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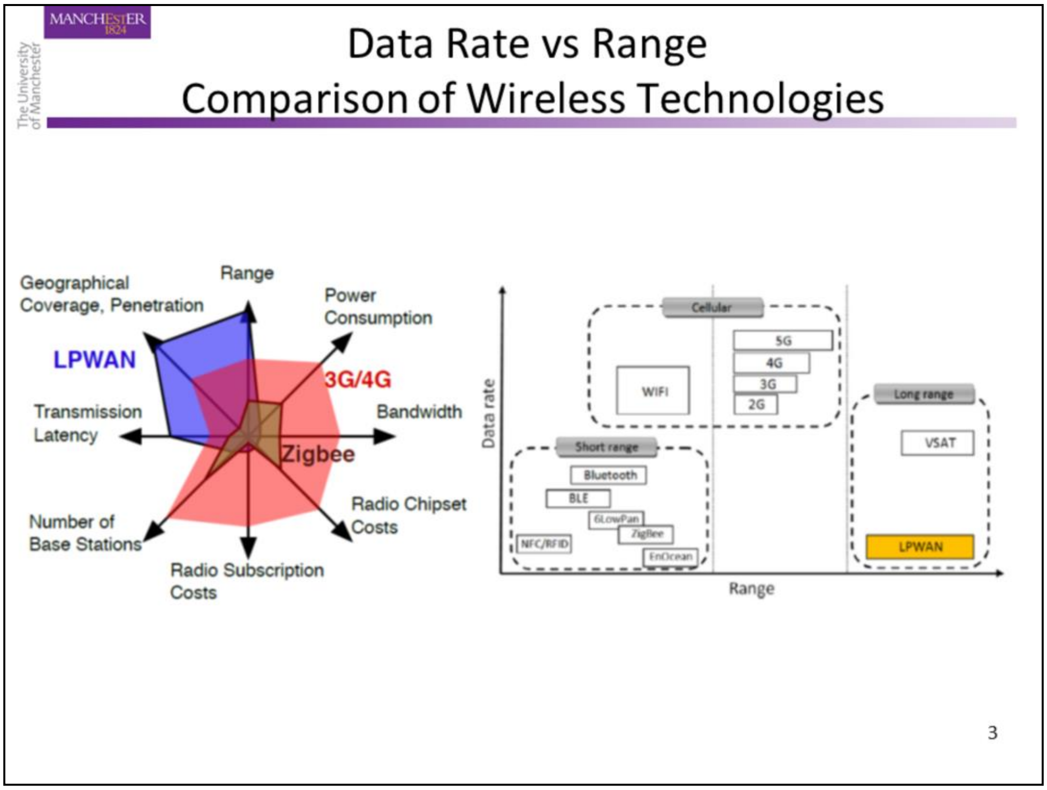
LOW POWER WIDE AREA NETWORKS (LPWAN)

- Most of the material relating to LPWAN and LoRaWAN come from the following sources:
- "LoRaWAN™ What is it? A technical overview of LoRa® and LoRaWAN" *LoRa Alliance*, November 2015.
- LoRaWAN™ 1.1 Specification, *LoRa Alliance Technical Committee*, October 2017.
- I. Cheikh *et al.,* "Multi-Layered Energy Efficiency in LoRa-WAN Networks: A Tutorial," *IEEE Access,* Vol. 10, pp. 9198-9231, January 2022.
- D. Magrin, M. Capuzzo, and A. Zanella, "A Thorough Study of LoRaWAN Performance Under Different Parameter Settings," *IEEE Internet of Things Journal,* Vol. 7, No. 1, pp. 116-127, January 2020.
- J. C. Liando, A. Gamage, A. W. Tengourtius, and M. Li, "Known and Unknown Facts of LoRa: Experiences from a Large-scale Measurement Study" *ACM Transactions on Sensors Networks*, Vol. 5, No. 2, Article 16, May 2019.

