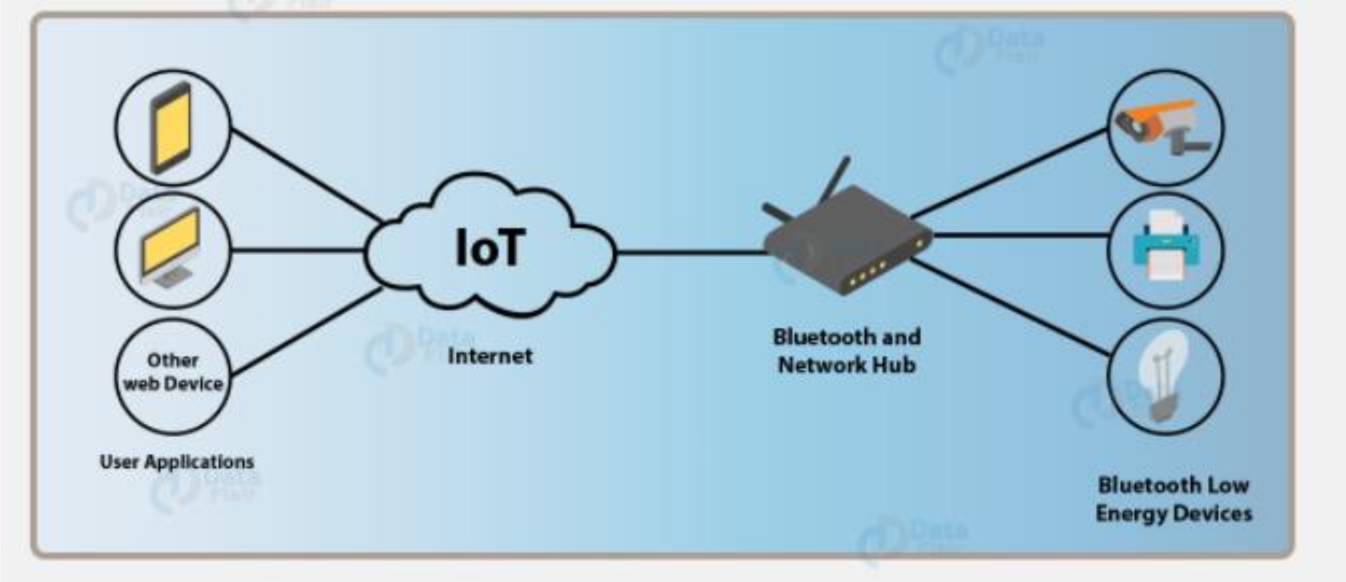
Bluetooth

- **Features:**
  - Low Power wireless technology
  - Short range radio frequency at 2.4 GHz ISM Band
  - Wireless alternative to wires
  - Creating PANs (Personal area networks)
  - Support Data Rate of 1 Mb/s (data traffic, video traffic)
  - Uses Frequency Hopping spread Spectrum

- **Bluetooth 5:**
  - 4x range, 2x speed and 8x broadcasting message capacity
  - Low latency, fast transaction (3 ms from start to finish) Data Rate 1 Mb/s: sending just small data packets

Class	Maximum Power	Range
1	100 mW (20 dBm)	100 m
2	2,5 mW (4 dBm)	10 m
3	1 mW (0 dBm)	1 m

Bluetooth Role in IoT Technology



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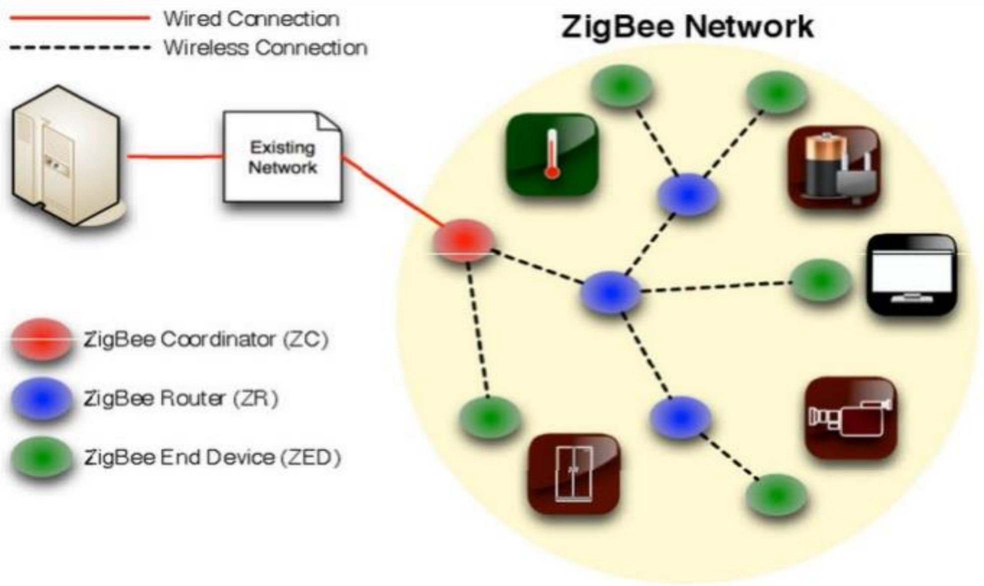
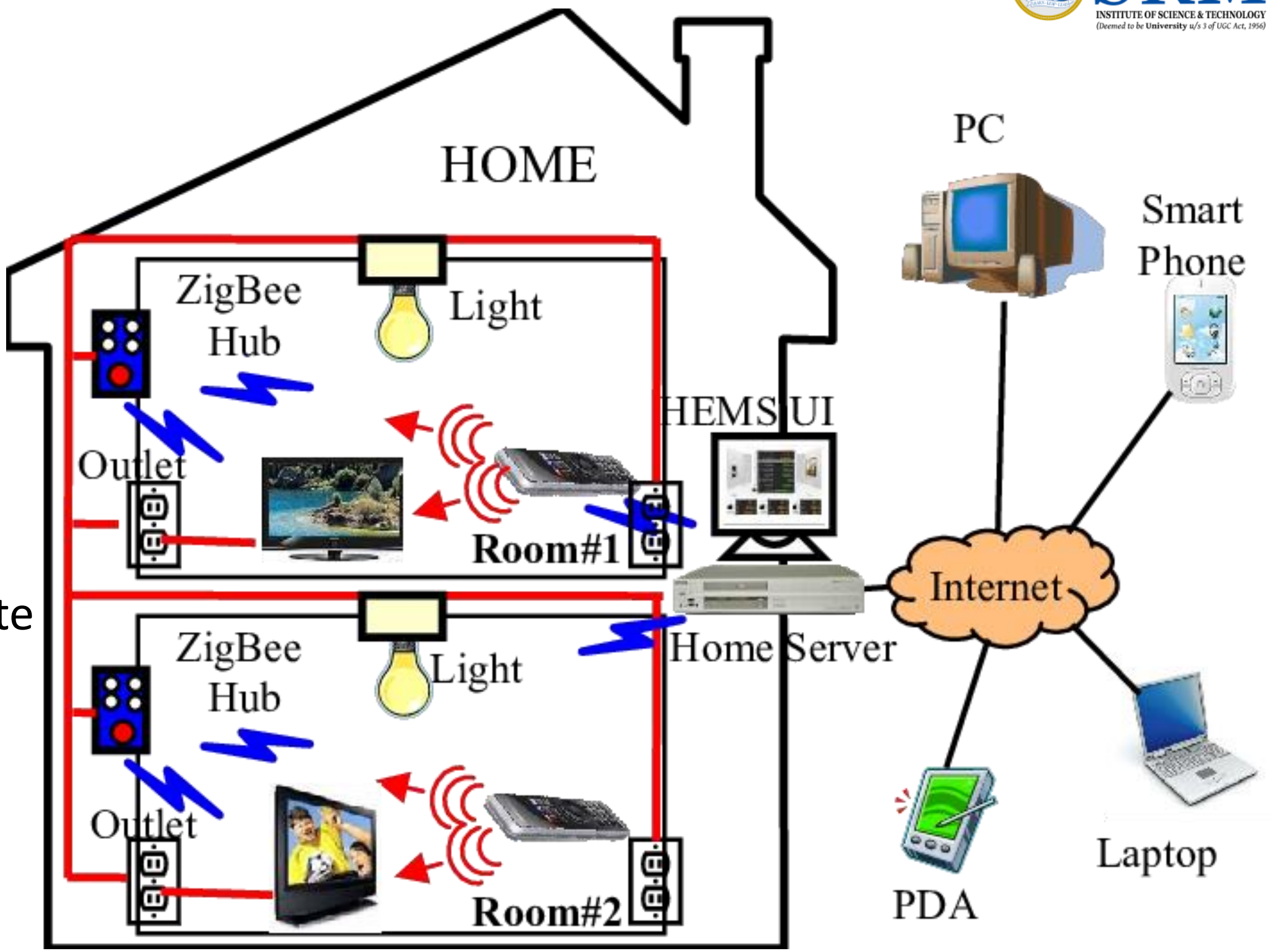


