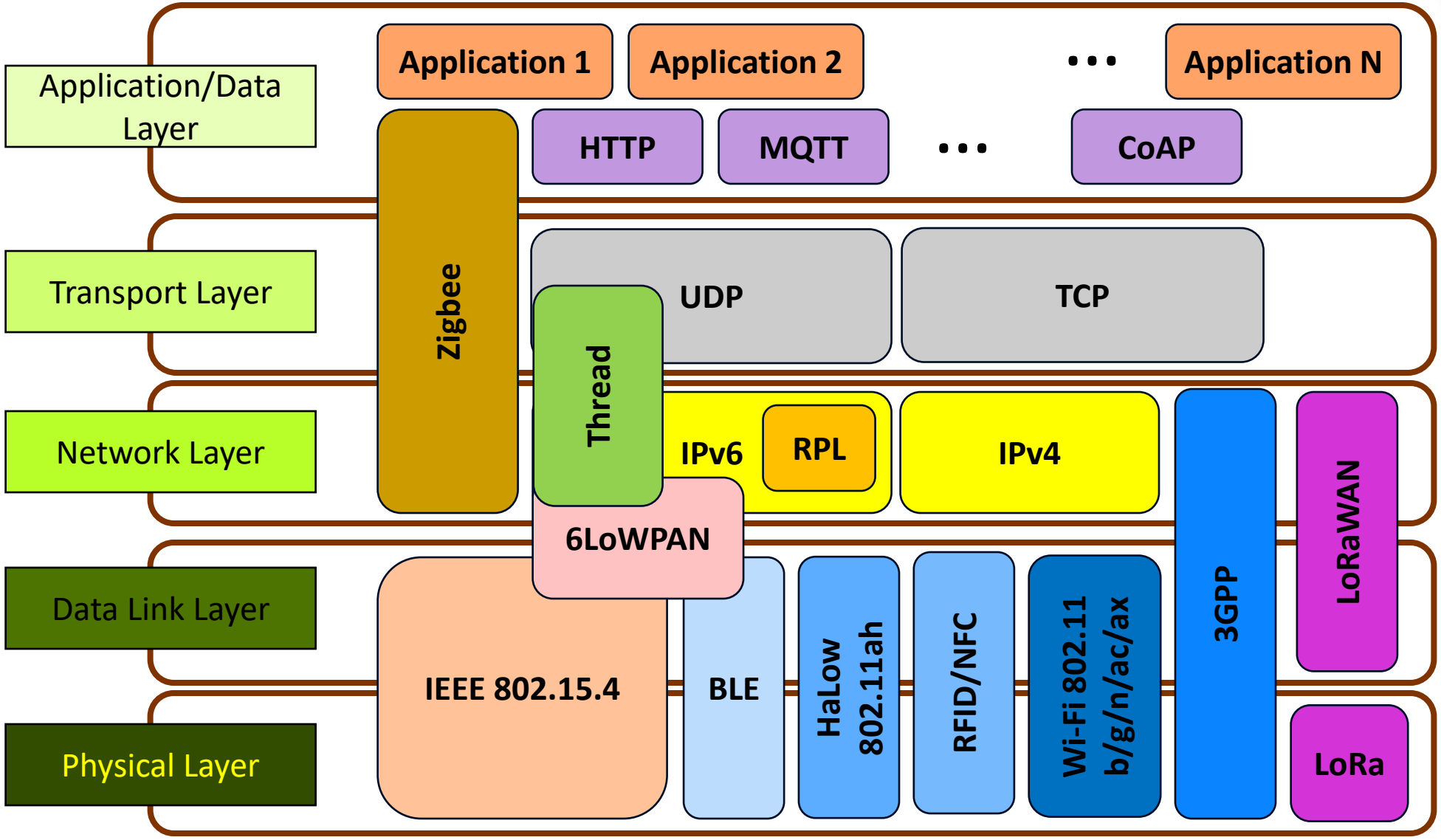
Internet of Things: Protocols and Networks

(CSC2006)