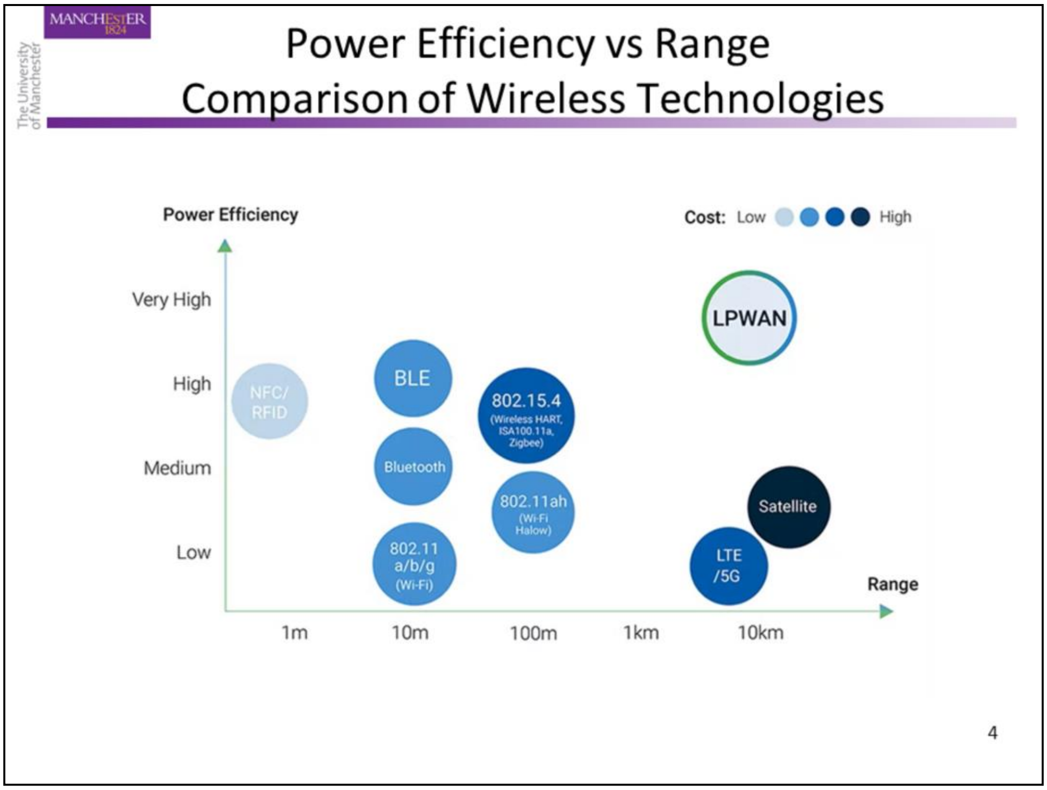
What is the Purpose of LPWANs?

- Low–Power, Wide-Area Networks (LPWAN) are projected to support a major portion of the billions of devices forecasted for the Internet of Things (IoT)
- Offer multi-year battery lifetime and are designed for sensors and applications that need to send small amounts of data over long distances a few times per hour from varying environments

	Local Area Network Short Range Communication	Low **P**ower **W**ide **A**rea (LPWAN) Internet of Things	**Cellular Network** Traditional M2M
	40%	**45%**	**15%**
	Well established standards In building	Low power consumption Low cost Positioning	Existing coverage High data rate
	Battery Live Provisioning Network cost & dependencies	High data rate Emerging standards	Autonomy Total cost of ownership
	Bluetooth 4.0, WiFi	LoRa	GSM, 3G / H+, 4G



- Images originate from the following sources:
  - D. Hernandez, G. Peralta, L. Manero, R. Gomez, J. Bilbao, and C. Zubia, ''Energy and coverage study of LPWAN schemes for industry 4.0,'' in Proc. IEEE Int. Workshop Electron., Control, Meas., Signals Their Appl. Mechatronics (ECMSM), May 2017, pp. 1–6.
  - K. Mekki, E. Bajic, F. Chaxel, and F. Meyer, ''A comparative study of LPWAN technologies for large-scale IoT deployment,'' ICT Exp., vol. 5, no. 1, pp. 1–7, Mar. 2019.