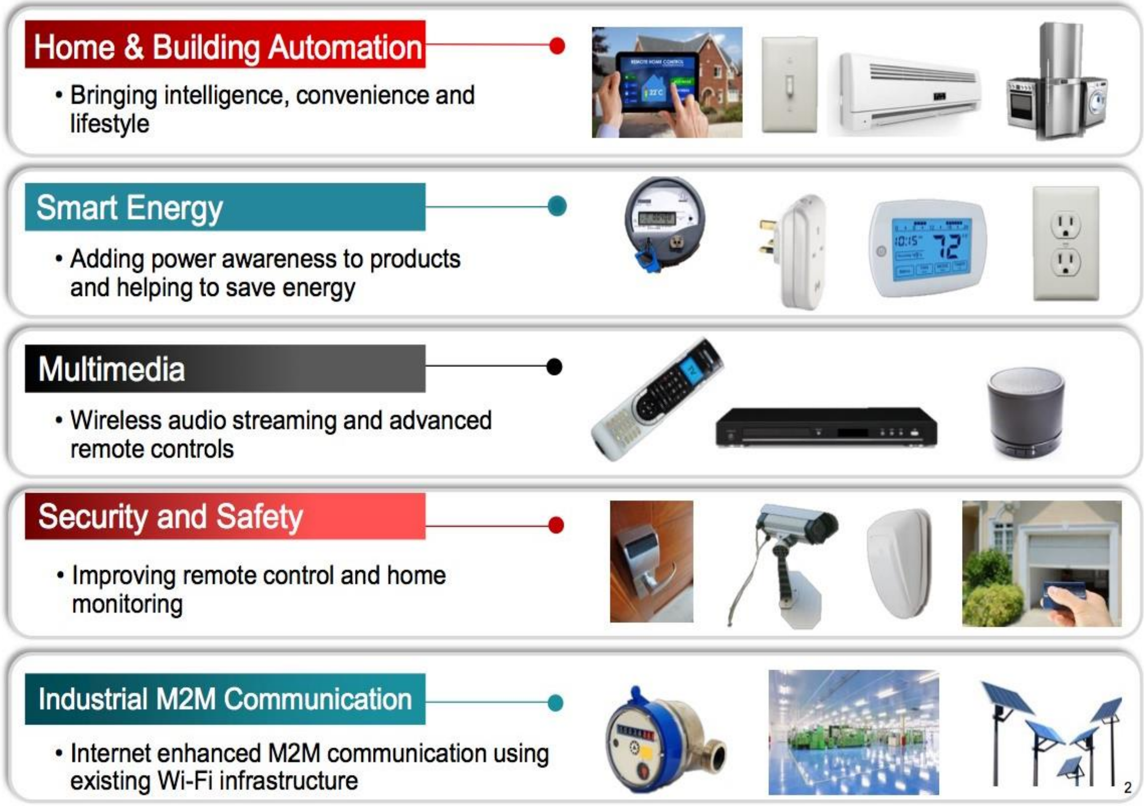


Low cost and available

Wi-Fi

- Wireless Alternative to Wired Technologies
- Standardized as IEEE 802.11 standard for WLANs

Standard	Frequency bands	Throughput	Range
WiFi a (802.11a)	5 GHz	54 Mbit/s	10 m
WiFi B (802.11b)	2.4 GHz	11 Mbit/s	140 m
WiFi G (802.11g)	2.4 GHz	54 Mbit/s	140 m
WiFi N (802.11n)	2.4 GHz / 5 GHz	450 Mbit/s	250 m
IEEE 802.11ah	900 MHz	8 Mbit/s	100 M



Wi-Fi HaLow

A new low-power, long-range version of Wi-Fi that bolsters IoT connections

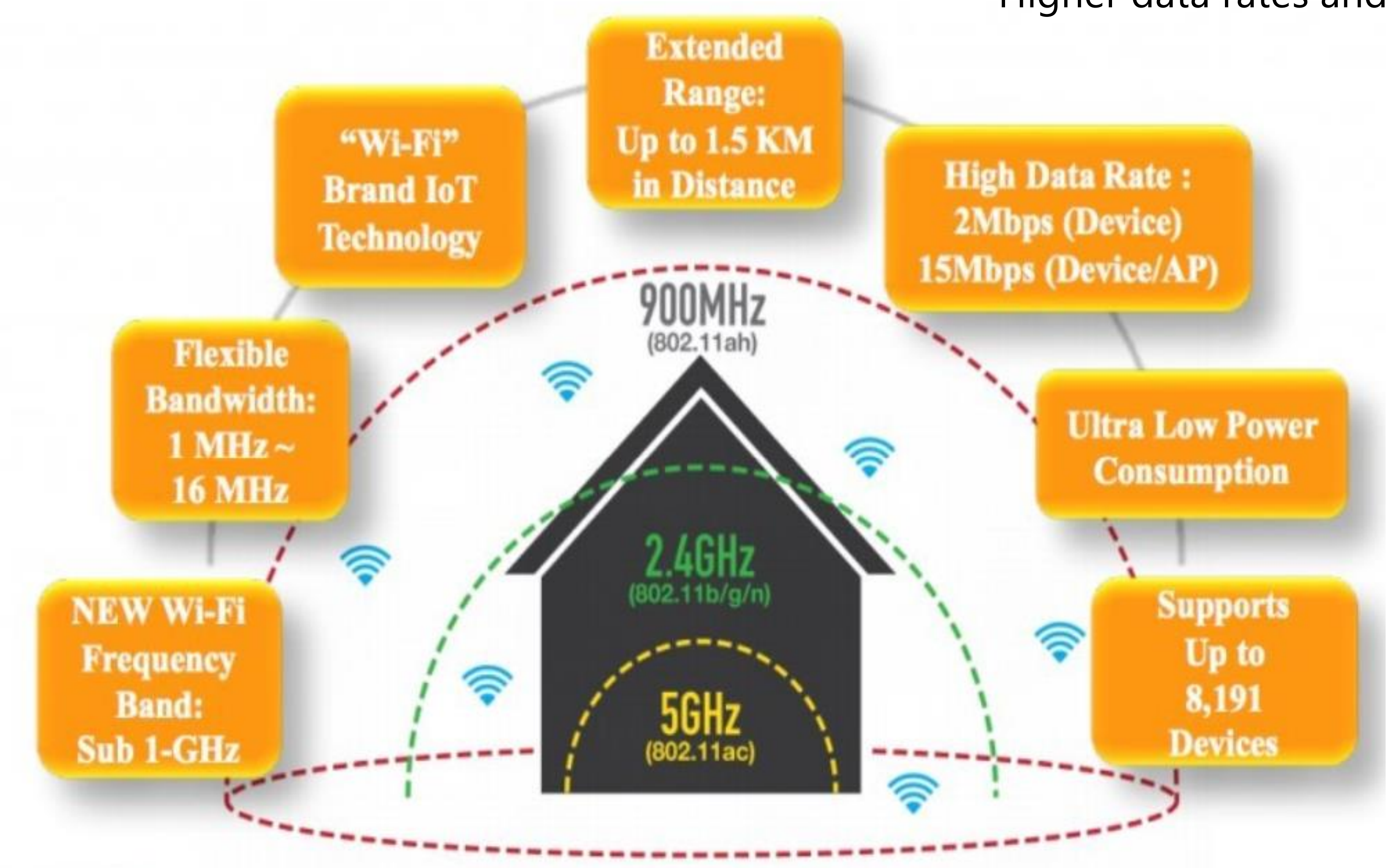
Wi-Fi HaLow is based on the **IEEE 802.11ah** specification