LoRa & LoRaWAN

Current Protocols for IoT



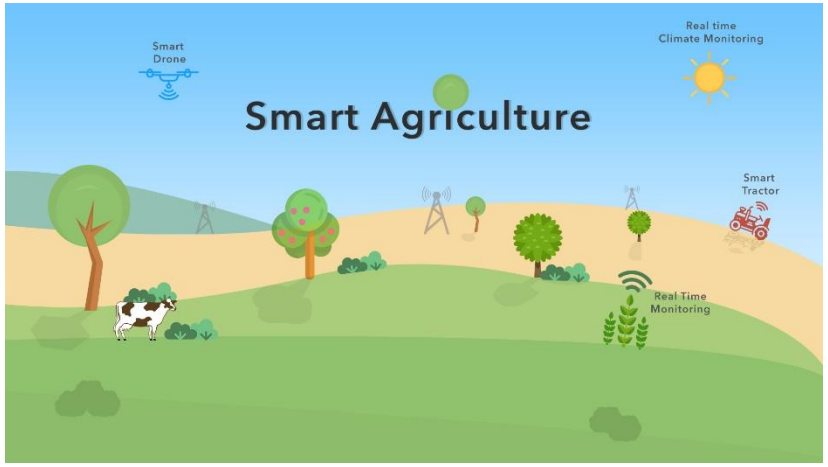
Short range vs. long-range IoT

Short Range

Z-Wave based home control

Radon Gas Monitor

Long Range

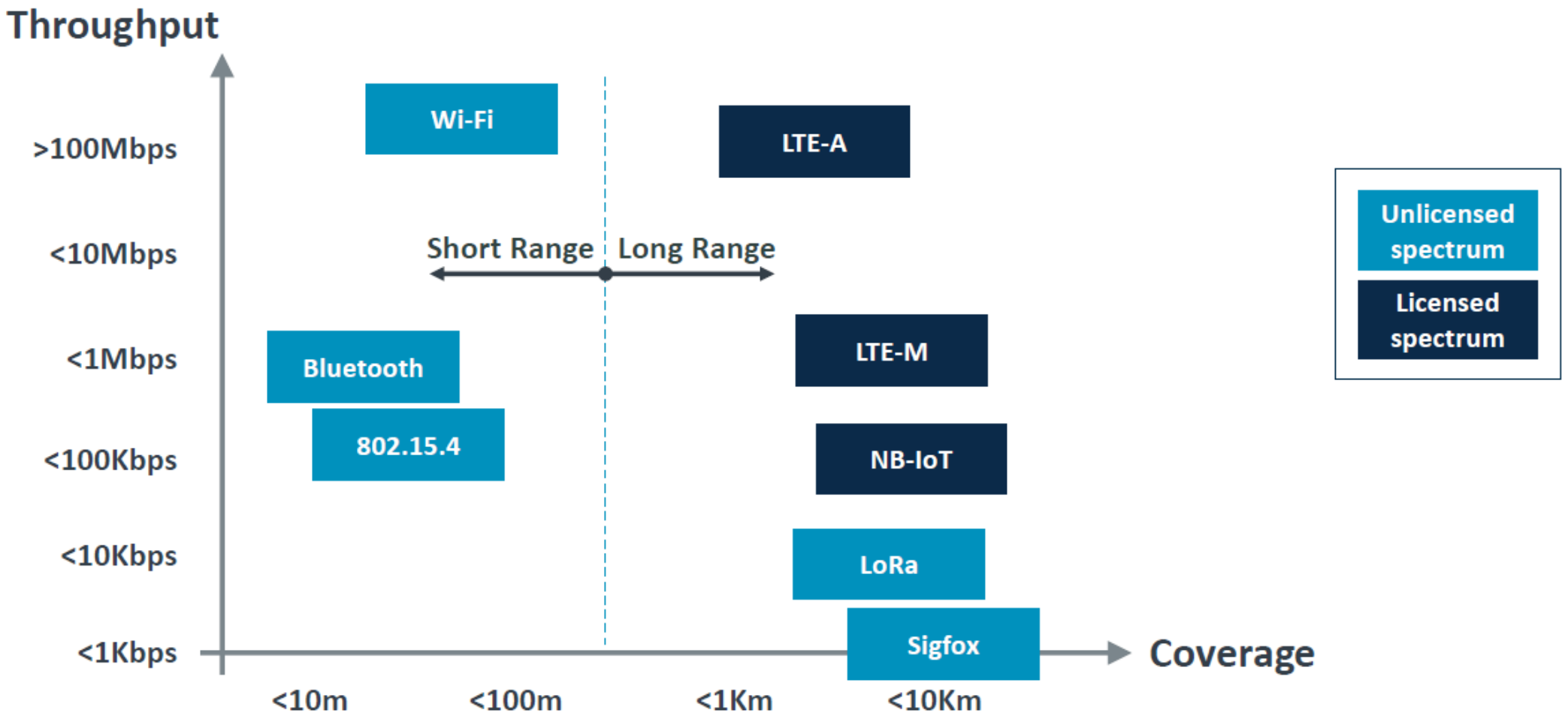


https://teks.co.in/site/blog/smart-agriculture-13-trends-to-watch-out-for/

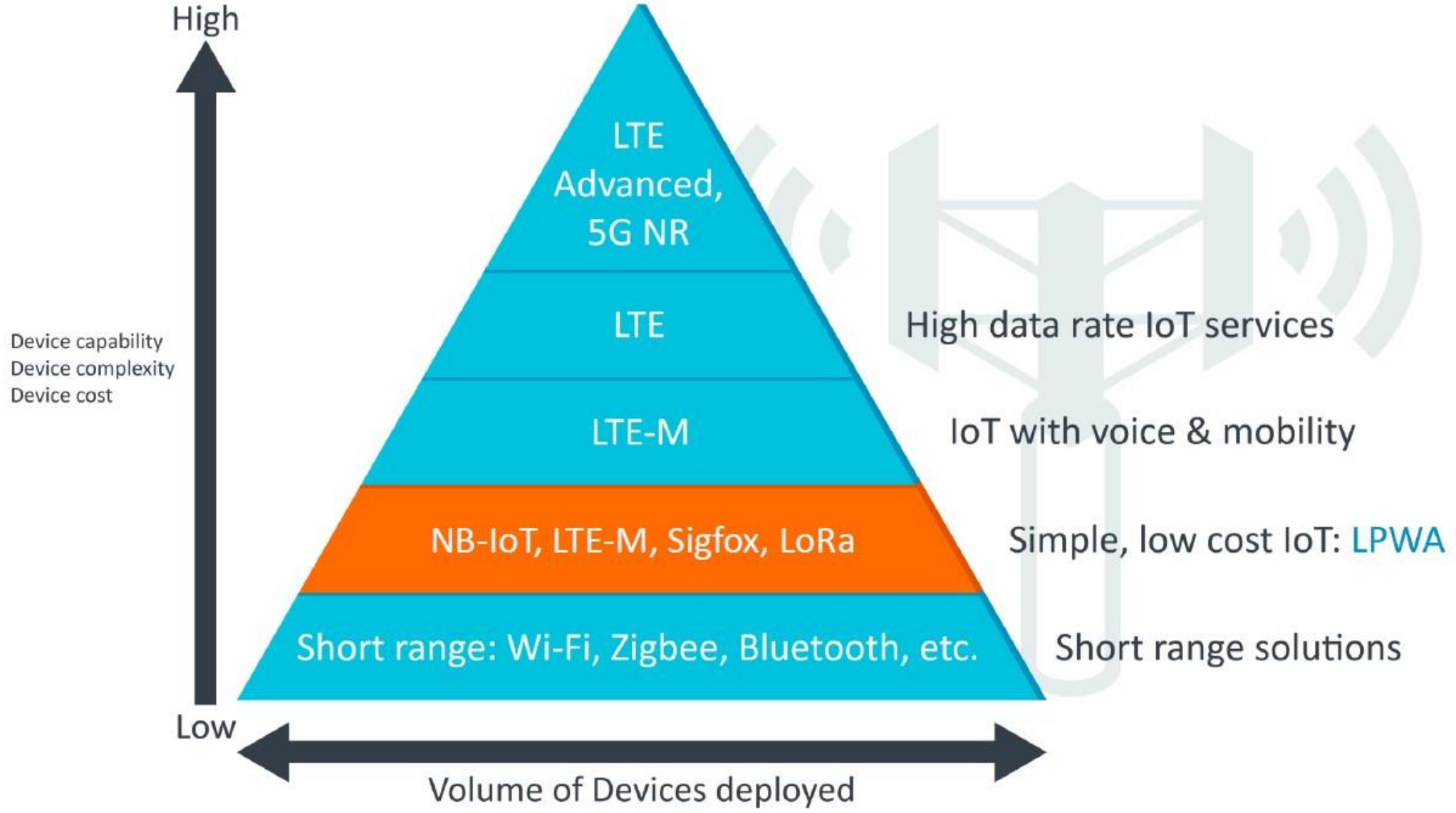
https://www.semtech.com/company/press/ofo-adopts-semtechs-lora-technology-to-expand-bicycle-tracking-coverage

IoT- Connectivity Technologies

Multiple standards, different attributes:



IoT - the Connectivity Pyramid



LPWAN requirements

- **Low Power Wide Area** wireless connects low bandwidth, low power devices and provides long-range coverage

Includes cellular (NB-IoT, LTE-M/Cat-M1) *and* non-cellular (Sigfox, LoRa etc) technologies

LoRa Technology

- Long Range Wide Area Network.
- LoRa technology was originally developed by a French company, Cycleo (founded in 2009 as an IP and design solution provider), a patented spread spectrum wireless modulation technology that was acquired by SemTech in 2012 for $5 million
- Originally developed by Cycleo in France.

