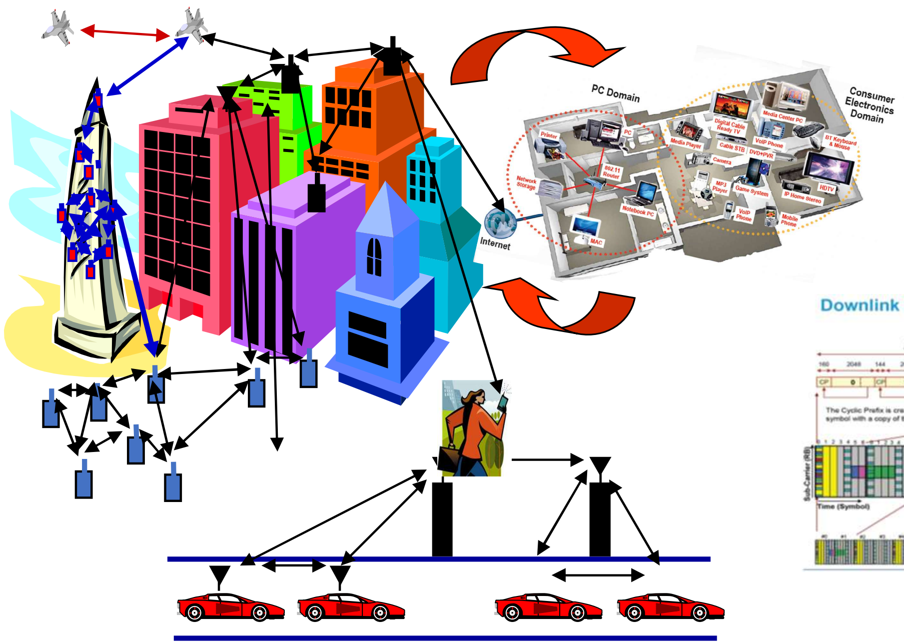
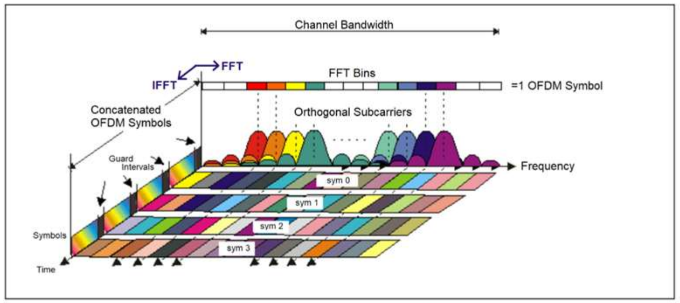
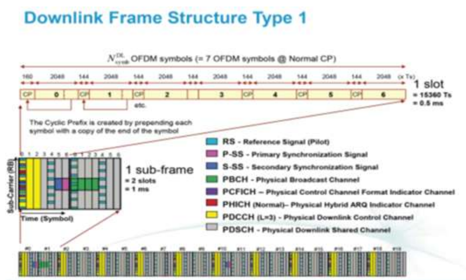
IEE2650: Cellular Communication Technologies

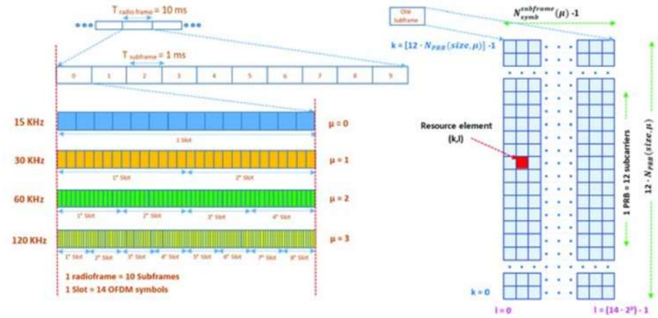
Muhammad Mahtab Alam, Professor





Frequency-Time Representative of an OFDM signal



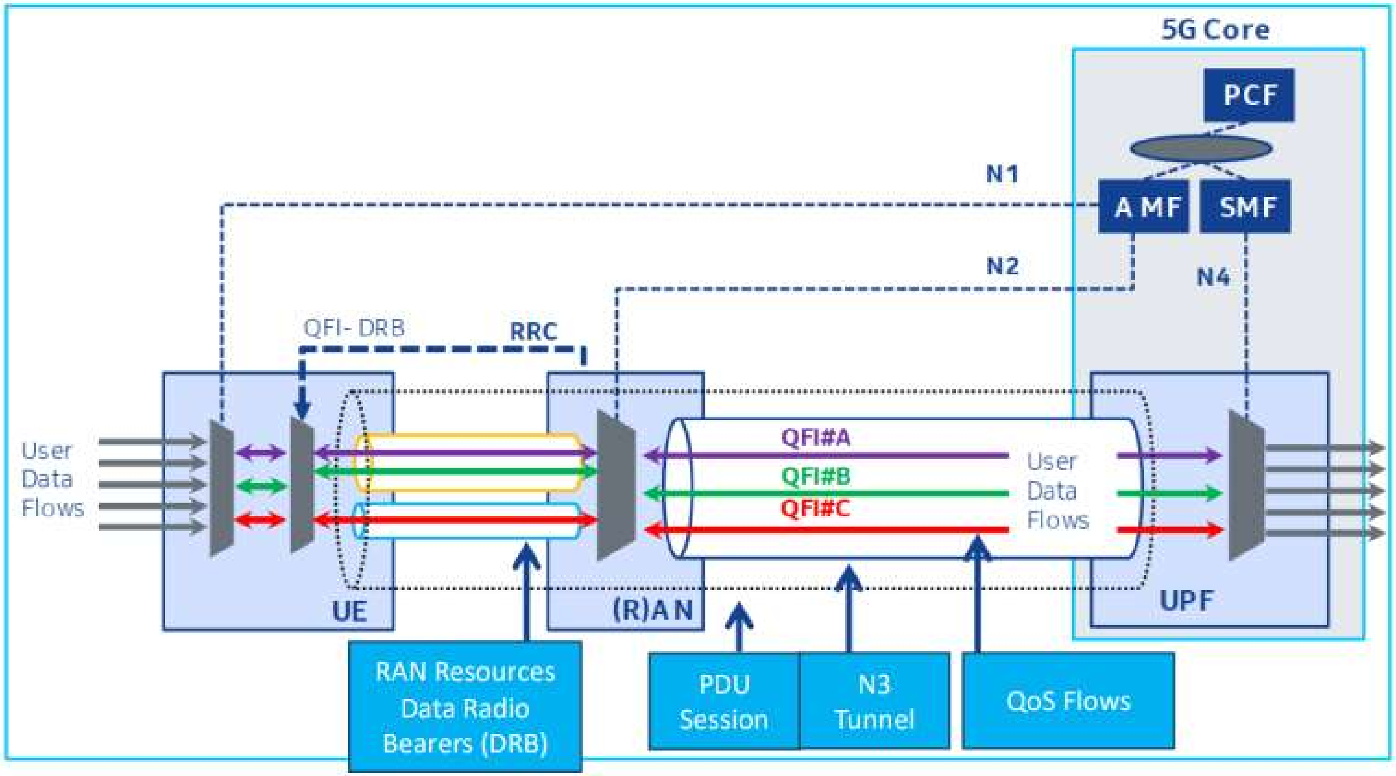


5G Core Network – Network Slicing Recap

5G QoS model

QoS flow

based framework



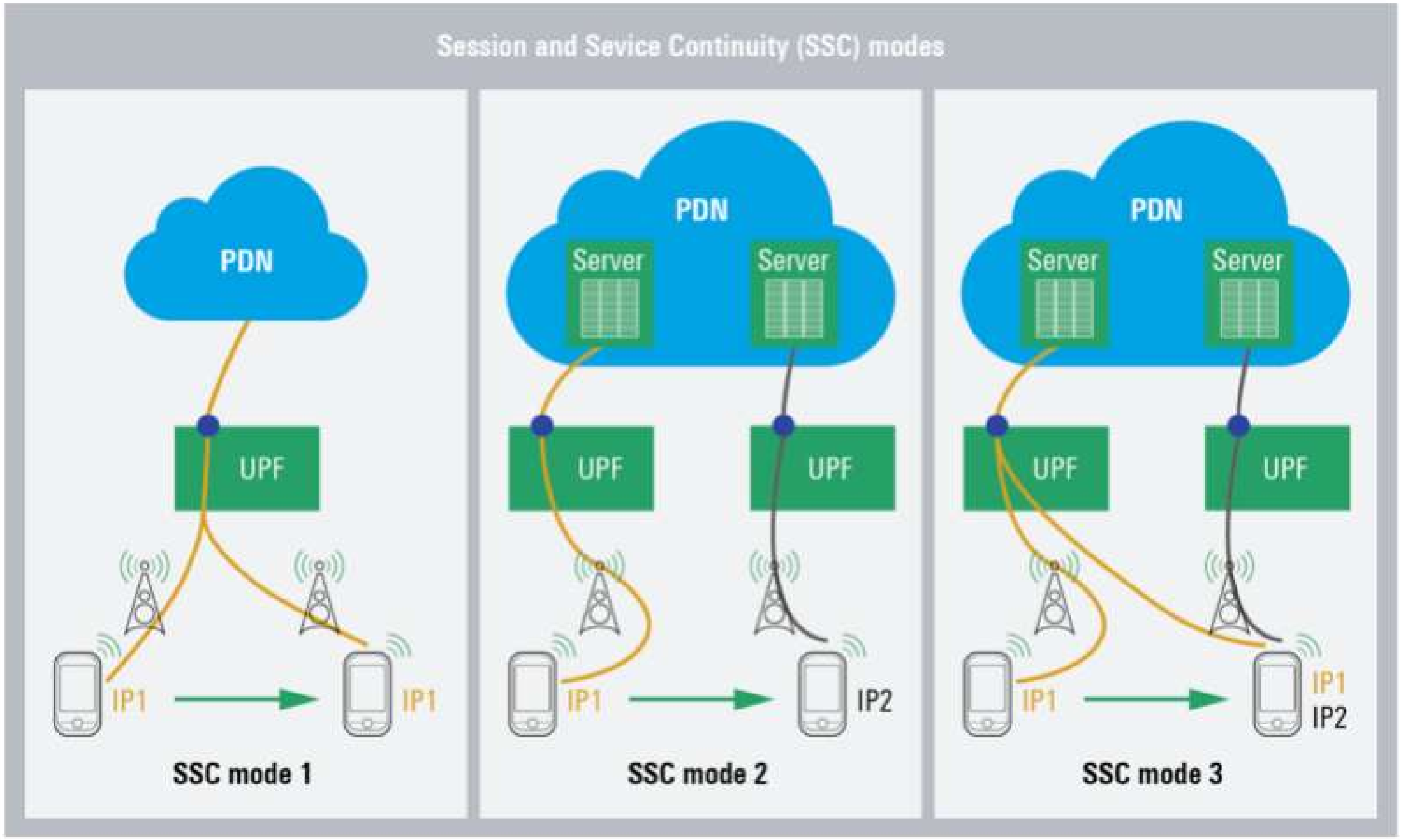
QFI – QoS flow index
DRB – Data Radio Bearer
RRC – Radio Resource Control
UPF – User Plane Function

Source: *Nokia & 3GPP*

SLICE DEFINITION BY 3GPP

- From a mobile operator's point of view, a network slice is an independent **end-to-end logical network** that runs on a shared physical infrastructure, capable of providing a negotiated service quality. The technology enabling network slicing is transparent to business customers. A network slice could span across **multiple parts of the network** (e.g. terminal, access network, core network and transport network) and could also be deployed across multiple operators. A network slice comprises dedicated and/or shared resources, e.g. in terms of processing power, storage, and bandwidth and has isolation from the other network slices.
- 5G networks, in combination with network slicing, permit **V2X customers to enjoy connectivity and data processing** tailored to the specific business requirements that adhere to a Service Level Agreement (SLA) agreed with the mobile operator. The customizable network capabilities include data speed, quality, latency, reliability, security, and services.

