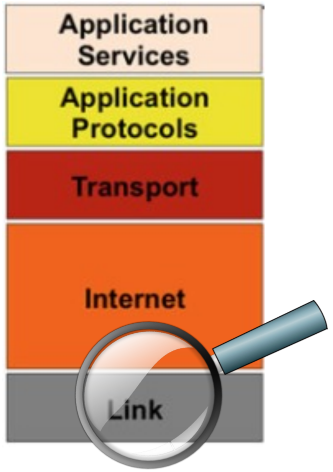
UCI University of California, Irvine

# Ch. 11 - IoT Link Layer

## Sec 3 – Long Range

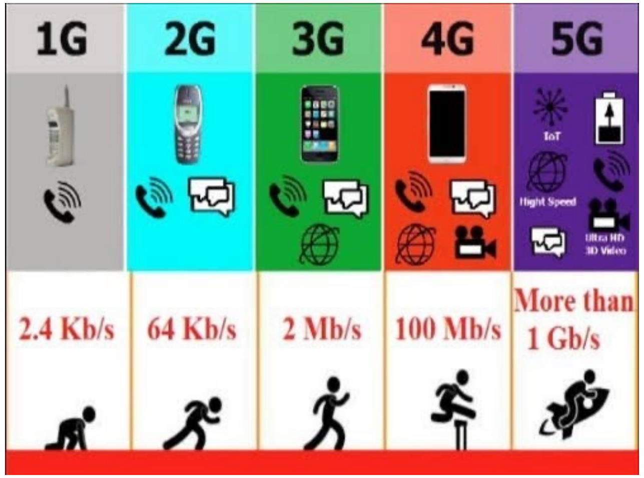
COMPSCI 147

Internet-of-Things; Software and Systems



# POPULAR PROTOCOLS IN THE IOT LINK LAYER

| Local Area Network<br>Short Range<br>Communication | Low Power Wide Area<br>(LPWAN)<br>Internet of Things | Cellular Network<br>Traditional<br>M2M |
|---|---|---|
| 40% | 45% | 15% |
| Well established standards<br>In building | Low power consumption<br>Low cost<br>Positioning | Existing coverage<br>High data rate |
| Battery Live<br>Provisioning<br>Network cost & dependencies | High data rate<br>Emerging standards | Autonomy<br>Total cost of ownership |
| Bluetooth 4.0 WiFi | LoRa | GSM 3G+ / H+ 4G 5G |

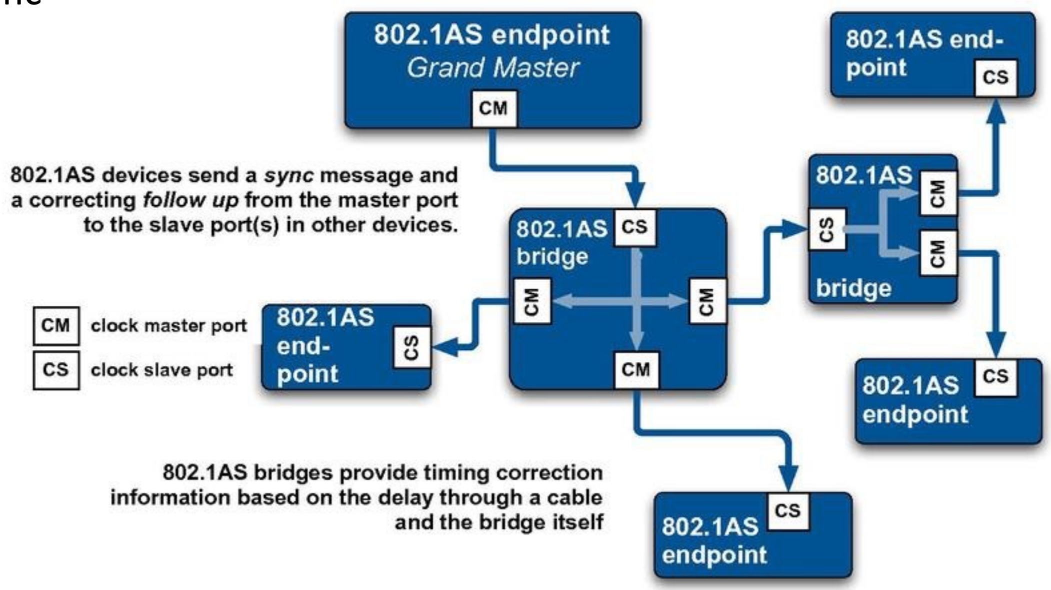


# IEEE 802.1 - TIME SENSITIVE NETWORKING (TSN)

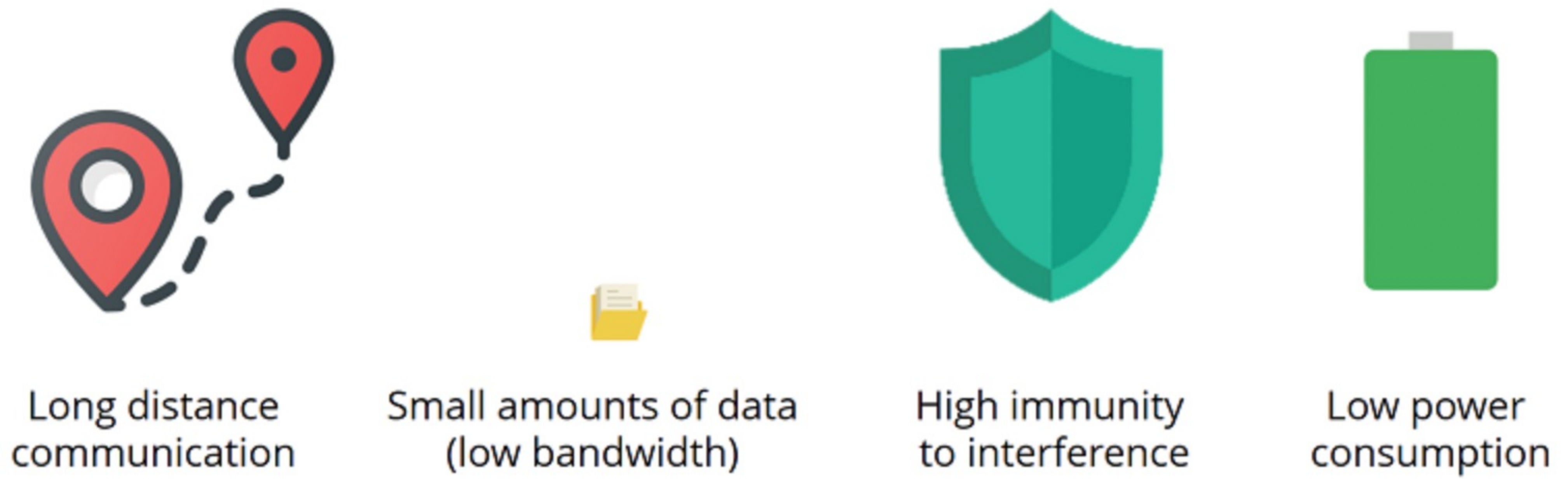
- For real-time control applications
  - Industrial automation and automotive networks
- Although TSN are considered short range networks, they can also be relatively large (one to several kilometers)
  - Up to **64 hops** for a **factory** and up to **5 hops** within a **work cell** (e.g., robot)
- Real-time control traffic + long-tailed traffic (e.g., video)
- Precise time synchronization
  - ± 500 ns within a work cell, and ± 100 μs factory wide
- Deterministic delay
  - <5 μs within a work cell
  - <125 μs factory wide
- Requirement for redundant paths