  Acquired by Semtech corporation, which is the founding member of the **LoRa Alliance**

  Now 160+ members.
- V1.0 spec dated January 2015. Released to public July 2015.
- Rapid Adoption: Products widely available

Transceiver

Arduino Radio Shield

Connectivity Kit for Arduino, Waspmote, Raspberry Pi

Ref: https://www.lora-alliance.org/What-Is-LoRa/Technology

Frequency

- Uses ISM license-exempt band:
  - 915 MHz MHz in US. Power limit. No duty cycle limit.
  - 868 MHz in Europe. 1% and 10% duty cycle limit
  - 433 MHz in Asia
- Singapore: Telecommunications Standards Advisory Committee (TSAC)
  - ≤ 500 mW Effective radiated power (erp) : No approvals required within this power limit and within this frequency range.

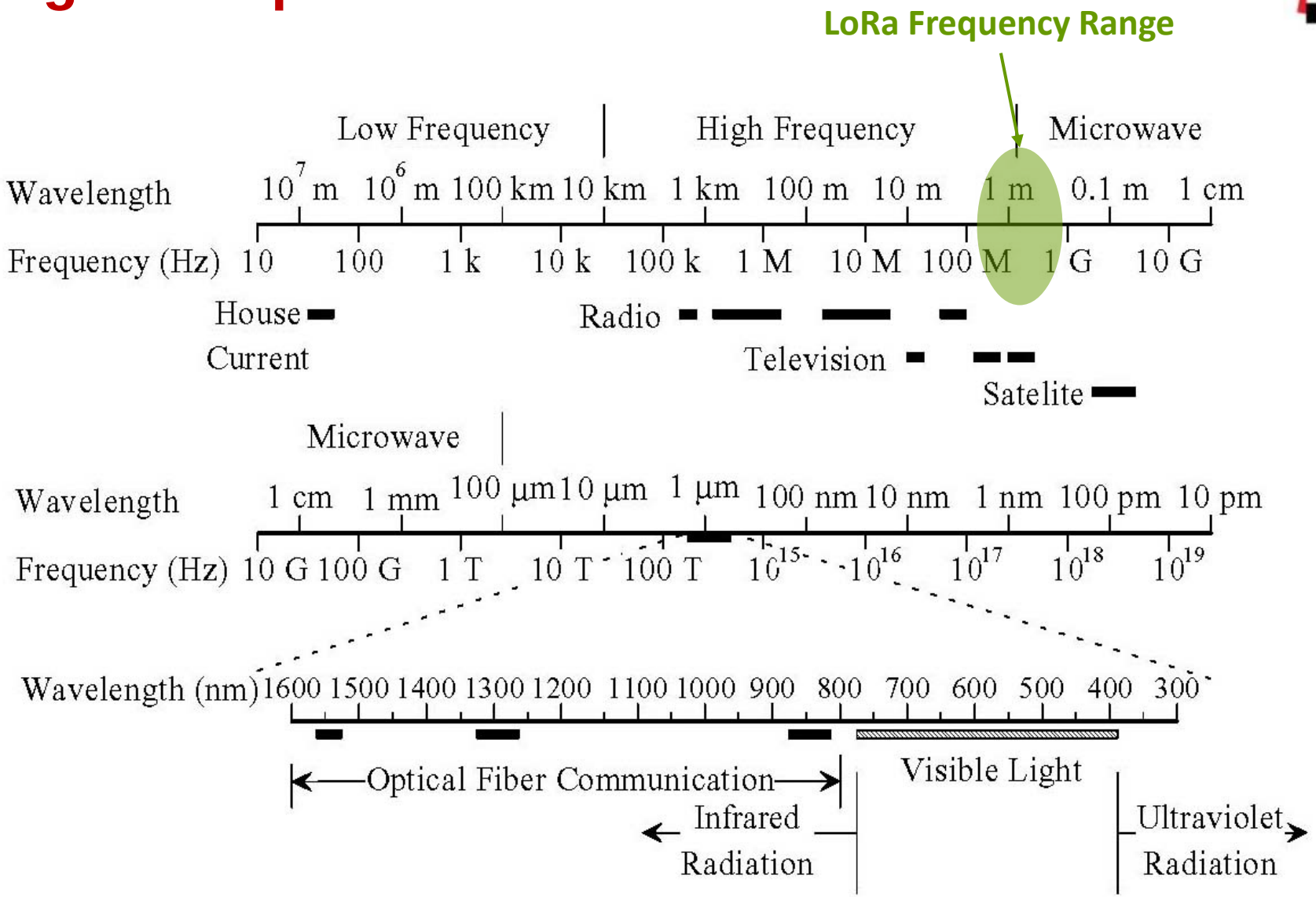
866 – 869 MHz	≤ 500 mW (e.r.p.)	Refer to limits given in Table1-a of this TS	EN 302 208	Radio Telemetry, Telecommand, RFID system
920 – 925 MHz	≤ 500 mW (e.r.p.)	Refer to limits given in Table1-a of this TS	FCC Part 15 §15.249 and ANSI C63.10-2013	Radio Telemetry, Telecommand, RFID system

https://www.imda.gov.sg/~/media/imda/files/regulation%20licensing%20and%20consultations/ict%20standards/telecommunication%20standards/radio-comms/imdatssrd.pdf?la=en

- Currently suitable for public deployment in an area
  - All gateways report to the same server
  - A device can talk to any gateway
  - All devices use the same frequency

Ref: http://www.link-labs.com/what-is-lora/
http://www.radio-electronics.com/info/wireless/lora/lorawan-network-architecture.php

Electromagnetic Spectrum



Source: Raj Jain http://www.cse.wustl.edu/~jain/cse473-19/

LoRa Modulation

- Designed to achieve low power transmissions over long distances
- Uses a form of **Chirp Spread Spectrum (CSS)**
- Data is encoded using the frequency increase/decrease rate
  - Data rate and link condition determines the frequency bandwidth required
- Multiple parallel transmissions with different data rates on the same frequency
- Power level is determined adaptively based on data rate and link condition.
  - Fast communication is used to save battery.
- Range: 2-5km for urban, up to 15km in sub-urban and up to 45km in rural.