5G Session and Service Continuity



In SSC mode 2 network may release the IP address (PDU session type IP) as there is a new PDU session anchor point.
In SSC mode 3 a new PDU sessioon will be established before the previous connection is terminated.
SSC mode is defined by the application requirements.

Source: ***Rohde&Schwarz*** *& 3GPP*

5G and Internet of Things

INTERNET OF THINGS - HISTORY

- ❑In the early 2000's, Kevin Ashton led the foundation of IoT at MIT's AutoID lab.
- ❑The concept was simple but powerful.
- ❑ In a 1999 article for the RFID Journal Ashton wrote:

"*If we had computers that knew everything—using data they gathered without any help from us* -- **we would be able to track and count everything, and greatly reduce waste, loss and cost**. **<u>We would know when things needed replacing, repairing or recalling, and whether they were fresh or past their best</u>**. We need to empower computers with their own means of gathering information, so they can see, hear and smell the world for themselves, in all its random glory. RFID and sensor technology enable computers to observe, identify and understand the world—without the limitations of human-entered data."[1]

[1] http://kevinjashton.com/2009/06/22/the-internet-of-things/

INTERNET OF THINGS - HISTORY

History

❑At the time, the vision of IoT required major technology improvements and need to answer question such as:

- ✓ How would we connect everything on the planet?
- ✓ What type of wireless communications could be built into devices?
- ✓ What changes would need to be made to the existing Internet infrastructure to support billions of new devices communicating?
- ✓ What would power these devices?
- ✓ What must be developed to make the solutions cost effective?

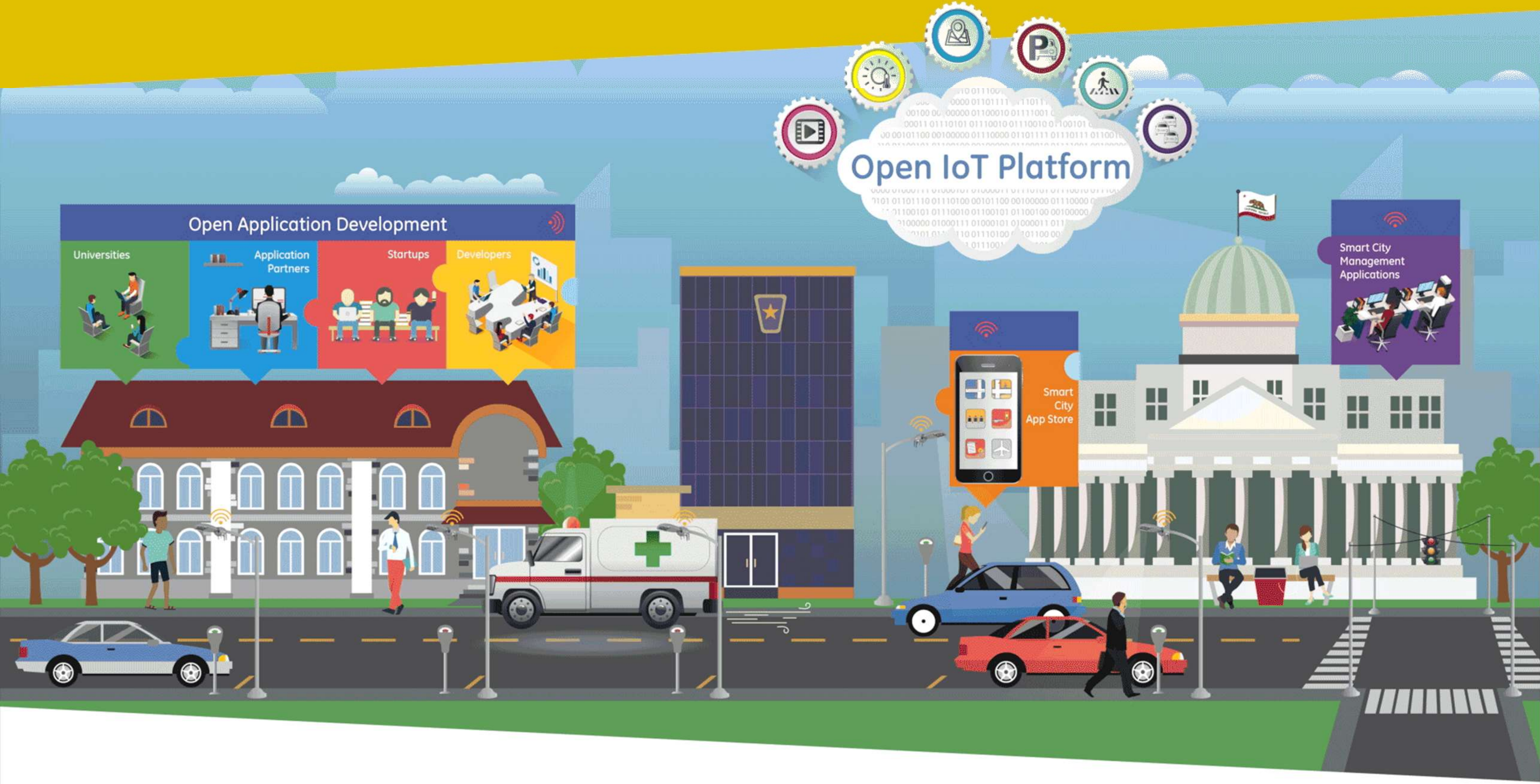
There were more questions than answers to the IoT concepts in 1999.

INTERNET OF THINGS - TODAY

- ❑Many of these obstacles have been solved.
  - ✓ The size and cost of wireless radios has dropped tremendously.
  - ✓ IPv6 allows us to assign a communications address to billions of devices.
  - ✓ Electronics companies are building Wi-Fi and cellular wireless connectivity into a wide range of devices.
  - ✓ ABI Research estimates over five billion wireless chips.[2]
  - ✓ Mobile data coverage has improved significantly with many networks offering broadband speeds.
  - ✓ While not perfect, battery technology has improved and solar recharging has been built into numerous devices.

[2] https://www.abiresearch.com/press/over-5-billion-wireless-connectivity-chips-will-sh/

INTERNET OF THINGS



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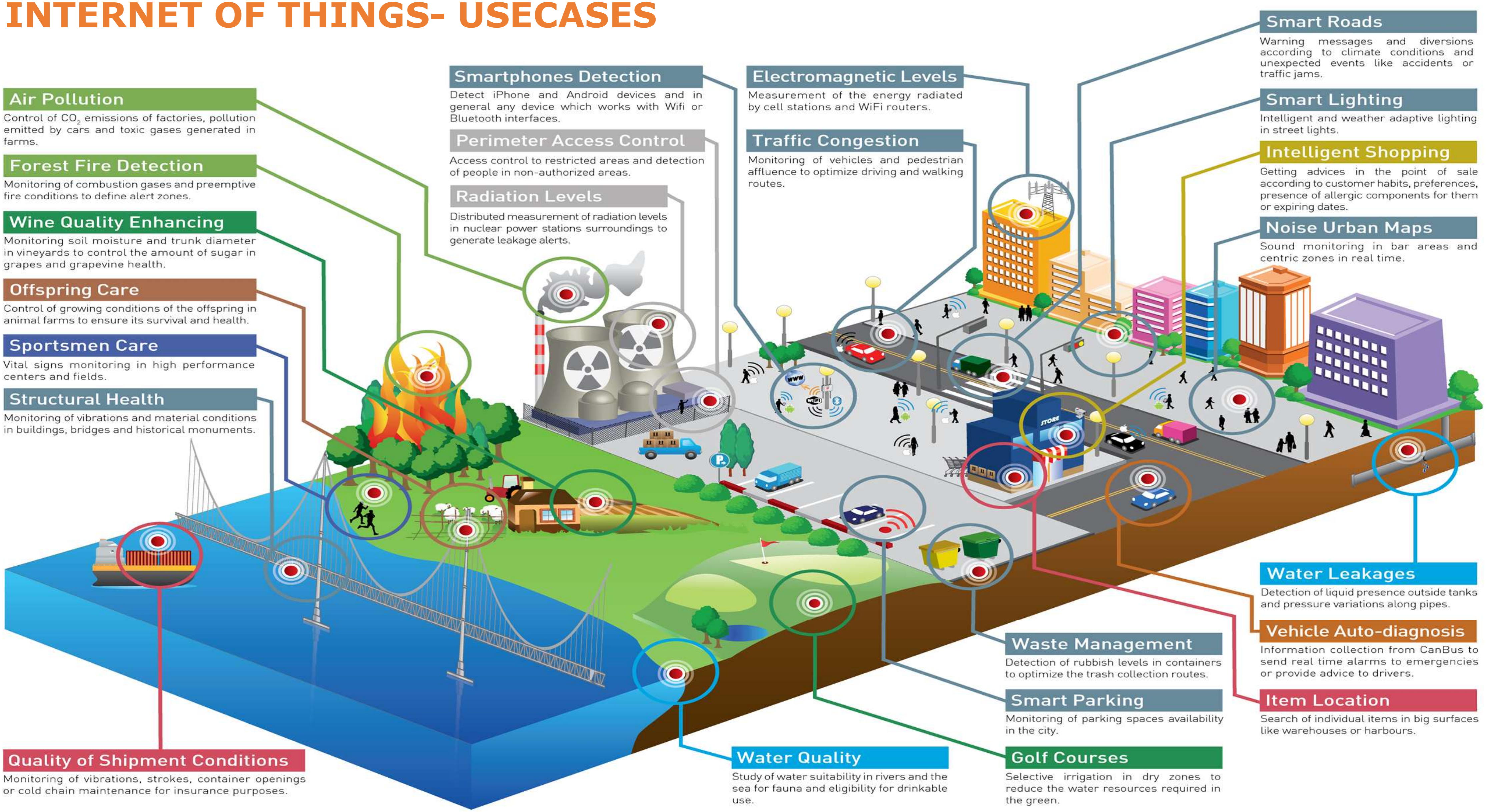
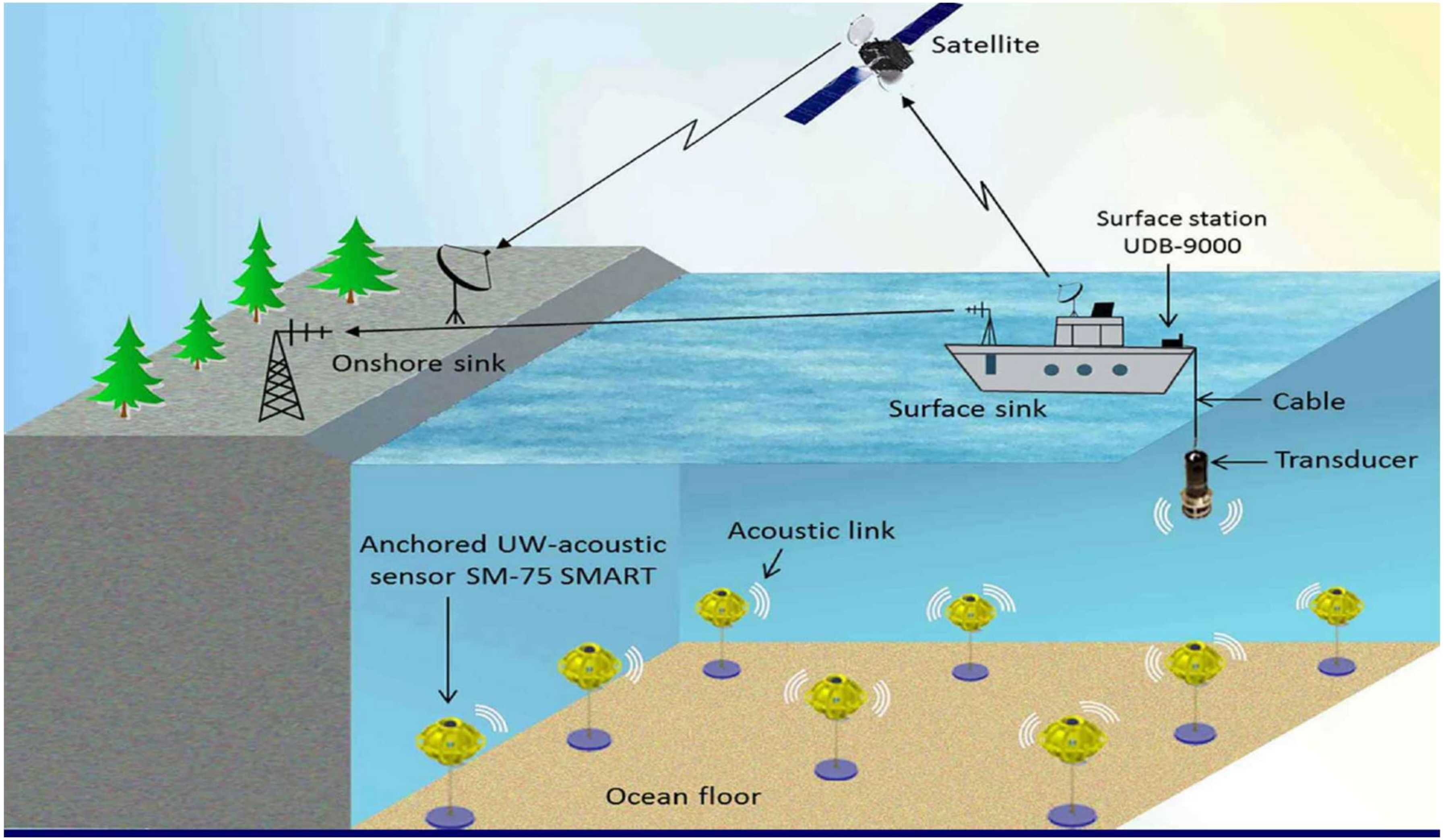
INTERNET OF THINGS- USECASES

