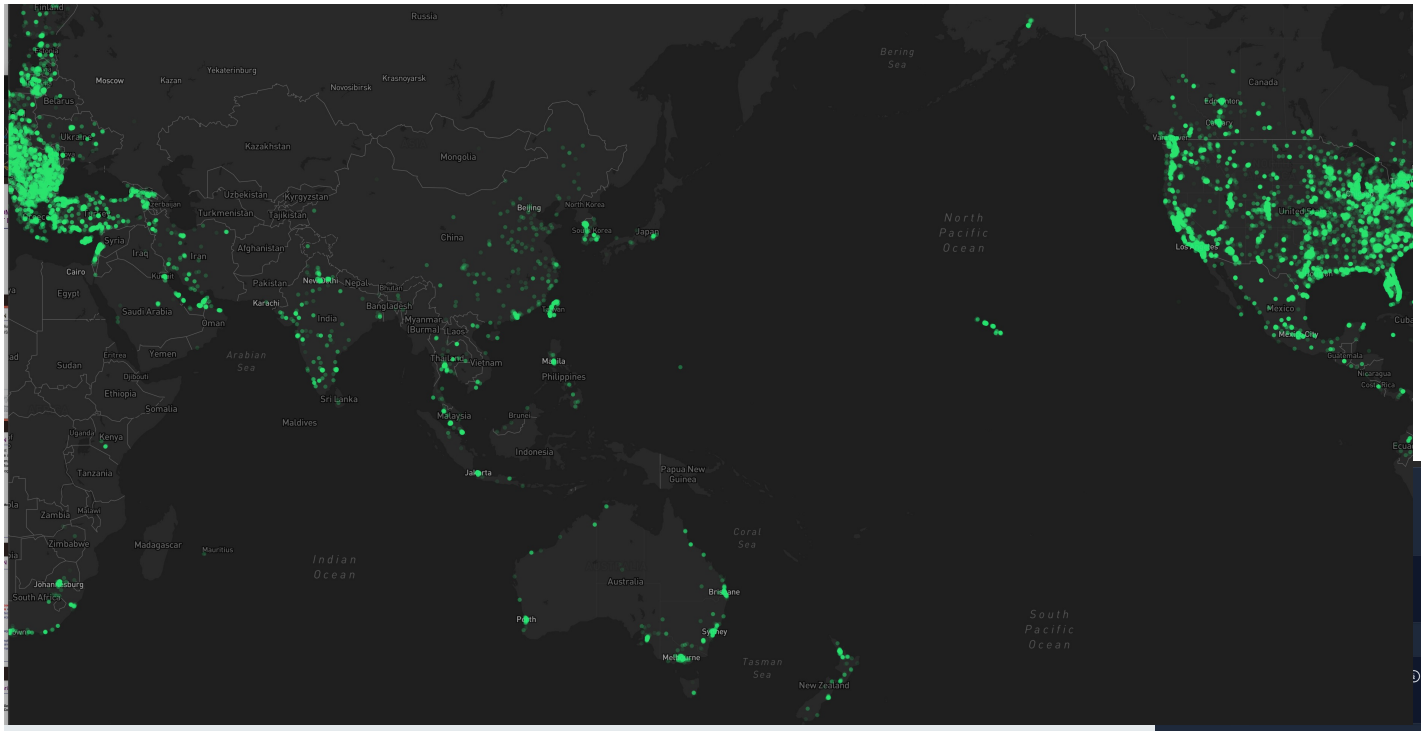
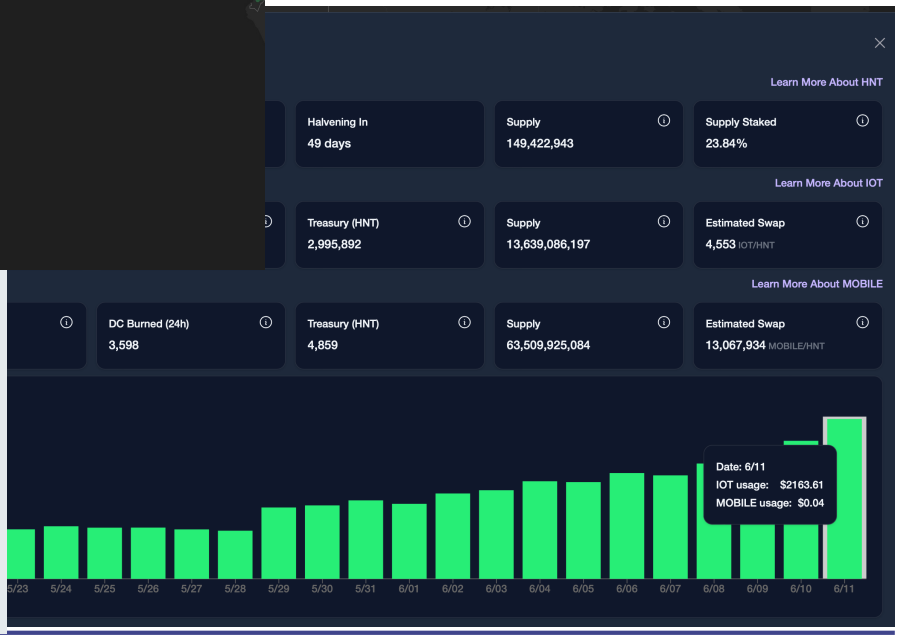
COMP6733
IoT Design Studio

Low Power Wide Area Networks (LPWAN)

LPWAN

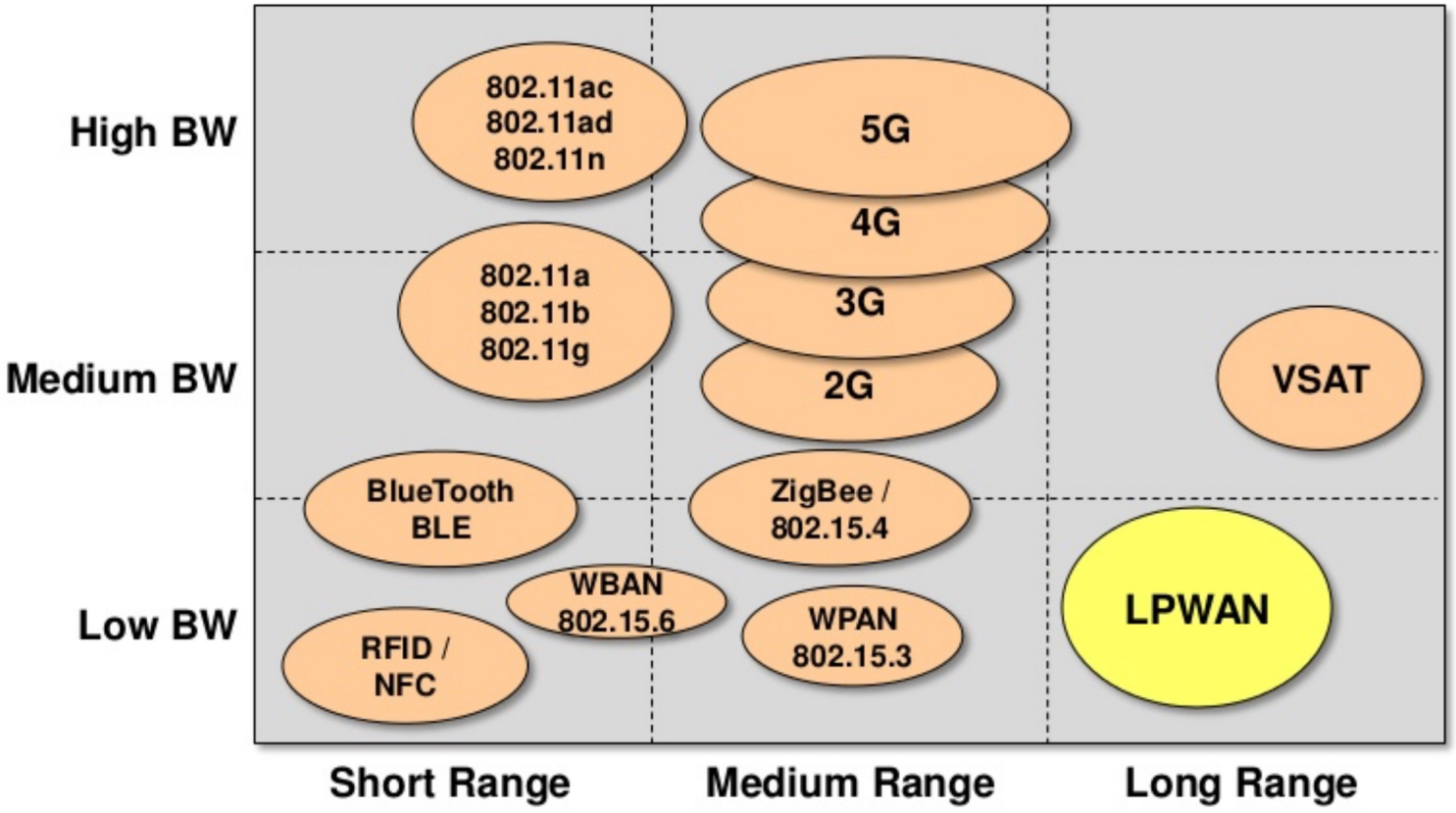
- Helium Networks (LoRaWAN hotspots + Blockchain)
- AWS IoT Core for LoRaWAN