# IEEE 802.1 – TSN STANDARDS

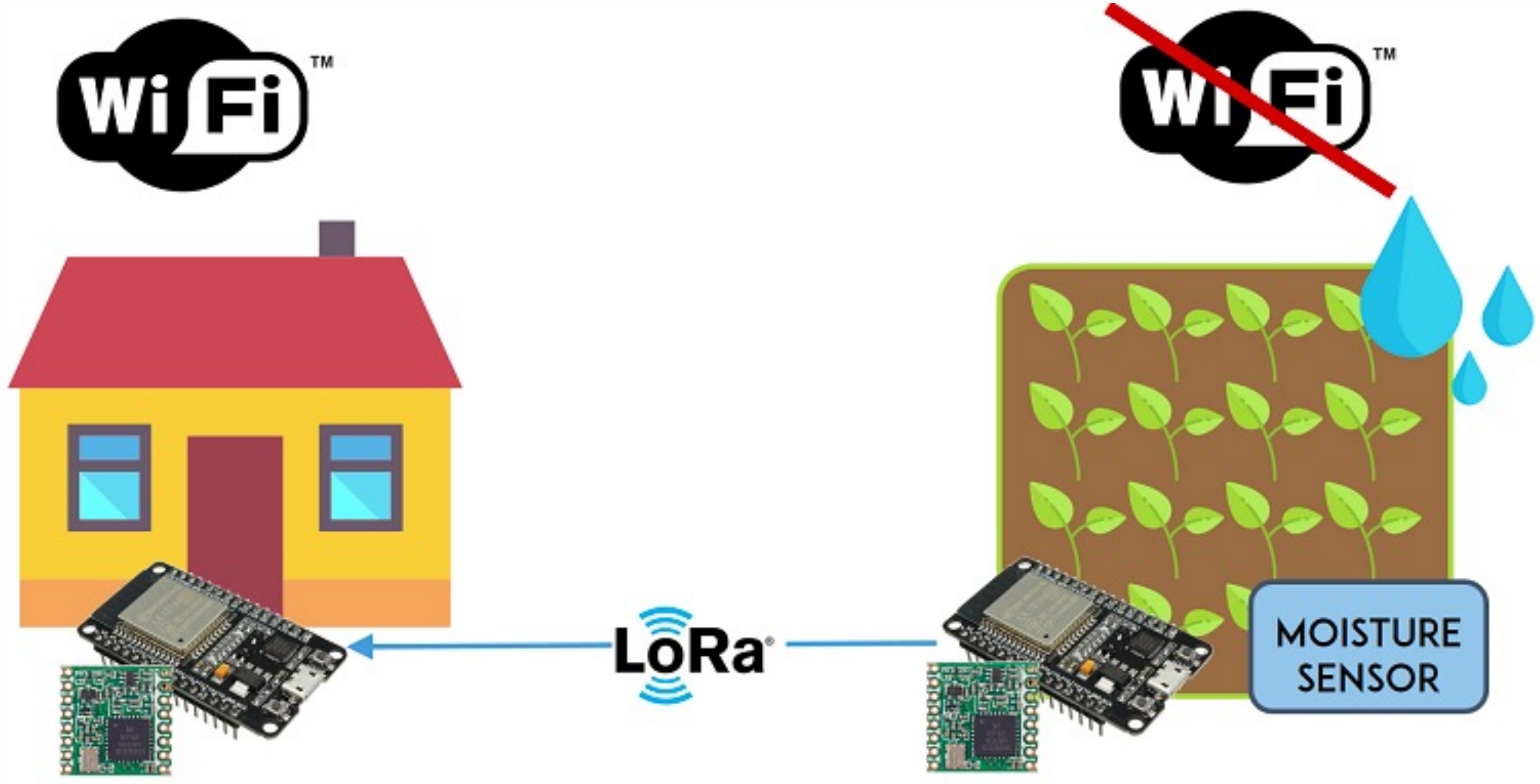
- **IEEE 802 family** of standards, which includes the popular **Ethernet**
  - Including L(ocal)A(area)N(etwork), M(etropolitan)AN and W(ide)AN protocols
  - **IEEE 802.1AS** defines a profile for the Precision Timing Protocol (**PTP**)
    - Provides time synchronization of end-systems with accuracy better than ± 1 µs
  - **IEEE 802.1Qav** defines **forwarding** and **queuing rules** for time sensitive traffic in Ethernet.
    - Class-A traffic: maximum latency guarantees of 2 ms
    - Class-B traffic: maximum latency guarantees of 50 ms
    - Other traffics: Best Effort (BE)
  - **IEEE 802.1Qat** defines a **signaling protocol** for **dynamic registration** and **resource reservation** of **new streams**
    - **Per-hop delays** in the order of 130 µs on 1 Gbps Ethernet links
  - Other emerging standards: **IEEE 802.1Qca, IEEE 802.1Qbv, IEEE 802.1CB**



# LPWAN - LORAWAN



# LPWAN - LORAWAN



# LPWAN - LORAWAN

- **Long Range** Wide Area Network
- Originally developed by Cyclos in France
- Acquired by Semtech corporation, which formed **LoRa** Alliance.
- Now 160+ members
- V1.0 spec dated January 2015. Released to public July 2015.
- Rapid Adoption: Products already available in the market (e.g Amazon)

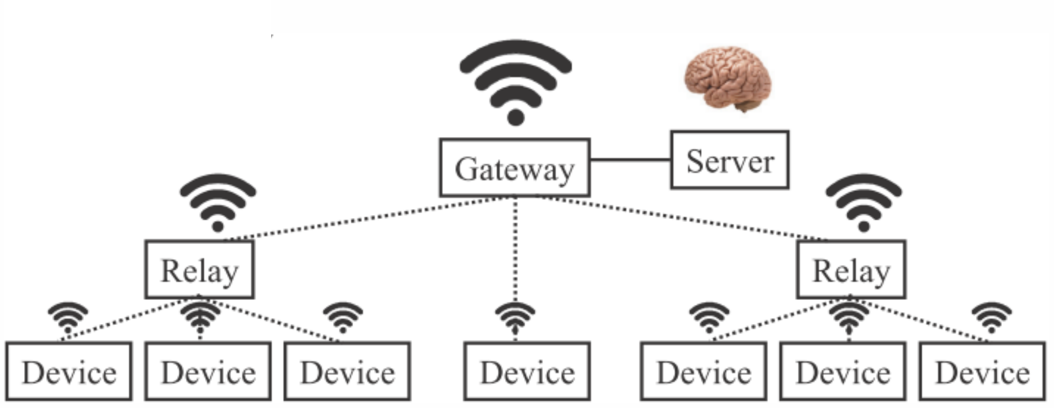
Transceiver

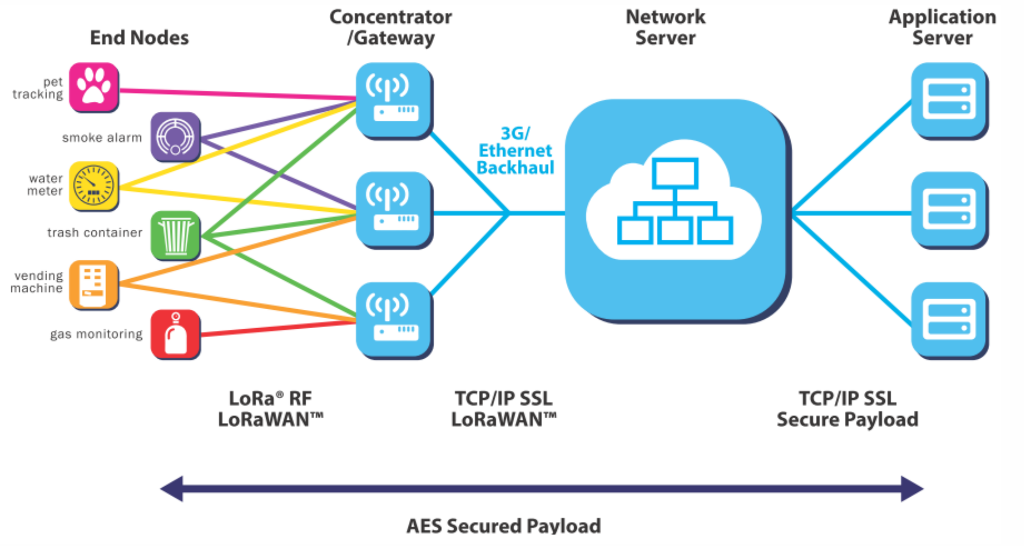
Arduino
Radio Shield


Connectivity Kit for
Arduino, Waspmote,
Raspberry Pi

# LPWAN - LORAWAN - KEY FEATURES

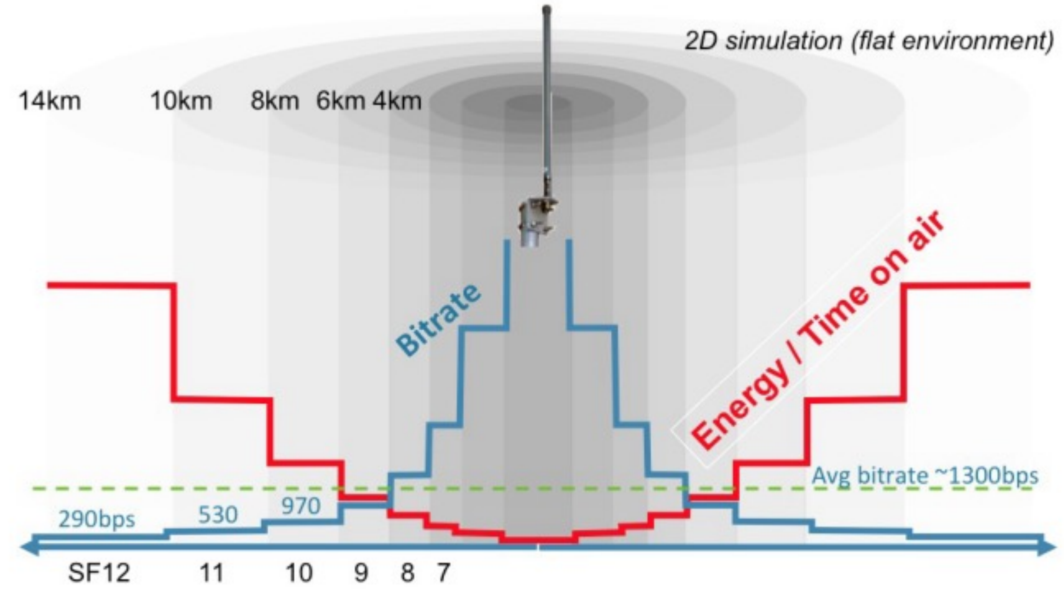
- **Bidirectional** communication
  - Allows firmware/software updates of end devices
- **Low Rate**: 0.3 kbps to 22 kbps in Europe, 0.9 kbps in US
- **Star of Stars Topology**: Gateways are transparent bridges. Server is the brain. Simple devices. Relays are optional.
- **Secure**: EUI128 Device Key, EUI64 Network Key, EUI64 Application Key