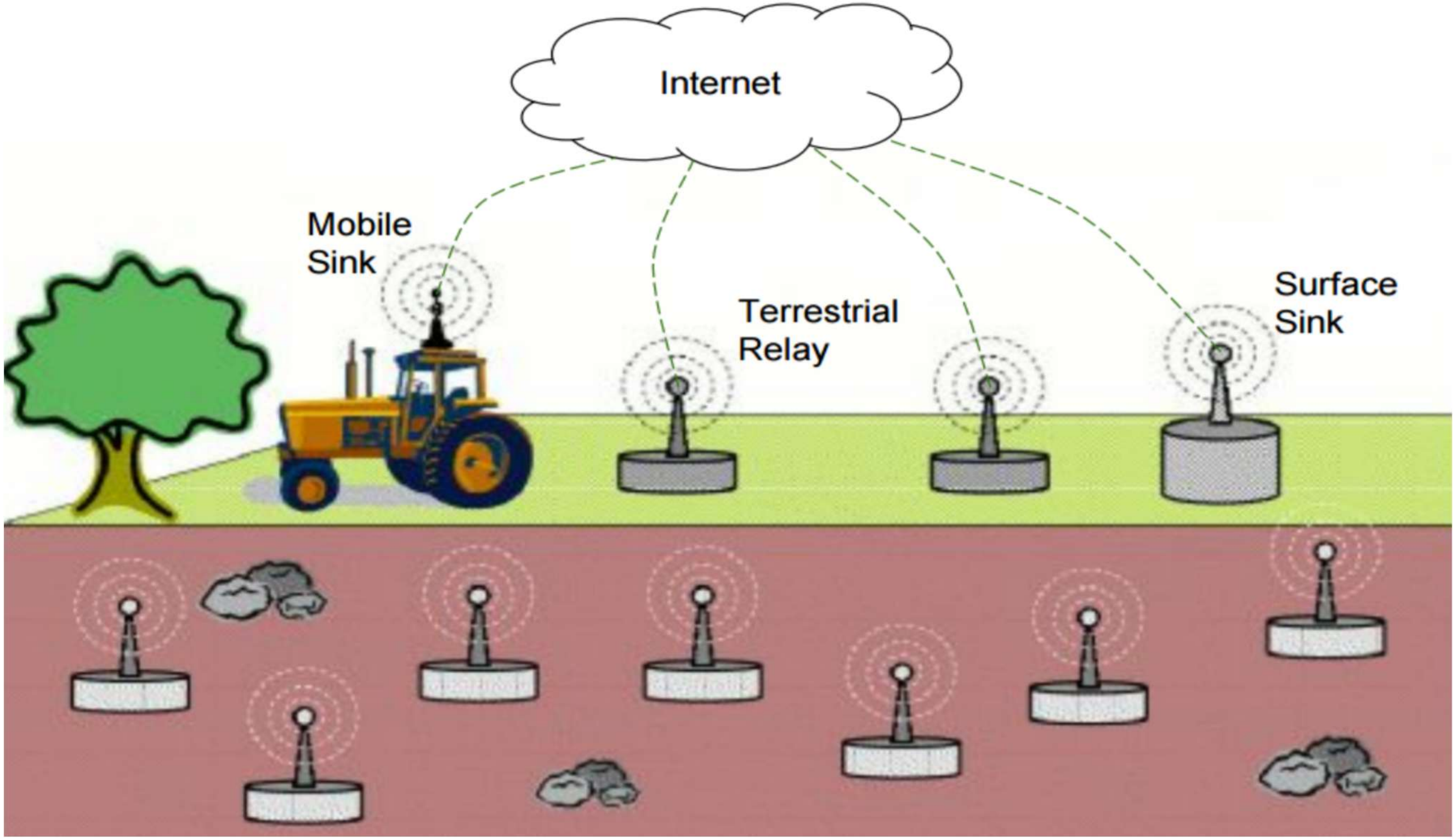


urce: http://www.libelium.com/resources/top_50_iot_sensor_applications_ranking/#show_infographic

INTERNET OF UNDERWATER THINGS

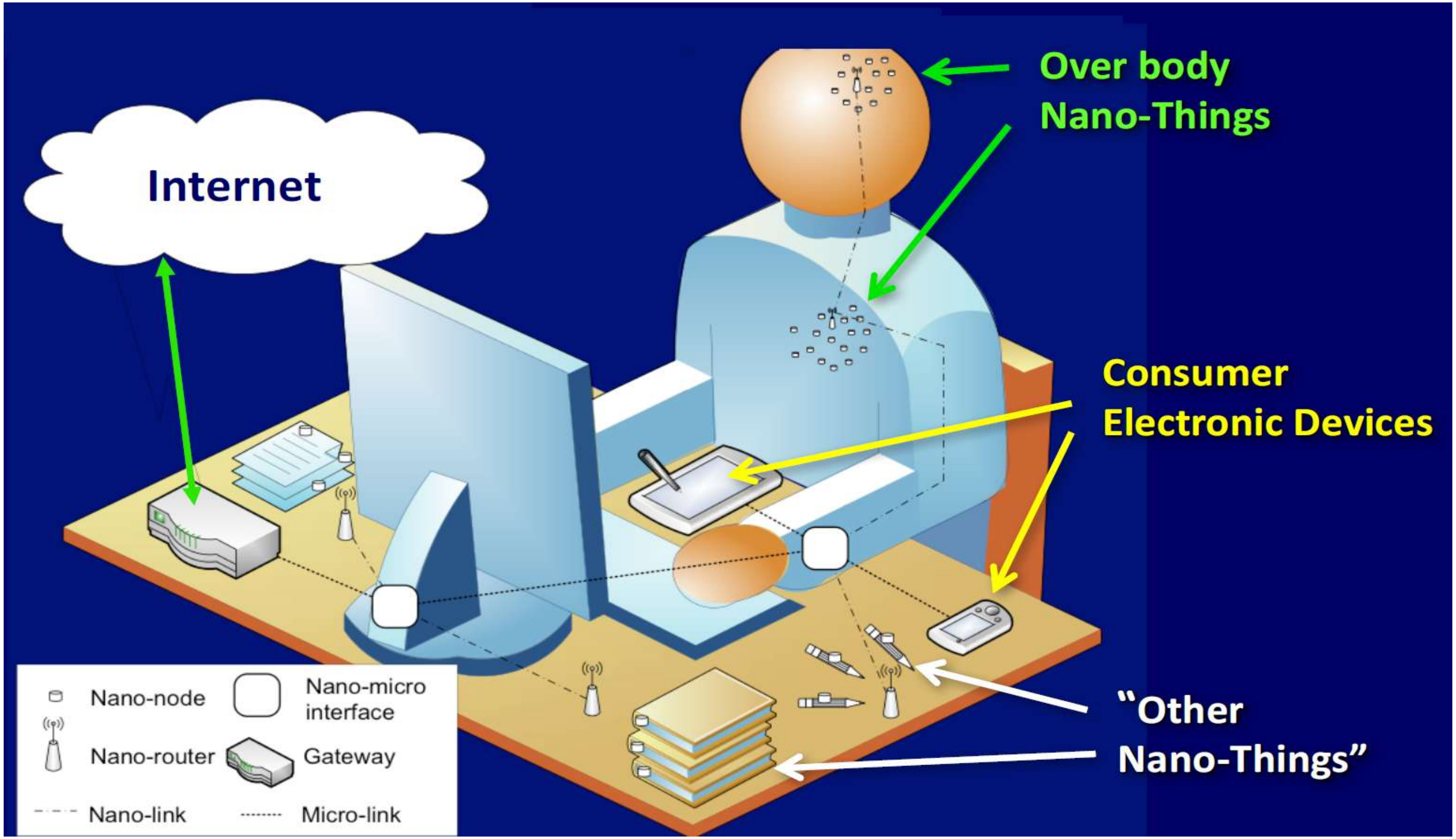


INTERNET OF UNDERGROUND THINGS



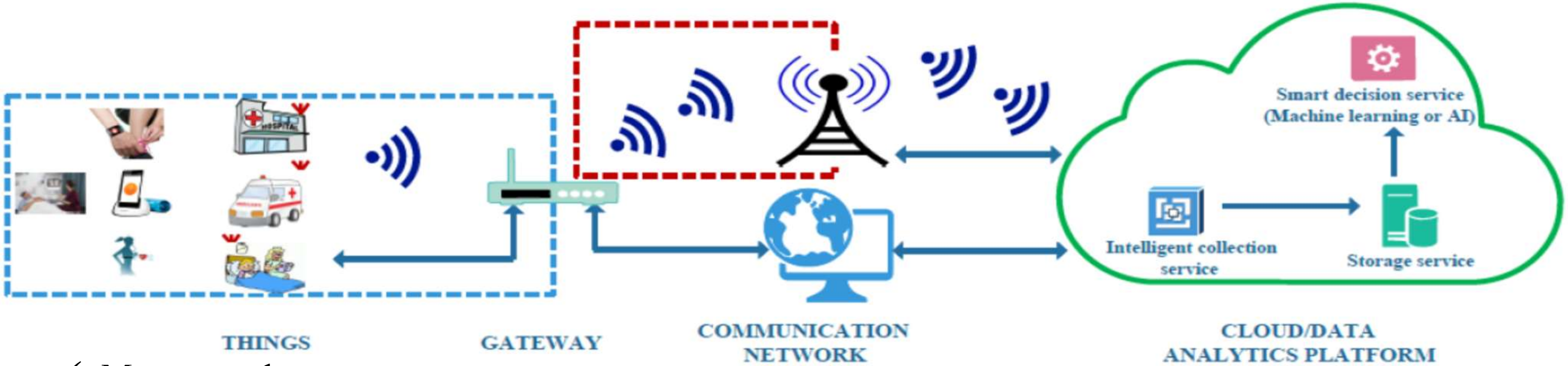
“INTERNET OF THINGS: TRENDS, DIRECTIONS, OPPORTUNITIES, CHALLENGES” by I. F. AKYILDIZ, Georgia Institute of Technology, USA