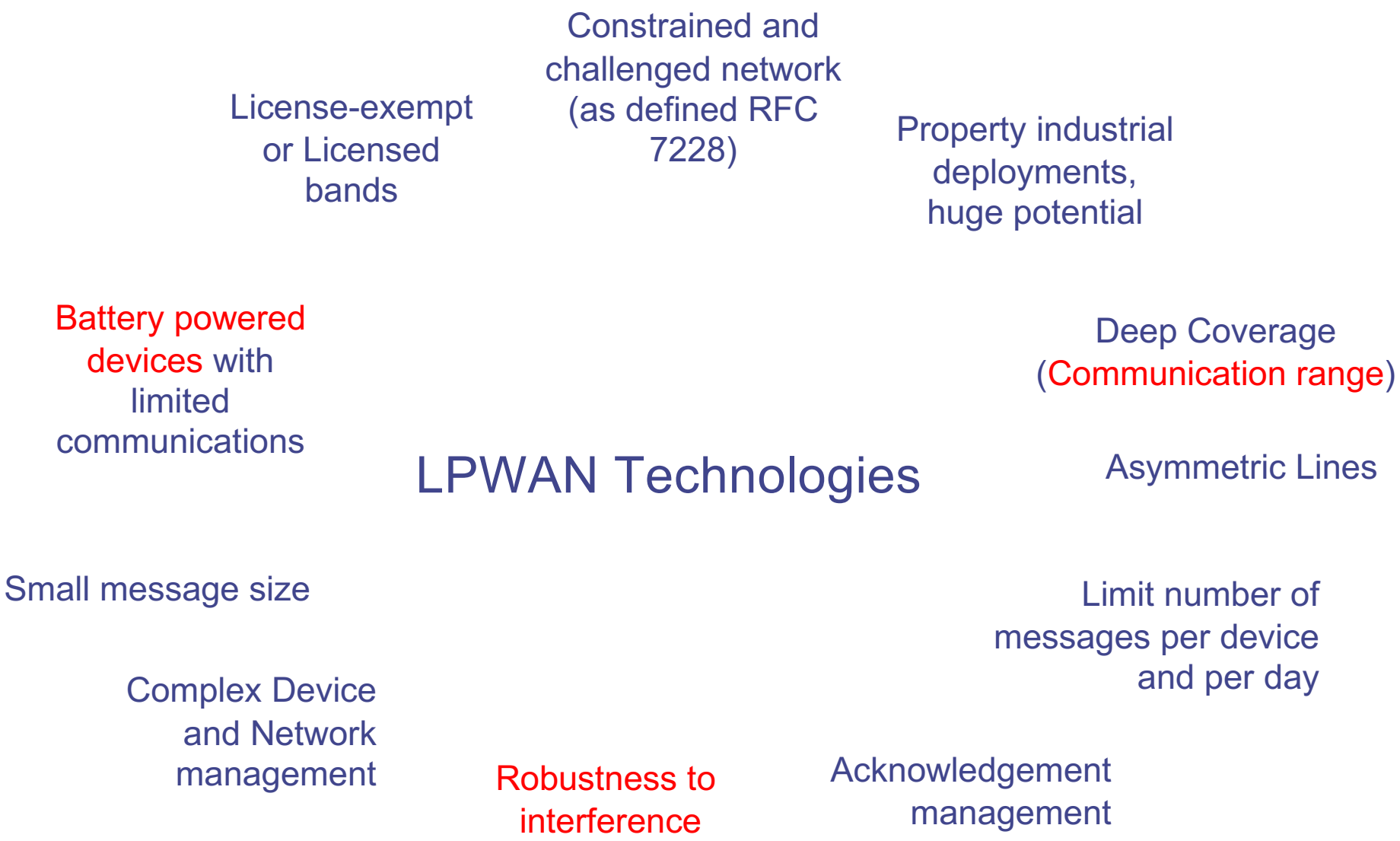


LPWAN in context

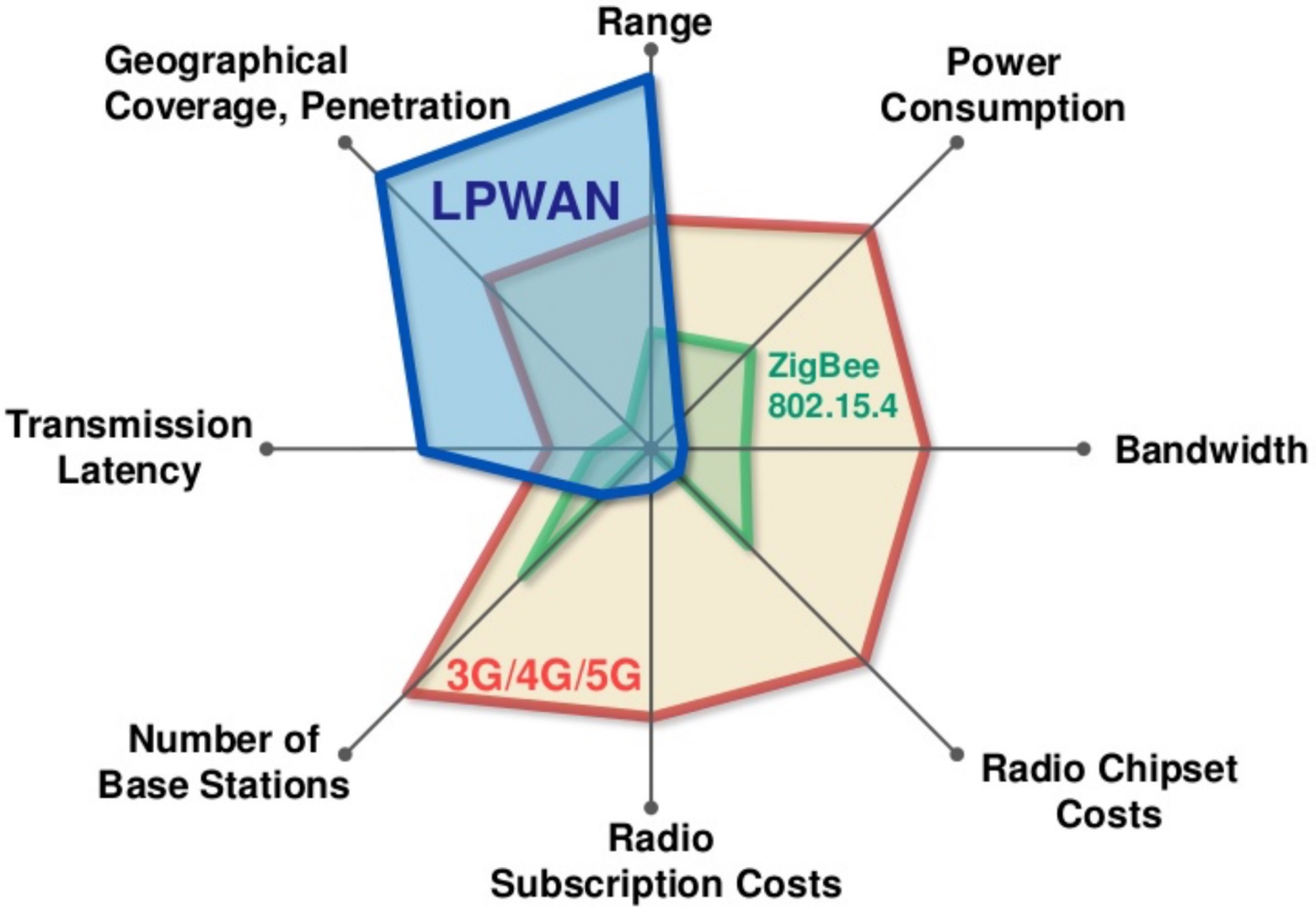
- Different wireless technologies cover different applications with regard to range and bandwidth
- Long-range applications with low bandwidth requirements that are typical for IoT scenarios are not necessarily well supported by existing technologies