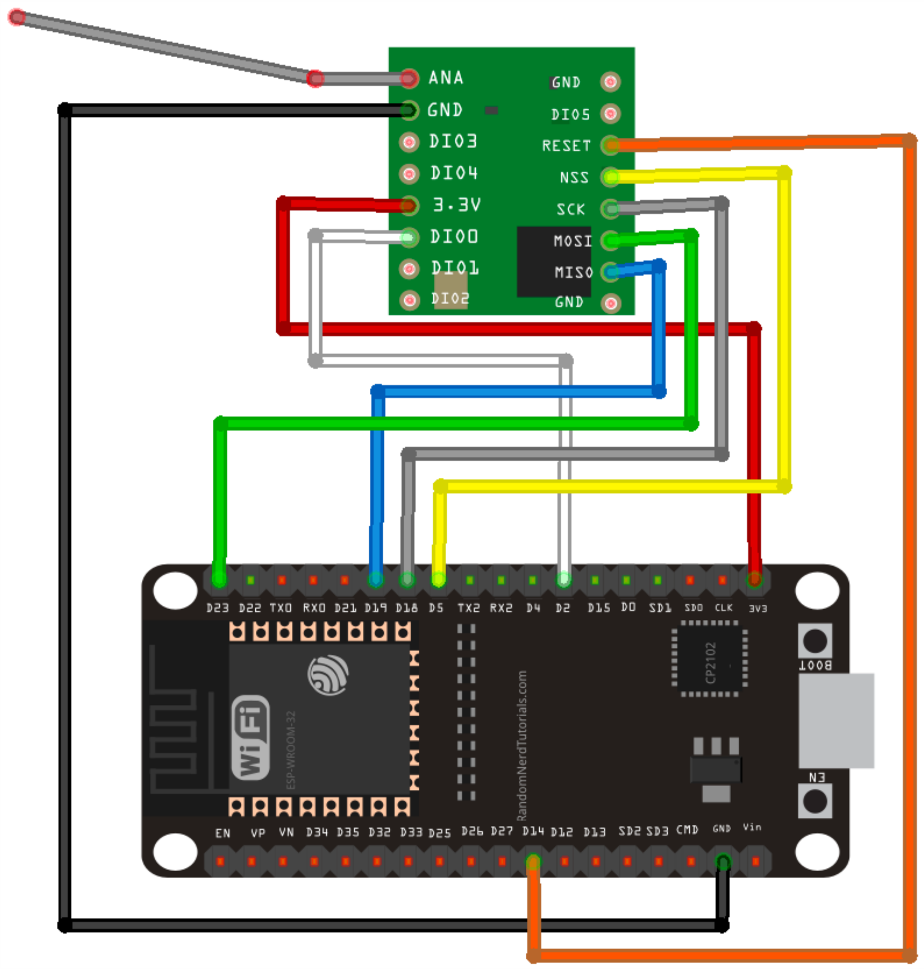



# LPWAN – LORAWAN - LORA - RF

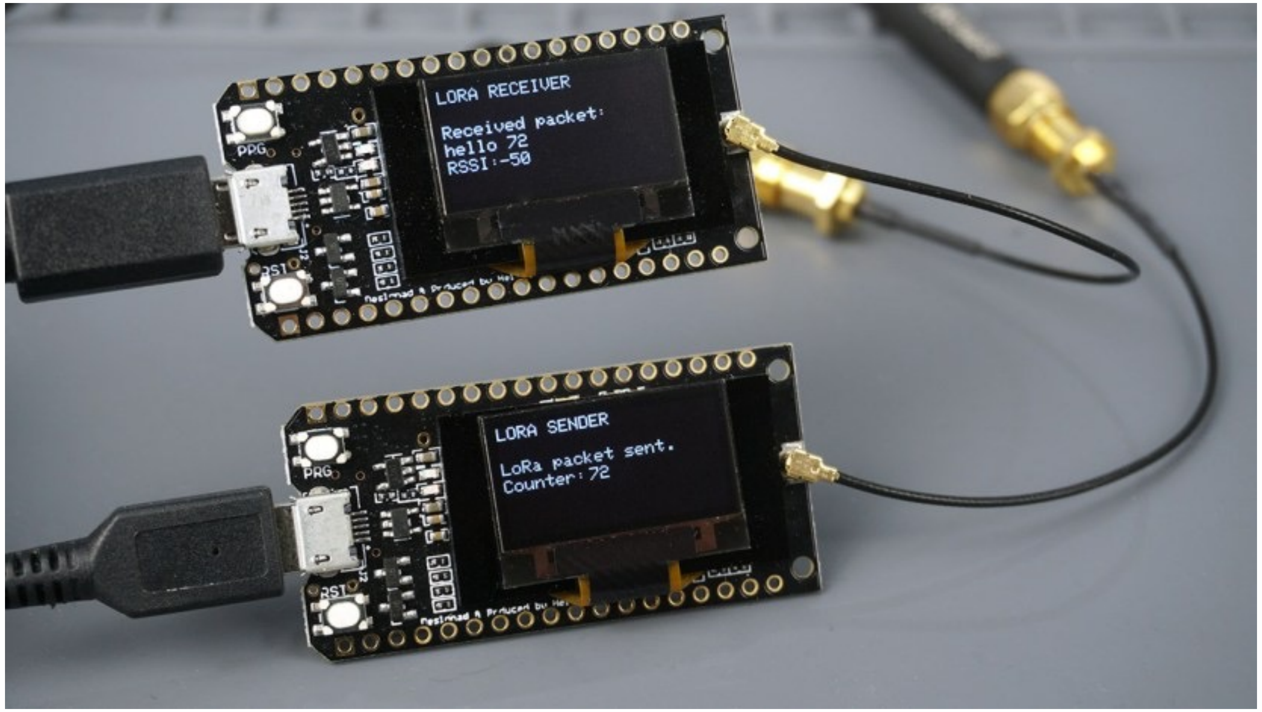
| Characteristics | LoRa RF |
|---|---|
| Modulation | LoRa (spread spectrum) |
| Frequency | Sub-GHz ISM |
| Channel bandwidth | 125-500 KHz |
| Data rate | 300 bps – 50 kbps |
| Gateway sensitivity | -142 dBm/300bps |
| Range | 10+ km, deep indoor coverage |
| Payload size | 11 – 242 bytes (variable) |
| Battery consumption | 10mA RX / 32mA (14dBm) TX -- 10+ year |
| Communication type | Bidirectional unicast, network multicast |
| Interference immunity | Spread-spectrum w/ FEC |
| Scalability | Self scaling network capability through Adaptive Data Rate |
| Mobility | Handover support, geo-location |