Ref: "LoRA Physical Layer and RF Interface," Radio-Electronics, http://www.radio-electronics.com/info/wireless/lora/rf-interface-physical-layer.php

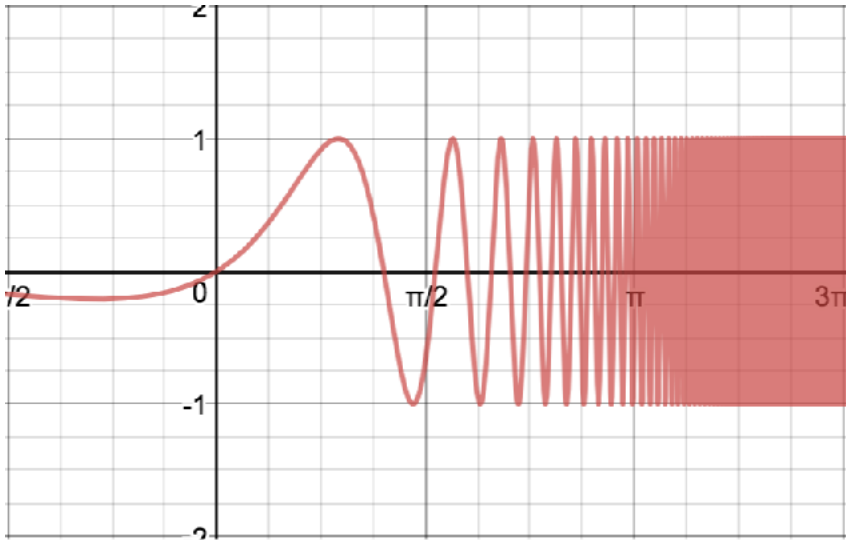
Chirp Spread Spectrum (CSS)

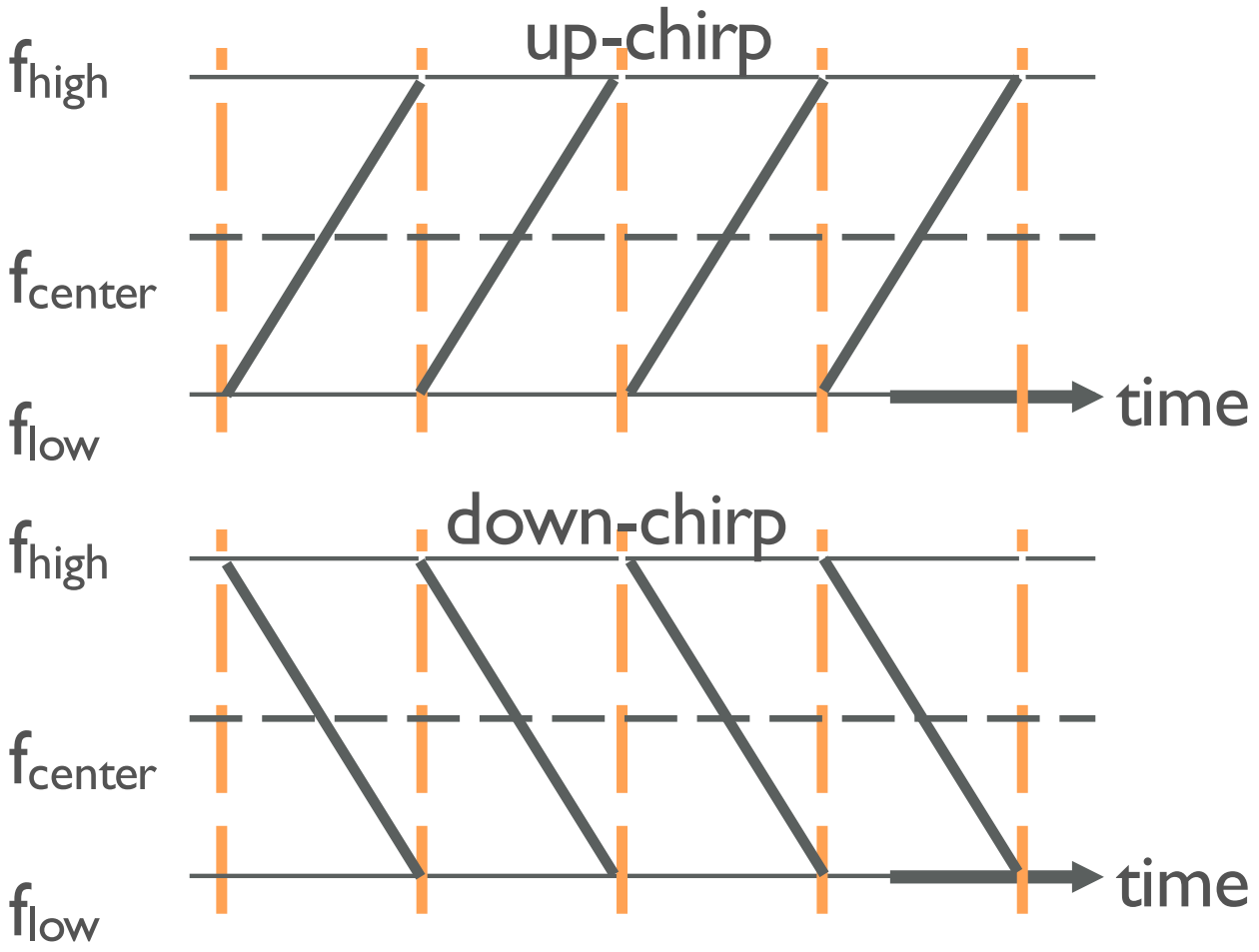
- LoRa is a proprietary spread spectrum modulation scheme based on **Chirp Spread Spectrum modulation (CSS).**
- Chirp Spread Spectrum is a spread spectrum technique that uses wideband linear frequency modulated chirp pulses to encode information.
- Spread spectrum techniques are methods by which a signal is deliberately spread in the frequency domain → **power is spread over the entire spectrum**
  - For example, a signal is transmitted in short bursts, "hopping" between frequencies in a pseudo-random sequence.
- A chirp, often called a sweep signal, is a tone in which the **frequency increases (up-chirp)** or **decreases (down-chirp)** with time.

https://www.youtube.com/watch?v=jHWepP1ZWTk&t

CHIRPS

Example of an up-chirp where the frequency increases in time.