LPWAN Characteristics



Comparison of requirements and characteristics



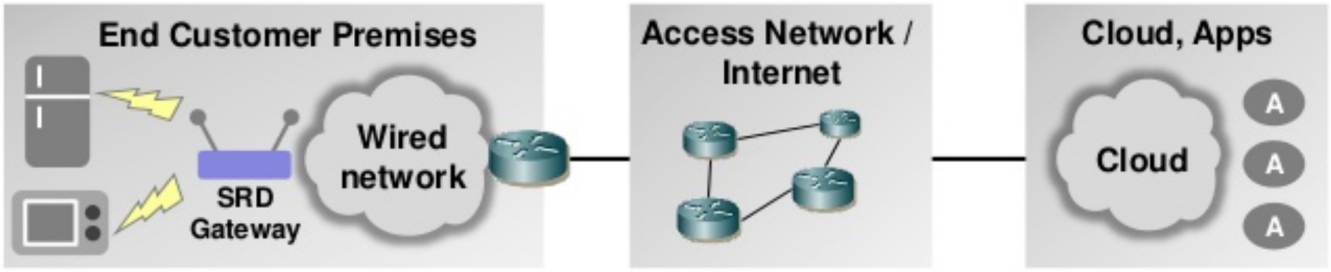
LPWAN Requirements and Characteristics

Characteristic	Target Value for LPWAN Technologies
Long range	5 – 40km in the open field
Ultra low power	Battery lifetime of 10 years
Throughput	Depends on the application, but typically a few hundred bit / s or less
Radio chipset costs	$2 or less
Radio subscription costs	$1 per device and year
Transmission latency	Not a primary requirement for LPWAN. IoT applications are typically insensitive to latency.
Required number of base stations for coverage	Very low. LPWAN base stations are able to serve thousands of devices.
Geographic coverage, penetration	Excellent coverage also in remote and rural areas. Good in-building and in-ground penetration (e.g. for reading power meters).

Benefits of LPWAN

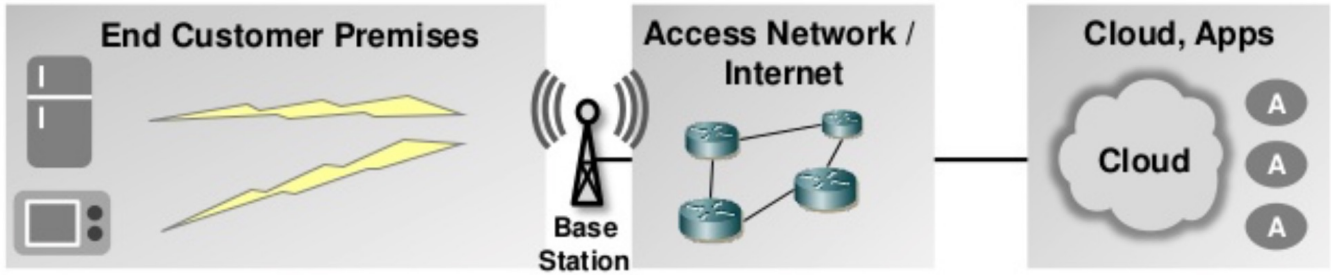
- IoT devices are often installed in the field on residential premises, public places or industrial plant sites
- Using short-range radio connectivity can complicate setup due to the implications of wired on-site connectivity (firewalls, NAT, port and protocol filtering)

Short range radio connectivity for IoT devices:



- Short range radio devices (SRD) such as ZigBee require using a gateway for long-range backhaul.
- The gateway is typically hooked up to some on-site wired network which is not under control of the IoT provider.

Direct long range connectivity (LPWAN) for IoT devices:

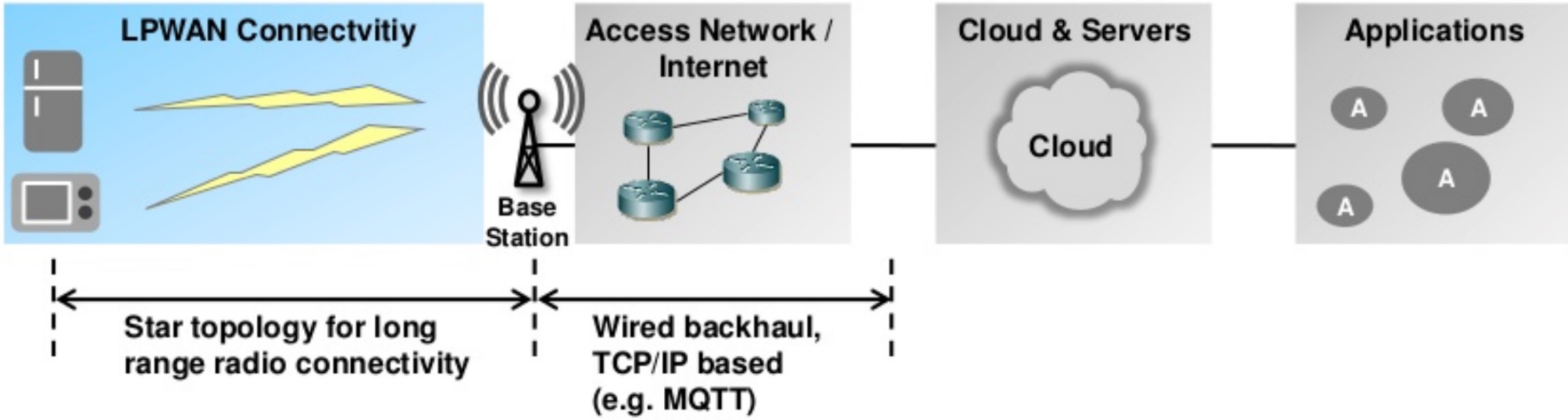


- Long range connectivity allows direct access to the devices in the field.
- The base station typically serves a large number of devices thus greatly reducing costs.