INTERNET OF NANOTHINGS THINGS



"INTERNET OF THINGS: TRENDS, DIRECTIONS, OPPORTUNITIES, CHALLENGES" by I. F. AKYILDIZ, Georgia Institute of Technology, USA

ELEMENTS OF IoT



THINGS

- ✓ Measure values
- ✓ Send raw data
- ✓ Low power

GATEWAY

- ✓ Get data from sensor
- ✓ Process data
- ✓ Send data to cloud
- ✓ Store data locally if needed

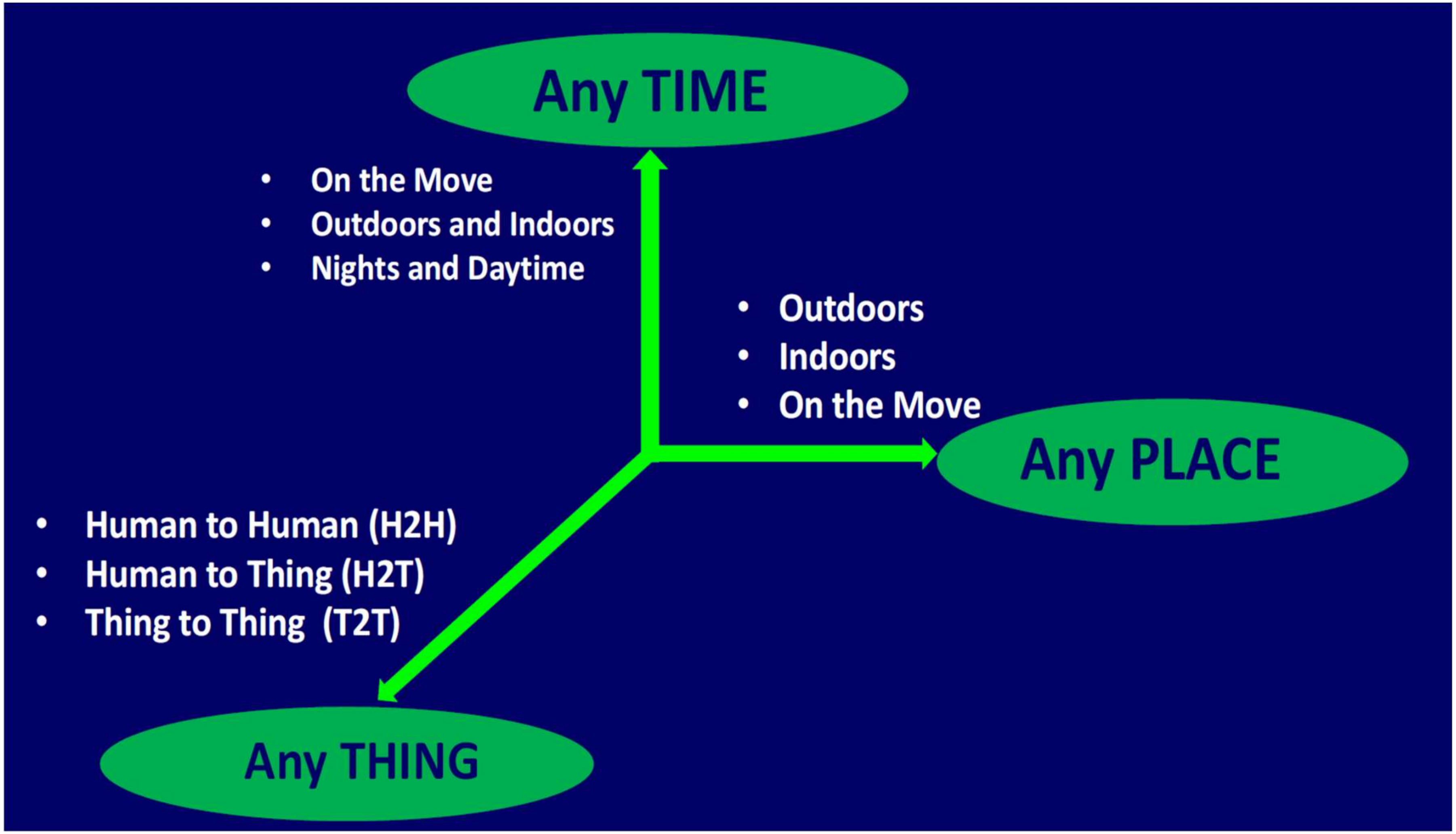
COMMUNICATION NETWORK

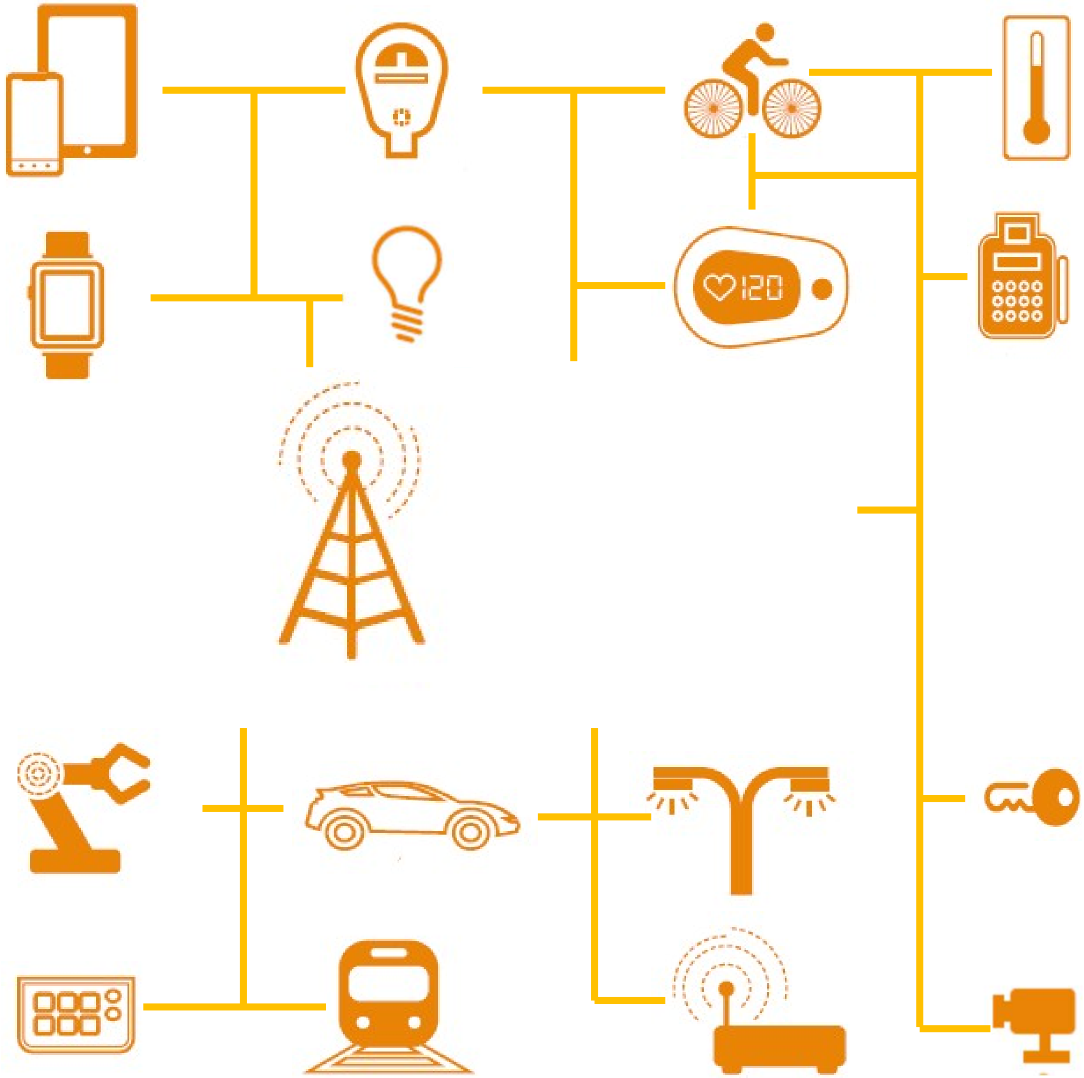
- ✓ Transfer data to cloud
- ✓ Low power
- ✓ Low data rate
- ✓ Low latency
- ✓ Secure and reliable

CLOUD/DATA ANALYTICS PLATFORM

- ✓ Aggregate data
- ✓ Process and analyse data
- ✓ Make decisions on data
- ✓ Store data