- Source: https://www.processingmagazine.com/process-control-automation/article/15587729/5-compelling-cases-of-lpwan-for-process-industries (accessed on 15/3/2022).

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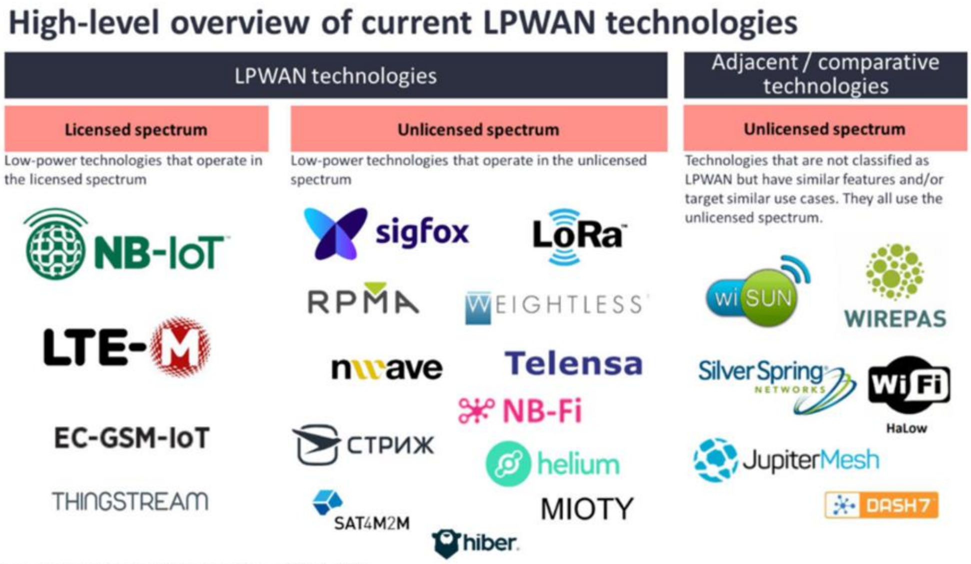
Overview of Current LPWAN Technologies



Source: IoT Analytics LPWAN Market Report 2018 - 2023

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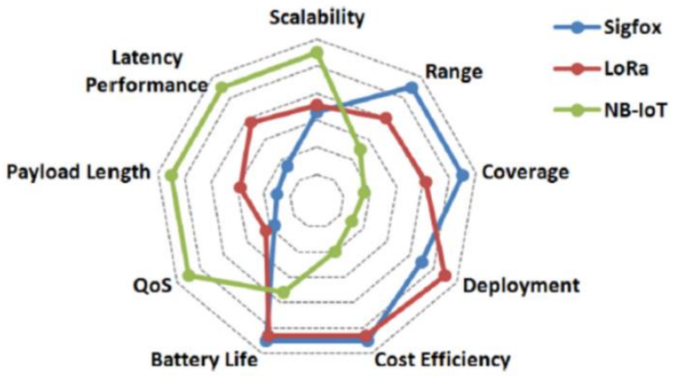
Comparison of LPWAN Technologies

Technology	Spectrum cost	Deployment cost	End-device cost
SigFox	Free	>4000 €/base station	<2 €
LoRa	Free	>100€/gateway >1000€/base station	3-5 €
NB-IoT	Licensed	>15,000€/base station	>20 €



- Among LPWAN standards, there are those operating in unlicensed bands (e.g., LoRa, SigFox, etc.), and those designed for licensed frequency bands as a component of cellular systems (e.g., NB-IoT, EC-GSM-IoT, LTE-M-IoT, 5G IoT).
- **Narrowband IoT (NB-IoT)**: Refers to an LPWAN radio technology standard developed by the Third Generation Partnership Project (3GPP) to support a wide range of cellular devices and IoT services. Thus, NB-IoT devices with an average of 200 bytes per day can achieve battery lifetimes of 10 years while covering a distance of 1 km in urban areas and 20 km in rural areas. NB-IoT, unlike LoRaWAN, can support both low latency and high data rates.
- **Sigfox**: It is primarily used to establish IoT networks in situations where the volume of data transmitted is low. According to Sigfox2 an uplink message might have a payload of up to 12 bytes and takes about 2 seconds to reach the base stations over the air, the range is long, up to tens of kilometres, and the current consumption is very low, averaging around 1–10 mA per transmission.
- **LoRaWAN**: In 2015, a group of approximately 500 companies formed the LoRa Alliance, resulting in the creation of a new LPWAN technology standard known as LoRaWAN, which defines the network and MAC stacks that allow network nodes to transmit messages to gateways.