LPWAN Network Topology

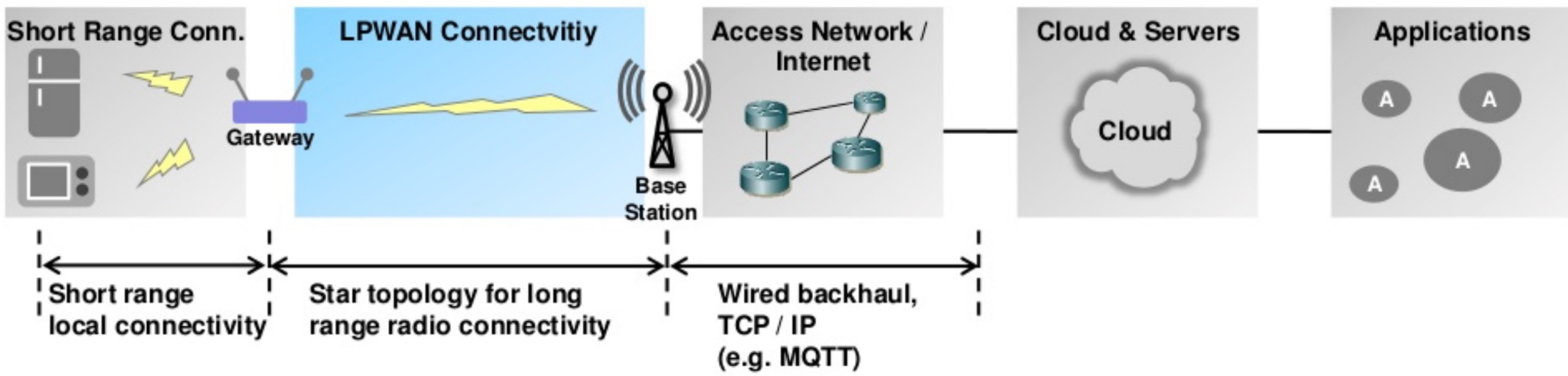
The wireless portion of LPWAN networks uses a star topology.
This obviates the need for complicated wireless mesh routing protocols which would greatly complicate the implementation of end devices and drive up power consumption.

A. Direct device connectivity (base station):



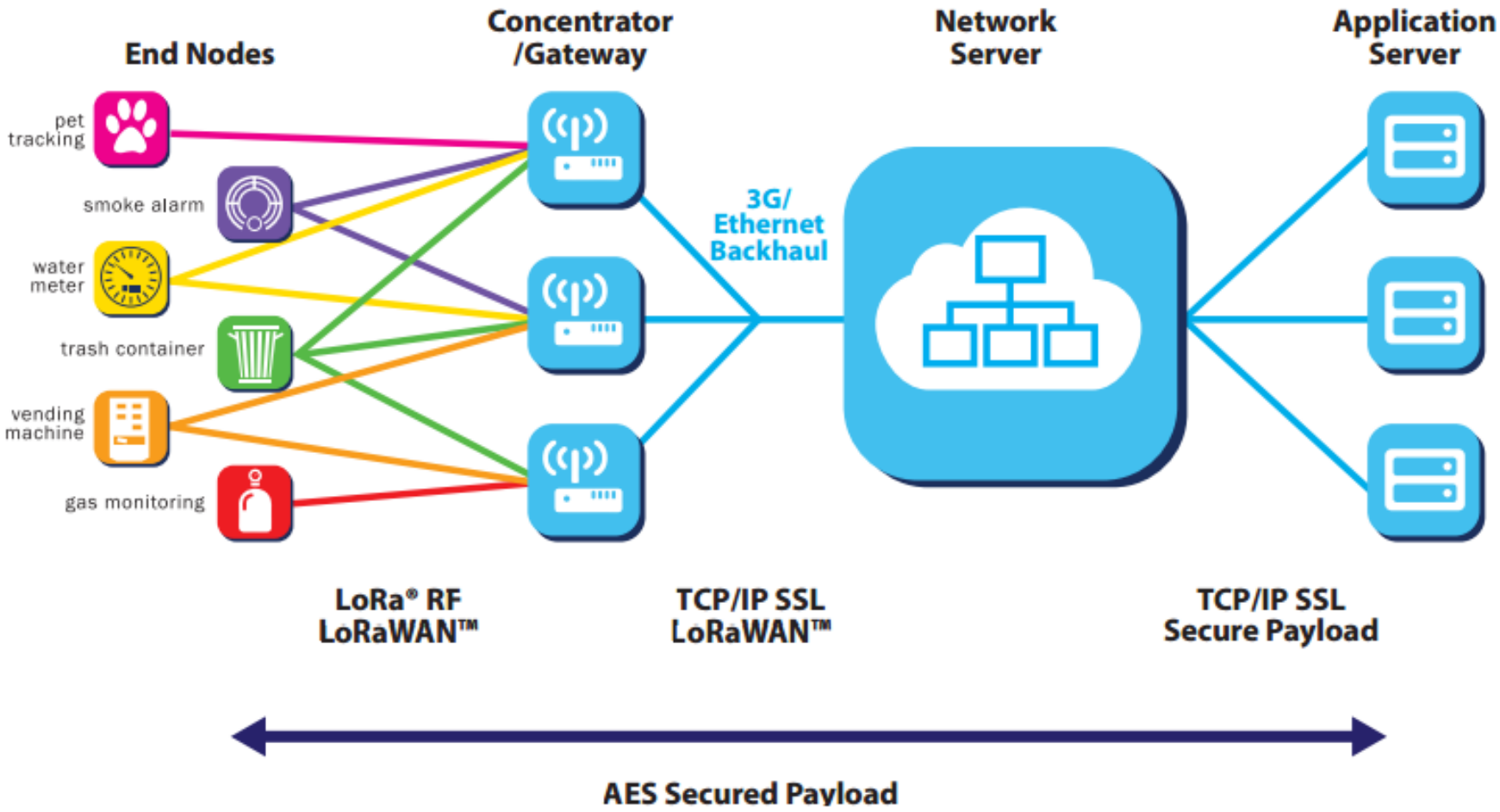
- **A base station provides connectivity to a large number of devices.**
- **The traffic is backhauled to servers (cloud) through TCP/IP based networks (Internet).**

Indirect device connectivity through a LPWAN gateway



- In setups where devices cannot be directly reached through LPWAN, a local gateway bridges LPWAN connectivity to some short range radio (SRD) technology (e.g. ZigBee, BLE).
- The gateway typically runs on mains power since it serves a larger number of devices and must convert between LPWAN and SRD radio technologies and protocols.
- Gateways may help to improve security since more powerful security algorithms can be implemented on the gateway than is possible on the constrained devices.

Similar architecture: : Lorawan, NB-IoT, SIGFOX



LPWAN Characteristics

- Thousand of nodes per gateway
- Star Topology
- Very small frame payload (8 – 250bytes)
- Limit number of frames per day (10)
  - Duty cycle limits the transmission in unlicenced bands
- Low bandwidth offering throughput between 50 bit/s to 250kbit/s
- High packet loss (caused by collisions or bad transmission conditions)
- MTU variable (changing with modulation)
- Highly asymmetric (up/down) links or unidirectional links only
- Sleepy nodes
- Long Range: Several km

Radio Characteristics

- LoRaWAN – Sigfox : Mostly in unlicensed spectrum
  - 868 MHz (EU), 915 MHz (US, AU), 433 MHz (Asia),
  - Duty cycle : 1% (up), 10% (down)
- NB-IoT – licensed bands
  - LTE/GSM spectrum
  - Subset of LTE standard but limits bandwdith to a single narrow-band of 200Khz
  - No duty cycle