INTERNET OF THINGS: COMMUNICATION PRESPECTIVE

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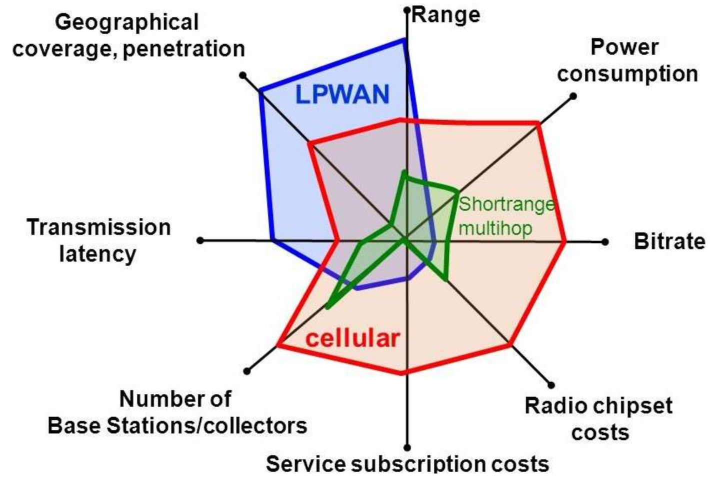
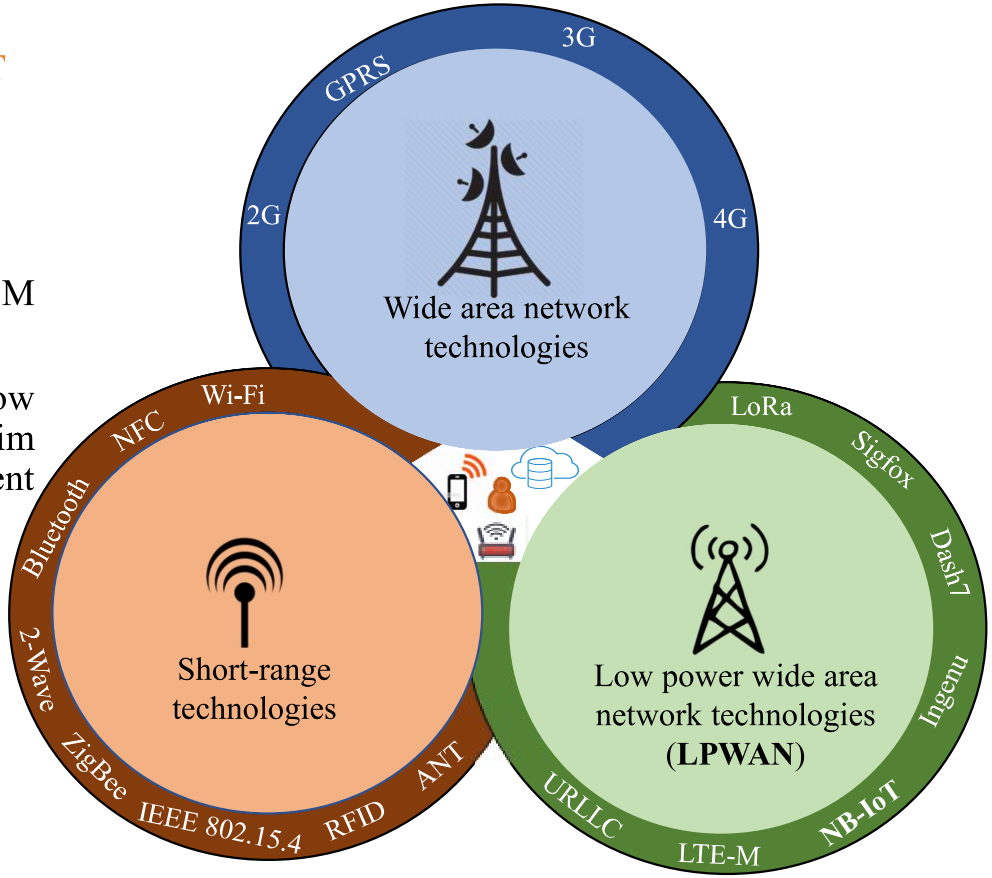
COMMUNICATION TECHNOLOGIES

- ❑ Existing long-rang networks (2G/3G/LTE/WiFi) will meet the applications that need long range and high data rates. (**10% OF IOT MARKET VOLUME**)
- ❑ Existing short-range technologies such as ZigBee, RF Mesh (802.15.4), PLC, WiFi, etc.. will be used for short range applications such as smart meter, smart home, smart parking, etc…. A GW or aggregator can be used to aggregate and send the data to the IoT/M2M platform. (**30% OF IOT MARKET VOLUME**)
- ❑ NEW LPWA network to meet long range coverage, low power, low data rate and low cost of end device in unlicensed bands as an interim and complementary solution and to avoid niche deployment competition. (**60% OF IOT MARKET VOLUME**)





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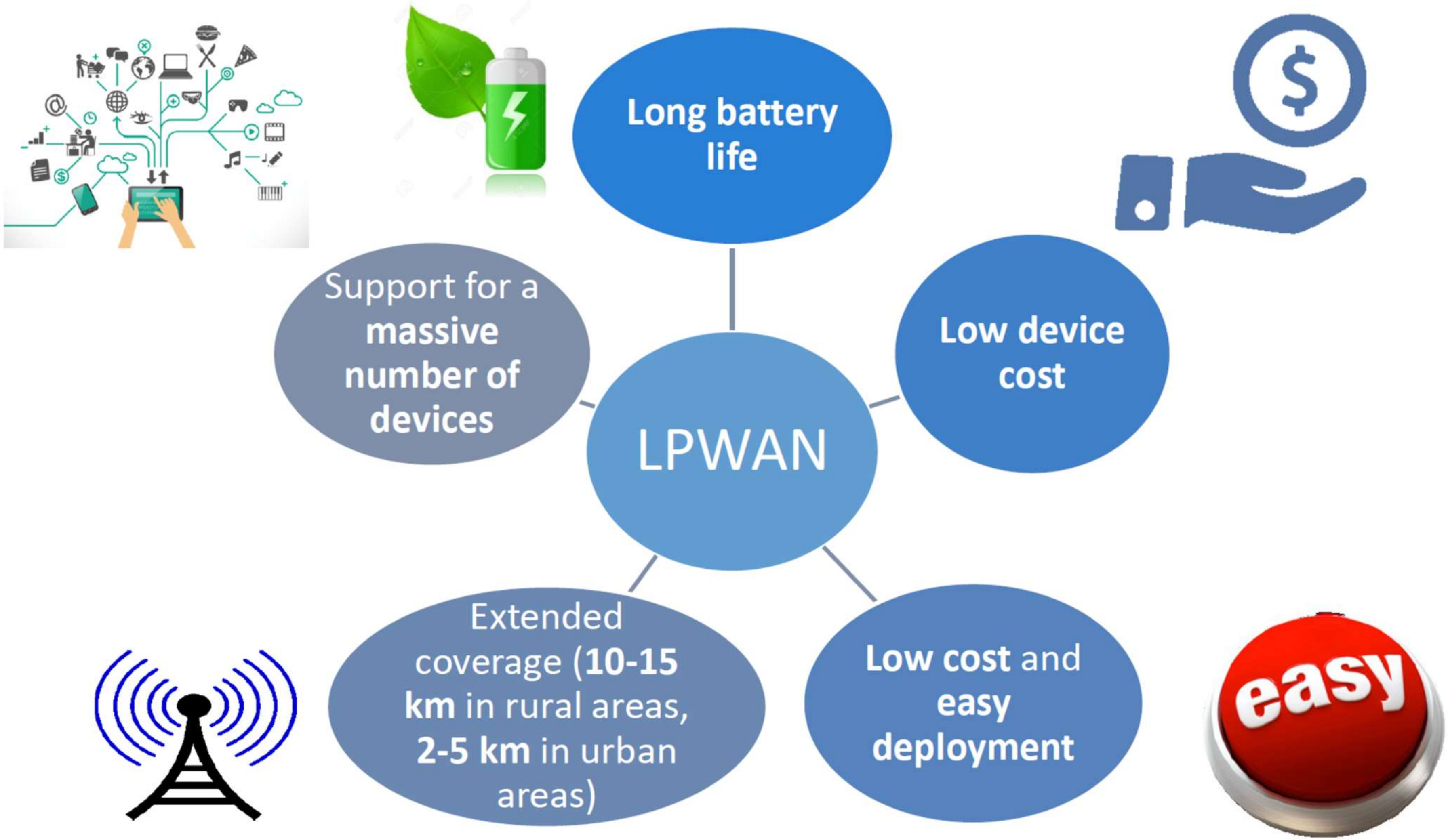
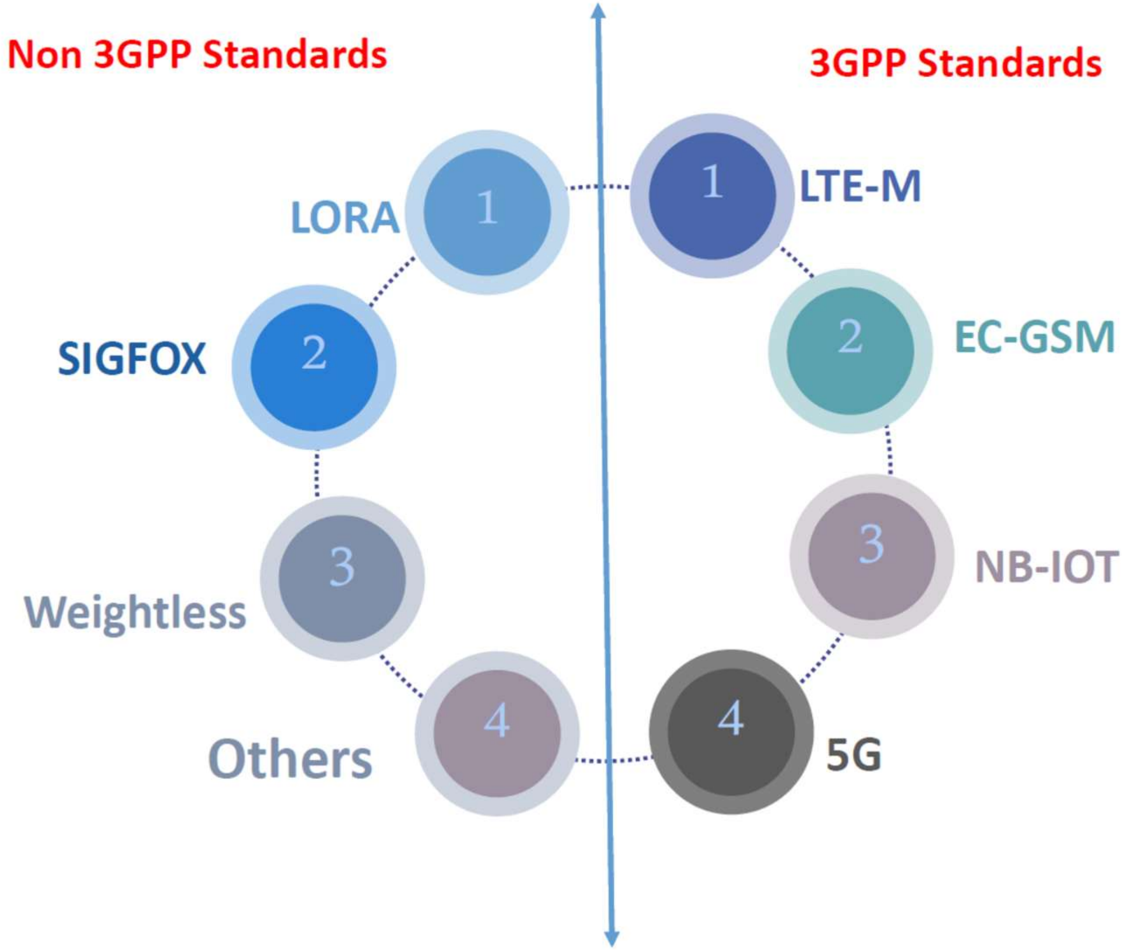
LPWAN REQUIREMENTS