# LPWAN – LORAWAN - LORA – HOW TO USE WITH ESP32




Example 1: RFM95 – LoRa Transceiver Module

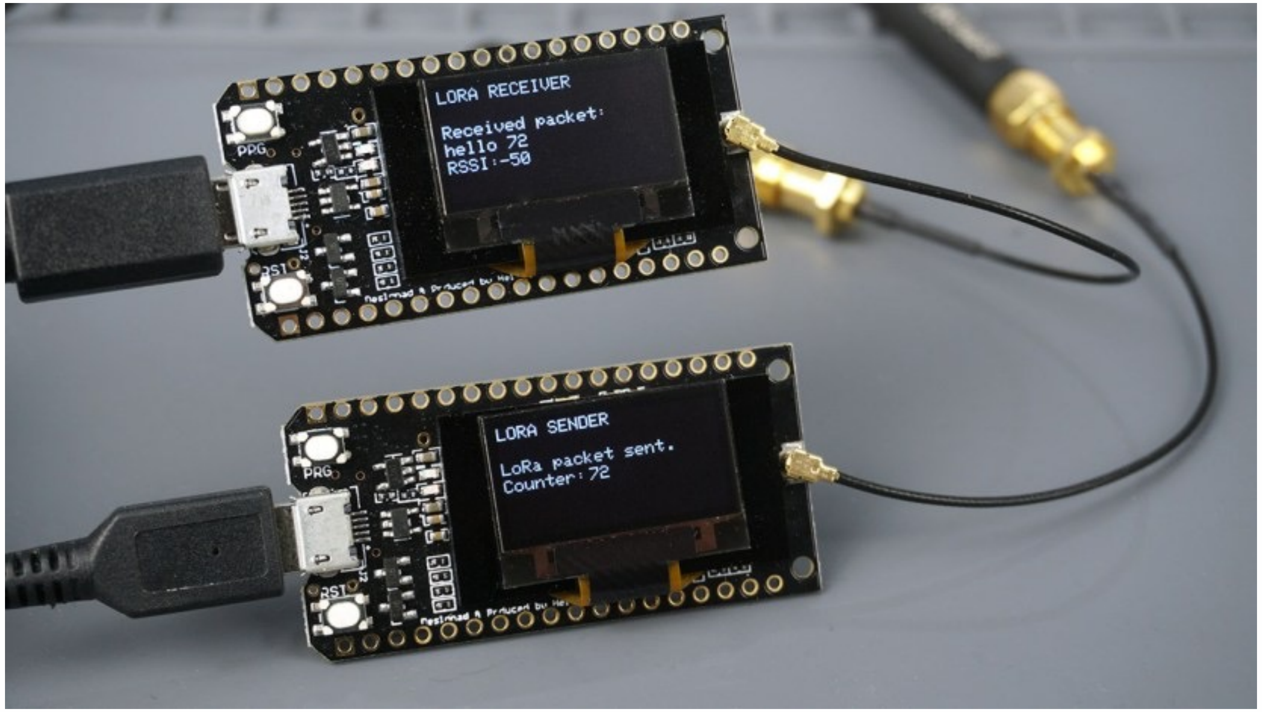



Example 2: TTGO Lora 32 + OLED board

# LPWAN – LORAWAN - LORA – HOW TO USE WITH ESP32

initializing LoRa module and sending a "Hello, world!" message every second.
You can modify the code to receive data as well using LoRa.parsePacket()

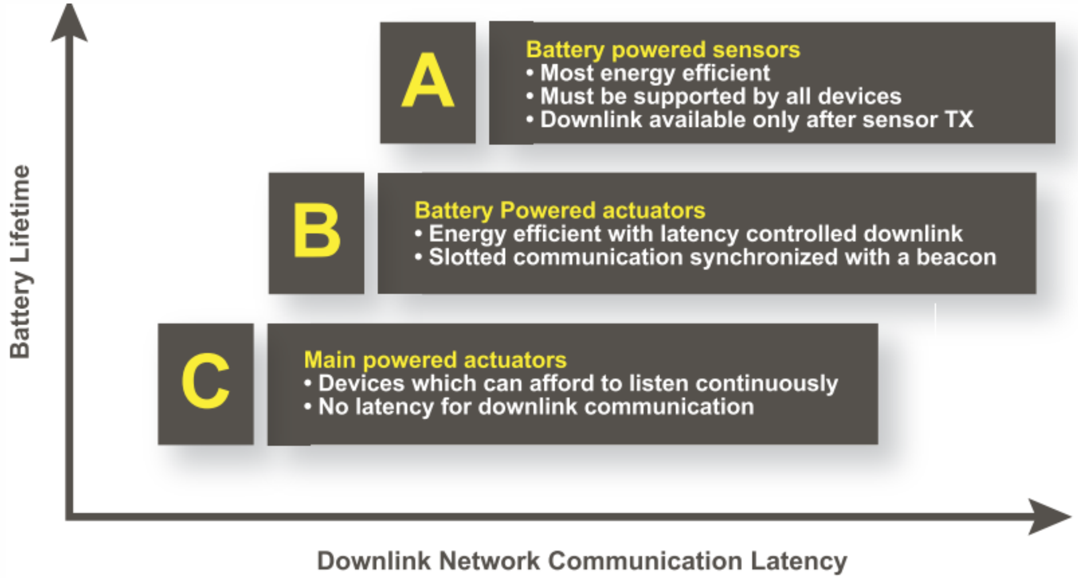
```
#include <SPI.h>
#include <LoRa.h>

#define BAND 433E6

void setup() {
  Serial.begin(9600);
  while (!Serial);

  LoRa.setPins(SS, RST, DIO);
  if (!LoRa.begin(BAND)) {
    Serial.println("LoRa init failed");
    while (1);
  }
  Serial.println("LoRa init OK!");
}

void loop() {
  LoRa.beginPacket();
  LoRa.print("Hello, world!");
  LoRa.endPacket();

  delay(1000);
}
```

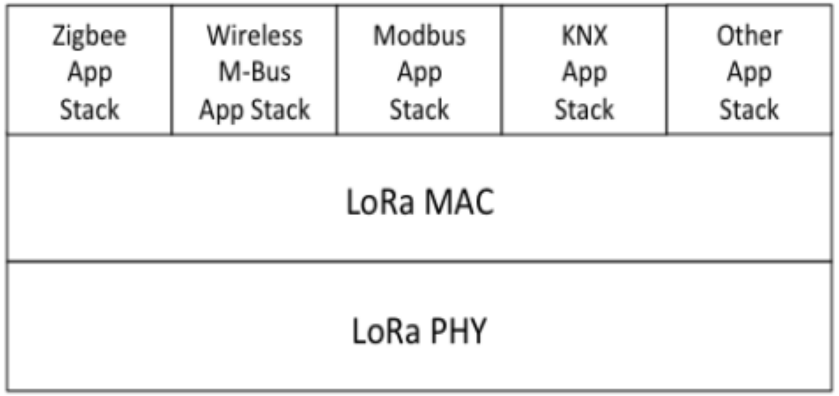


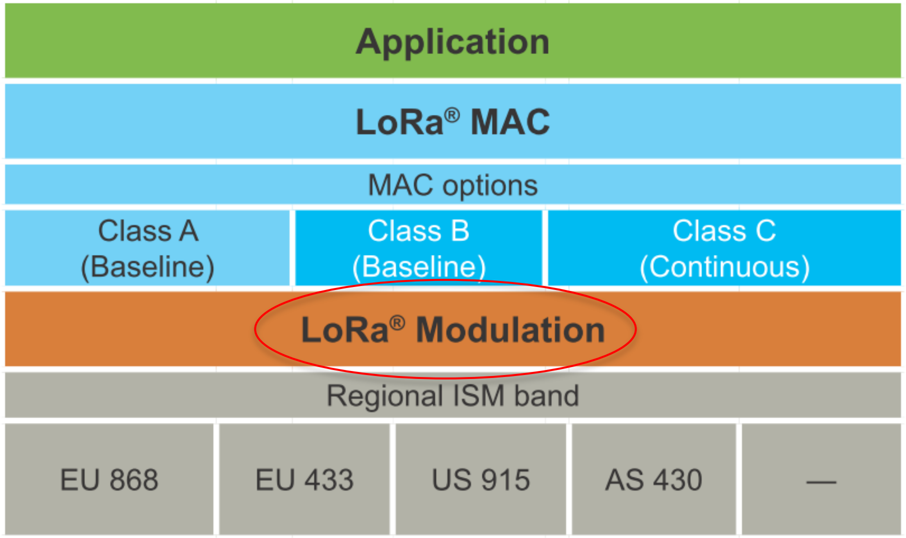

Example 2: TTGO Lora 32 + OLED board

# LPWAN – LORAWAN - LORA - DEVICE CLASSES AND APP STACK

| Class name | Intended usage |
|---|---|
| **A** (« all ») | **Battery powered sensors**, or actuators with no latency constraint.<br>Most energy efficient communication class.<br>Downlink TX can only happen after uplink. |
| **B** (« beacon ») | **Battery powered actuators**<br>Device opens receive window at scheduled slots. |
| **C** (« continuous ») | **Mains powered actuators**<br>Devices which can afford to listen continuously.<br>No latency for downlink communication. |