Wi-Fi HaLow will operate in the unlicensed wireless spectrum in the 900MHz band

Its range will be nearly double today's available Wi-Fi (1 kilometer)

Wi-Fi HaLow

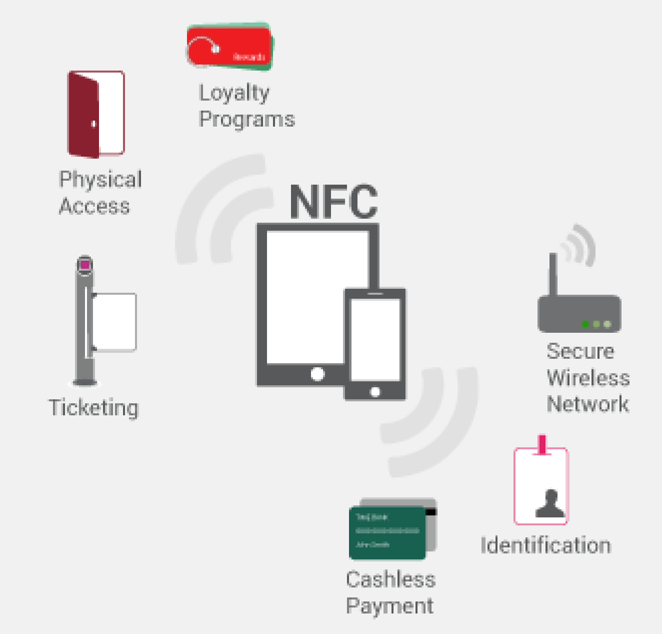
- More flexible
- The protocol's low power consumption competes with Bluetooth
- Higher data rates and wider coverage range



Picture Source: Newracom

NFC

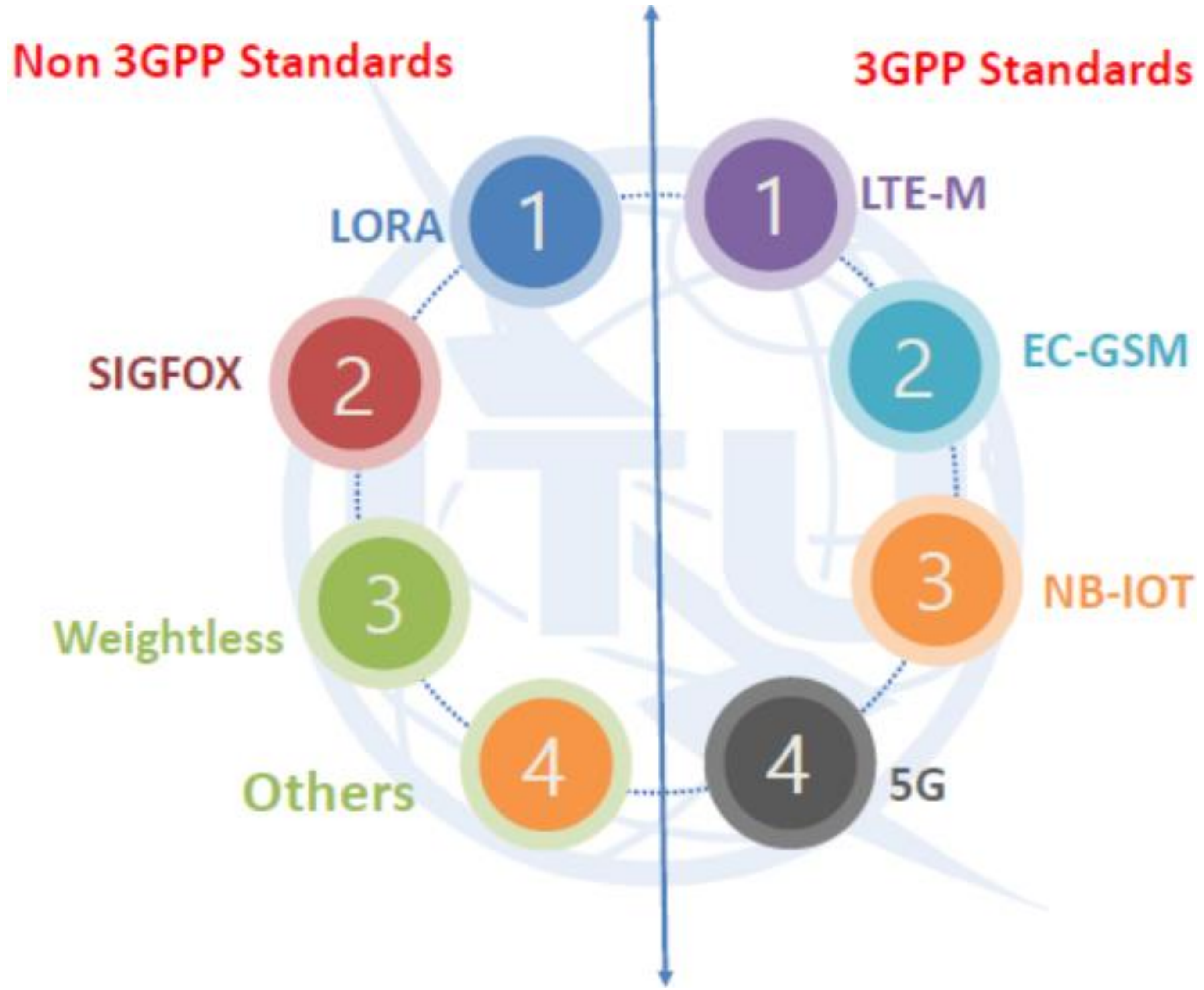
- NFC (Near Field Communication) is an IoT technology.
- It enables simple and safe communications between electronic devices, and specifically for smartphones, allowing consumers to perform transactions in which one does not have to be physic
- It helps the user to access digital content and connec
- Essentially it extends the capability of contactless car enables devices to share information at a distance th