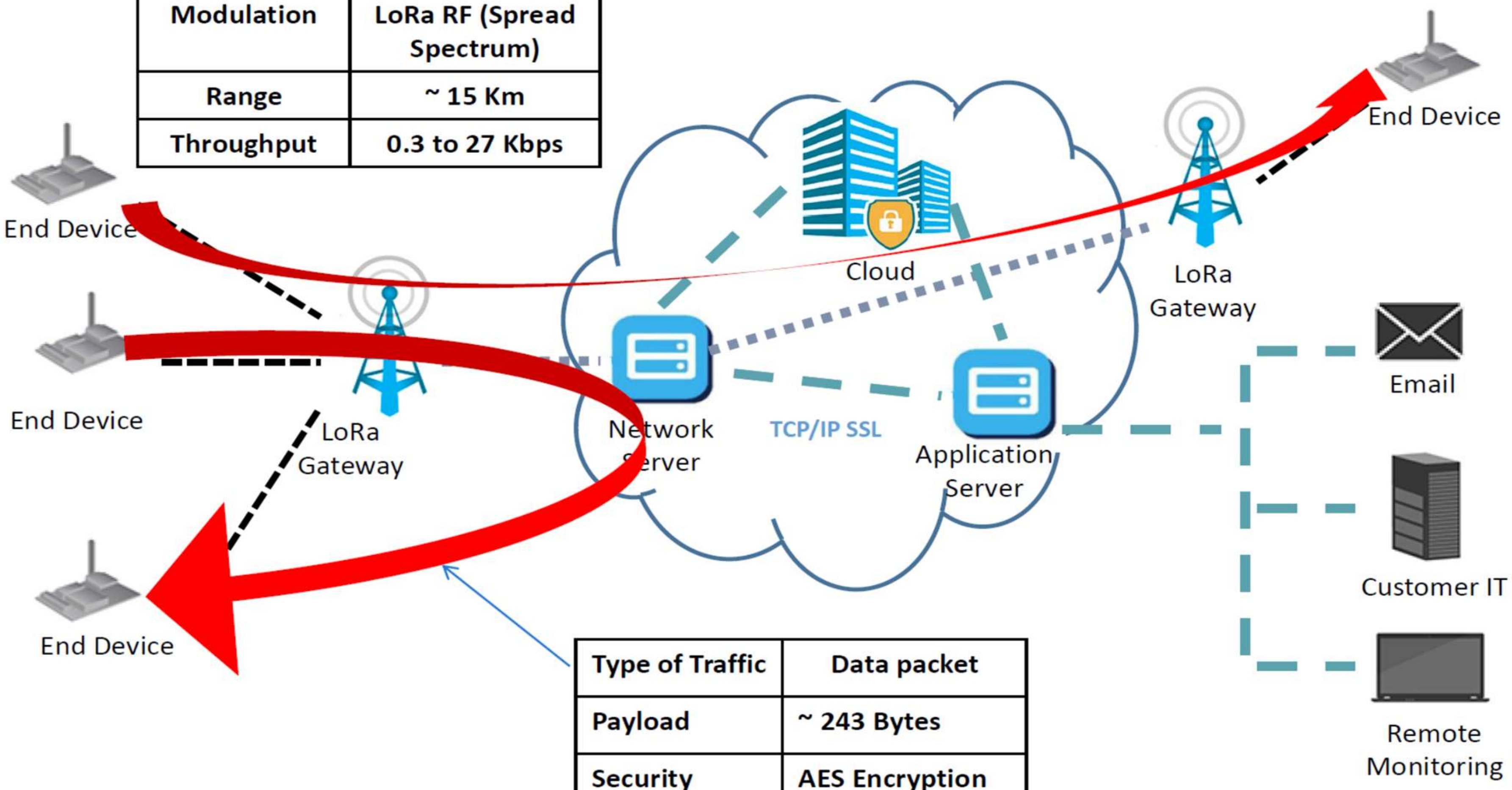
LPWAN TECHNOLOGIES



LORAWAN

- LoRaWAN is a *Low Power Wide Area Network*
- LoRa 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 communication (up to **15 Km**)
- Strong indoor penetration: With High Spreading Factor, Up to **20dB** penetration (**deep indoor**)
- 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.

LORAWAN ARCHITECTURE

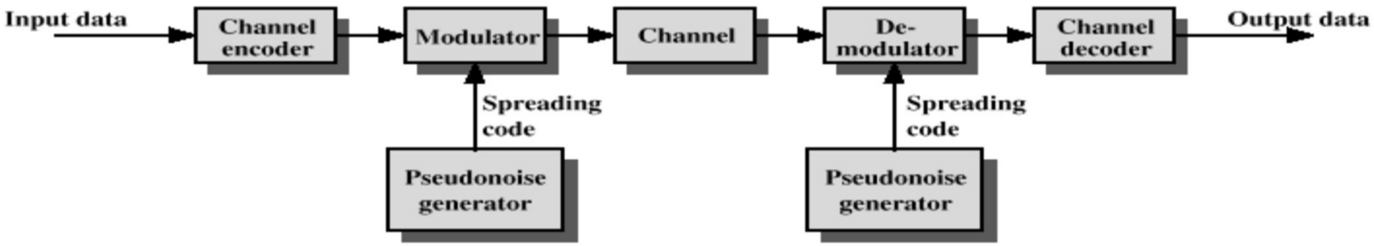


Modulation	LoRa RF (Spread Spectrum)
Range	~ 15 Km
Throughput	0.3 to 27 Kbps

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

SPREAD SPECTRUM: BASIC

- Spread Spectrum is a means of transmission in which the data sequence occupies a bandwidth in excess of the minimum bandwidth necessary to send it.
- Effectively the signal is mapped to a higher dimension signal space
- Signal spreading is done before transmission by using a spreading sequence. The same sequence is used at the receiver to retrieve the signal
- Spread Spectrum is most effective against interference (intentional or non-intentional) with fixed energy.
- Gained popularity by the needs of military communication
- Proved **resistant** against hostile jammers
- Ratio of information bandwidth and spreading bandwidth is identified as spreading gain or processing gain
- Processing gain does not combat white Noise



LORAWAN: DEVICE CLASSES

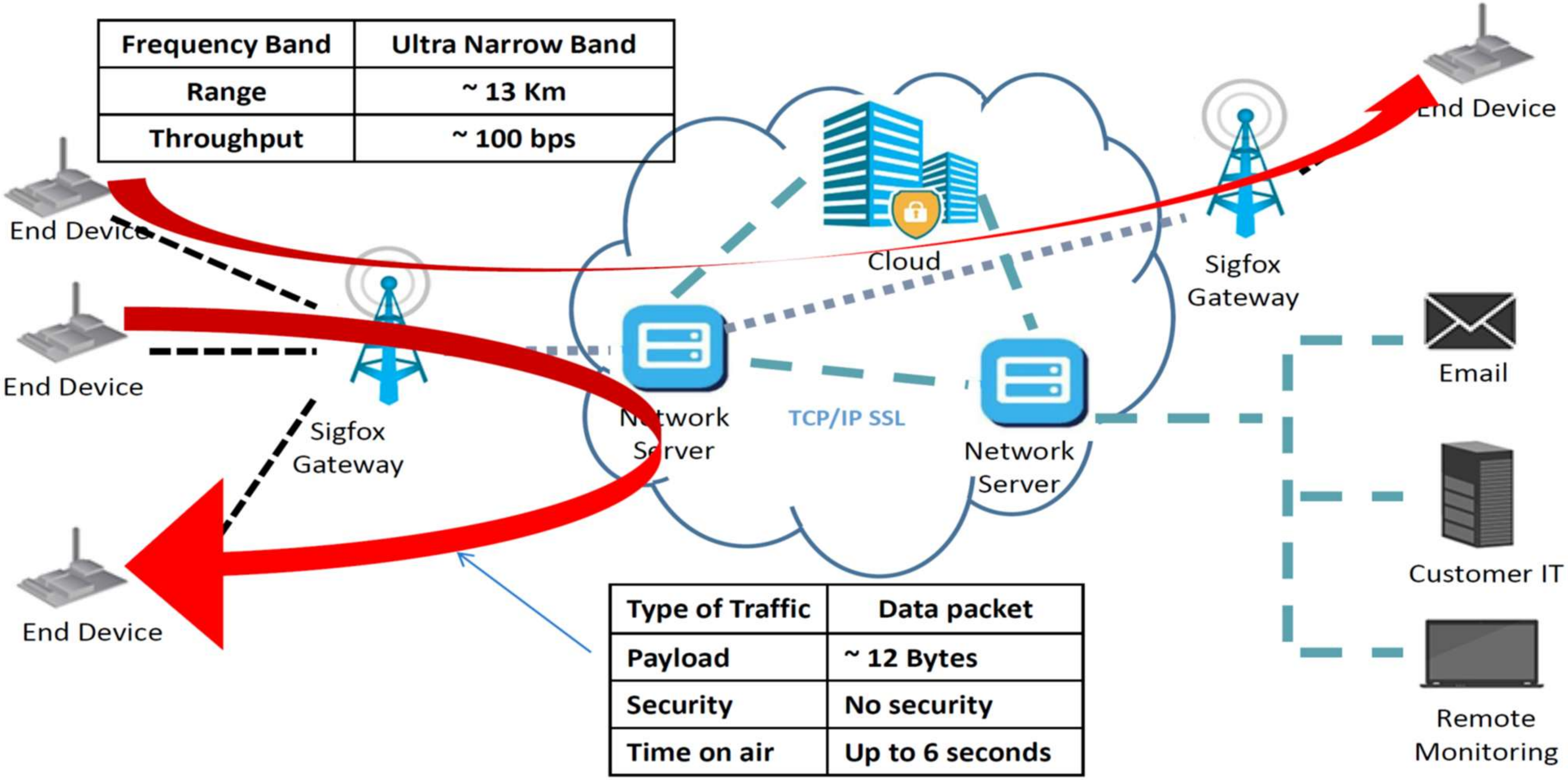
Classes	Description	Intended Use	Consumption	Examples of Services
A (« **all** »)	**Listens only after end device transmission**	Modules with **no latency constraint**	The **most economic** communication Class energetically.. **Supported by all modules.** **Adapted to battery powered modules**	• **Fire 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

- First LPWAN Technology
- 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 forserver access
- Roaming capability

LORAWAN ARCHITECTURE



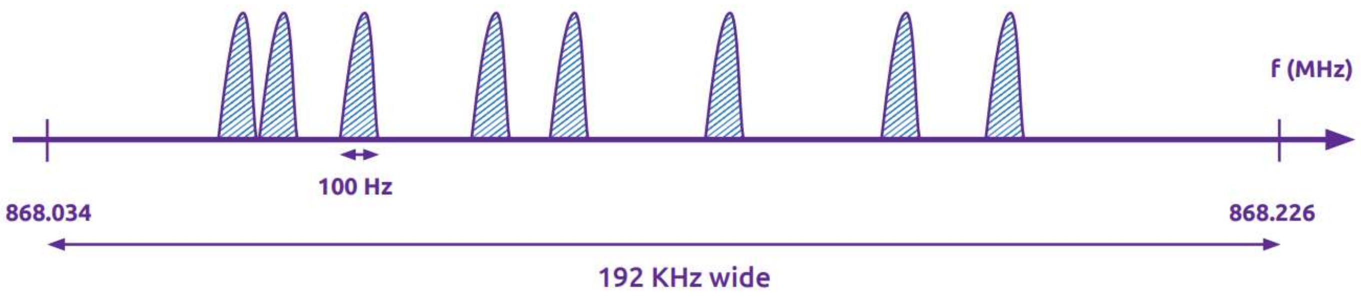
Frequency Band	Ultra Narrow Band
Range	~ 13 Km
Throughput	~ 100 bps

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

By default, data is conveyed over the air interface without any encryption. Sigfox gives customers the option to either implement their own end-to-end encryption solutions.