Maximum throughput per LoRaWAN Channel and ED

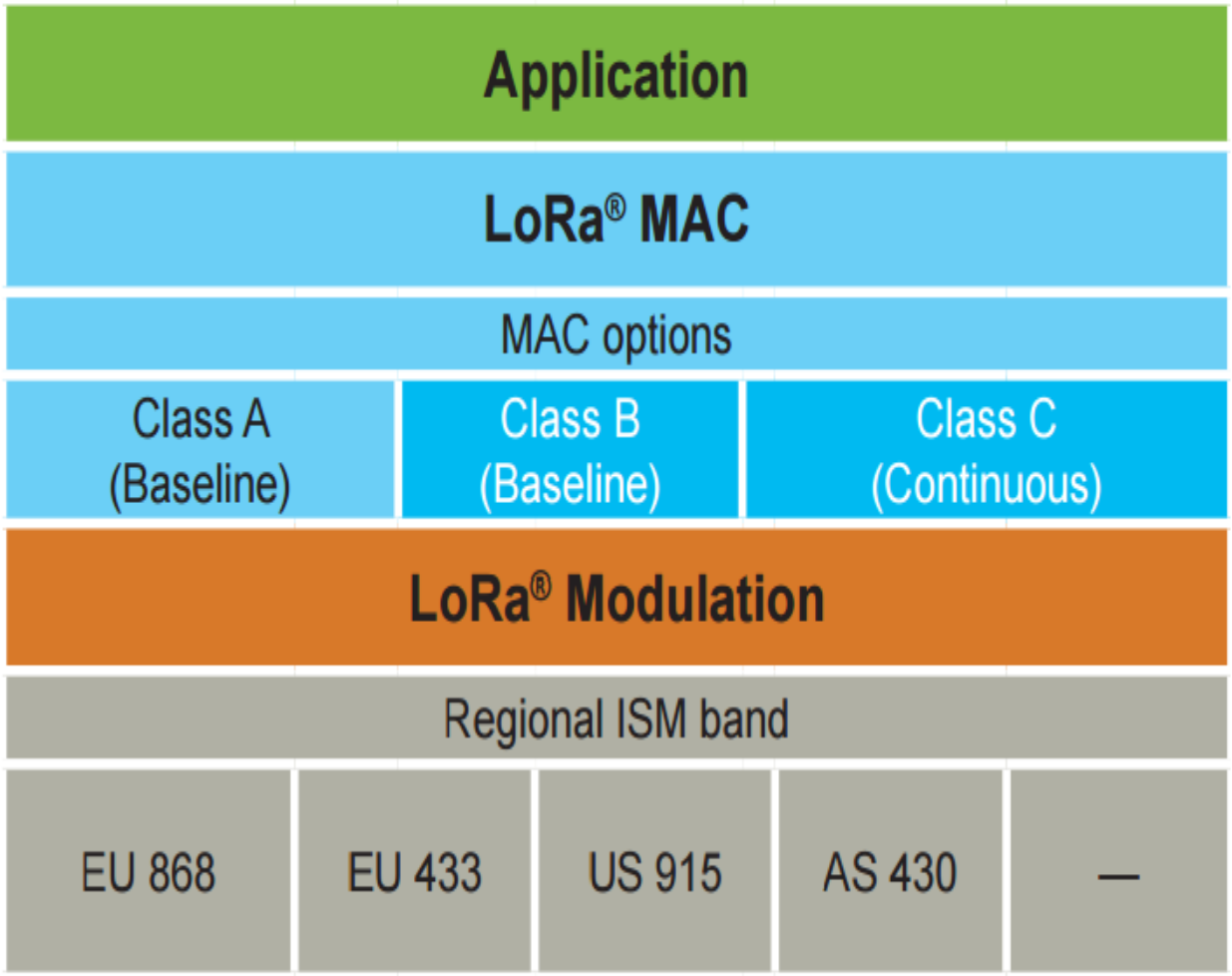
Table IV. Maximum throughput per LoRaWAN channel and ED

Data rate (DR)	Bandwidth, kHz	Maximum APP throughput per channel, bit/s	Maximum APP throughput per ED per channel, bit/s		
			10% duty cycle	1% duty cycle	0.1% duty cycle
0	125	146.1	14.61	1.46	0.15
1	125	261.4	26.14	2.61	0.26
2	125	584.2	58.42	5.84	0.58
3	125	1 359.2	135.92	13.59	1.36
4	125	2 738.1	273.81	27.38	2.74
5	125	4 844.7	484.47	48.45	4.84
0-5 cumulative[1]	125	9 933.6	n/a	n/a	n/a
6	250	9 689.3	968.93	96.89	9.69
7	150	45 660.4	1 851.6[2]	456.6	45.66

[1]- given that the spreading factors for DR0-DR5 are orthogonal, the transmissions with different SF may coexist in the same channel at the same time

[2]- due to the need for opening RX windows after each frame, the maximum possible duty cycle is 4.1% (see Table II, acknowledged transmission)

LoRaWAN Network Protocol



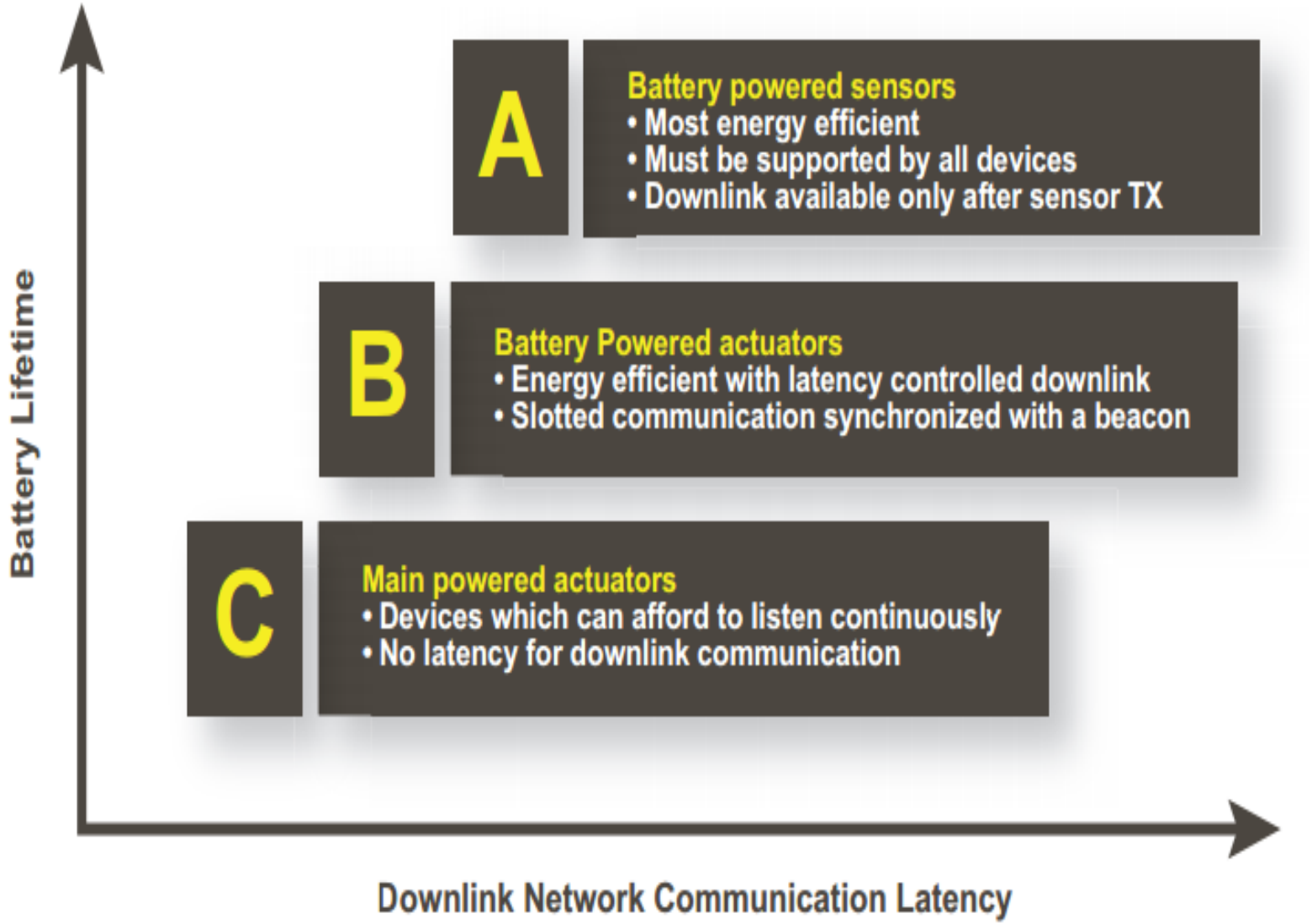
Frame Characteristics: Maximum Payload

- LoRaWan:
  - 19 – 242 bytes (AU)
  - 59-230 bytes (EU)
  - 19-250 bytes (US)
- NB-IOT:
  - 1600 Bytes
- Sigfox:
  - 12 bytes down stream (* 140/day)
  - 8 bytes upstream (* 4/day)