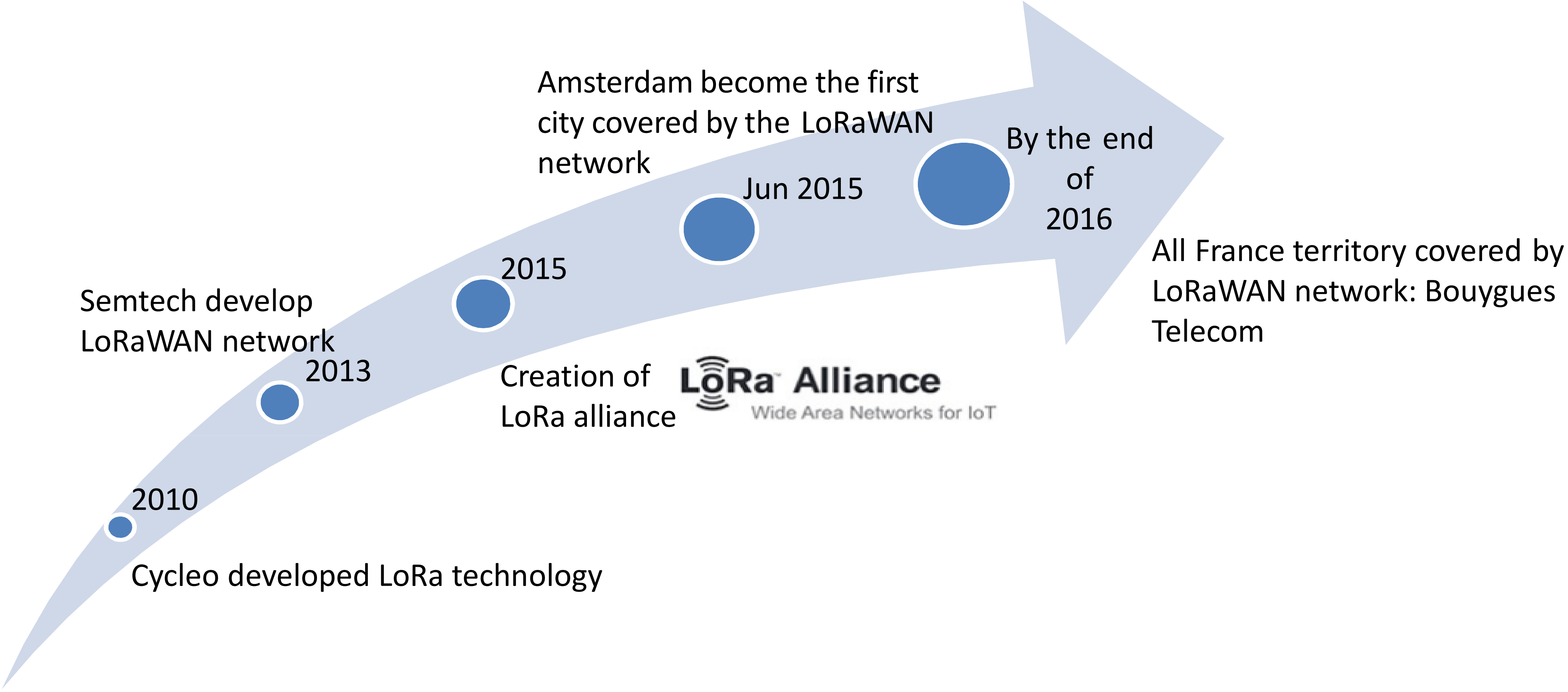
IoT Communication Protocols – NFC

Long Range IoT Solutions

IoT Long Range Technical Solutions



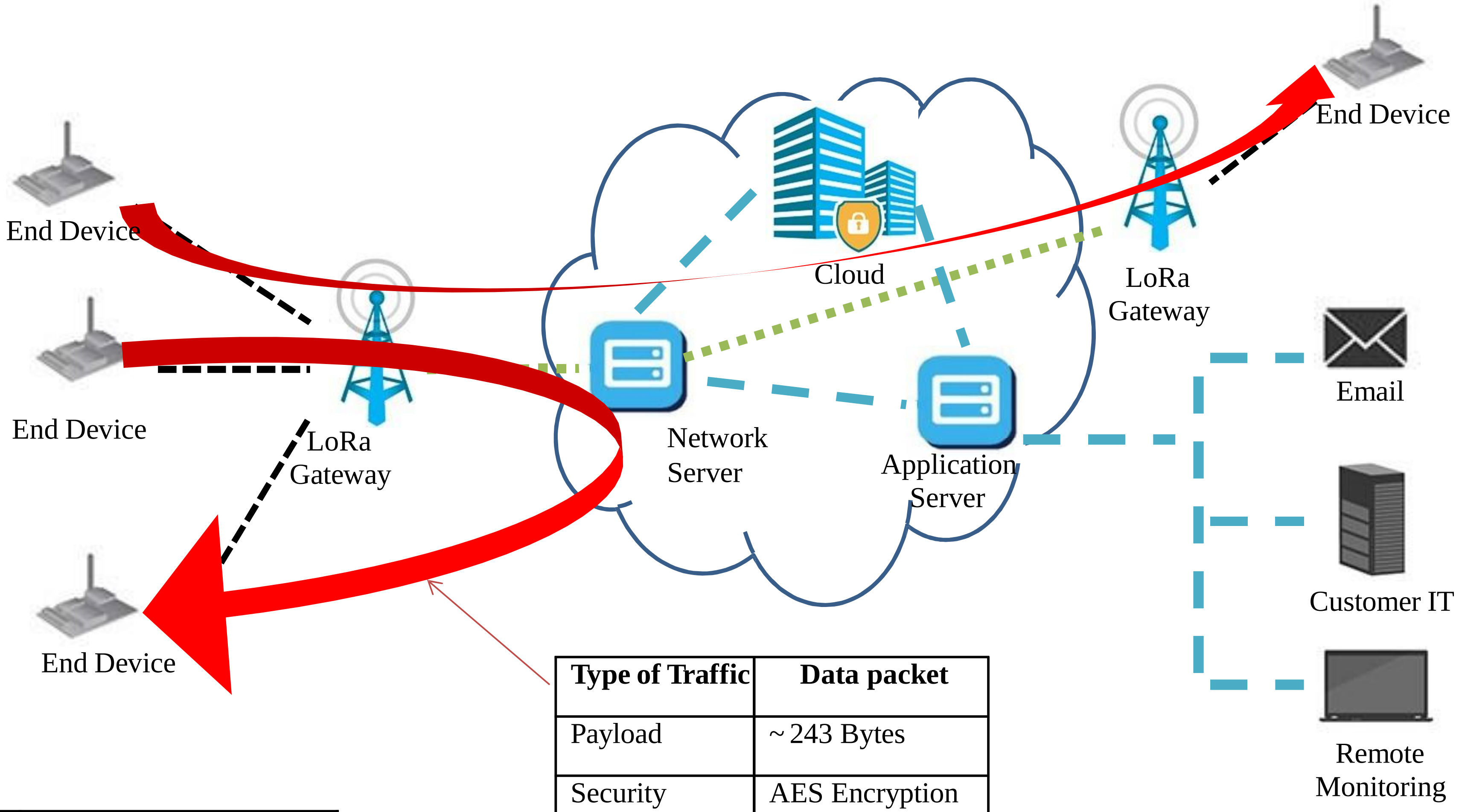
LORA


2010
Cycleo developed LoRa technology
2013
Semtech develop LoRaWAN network
2015
Creation of LoRa alliance
LoRa Alliance
Wide Area Networks for IoT
Jun 2015
Amsterdam become the first city covered by the LoRaWAN network
By the end of 2016
All France territory covered by LoRaWAN network: Bouygues Telecom

LORA - Features

- **LoRaWAN is a Low Power Wide Area Network**
- **Modulation:** a version of Chirp Spread Spectrum (CSS) with a typical channel bandwidth of 125KHz
- **High Sensitivity:** End Nodes: Up to -137 dBm, Gateways: up to -142 dBm
- **Long range:** up to 15 Km
- **Strong indoor penetration:** With High Spreading Factor, Up to 20dB penetration (deep indoor)
- **Robust** Occupies the entire bandwidth of the channel to broadcast a signal, making it robust to channel noise
- **Resistant to Doppler effect multi-path and signal weakening.**