SIGFOX: SPECTRUM

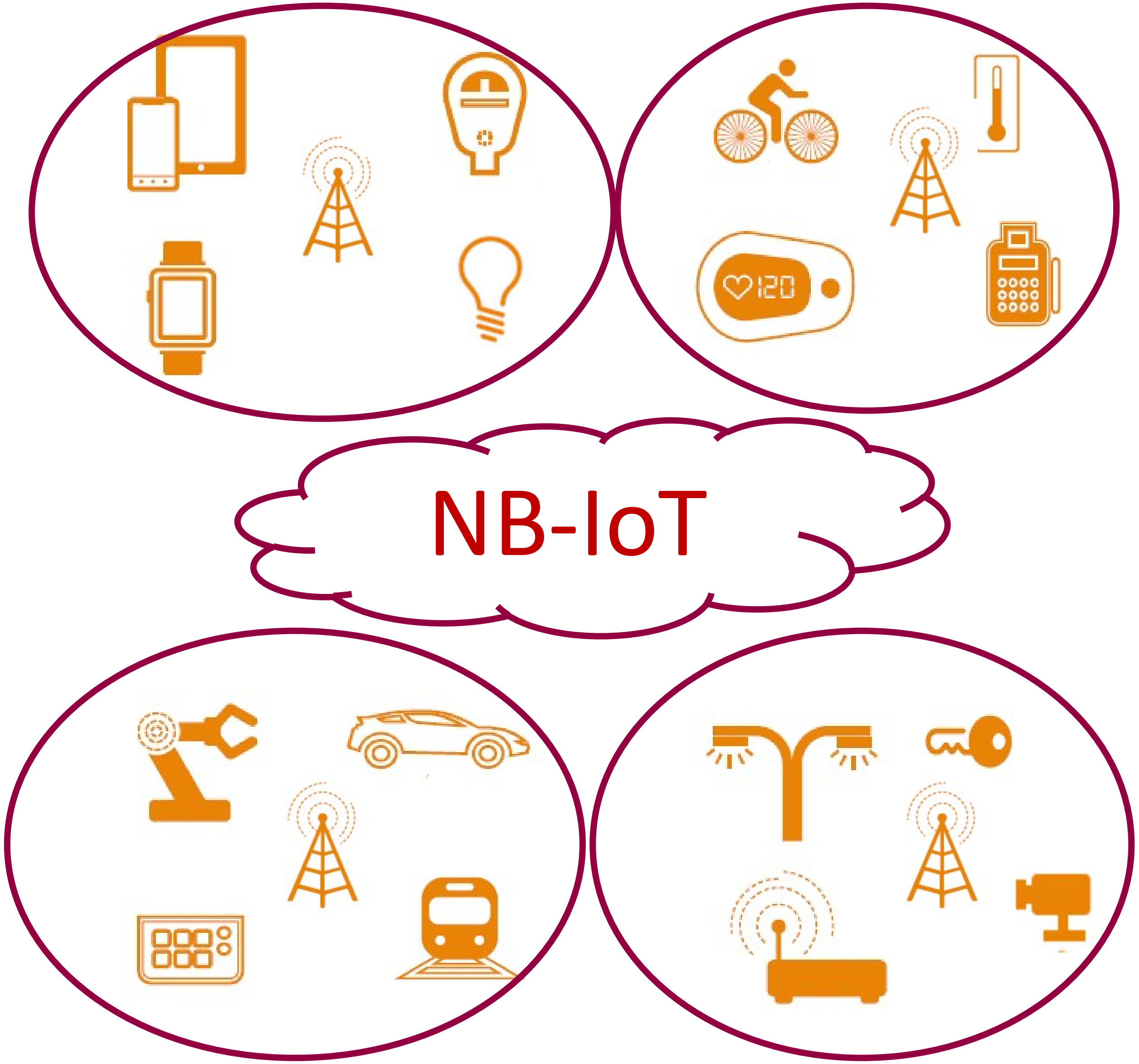
- ❑ Narrowband technology
- ❑ Standard radio transmission method: binary phase-shift keying (BPSK)
- ❑ Takes very narrow parts of spectrum and changes the phase of the carrier radio wave to encode the data.
- ❑ Sigfox is using 192KHz of the publicly available band to exchange messages over the air.
- ❑ The modulation is Ultra-Narrow band. Each message is 100 Hz wide and transferred with a data rate of 100 or 600 bits per second depending on the region



LPWAN TECHNOLOGIES

	LoRa	Sigfox	NB-IoT	LTE-M
Spectrum	Unlicensed	Unlicensed	Licensed	Licensed
Bandwidth	125 kHz	100 Hz	180 kHz	1.4 MHz
Coverage (dB)	157	149	~164 dB	~156 dB
Data Rate	50 kbps	100 bps	250 kbps	1 Mbps
Scalability	Medium	Low	High	High
Location support	Yes	No	Yes	Yes
OTA upgrade	Yes	-	Yes	Yes
Battery Life	10 year +	10 year +	10 year +	10 year +

Licensed Technologies (e.g. **NB-IoT**) outperform in terms of LPWAN network support due to their global outreach, existing infrastructure, high data rate, extended coverages, etc.


NB-IoT

NB-IOT

- NB-IoT standard development
  - ✓ 3GPP has been working on 3 different IoT standard solutions
  - ✓ LTE-M – based on LTE evolutions, Cat0(rel 12) and cat-1(rel 13)
  - ✓ EC-GSM – A narrowband solution based on GSM evolution,
  - ✓ NB-LTE – A narrowband cellular IoT solution, also known as clean state solutions, Cat200KHz.
  - ✓ Later, EC-GSM and NB-LTE, were combined for standardization as a single NB-IoT technology.

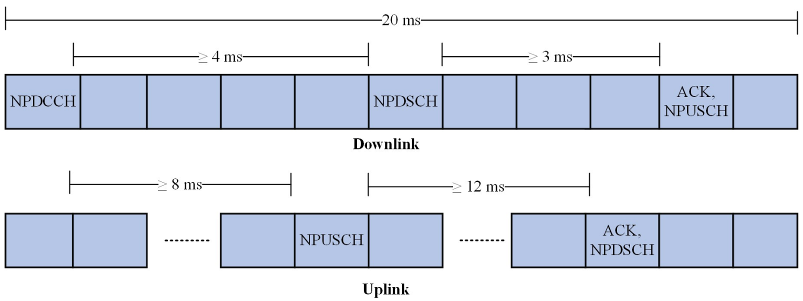
NB-IoT is a Low Power Wide Area Network (LPWAN) radio technology standard that has been developed to enable a wide range of devices and services to be connected using cellular telecommunications bands.

NB-IOT: OBJECTIVES

- NB-IoT targets the low-end “Massive MTC” scenario
- Support for small data transmission
- Low device cost/complexity: <$5 per module
- Extended coverage: 164 dB MCL, 20 dB better compared to GPRS
- Long battery life: >10 years
- Capacity: 40 devices per household, ~55k devices per cell
- Uplink report latency : <10 seconds

NB-IOT: LOW DEVICE COMPLEXITY AND COST

- Device complexity and cost are primarily related to the complexity of baseband processing, memory consumption, and radio-frequency (RF) requirements.
- Restrict the DL transport block size (TBS) to 680 bits and uplink to 1000 bits relax the processing time requirements compared with LTE.
- Simple convolutional code (tail-biting) than LTE turbo code for channel coding
- NB-IoT does not use higher-order modulations
- Reduced peak rate
- Single receive antenna
- Reduced bandwidth i.e., 180 kHz
- Reduced maximum transmit power to either 20 or 23 dBm in Release 13. This allows on-chip integration of the power amplifier (PA), which can contribute to the device cost reduction.
- Scheduling delay



NB-IOT: COVERAGE ENHANCEMENT

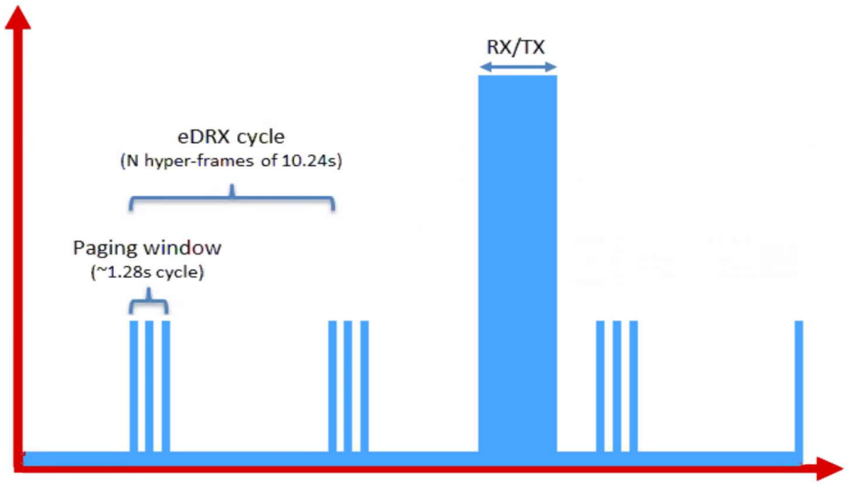
- ❑ Objective to achieve a 20 dB better coverage than in then existing LTE networks to provide coverage for devices with challenging coverage conditions, for example stationary utility metering devices located in basements.
- ❑ Mainly achieved by trading off data rate for coverage.
- ❑ Retransmission as a base solution
  - ✓ The decoding of each repeated packet can be done separately, or multiple packets can be combined for improving the rate.
  - ✓ NB-IoT defines three coverage classes (i.e., 0 dB, 10 dB and 20 dB for Normal, Robust, and Extreme conditions, respectively) based on the signal strength, which depends on cell deployment, user distribution and propagation channel.
  - ✓ The maximum number of retransmissions allowed in downlink and uplink are 2048 and 128 , respectively
- ❑ Power boosting of reference and data.
- ❑ Keeping low performance requirement (error targets etc.)

NB-IOT: LONG DEVICE BATTERY LIFETIME

- Minimizing power back-off also gives rise to higher PA power efficiency, which helps extend device battery lifetime.
- NB-IoT introduced
  - ✓ extended Discontinuous Reception (eDRX)
  - ✓ Power-Saving Mode (PSM)

EXTENDED DISCONTINUOUS RECEPTION

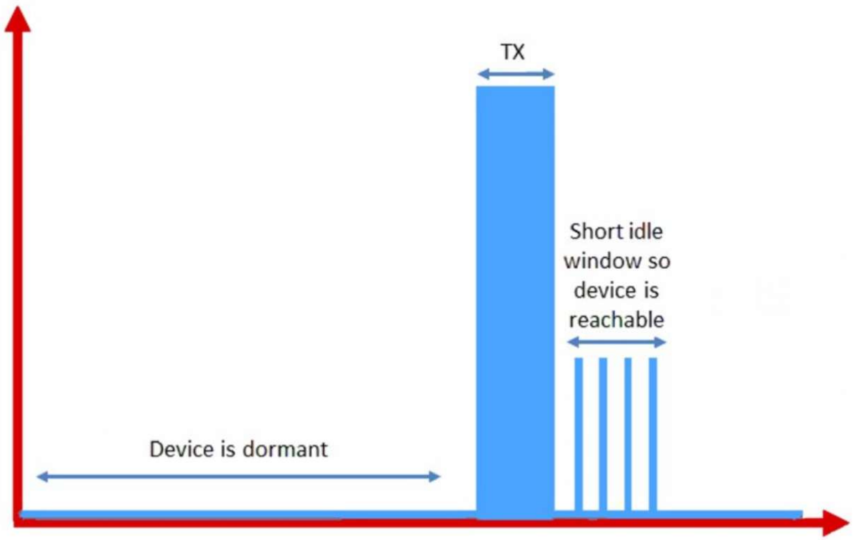
- Even while there is no traffic between the network and UE, UE has to keep listening to Network. At least it should be ready to decode PDCCH. It means UE has to be "ON" all the time even when there is no traffic. But being ON all the time would drain the battery.
- Let UE get into sleeping mode for a certain period of time and wake up again checking if there is any data coming from the network and getting into sleeping mode again. This kind of periodic repetition of "sleep mode and wake up mode" is called DRX (Discontinuous Reception)".
- A normal LTE paging cycle is 1.28s, during which the device can be contacted by the network if traffic is queued for that device
- LTE DRX improvement to LTE allowed UE devices to sleep for 10.24s between paging cycle
- eDRX innovation allows the UE to tell the network how many “hyper frames” (HF) of 10.24s it would like to sleep before checking back in. The maximum number of HFs a UE can sleep is settable by the mobile network operator.
- In NB-IoT, eDRX can be configured with a DRX cycle just below 3 hours