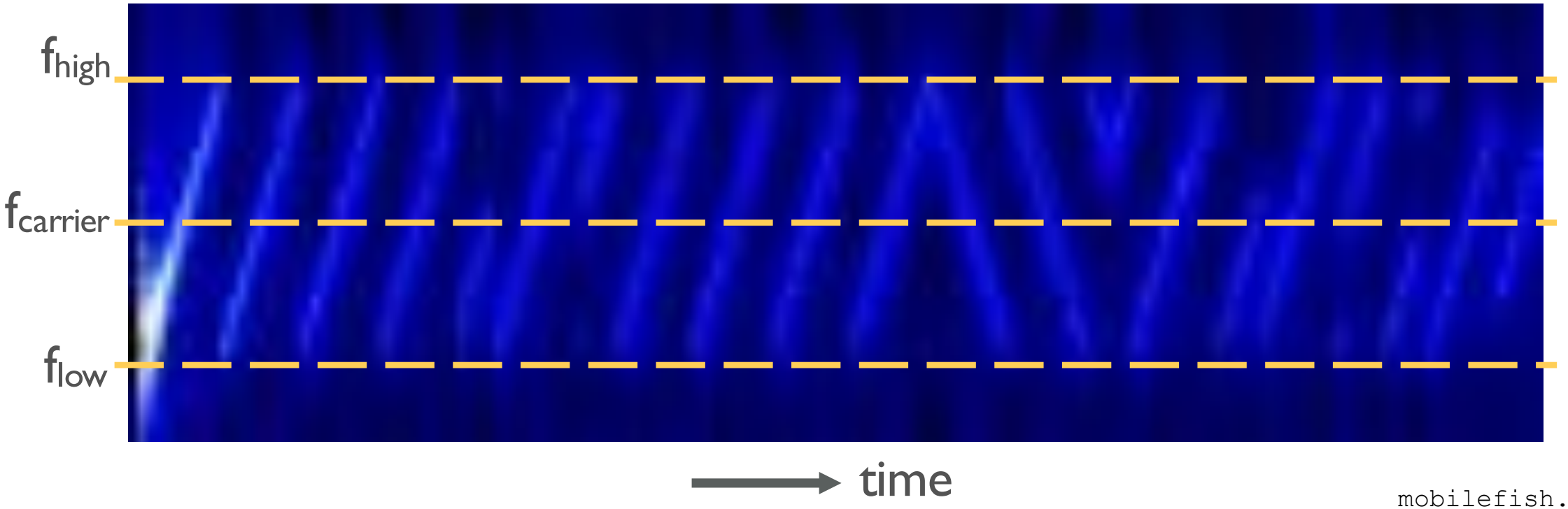


https://www.youtube.com/watch?v=dxYY097QNs0&t

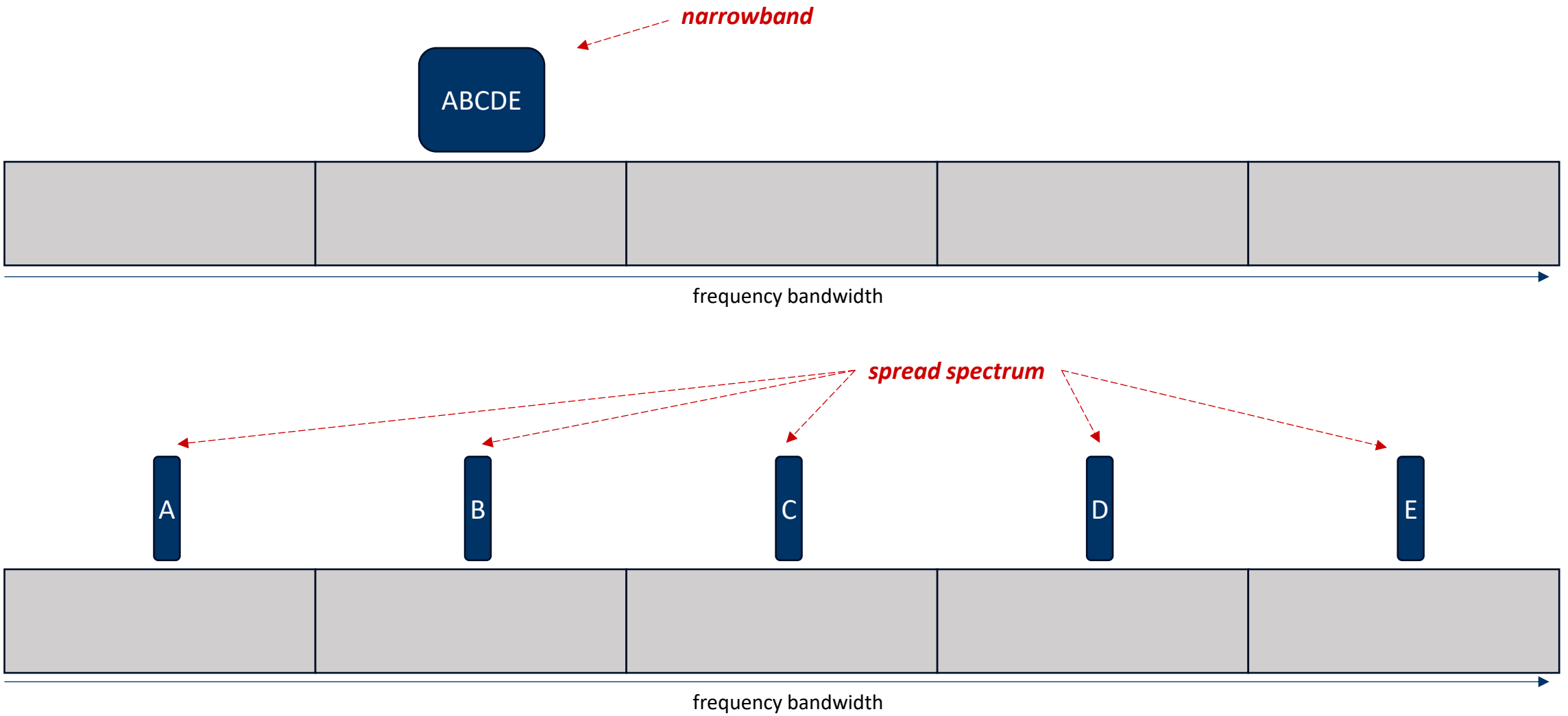
LoRa Modulated Signal

- These chirp signals are used as carrier signals where a message is encoded on.
- Here is an actual LoRa-modulated signal.