# LPWAN - COMPARING TECHNOLOGY OPTIONS

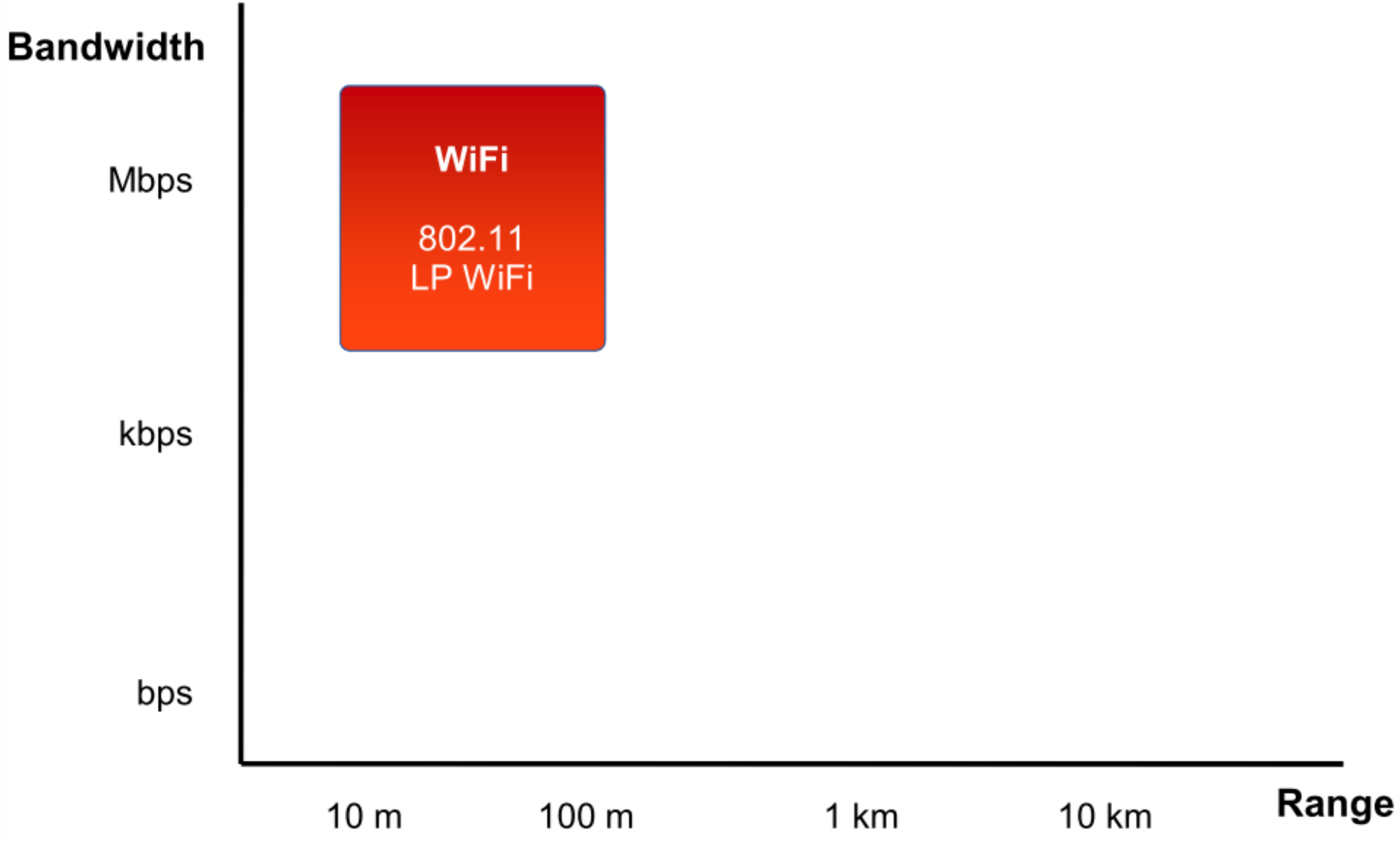
| Feature | LoRaWAN | Narrow-Band | LTE Cat-1<br>2016 (Rel12) | LTE Cat-M<br>2018 (Rel13) | NB-LTE<br>2019(Rel13+) |
|---|---|---|---|---|---|
| Modulation | SS Chirp | UNB / GFSK/BPSK | OFDMA | OFDMA | OFDMA |
| Rx bandwidth | 500 - 125 KHz | 100 Hz | 20 MHz | 20 - 1.4 MHz | 200 KHz |
| Data Rate | 290bps - 50Kbps | 100 bit/sec<br>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 |

# OTHER LPWANS

- SIGFOX, http://www.sigfox.com/
- Weightless-N (Narrowband), http://www.weightless.org/
- Weightless-P (High Performance), http://www.weightless.org/
- NWAVE, http://www.nwave.io/nwave-network/
- OnRamp Wireless, http://www.onrampwireless.com/
- ATANUS, http://www.m2comm-semi.com/our-protocol/#
- Telensa, http://www.telensa.com/unb-wireless/
- M-Bus by Amber Wireless, https://www.amber-wireless.com/en/products/wireless-m-bus.html
- M2M Spectrum, http://m2mspectrum.com

# Summing things up

# M2M TECHNOLOGIES - OVERVIEW



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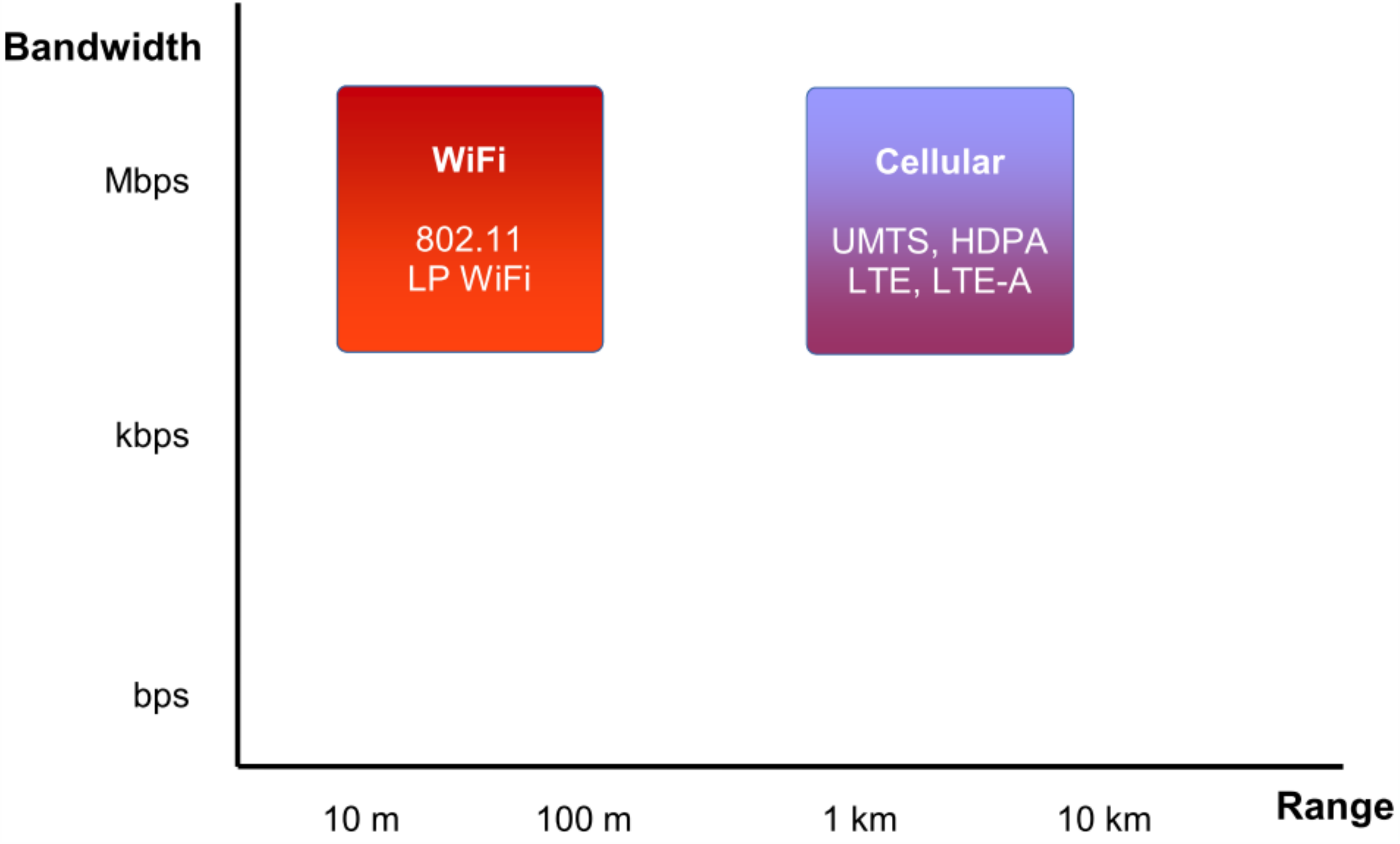