Source: https://industryeurope.com/time-running-out-for-chipset-manufacturers-to-meet-iot-forec/

POWER SAVING MODE (PSM)

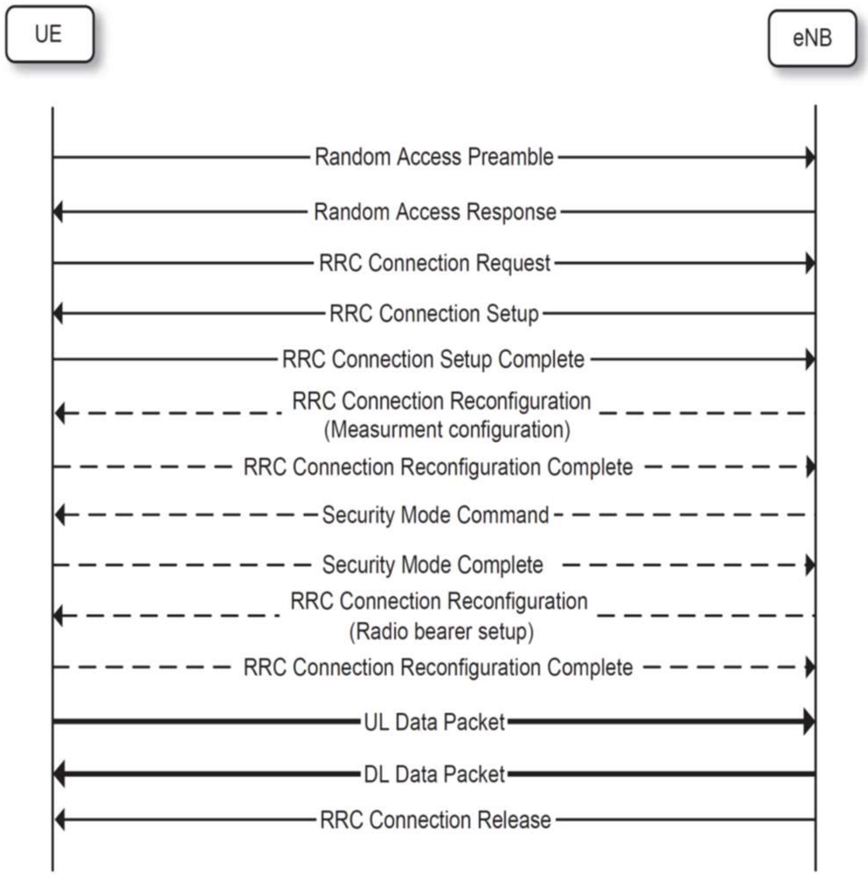
- Power Saving Mode is a mode that the UE tells the network it is going to go dormant indefinitely.
- When the UE host device decides, based on some logic or timer, that it is time to transmit, it wakes up and transmits to the network, and remains in RX mode for 4 idle frames so that it can be reachable if needed.
- Whereas, in typical Idle Mode behaviour, device still performs energy consuming tasks such as neighbour cell measurements and maintaining reachability by listening for paging messages.
- In PSM the device also stays registered in the network and maintains its connection configurations. As such, when leaving the power saving state in response to a MO event the device does not need to first attach to the network and setup the connection, as it would otherwise need to do when being turned on after previously performing a complete power off. This reduces the signalling overhead and optimizes the device power consumption.
- Max duration of PSM is 12.1 days.



Source: https://industryeurope.com/time-running-out-for-chipset-manufacturers-to-meet-iot-forec/

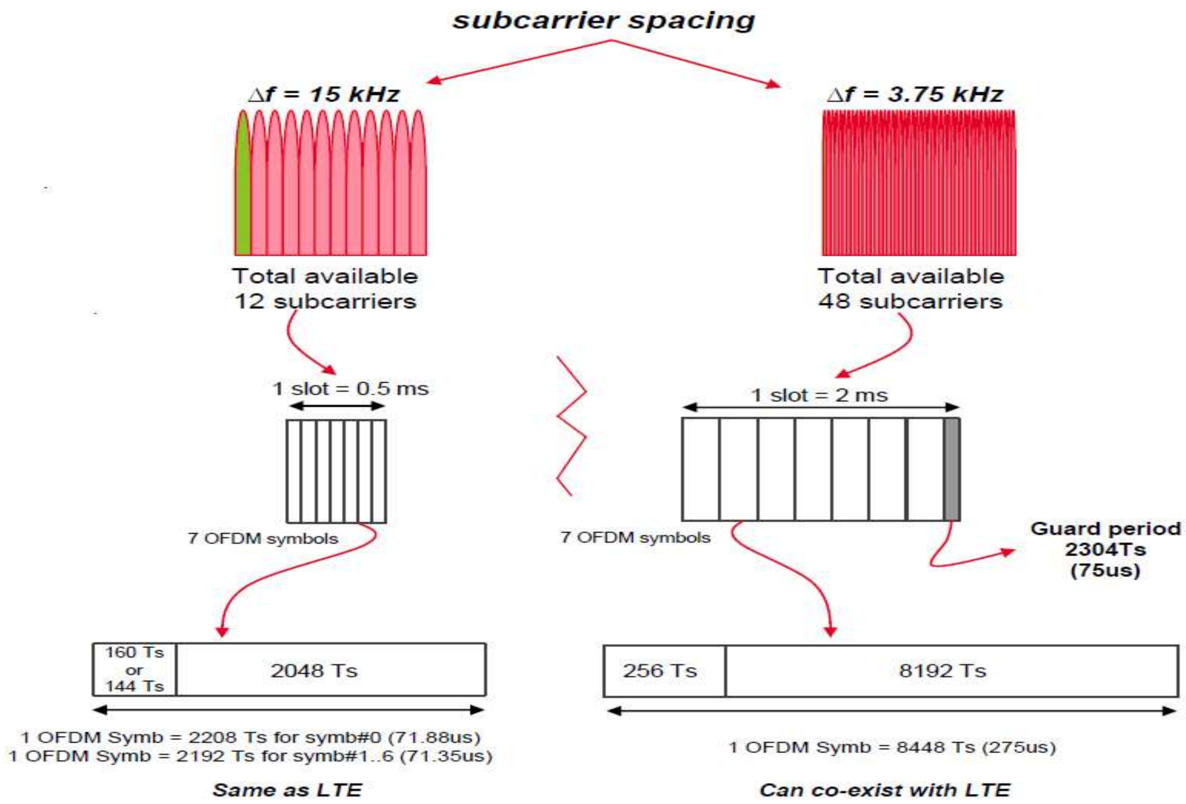
NB-IOT: SMALL DATA TRANSMISSION

- ❑ User Plane CIoT Evolved Packet System (EPS) optimization
- ❑ Control Plane CIoT EPS optimization
  - ✓ Both aims to optimize or reduce the message exchanges that are needed before a device transmits its data.
  - ✓ Part of the user plane optimizations is the RRC Resume procedure where the basic idea is to resume configurations established in a previous connection.
  - ✓ This is achieved by using a Resume Identity that is used by the network to retrieve the device context stored in the network.
  - ✓ The RRC Resume procedure minimizes the signalling needed to setup the data radio bearer.
  - ✓ The Control Plane CIoT EPS optimization procedure allows data to be transmitted over a signalling radio bearer in a Non-Access Stratum container. This allows data transmission before setting up a data radio bearer.
  - ✓ In short, this optimization uses the control plane to forward the UE's data packets



NB-IOT: MASSIVE DEVICE SUPPORT

- 1-sub-carrier Granularity
  - ✓ NB-IoT introduces the concept of resource unit (RU) for the allocation of uplink resources.
  - ✓ The RU is defined as the combination of a number of sub-carriers (i.e., tones, the term used in the standard) and a number of symbols grouped together



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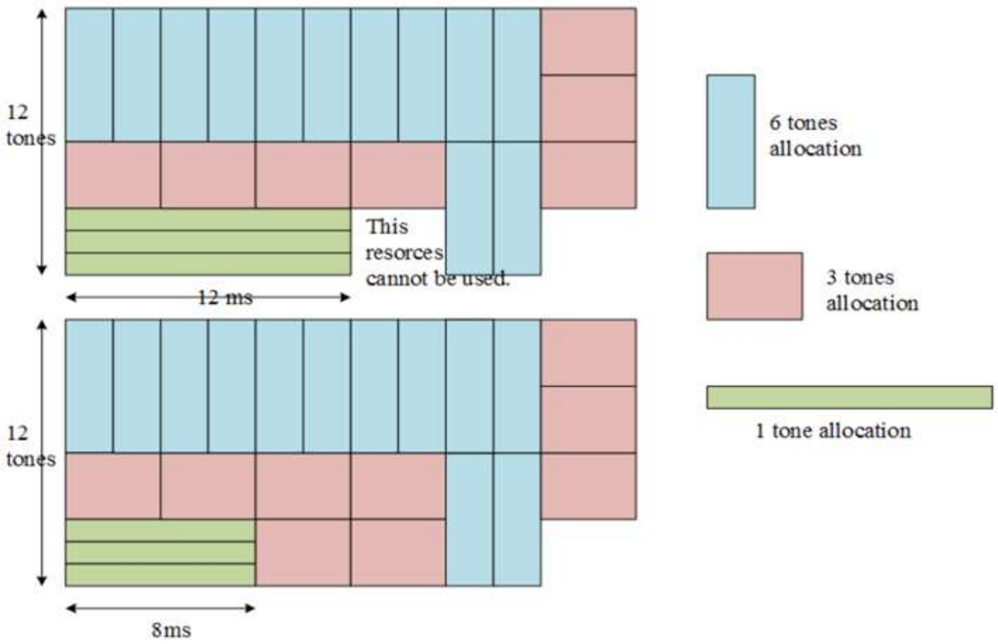
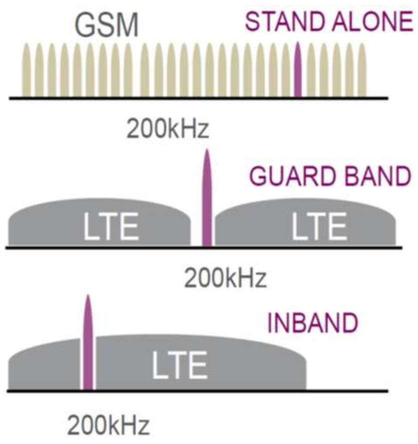
NB-IOT: MASSIVE DEVICE SUPPORT

- ❑ Recommended RU configuration for uplink by 3GPP
- ❑ 15 kHz
  - ✓ 12 tone
  - ✓ 6 tone
  - ✓ 3 tone
  - ✓ 1 tone
- ❑ 3.75 kHz
  - ✓ 1 tone



DEPLOYMENT FLEXIBILITY

- With System of 180 kHz, NB-IoT Can be deployed in three mode
  - ✓ Stand-alone Mode
  - ✓ Guard band Mode
  - ✓ In-band Mode



CONCLUSION

With these design changes, NB-IoT is able to provide

- Reduced Device Complexity and Cost
- Low Power Consumption
- Massive Device Support
- Extended Coverage
- Flexibility in development

However, there are still some of the challenges associated with these changes that need to be investigated.