Message encoded on the chirp signals



“Spreading Code”

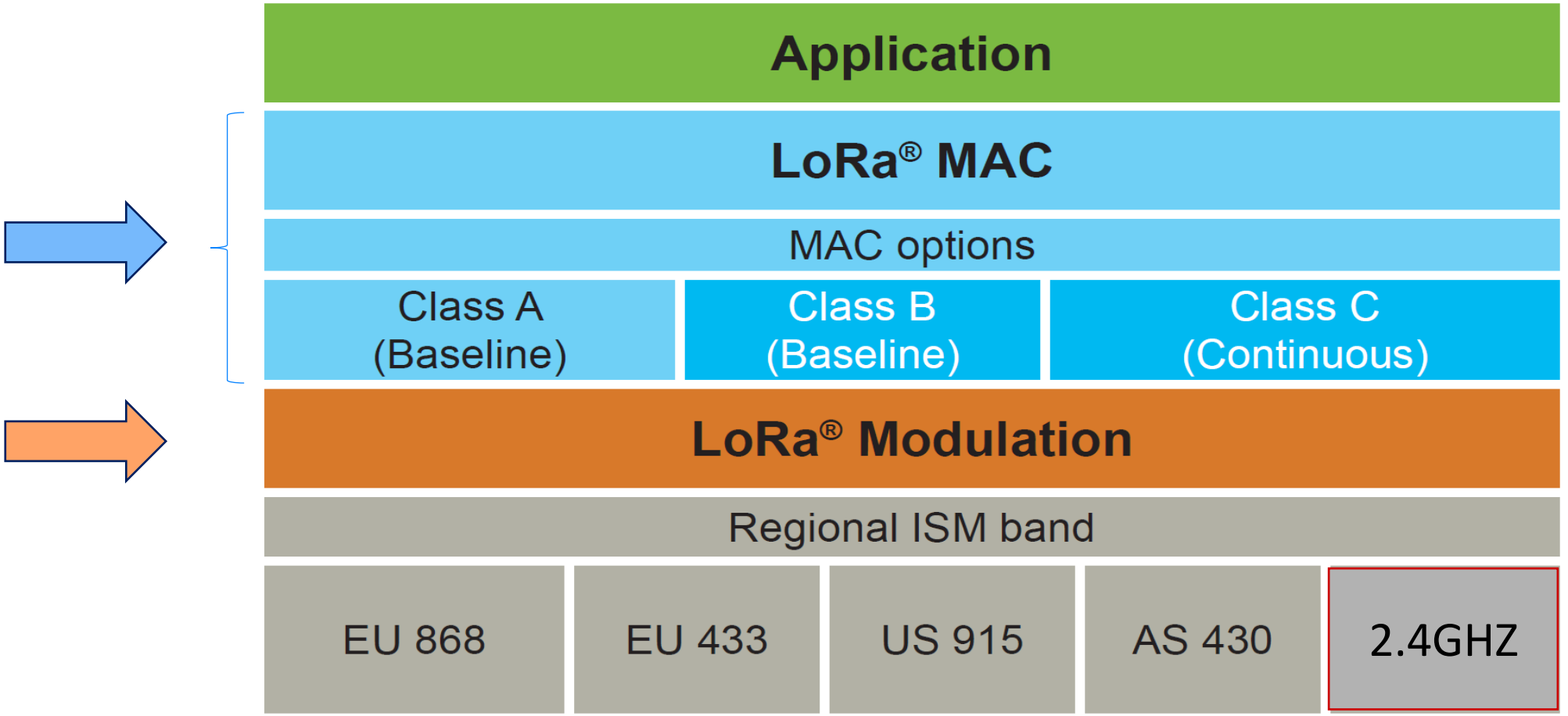


Benefits of CCS

- **Resistance to Interference**: If some frequencies are affected by noise or interference, the signal can still be recovered from other frequencies.
- **Increased Range**: Spreading the signal reduces its power at any single frequency, allowing it to travel further without exceeding regulatory limits.
- **Improved Security**: The spreading code makes it harder for unauthorised individuals to manipulate the data without notice.

What is LoRaWAN?

- LoRaWAN defines the MAC layer protocol and system architecture for the network while the LoRa physical layer enables the long-range communication link.