LORA - Architecture



Type of Traffic	Data packet
Payload	~ 243 Bytes
Security	AES Encryption

Modulation	LoRa RF (Spread Spectrum)
Range	~ 15 Km
Throughput	~ 50 Kbps

LORA – Device Classes

Classes	Description	Intended Use	Consumption	Examples of Services
A (« all »)	Listens only after end device transmission	Modules with no latency constraint	The most economic communication Class energetically.. Supported by all modules. Adapted to battery powered modules	• Fire Detection • Earthquake Early Detection
B (« beacon »)	The module listens at a regularly adjustable frequency	Modules with latency constraints for the reception of messages of a few seconds	Consumption optimized. Adapted to battery powered modules	• Smart metering • Temperature rise
C (« continuous »)	Module always listening	Modules with a strong reception latency constraint (less than one second)	Adapted to modules on the grid or with no power constraints	• Fleet management • Real Time Traffic Management

Any LoRa object can transmit and receive data

Sigfox – Development

2012

Launch of the Sigfox network

2013

First fundraising of Sigfox company to cover France

2014

All France territory is covered by Sigfox network

Mar 2016

San-Francisco become the first US. State covered by Sigfox

2017

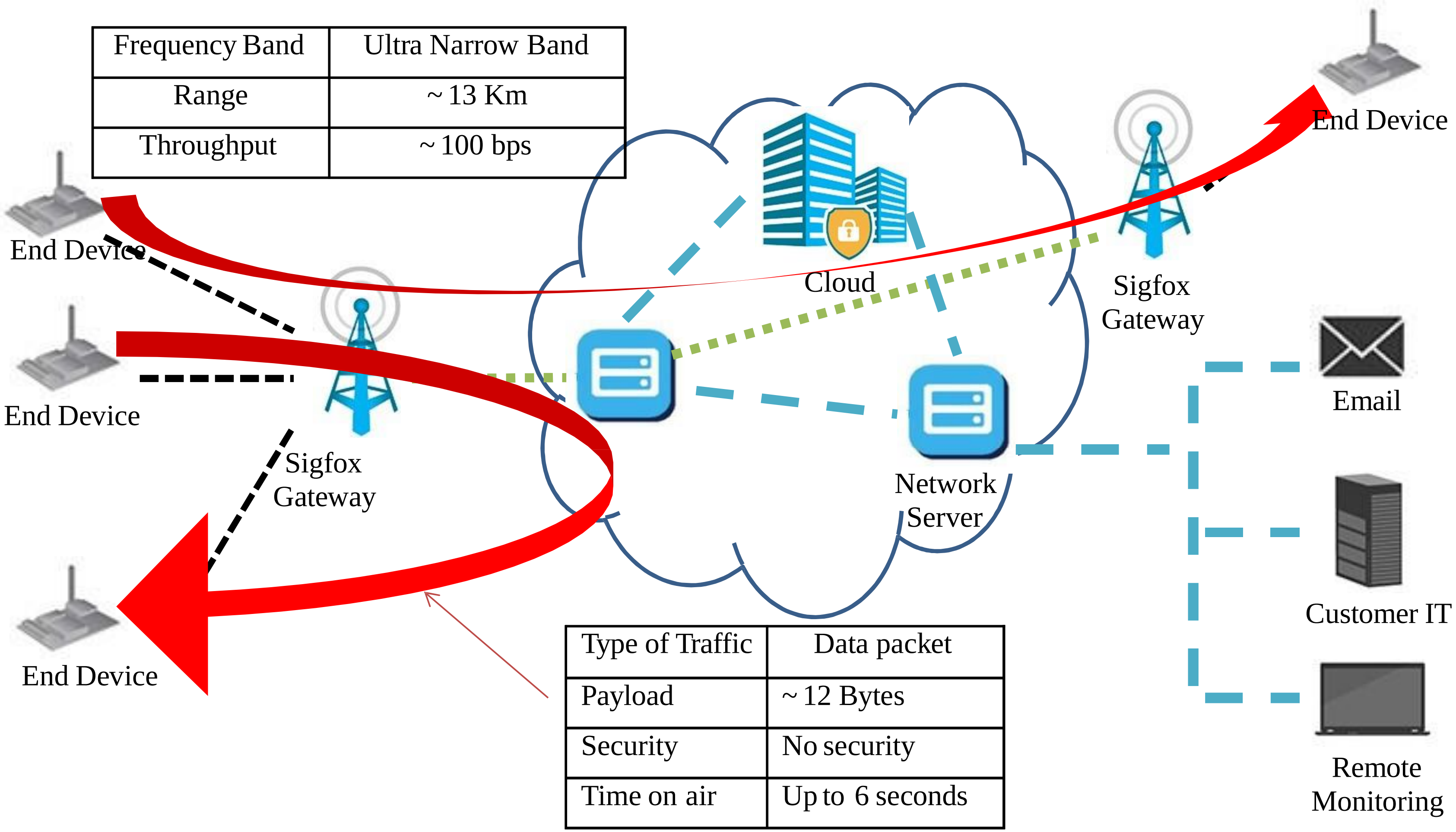
42 countries, 1000 customers

60 countries covered by the end of 2018

Sigfox – Overview

- First LPWAN Technology (BPSK based transmission)
- The physical layer based on an Ultra-Narrow band wireless modulation
- Proprietary system
- Low throughput (~100 bps)
- Low power
- Extended range (up to 50 km)
- 140 messages/day/device
- Subscription-based model
- Cloud platform with Sigfox –defined API for server access
- Roaming capability
- Takes very narrow parts of spectrum and changes the phase of the carrier radio wave to encode the data

Sigfox - Architecture



Frequency Band	Ultra Narrow Band
Range	~ 13 Km
Throughput	~ 100 bps

Type of Traffic	Data packet
Payload	~ 12 Bytes
Security	No security
Time on air	Up to 6 seconds

Weightless - Overview

- Low cost technology to be readily integrated into machines
- Operates in an unlicensed environment where the interference caused by others cannot be predicted and must be avoided or overcome.
- Ability to operate effectively in unlicensed spectrum and is optimized for M2M.
- Ability to handle large numbers of terminals efficiently.

Frequency Band	Narrow Band
Range	~ 13 Km
Throughput	~ 10 Mbps

Type of Traffic	Data packet
Payload	~ 200 Bytes
Security	AES Encryption

Weightless – Development

2012

Starts specification

Creation of Weightless Special Interest Group

2014

White Space spectrum is coming - ratified in USA Q3 2012, UK expected Q2 2014

First version released

First Weightless-N network deployed in London

Weightless – Versions

	Weightless-N	Weightless-P	Weightless-W
Communication	1-way	2-ways	2-ways
Range	5Km+	2Km+	5Km+
Battery life	10 years	3-8 years	3-5 years
Terminal cost	Very low	Low	Low-medium
Network cost	Very low	Medium	Medium
Data Rate	Up to 10 Mbps	Up to 100 Kbps	Up to 200 Kbps

RPMA – Overview

- **Random Phase Multiple Access (RPMA) technology is a low-power, wide-area channel access method used exclusively for machine-to-machine (M2M) communication**
  - Uses the popular 2.4 GHz band
  - Offer extreme coverage and High capacity
  - Allows handover (channel change) with Excellent link capacity

- **RPMA is a Direct Sequence Spread Spectrum (DSSS) using**
- Convolutional channel coding, gold codes for spreading
- 1 MHz bandwidth
- TDD frame with power control in both open and Closed Loop Power Control

TDD frame

RPMA – Development

2008

RPMA was developed by On-Ramp Wireless to provide connectivity to oil and gas actors

September 2015

it was renamed Ingenu, and targets to extend its technology to the IoT and M2M market

2016

RPMA was implemented in many places
Austin, Dallas/Ft. worth, Hostton,TX,Phenix,AZ, ….