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Long Range WAN (LoRaWAN) Architecture

- LoRaWAN is an energy efficient LPWAN technology designed to address power consumption and coverage issues in IoT applications
- As such LoRaWAN guarantees secure and reliable communication, as well as extended battery lifetime and cost savings

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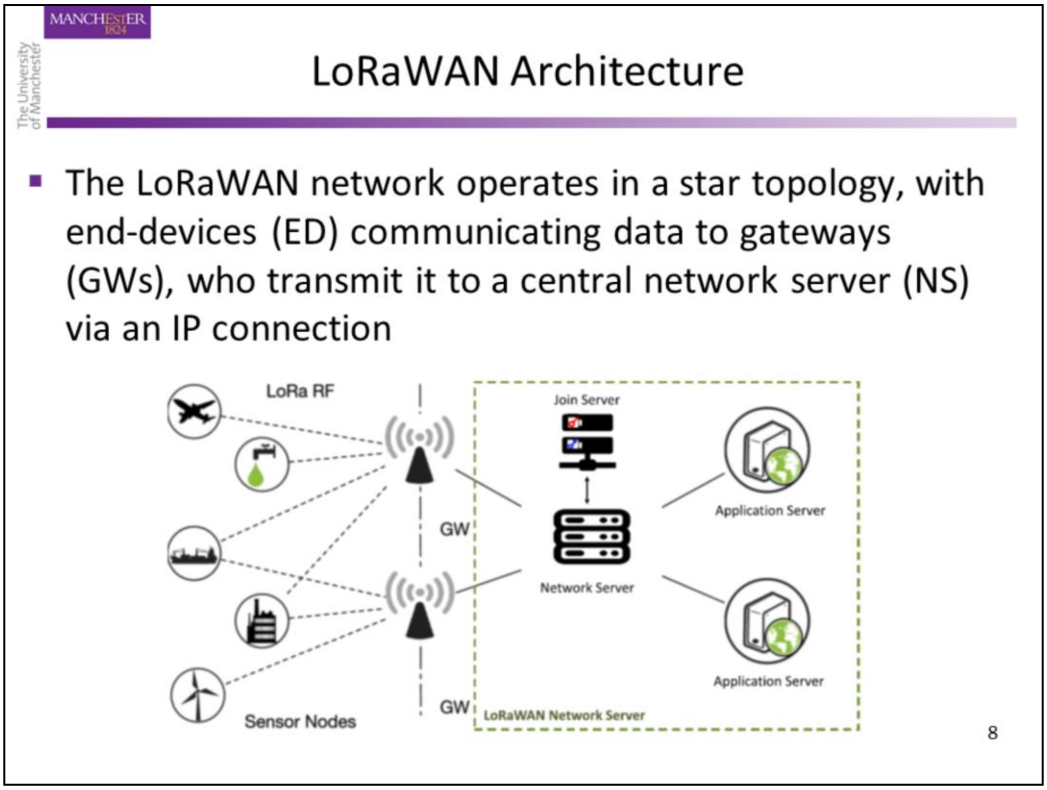
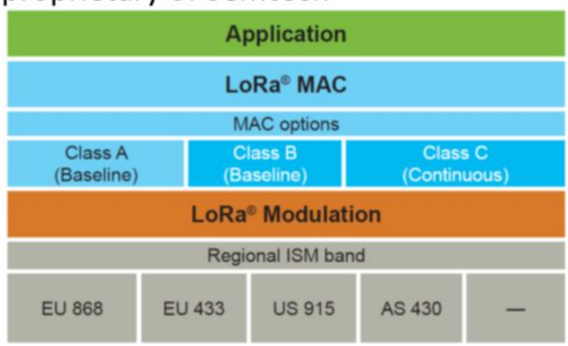
- SigFox, Weightless, Thread, NB-IoT, and LoRa, most of them are designed to operate in subGHz Industrial Scientific Medical (ISM) bands. A benefit of the PHY operating in industrial, scientific, and medical (ISM) bands in the megahertz range, is that the deployment cost of the technology is maintained low. For example, Long Range (LoRa) provides very long communication range, but no support for real-time data flow.