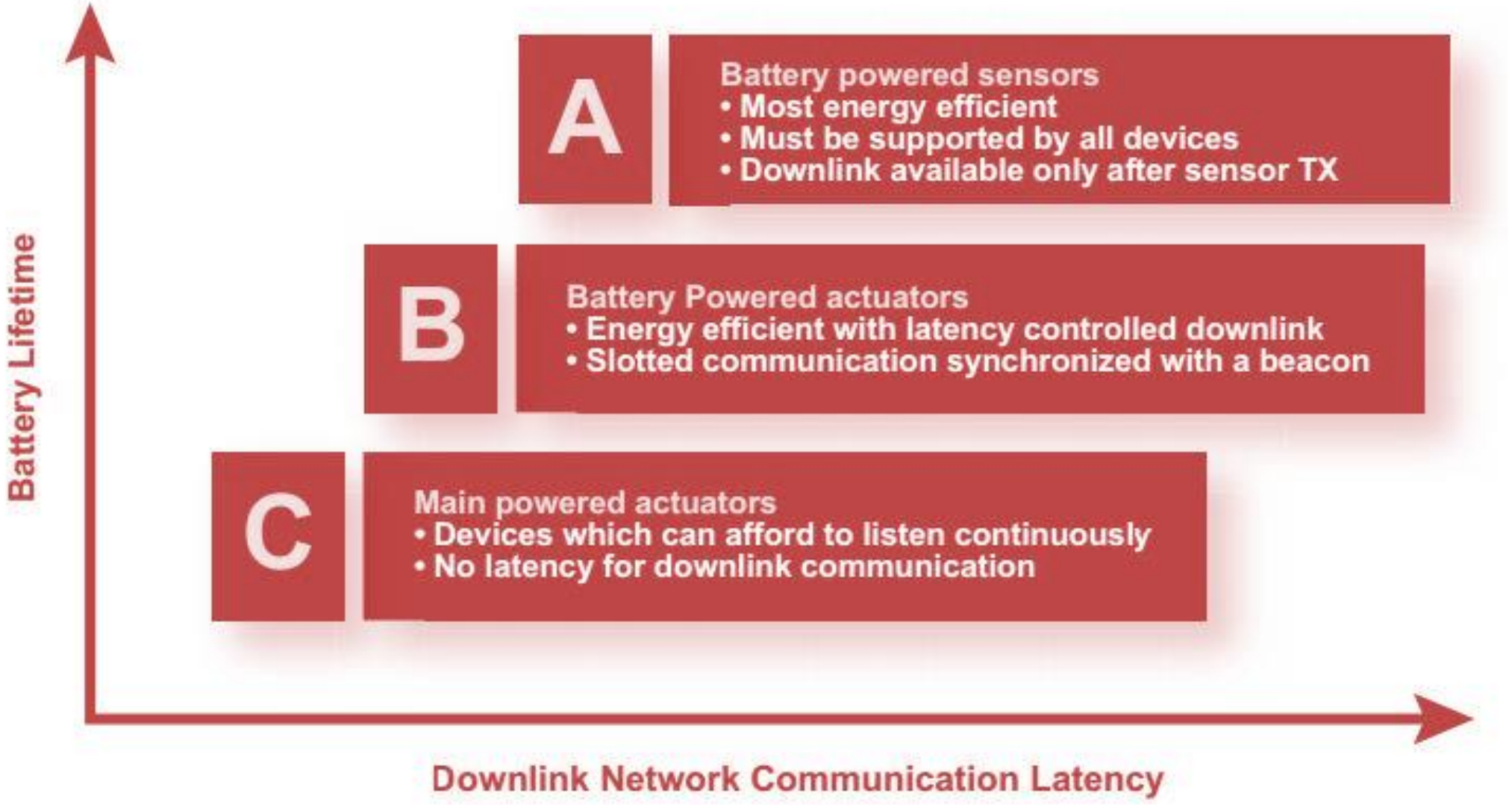
Three Classes of End Devices

power

Classes	Description	Intended Use	Consumption	Use Cases
A (« **a**ll »)	**Listens only <u>after</u> end device <u>transmission</u>**	Modules with **no latency constraint**	• The **most economic** communication class. • **Supported by all modules**. • **Adapted to battery powered modules**	• **Fire Detection** • **Earthquake Early Detection**
B (« **b**eacon »)	The module listens at a **<u>regularly</u> 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 (« **c**ontinuous »)	Module **<u>always</u> 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**