Frame Characteristics: Addresses

- LoRaWAN:
  - EUI64 (64-bit Global Identifier) : Identifier
  - NwkAddr: 4 bytes
- SIGFOX:
  - 4 bytes

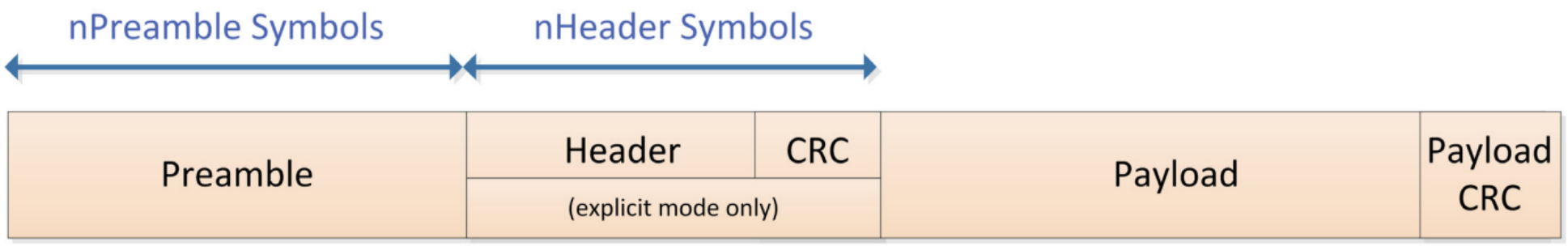
Three classes of EDs



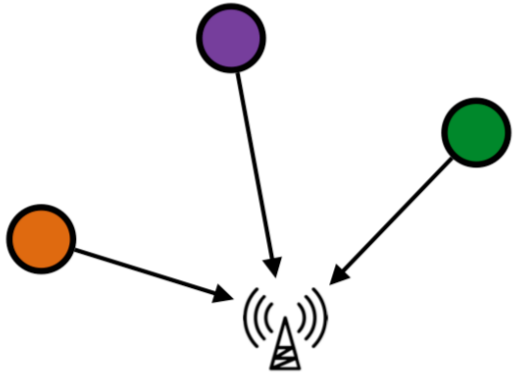
Three classes of EDs

LoRa Class A	LoRa Class B	LoRa Class C
Battery Powered	Low Latency	No Latency
Bidirectional communications	Bidirectional with scheduled receive slots	Bidirectional communications
Unicast messages	Unicast and Multicast messages	Unicast and Multicast messages
Small payloads, long intervals	Small payloads, long intervals, Periodic beacon from gateway	Small payloads
End-device initiates communication (uplink)	Extra receive window (ping slot)	Server can initiate transmission at any time
Server communicates with end-device (downlink) during predetermined response windows	Server can initiate transmission at fixed intervals	End-device is constantly receiving