2017

RPMA will be introduced in many others countries: Los Angeles, San Franscisco-West Bay,CA,Washington,DC, Baltimore,MD, Kanasas City

EnOcean

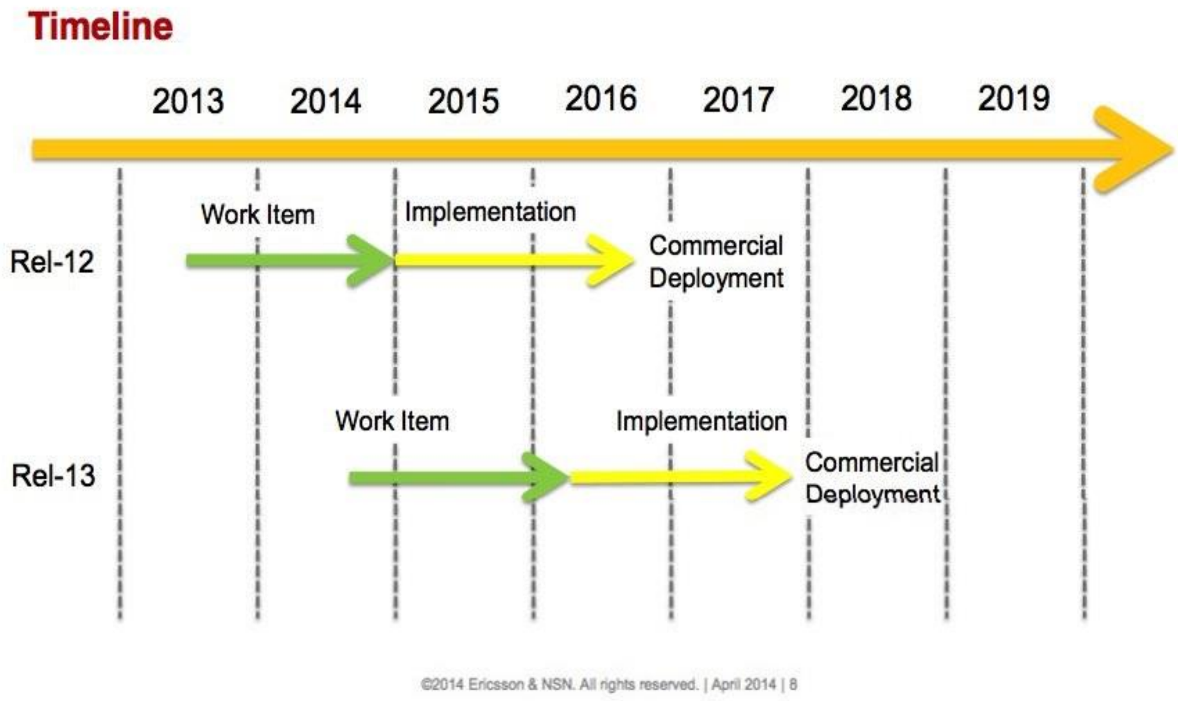
- **Ultra low power radio technology based on miniaturized power converters**
  - Power is generated by harvesting energy from motion, light or temperature (e.g. pressure on a switch or by photovoltaic cell)
  - These power sources are sufficient to power each module to transmit wirelessly and have battery-free information.
- **Frequencies:**
  - 868 MHz for Europe and 315 MHz for the USA
- **EnOcean Alliance**
  - By 2014 = more than 300 members (Texas, Leviton, Osram, Sauter, Somfy, Wago, Yamaha ...)

Z-Wave

- **Low power radio protocol**
- **Home automation (lighting, heating, ...) applications**
- **Low-throughput: 9 and 40 kbps**
- **Battery-operated or electrically powered**
- **Frequency range: 868 MHz in Europe, 908 MHz in the US**
- **Range: about 50 m (more outdoor, less indoor)**
- **Mesh architecture possible to increase the coverage**
- **Access method type CSMA / CA**
- **Z-Wave Alliance:** more than 100 manufacturers

LTE-M - Overview

- Evolution of LTE optimized for IoT
- Low power consumption and autonomous
- Easy Deployment
- Interoperability with existing LTE networks
- Coverage upto 11 Km
- Max Throughput ≤ 1 Mbps



- ✓ First released in Rel.1 in 2 Q4 2014
- ✓ Optimization in Rel.13
- ✓ Specifications completed in Q1 2016
- ✓ Available since 2017

LTE to LTE-M

3GPP Releases	8 (Cat.4)	8 (Cat. 1)	12 (Cat.0) LTE-M	13 (Cat. 1,4 MHz) LTE-M
Downlink peak rate (Mbps)	150	10	1	1
Uplink peak rate (Mbps)	50	5	1	1
Number of antennas (MIMO)	2	2	1	1
Duplex Mode	Full	Full	Half	Half
UE receive bandwidth (MHz)	20	20	20	1.4
UE Transmit power (dBm)	23	23	23	20

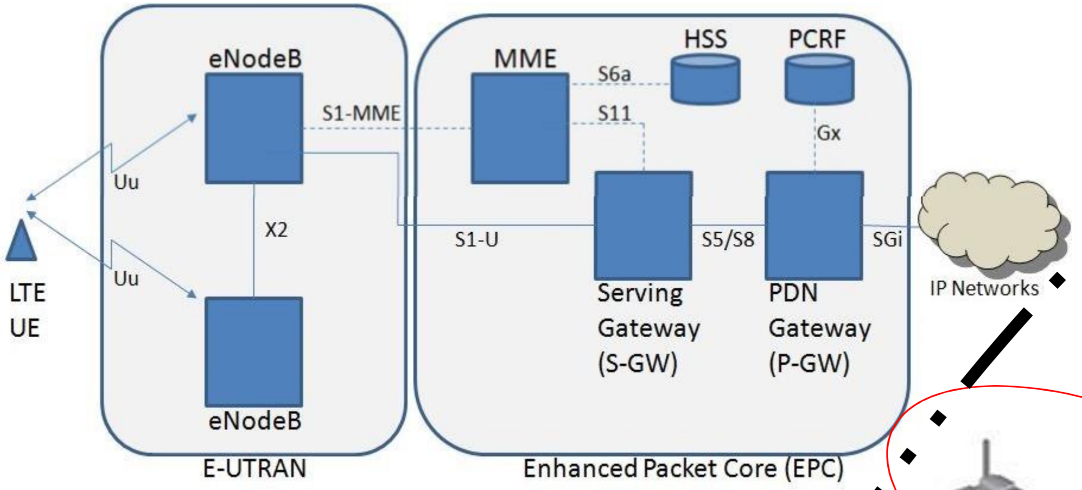
Release 12

- New category of UE ("Cat-0"): lower complexity and low cost devices
- Half duplex FDD operation allowed
- Single receiver
- Lower data rate requirement (Max: 1 Mbps)