- End devices (ED): They are equipped with sensor nodes that can collect and transmit data to the gateways.
- Gateways (GW): They redirect the received data to the network servers.
- Gateways are connected to the Network Server via secured standard IP connections while end-devices use single-hop LoRa™ or FSK communication to one or many gateways. All communication is generally bi-directional, although uplink communication from an end device to the Network Server is expected to be the predominant traffic.
- LoRaWAN network server: It consists of three main components: a network server, an application server, and a join server. The most important functions of the LoRaWAN network server are as follows:
  - The Network Server (NS): It plays an important role in a LoRaWAN network, filtering duplicated packets, providing security, sending acknowledgements, and transferring data to the application server. The NS forwards the messages to the Application Server and Join Server.
  - The Application Server (AS): The AS forwards all packets received from the network server to the specific associated application. Alternatively, an incoming message from an application is forwarded by the application server to the network server.
  - The Join Server (JS): The JS is responsible for the authentication process of the end devices, both for the generation and distribution of the authentication keys. Two network entry methods are allowed in LoRaWAN: Activation By Personalization (ABP) and Over-The-Air Activation (OTAA).

LoRaWAN Protocol Stack

- The LoRaWAN application layer is not defined at all in the specification
- LoRa Alliance has proposed an open standard that defines medium access control (MAC) and network management protocols
- The physical (PHY) layer is the long-range (LoRa) which is proprietary of Semtech[1]



SparkFun 1-Channel LoRa Gateway supports BT and WiFi (£32, sparkfun)

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1. https://www.semtech.com/products/wireless-rf/lora-transceivers

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LoRa Modulation (PHY)

- LoRa™ is a wireless modulation for long-range low-power low-data-rate applications developed by Semtech
- LoRa data rates range from 0.3 kbps to 50 kbps
- LoRa is a proprietary spread spectrum modulation scheme that is derivative of Chirp Spread Spectrum modulation (CSS) and which trades data rate for sensitivity within a fixed channel bandwidth
  - Allows the system designer to trade data rate for range or power

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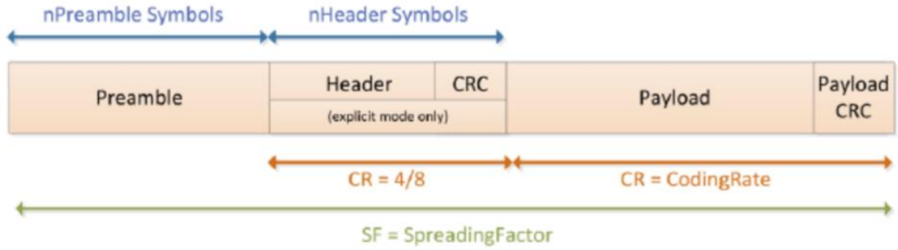
- LoRaWAN, achieves low power consumption and long-range communications via chirp spread spectrum modulation (CSS), a SS technique used to modulate the signal using chirp pulses (variable frequency sinusoidal pulses). Indeed, the CSS modulation used in LoRa converts each data symbol into a chirp, defined as a signal whose frequency increases or decreases linearly over time. A chirp also refers to a sweep signal, and each CSS symbol sweeps the bandwidth (BW) once.
- To maximize both battery life of the end-devices and overall network capacity, the LoRa network infrastructure can manage the data rate and RF output for each end-device individually by means of an adaptive data rate (ADR) scheme.