LoRaWAN Frame

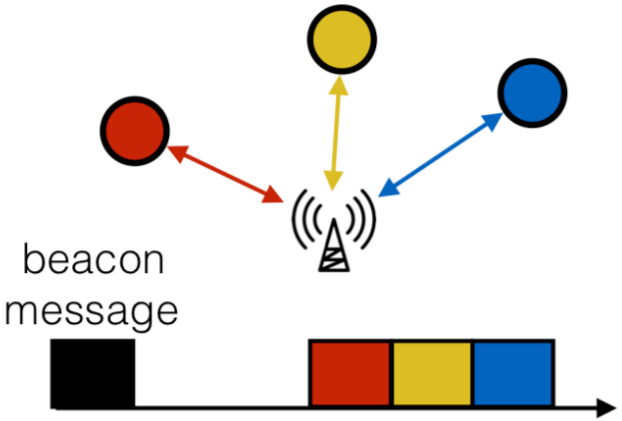


LoRaWAN: MAC Layer



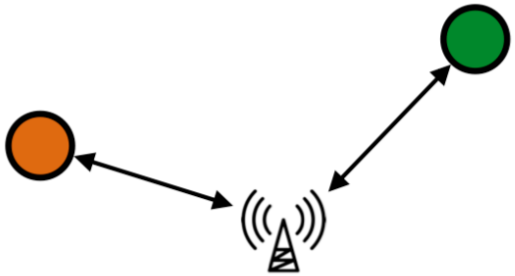
Class A
ALOHA + (optional) ACK

low-power sensor



Class B
Beacon + Time Slots

low-power actuator

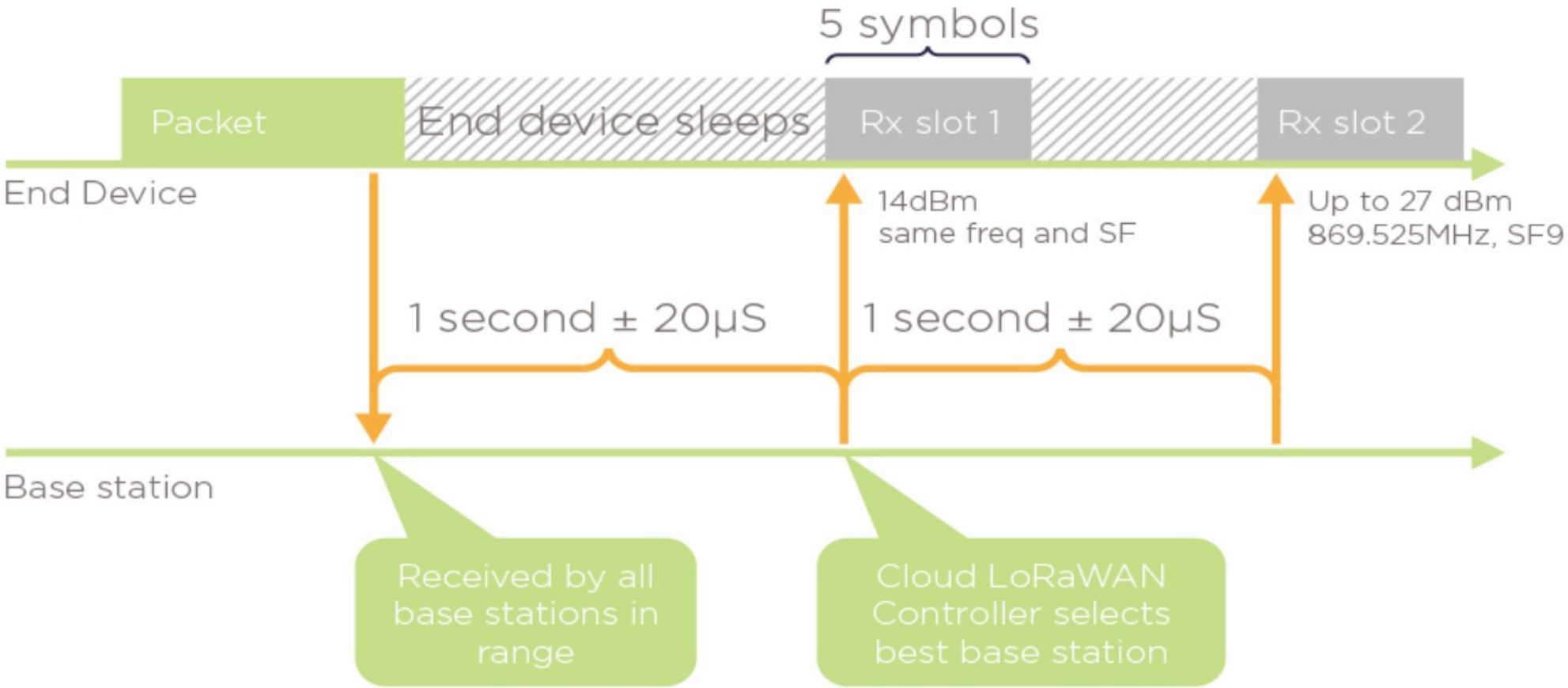


Class C
Always Listening

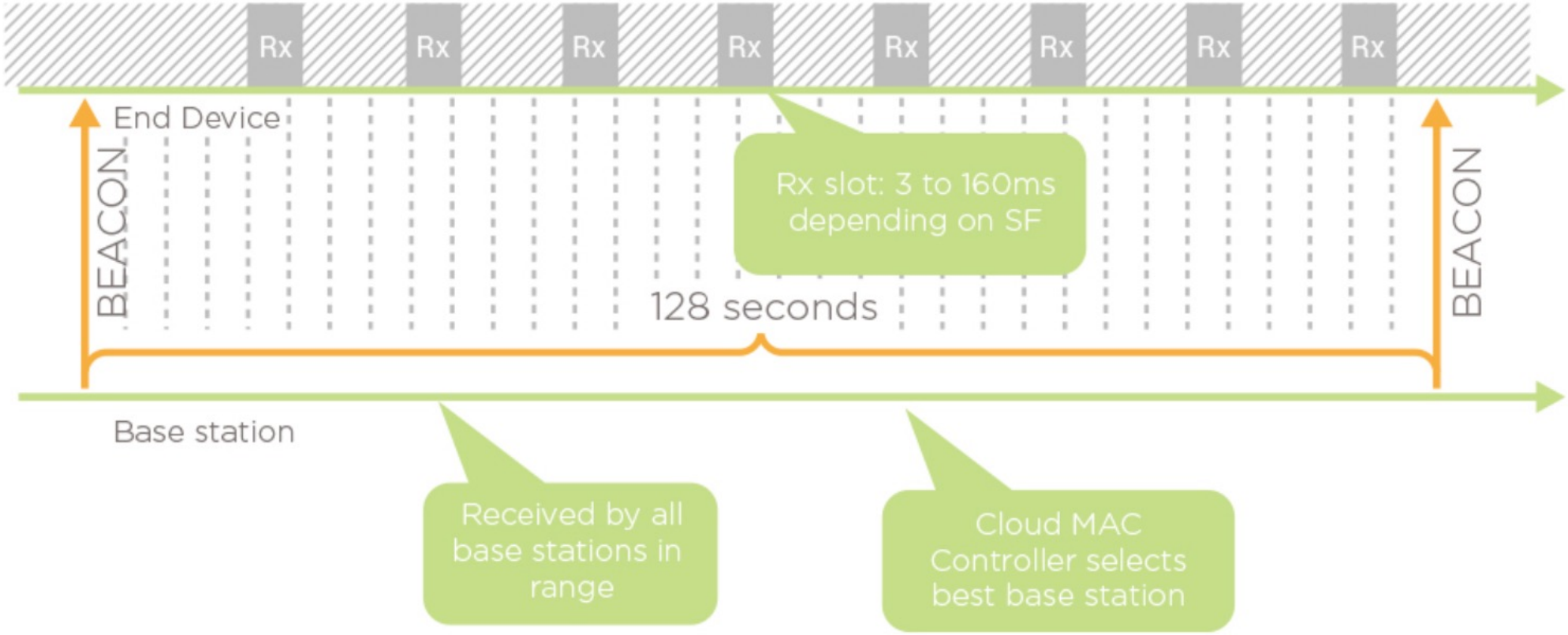
low-latency
applications

Base stations are always listening

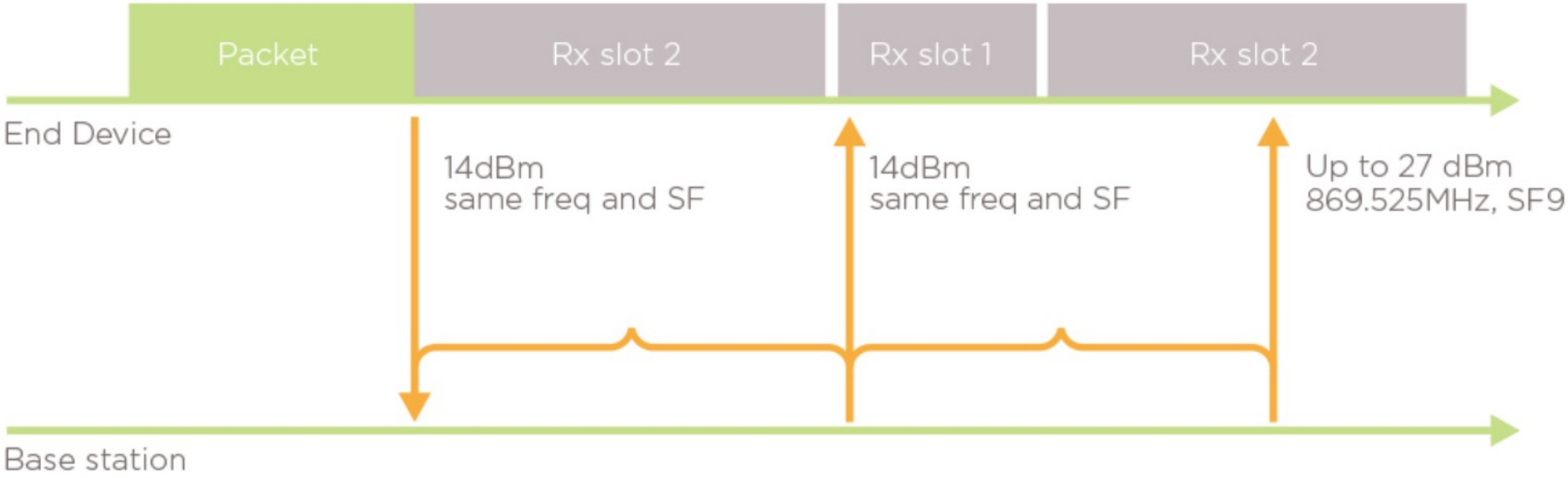
Class A


5 symbols
Packet
End device sleeps
Rx slot 1
Rx slot 2
End Device
14dBm
same freq and SF
Up to 27 dBm
869.525MHz, SF9
1 second ± 20µS
1 second ± 20µS
Base station
Received by all base stations in range
Cloud LoRaWAN Controller selects best base station

Class B

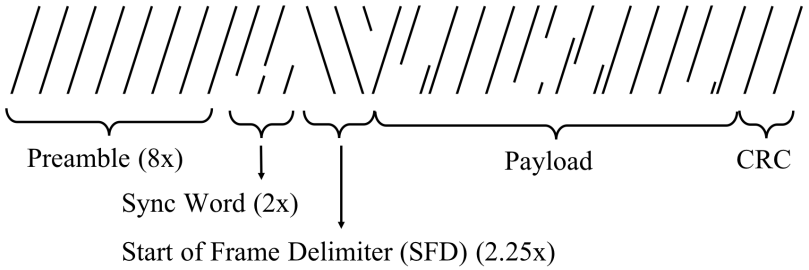

Rx
Rx
Rx
Rx
Rx
Rx
Rx
Rx
End Device
BEACON
Rx slot: 3 to 160ms depending on SF
128 seconds
BEACON
Base station
Received by all base stations in range
Cloud MAC Controller selects best base station