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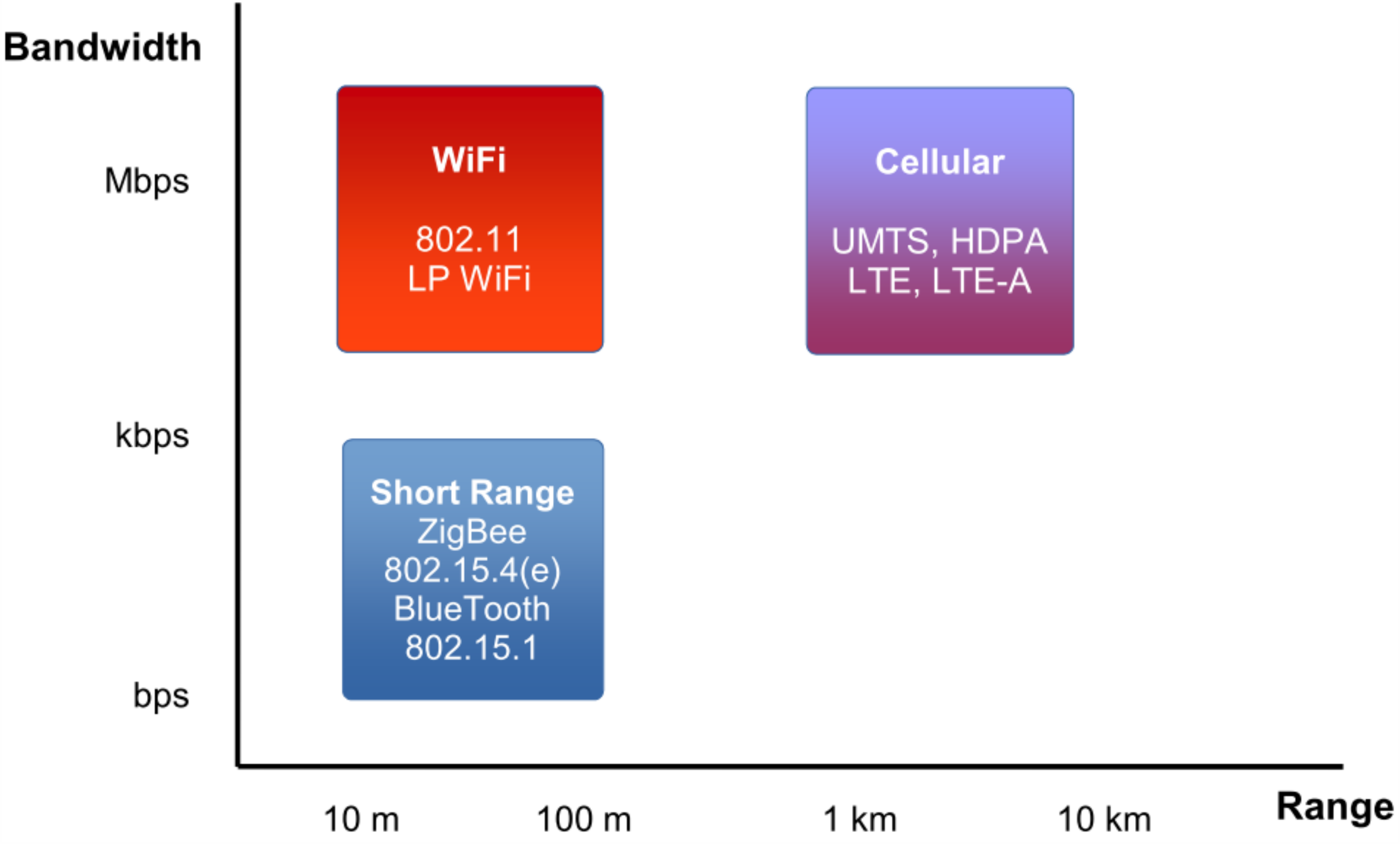

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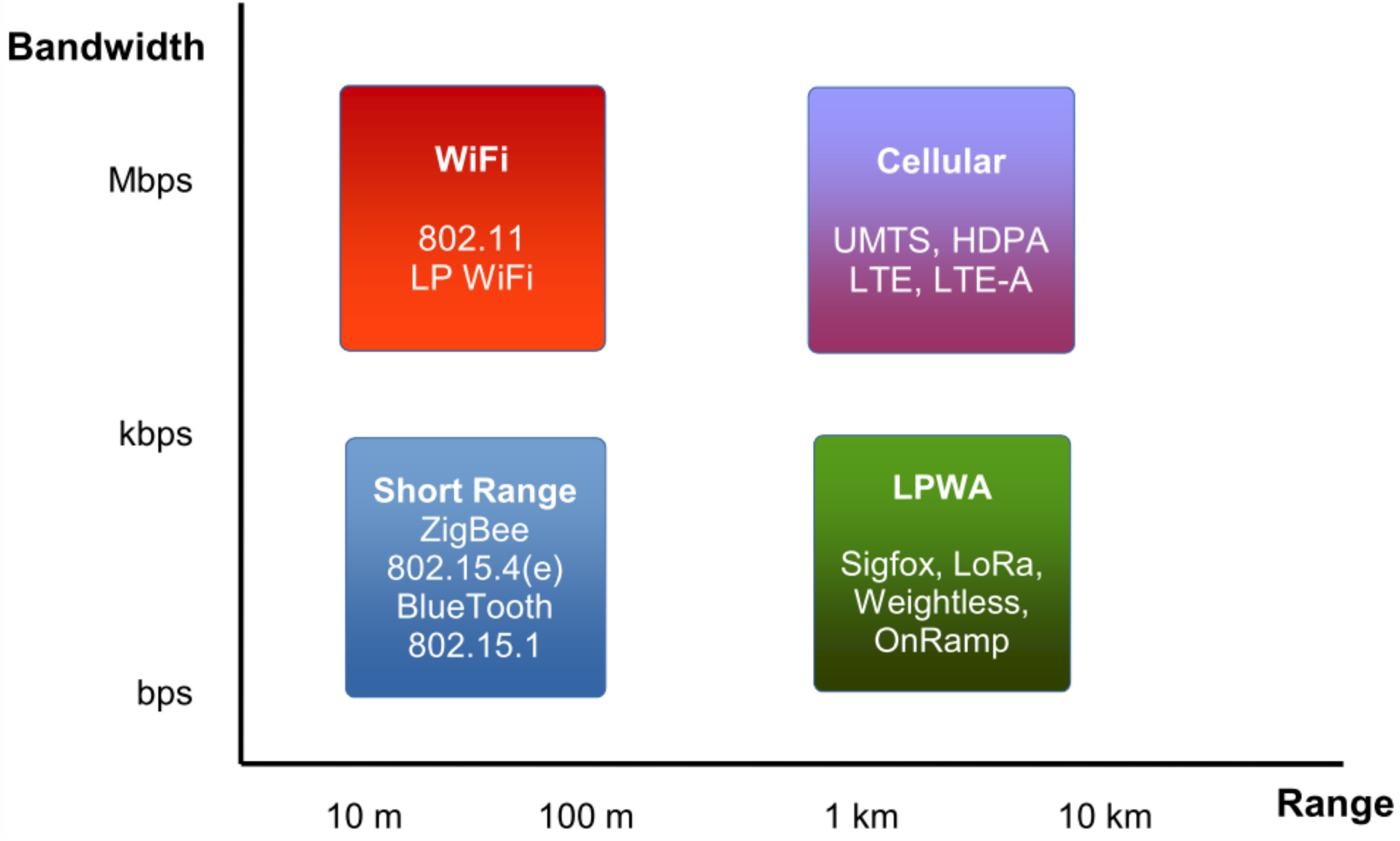

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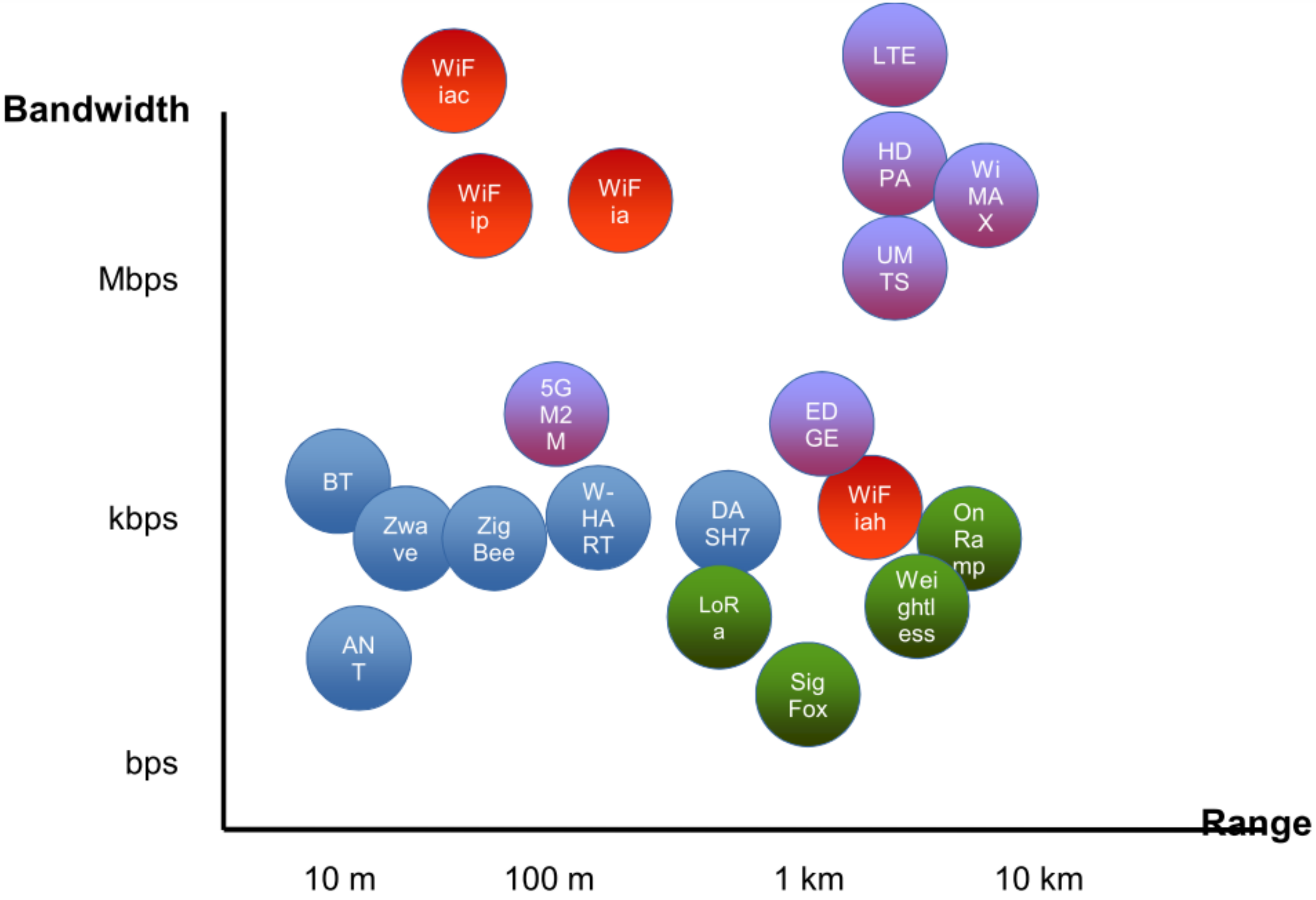