LoRa (PHY) Packet Format



		if Implicit Header disabled			if Uplink
Preamble	Mandatory Preamble	PHY Header	PHY Header CRC	Payload	CRC
6 - 65535 symbols	4.25 symbols	0 – 3 bytes (encoded in CR4/8)		0 – 255 bytes	0 – 2 bytes

- SF affects the time duration of the packet

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LoRa Configurable Parameters

- The spreading factor (SF) is the most relevant variable in the CSS system
  - The higher the SF, the larger the communication range

SF	ToA (ms)
7	112.90
8	195.07
9	349.18
10	616.45
11	1150.98
12	2138.11

- Message size is 51 bytes

Data Rate	SF	Channel, width (kHz)	Coding Rate	PHY bit rate (bps)	RF sensitivity (dBm)
0	12	125	4/6	250	-137
1	11	125	4/6	440	-136
2	10	125	4/5	980	-134
3	9	125	4/5	1760	-131
4	8	125	4/5	3125	-128
5	7	125	4/5	5470	-125
6	7	250	4/5	11000	-122

- Data rates in EU 863-780 MHz ISM band

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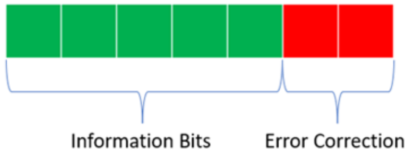
- The CSS order of modulation is given by $M = 2^{SF}$, indicating that each CSS symbol carries *SF* bits. *SF* refers to the number of chirps required to encode a bit, providing a flexible trading range for the data rate.
- Higher SF values correspond to lower transmission bitrates, but require a lower signal received power for correct reception, which turns into a longer coverage range. For each value of the SF parameter, the table shows the associated data rate (DR) index, the nominal DR, and the receiver sensitivity level.

Code Rate in LoRa

- Code Rate (CR) is represented as 4/x, which indicates 4 information bits padded with x – 4 number of parity bits
- Different CR for the Header field (CR4/8) and the Payload (x = 1…..4)
- An example of 5/7 FEC is shown below



  - For every 5 bits of useful information, the coder generates a total of 7 bits of data, of which 2 bits are redundant

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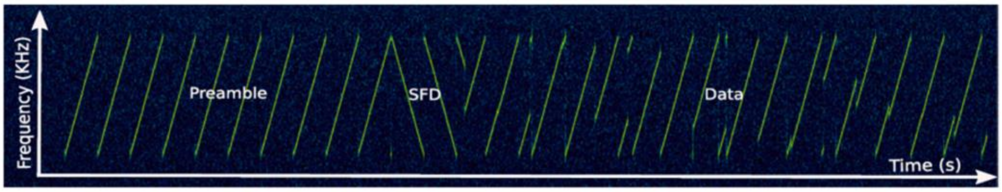
What is a Chirp?



- A **chirp** includes 2^{SF} chips and carries SF data bits
- For a given BW, there are "BW" chips per second
  - If BW = 125 kHz, then 125,000 chips per second
- Therefore, the duration of chirp (or symbol) is

$$T_{sym} = \frac{2^{SF}}{BW}$$

- Hence, each data bit consists of $2^{SF}/SF$ chips

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PHY Related Regulations

- The different bands that LoRa can use are heavily regulated, in particular, the "duty cycle" (DC) parameter

Frequency (MHz)	Direction	DC	Power limit (dBm)
868.1	DL, UL	1%	14
868.3	DL, UL	1%	14
868.5	DL, UL	1%	14
869.525	DL	10%	27

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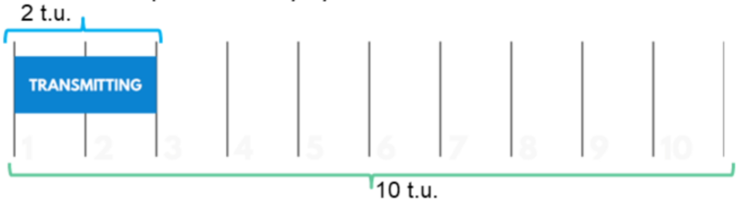
- DC is defined as "the maximum percentage of time during which an end device can occupy a channel." As a result, the end device's emission is limited to these parameters. LoRaWAN's duty cycle, depending on the frequency band used, could be 0.1%, 1%, or 10%, with a recommended duty cycle of less than 1%. For a value of 1%, the device must wait for 99 times the duration of the previous frame for a new transmission in the same channel.