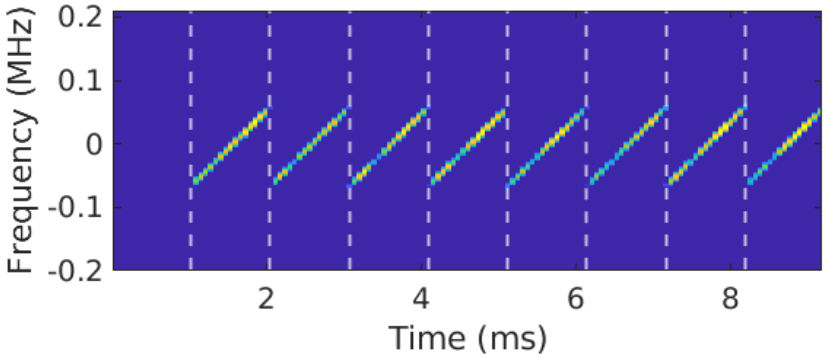
Class C

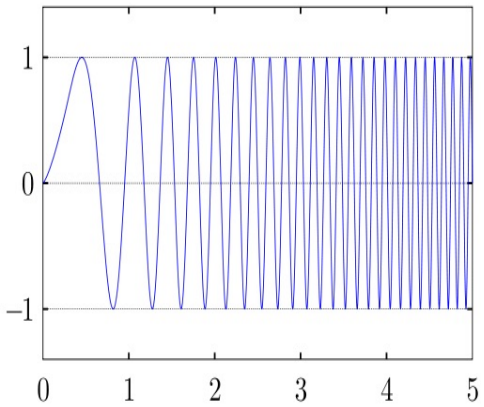

Packet
Rx slot 2
Rx slot 1
Rx slot 2
End Device
14dBm
same freq and SF
14dBm
same freq and SF
Up to 27 dBm
869.525MHz, SF9
Base station

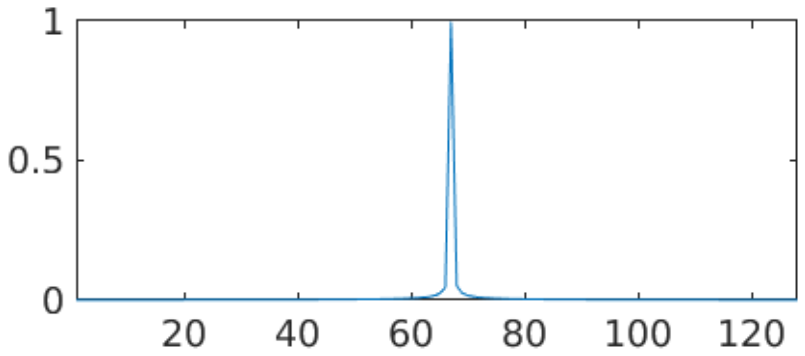
LoRa PHY: Chirp Spread Spectrum (CSS)

- Entire allocated bandwidth is used making it robust to noise
- Resistant to multi-path and doppler even at low power









Data Rates and Frame Characteristics

Table I. LoRaWAN data rates settings and frames characteristics

Data rate (DR)	SF	Band width, kHz	Modu-lation	maximum MACPayload size, bytes	Maximum FRMPayload size[1], bytes	Shortest downlink frame ToA, s	Longest downlink frame ToA, s	Shortest uplink frame ToA, s	Longest uplink frame ToA, s
0	12	125	LoRa	59	51	0.991	2.793	1.155	2.793
1	11	125	LoRa	59	51	0.578	1.479	0.578	1.561
2	10	125	LoRa	59	51	0.289	0.698	0.289	0.698
3	9	125	LoRa	123	115	0.144	0.677	0.144	0.677
4	8	125	LoRa	250	242	0.072	0.697	0.082	0.707
5	7	125	LoRa	250	242	0.041	0.394	0.041	0.400
6	7	250	LoRa	250	242	0.021	0.197	0.021	0.200
7	n/a	150	GFSK	250	242	0.0032	0.0421	0.0035	0.0424

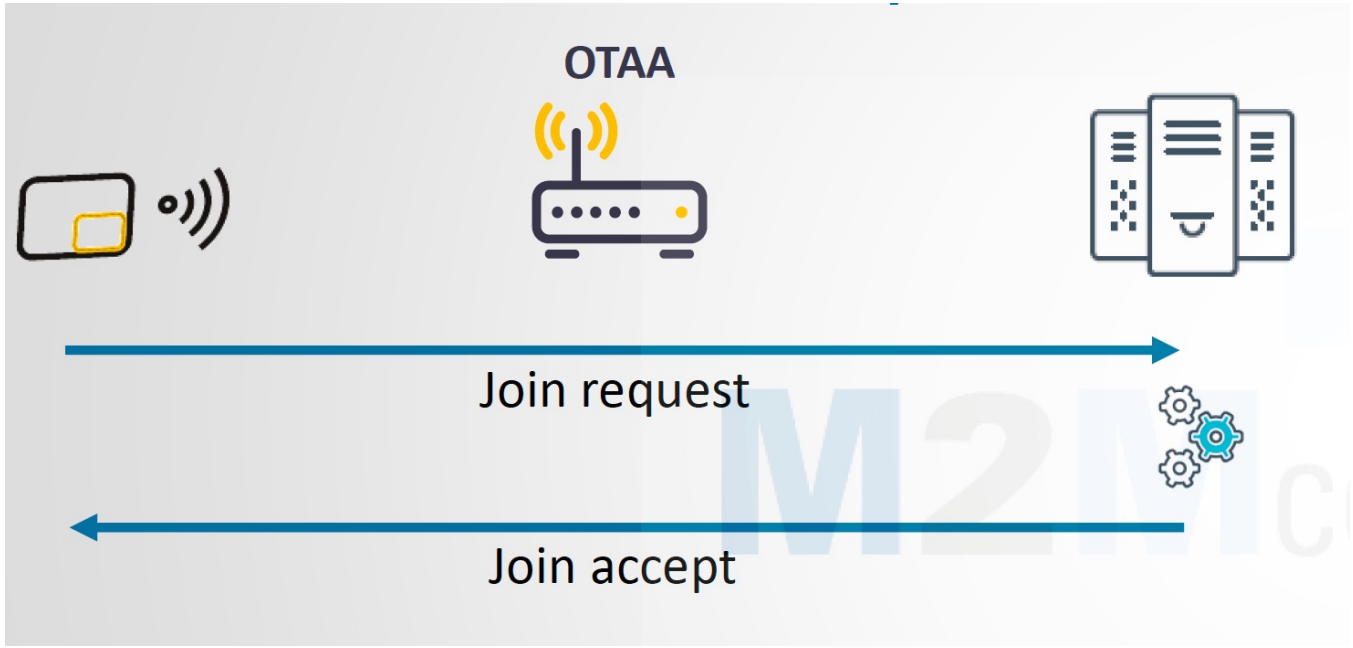
[1] - given that $FHDR_{OPTS}$=0

Information Stored in End Device

- 64 bit unique identifier (DevEUI)
- Device Address (DevAddr, 32 bits)
  - 7 MSB: Network Identifier (NwkID)
  - 25 LSB: Network Address (NwkAddr)
- Application Identifier (AppEUI)
- Network Session Key (NwkSKey)
- Application Session Key (AppSKey)
- Frame Counters

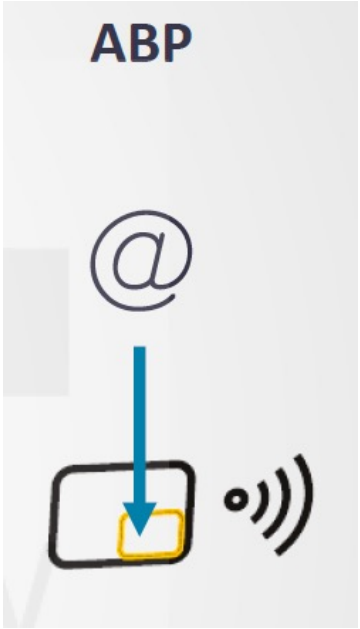
Activation (1): Over The Air Activation (OTAA)

- Manually Configured
  - DevEUI
  - AppEUI
  - AES-128 Key (AppKey)
- From accept message
  - DevAddr
  - NwkSKey
  - AppSKey



Activation (2): Activation by Personalisation

- Manually configured
  - DevAddr
  - NwkSKey
  - AppSKey



Frame Characteristics: Security

- LoRAWAN:
  - Uses AES
  - 128 bit keys
  - NwkSkey: interaction between the node and network (frame integrity)
  - AppSkey: payload encryption
  - Key deployment
    - Over the air activation (OTAA)
    - Activation by Personalization (ABP)
- SIGFOX:
  - Pre provisioned security key for authentication and integrity
  - Application can encrypt payload