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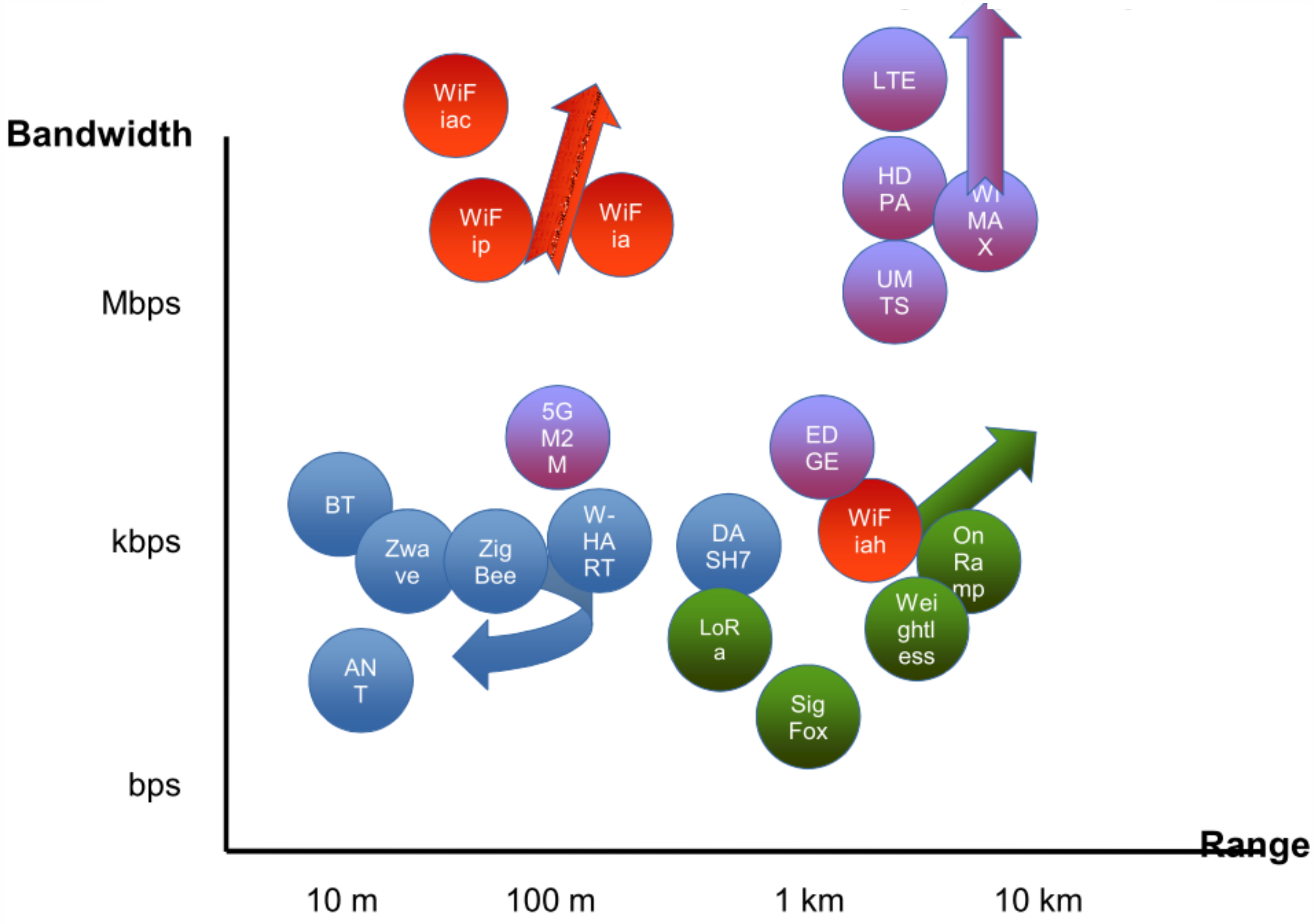
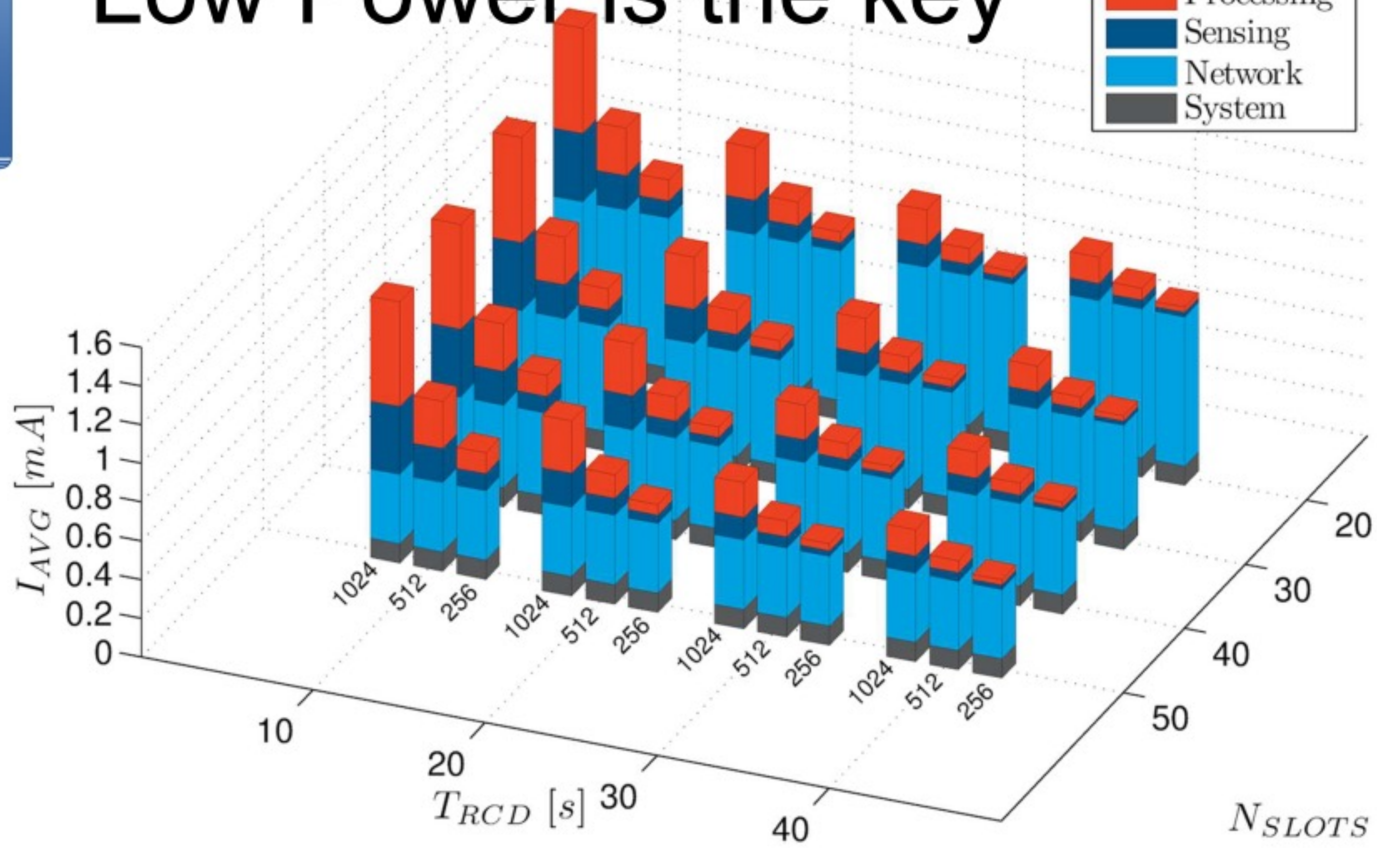