Release 13

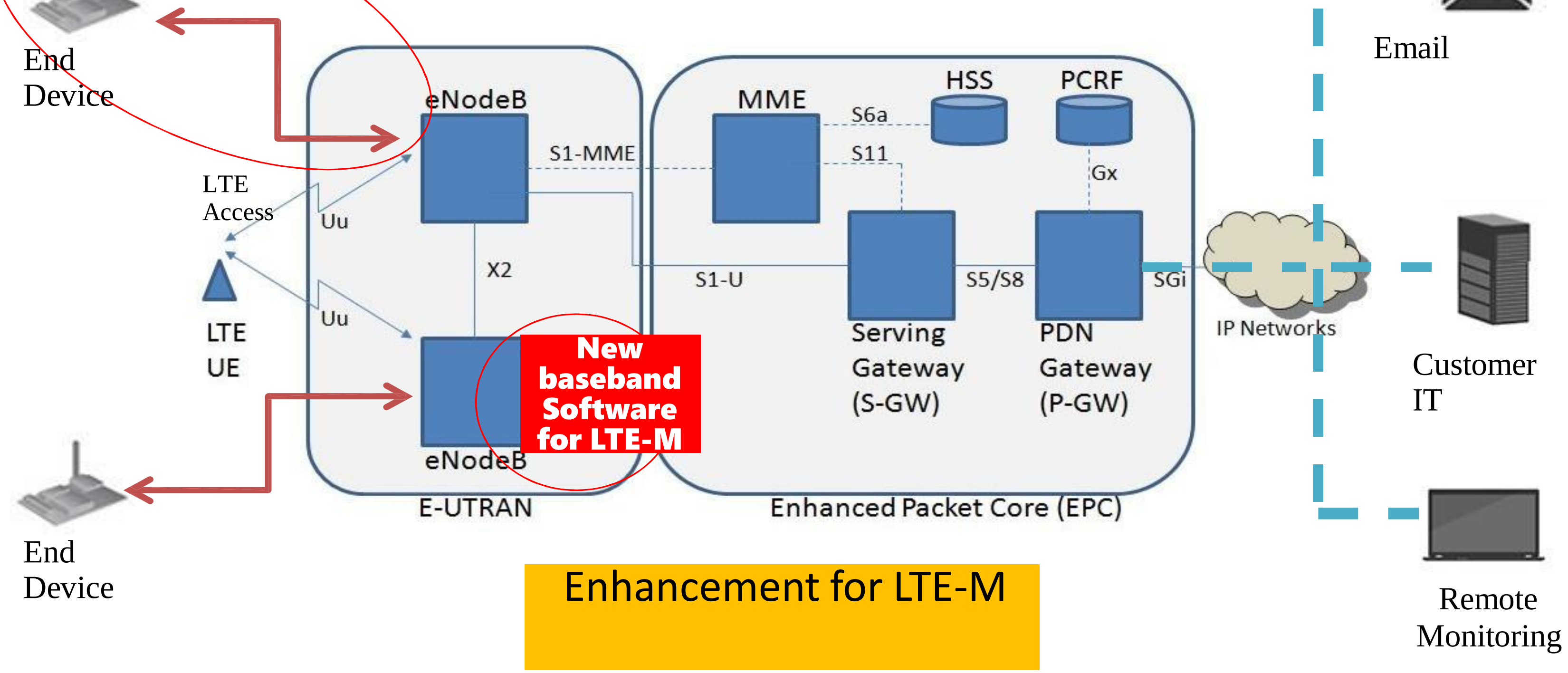
- Reduced receive bandwidth to 1.4 MHz
- Lower device power class of 20 dBm
- 15dB additional link budget: better coverage
- More energy efficient because of its extended discontinuous repetition cycle (eDRX)

LTE to LTE-M - Architecture



Present LTE Architecture

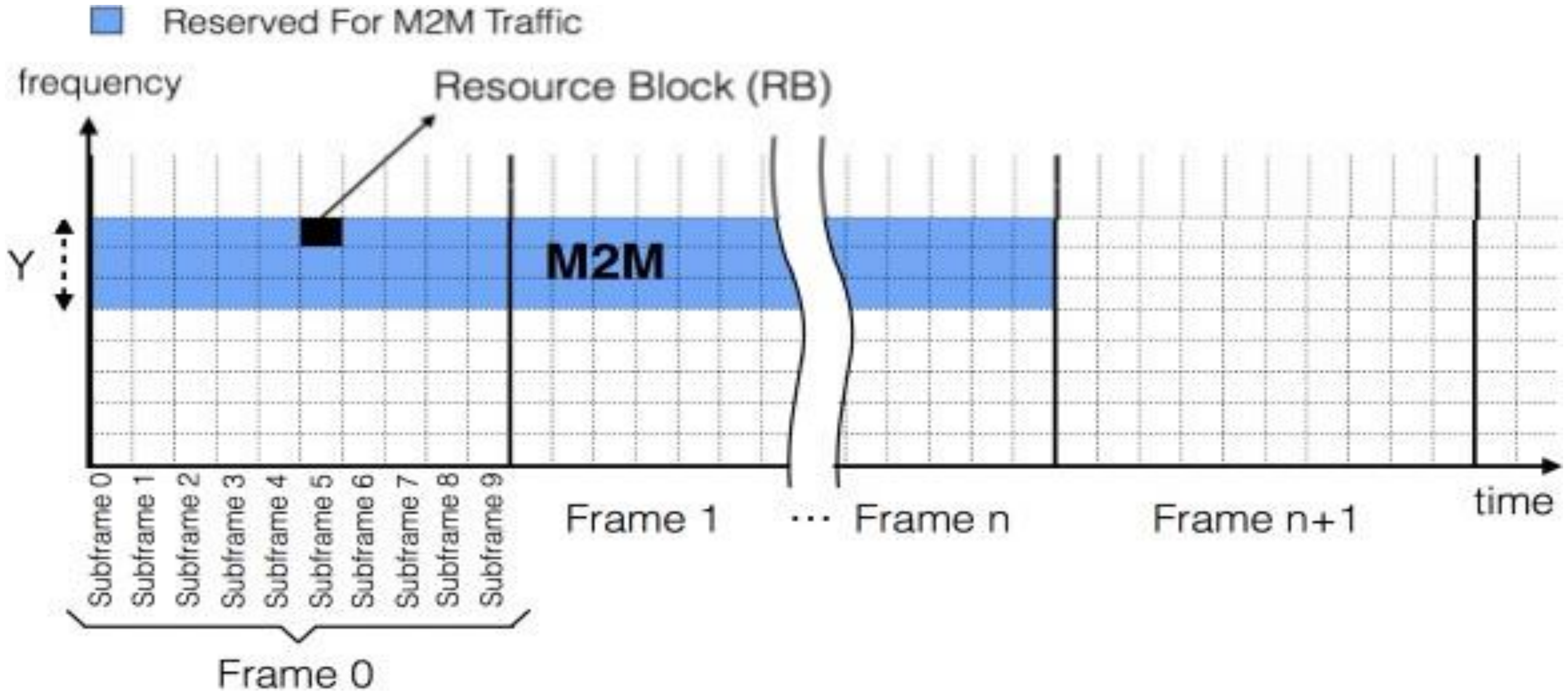
Frequency Band	Narrow Band
Access	LTE-M
Range	~ 11 Km
Throughput	~ 1 Mbps