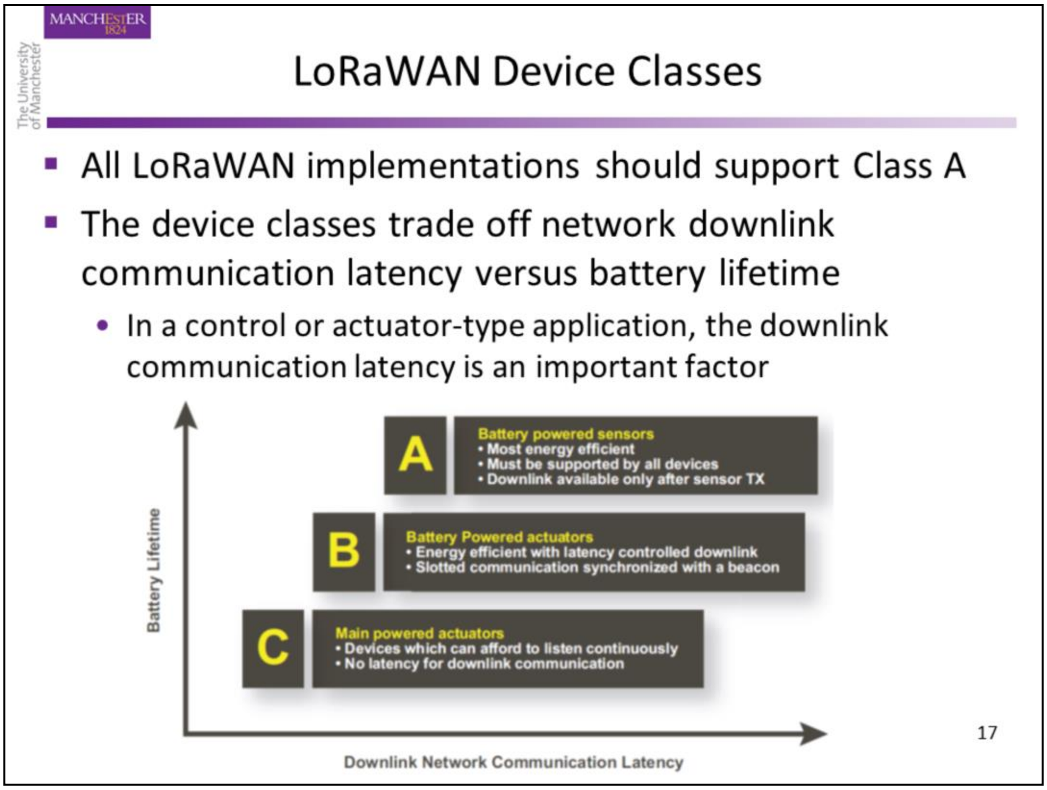
Duty Cycle

- Duty Cycle indicates the fraction of time a resource is busy
  - Example 20% duty cycle