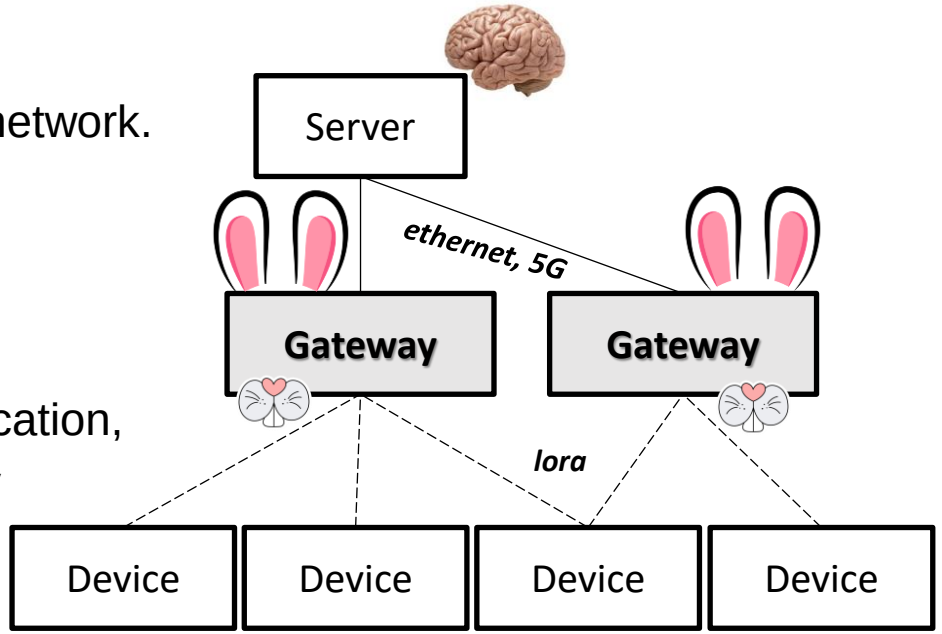
latency

Three Classes of End Devices



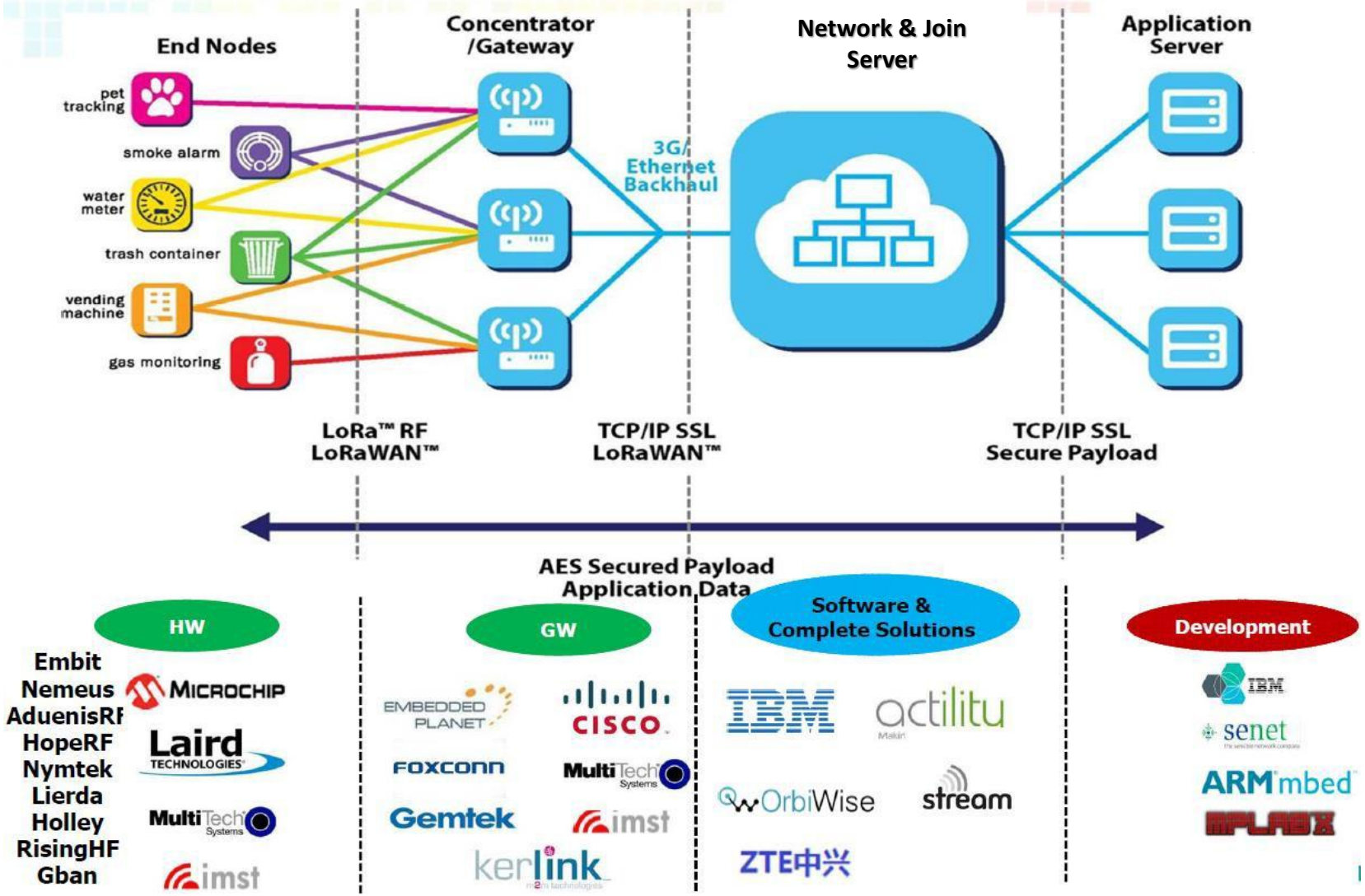
LoRaWAN - MAC Function over LoRa PHY

- **Role**: Acts as the traffic controller on top of the LoRa radio system.
- **Centralized Control**: A central server manages the entire LoRaWAN network.
- Key Functions:
  - **Device Assignment**: The server gives each device a unique frequency, spreading code, and initial data rate
  - **Optimized Communication**: The server prevents message duplication, schedules acknowledgments, and adjusts data rates for efficiency
  - **Network Synchronization**: All gateways in the network are synchronized for seamless communication (star topology).



  - **Adaptive Data Rate (ADR)**: The server intelligently determines the best data rate for each device based on its distance and communication needs. This helps to conserve energy and improve network performance.
  - **Robust Security**: LoRaWAN incorporates multiple security layers, including unique keys for devices, networks, and applications (EUI128 Device Key, EUI64 Network Key, EUI64 Application Key), along with encryption and authentication mechanisms to ensure data confidentiality and integrity.

Strong Ecosystem Enables Customized Deployment



LoRaWAN - Adaptive Data Rate (ADR)

What is it?

- ADR is a LoRaWAN feature that automatically adjusts the data rate of a device based on its network conditions and communication needs.
- It's like having a smart transmission system that optimizes the data rate for each device.

How it works?

- The LoRaWAN **server** monitors the signal quality of each device.
- It considers factors like **signal** strength, **distance** to the gateway, and **interference** levels.
- Based on these factors, the server sends commands to the device to **adjust its data rate**.

LoRaWAN - Adaptive Data Rate (ADR)

Benefits

- **Improved Network Capacity**: ADR helps to *increase the overall network capacity* by allowing more devices to share the available bandwidth efficiently.
- **Reduced Power Consumption**: By using the lowest data rate necessary for reliable communication, ADR helps to *extend the battery* life of devices.
- **Optimized Data Transmission**: ADR ensures that data is transmitted at the optimal speed for the given conditions, *minimizing transmission time and energy use*.

ADR in Action!

- Imagine a LoRaWAN sensor monitoring a remote water tank.
- When the sensor is close to the gateway, it can use a higher data rate to send frequent updates.
- As the sensor moves further away or encounters interference, ADR automatically lowers the data rate to maintain reliable communication while conserving energy..

Comparing LPWAN Technologies

SINGAPORE INSTITUTE OF TECHNOLOGY

Sigfox

Feature	LoRaWAN	Narrow-Band	LTE Cat-1 2016 (Rel12)	LTE Cat-M 2018 (Rel13)	NB-LTE 2019(Rel13+)
Modulation	SS Chirp	UNB / GFSK/BPSK	OFDMA	OFDMA	OFDMA
Rx bandwidth	500 - 125 KHz	100 Hz	20 MHz	20 - 1.4 MHz	200 KHz
Data Rate	290bps - 50Kbps	100 bit/sec 12 / 8 bytes Max	10 Mbit/sec	200kbps – 1Mbps	~20K bit/sec
Max. # Msgs/day	Unlimited	UL: 140 msgs/day	Unlimited	Unlimited	Unlimited
Max Output Power	20 dBm	20 dBm	23 - 46 dBm	23/30 dBm	20 dBm
Link Budget	154 dB	151 dB	130 dB+	146 dB	150 dB
Batery lifetime - 2000mAh	105 months	90 months		18 months	
Power Efficiency	Very High	Very High	Low	Medium	Med high
Interference immunity	Very high	Low	Medium	Medium	Low
Coexistence	Yes	No	Yes	Yes	No
Security	Yes	No	Yes	Yes	Yes
Mobility / localization	Yes	Limited mobility, No loc	Mobility	Mobility	Limited Mobility No Loc

LoRa & LoRaWAN: A Summary

- **LoRaWAN** is a standardized MAC layer protocol built on top of the LoRa physical layer, which uses a variation of chirp spread spectrum modulation.
- **LoRa**'s Chirp Spread Spectrum (CSS) makes it less sensitive to noise and allows multiple devices to send data simultaneously on the same frequency.
- **LoRaWAN** networks use a centralized server for efficient management and control.
- **LoRa** devices broadcast messages to all gateways, and the gateway with the strongest signal typically replies.
- While **LoRaWAN** offers long range and low power consumption, it can have limitations in downlink traffic performance.

References and Additional Material

- https://www.youtube.com/watch?v=jHWepP1ZWTk&t
- https://www.youtube.com/watch?v=0FCrN-u-Vpw&ab_channel=Mobilefish.com
- https://www.youtube.com/watch?v=dxYY097QNs0&ab_channel=Mobilefish.com
- https://www.youtube.com/watch?v=lg0eZWZFKiE&ab_channel=Mobilefish.com
- https://lora-developers.semtech.com/library/tech-papers-and-guides/lora-and-lorawan/
- https://www3.cs.stonybrook.edu/~mdasari/courses/cse570/
- https://www.youtube.com/watch?v=T3dGLqZrjIQ&ab_channel=TheThingsNetwork → Watch this for a very nice tutorial on Wireless Communication and its challenges
- https://youtu.be/NoquBA7IMNc → Nice tutorial on LoRa by Matt Knight