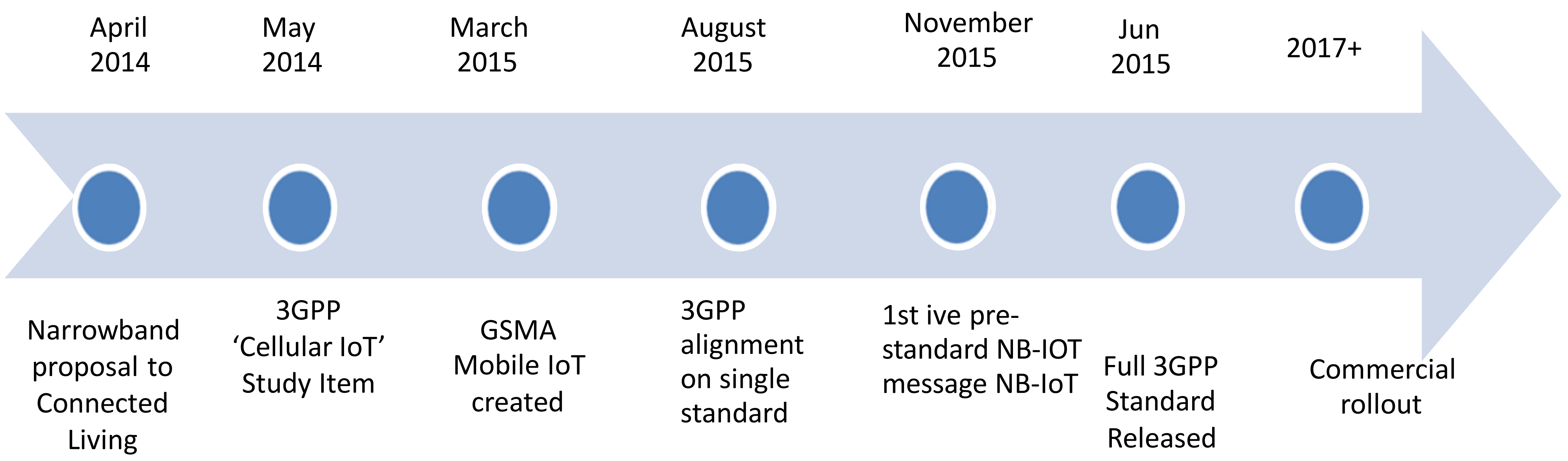
Enhancement for LTE-M

LTE-M

- Licensed Spectrum
- Frequency Bands: 700-900 MHz for LTE
- Some resource blocks are allocated to IoT on LTE bands



NB-IoT


April 2014
May 2014
March 2015
August 2015
November 2015
Jun 2015
2017+
Narrowband proposal to Connected Living
3GPP 'Cellular IoT' Study Item
GSMA Mobile IoT created
3GPP alignment on single standard
1st ive pre-standard NB-IOT message NB-IoT
Full 3GPP Standard Released
Commercial rollout

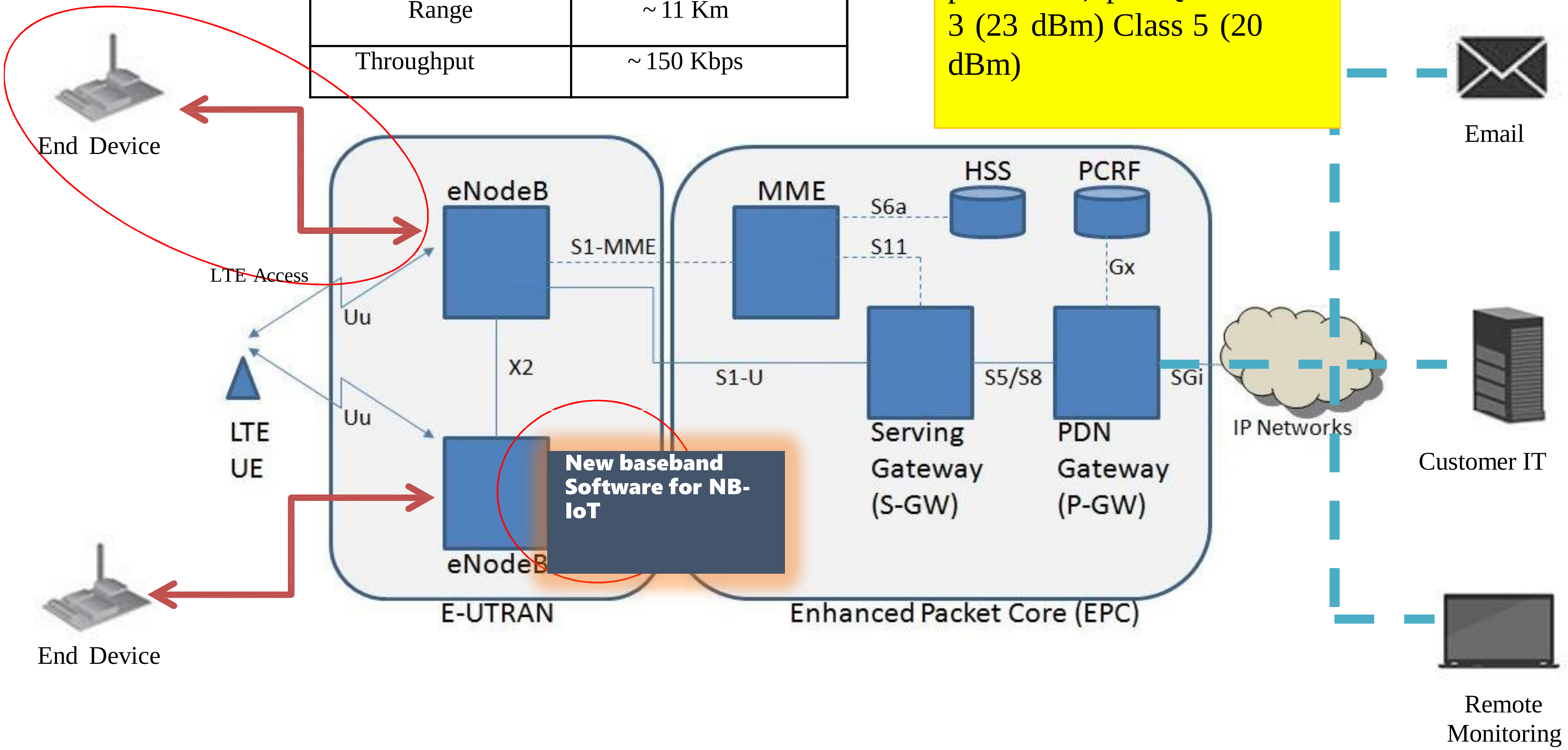
NB-IoT

- **Uses LTE design extensively** e.g. DL: FDMA, UL: SC-FDMA
- **Lower cost** than eMTC (Narrow band: supports 180 KHz channel)
- **Extended coverage:** 164 dB maximum coupling loss or link budget (at least for standalone) in comparison to GPRS link budget of 144dB and LTE of 142.7 dB
- **Low Receiver sensitivity** = -141 dBm
- **Long battery life**: 10 years with 5 Watt Hour battery (depending on traffic and coverage needs)
- **Support for massive number of devices**: at least 50.000 per cell
- **3 modes of operation:**
  - **Stand-alone**: *stand-alone carrier, e.g. spectrum currently used by GERAN (GSM Edge Radio Access Network) systems as a replacement of one or more GSM carriers*
  - **Guard band:** *unused resource blocks within a LTE carrier's guard-band*
  - **In-band:** *resource blocks within a normal LTE carrier*

NB-IoT - Architecture

Frequency Band	Ultra Narrow Band
Range	~ 11 Km
Throughput	~ 150 Kbps

HD-FDD
p/2 BPSK, p/4 QPSK Class 3 (23 dBm) Class 5 (20 dBm)



References

- https://www.researchgate.net/publication/41392302_Interconnection_between_802154_Devices_and_IPv6_Implications_and_Existing_Approaches/figures?lo=1
- https://data-flair.training/blogs/iot-technology/
- Hanes David, Salgueiro Gonzalo, Grossetete Patrick, “IoT fundamentals: Networking technologies, protocols and use cases for the Internet of Things”, Cisco, Pearson India, 2015.
- Jean-Philippe Vasseur, Adam Dunkels, “Interconnecting Smart Objects with IP, The next Internet”, Morgan Kofmann, 2010.
- Arsheep Bahga, Vijay Madlseti, “Internet of Things: A hands-on approach”, Elsevier, 2009.
- Adrin McEwan, Hakim Cassimally, “Designing for Internet of Things”, John Wiley, 2014.
- https://www.3gpp.org/specifications/67-releases
- https://en.wikipedia.org/wiki/Weightless_(wireless_communications)
- https://www.iotglobalnetwork.com/companies/single/id/954/weightless