**Short Range**
ZigBee
802.15.4(e)
BlueTooth
802.15.1

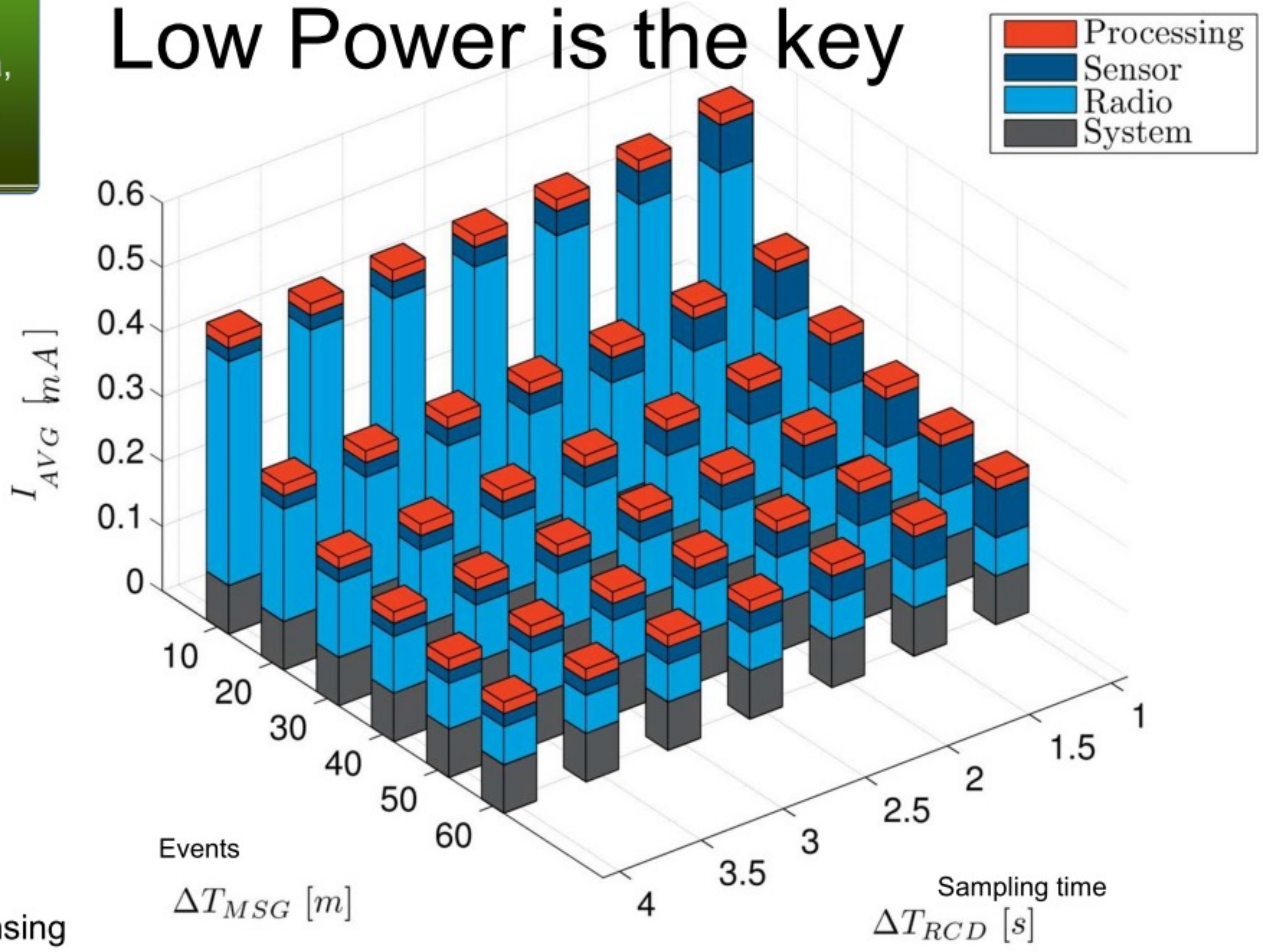
# Low Power is the key



**LPWA**

Sigfox, LoRa, Weightless, OnRamp

# Low Power is the key

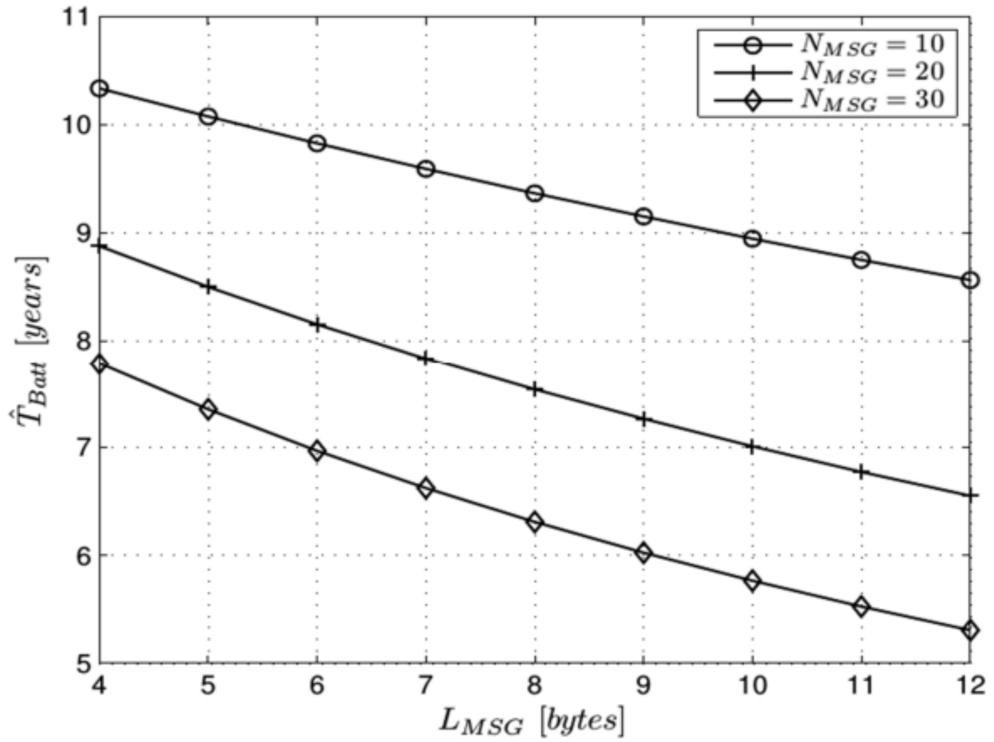


**LPWA**

Sigfox, LoRa, Weightless, OnRamp

# Low Power is the key

- New restrictions
  - Memory
  - CPU process
  - % duty cycling
- Every single bit is valuable




*Mote's battery duration depending the bytes sent*

© "Balancing power consumption in IoT devices by using variable packet size" by M. Domingo-Prieto et al. (2014)

WiFi

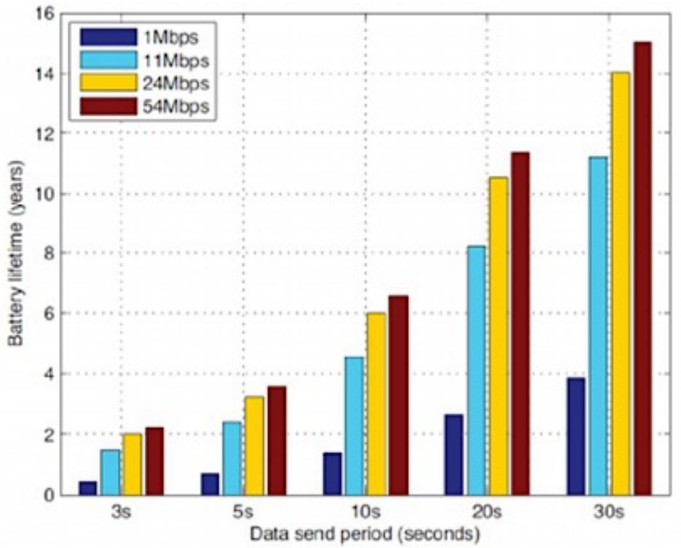
802.11
LP WiFi

# What technology to use?

6LoWPAN vs. Low-power Wi-Fi at 54Mbps

| | 6LoWPAN | | Low-power Wi-Fi | |
|---|---|---|---|---|
| *Packet size* | 8 Bytes | 1024 Bytes | 8 Bytes | 1024 Bytes |
| *Time (ms)* | 6 | 23.61 | 11.3 | 16.58 |
| *Energy (mJ)* | 2.5 | $\boxed{9.17}$ | 0.55 | $\boxed{1.28}$ |

7x




*Wakeup Interval Impact on Energy Consumption*