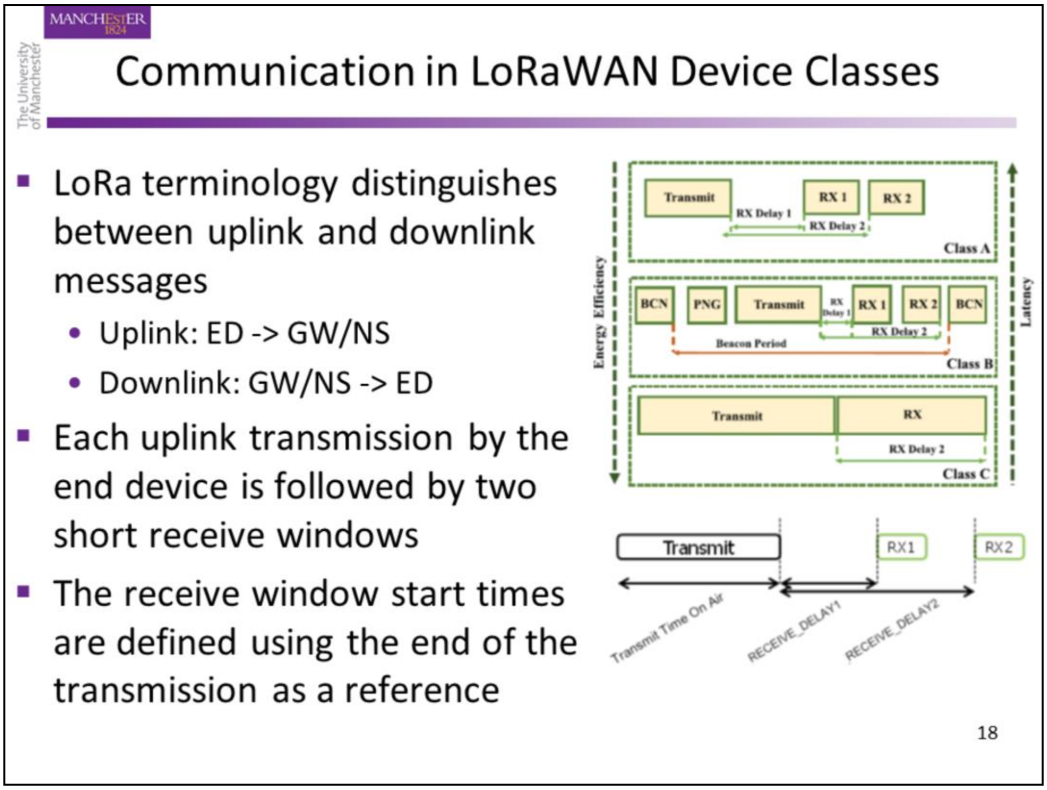


- Duty cycle applied to three channels

- Duty cycle applied to sub-band within a channel



- Bi-directional end-devices (**Class A**): End-devices of Class A allow for bi-directional communications whereby each end-device's uplink transmission is followed by two short downlink receive windows (RX1 and RX2) . This Class A operation is the lowest power end-device system for applications that only require downlink communication from the server shortly after the end-device has sent an uplink transmission and can optimize battery life to last for years. Downlink communications from the server at any other time will have to wait until the next scheduled uplink.
- Bi-directional end-devices with scheduled receive slots (**Class B**): Class B devices open extra receive windows at scheduled times. In order for the end-device to open its receive window at the scheduled time, it receives a time-synchronized beacon from the gateway. In terms of latency and power consumption, Class B offers a balanced solution.
- Bi-directional end-devices with maximal receive slots (**Class C**): End-devices of Class C have almost continuously open receive windows, only closed when transmitting. It is used for real-time applications, so the energy consumption is higher. Among the three classes, Class C has the lowest latency for the ED.



- Configuration data related to the end-device and its characteristics must be known by the Network Server at the time of provisioning (this provisioned data is called the "contract"). This contract cannot be provided by the end-device and must be supplied by the end-device provider using another channel (out-of-band communication). This end-device contract is stored in the Network Server. It can be used by the Application Server and the network controller to adapt the algorithms. This data will include:
    - End-device specific radio parameters (device frequency range, device maximal output power, device communication settings - RECEIVE_DELAY1, RECEIVE_DELAY2)
    - Often these delays are set to 1 sec and 2 sec for RECEIVE_DELAY1 and RECEIVE_DELAY2, respectively.
    - Application type (Alarm, Metering, Asset Tracking, Supervision, Network Control)
- The first receive window RX1 uses a frequency that is a function of the uplink frequency and a data rate that is a function of the data rate used for the uplink.
- The second receive window RX2 uses a fixed configurable frequency and data rate. The frequency and data rate used can be modified through MAC commands. The default frequency and data rate to use are region specific.