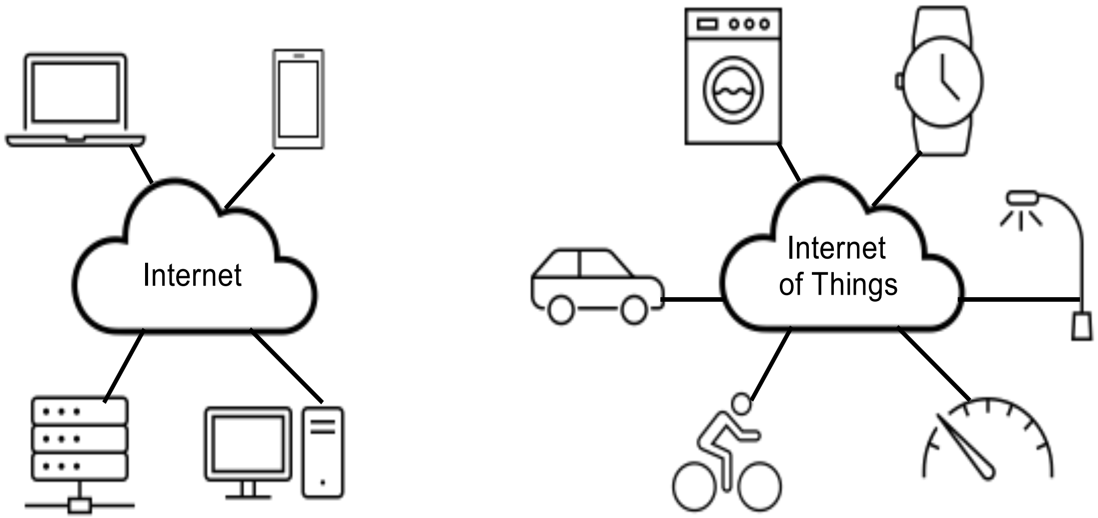
IoT
LoRa-LoRaWAN

Overview

1. IoT
2. Low Power WANs
3. LoRa
4. LoRaWAN

Internet of Things (IoT): What are *things*?



<1% of the things are connected

Anything not a computer is a thing

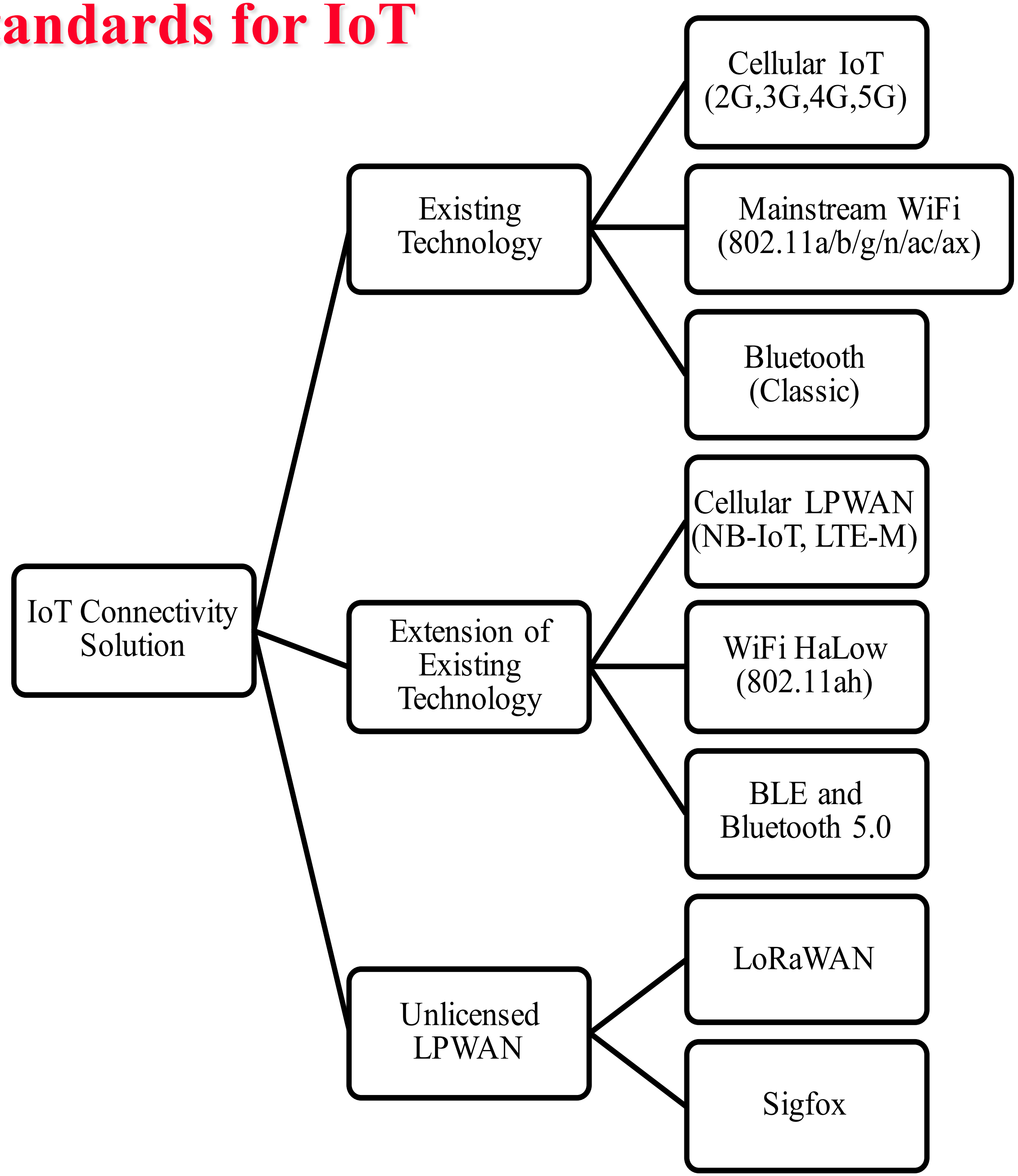
Why IoT Now?

- To be smart, things need sensing, computing, and wireless communications
- Advancements in sensor technology
  - Many varieties of sensors; small form factor, low-power, and low-cost
- Advancements in computing
  - low-cost micro-computing platforms, e.g., Raspberry Pi, Intel Curie, etc.
  - Cloud computing has become affordable (things can offload computing to the cloud)
  - Open-source micro-OS, e.g., Tiny Core Linux etc.
- Advancements in wireless communications
  - Low-power wireless communications; extensions of Bluetooth, WiFi, cellular, as well as new technologies, e.g., LoRa and LoRaWAN

IoT Applications and Business Opportunities

- Digitize all processes and workflows as much as possible; requires things to sense, compute and communicate useful data
- Massive data helps unearth valuable knowledge, which in turn helps make more intelligent decisions. IoT thus helps businesses to be more efficient, more profitable, more eco-friendly, and so on.
- All sectors are expected to benefit from IoT: agriculture, health, transport, homes, industry ….
- IoT is the next big evolution of the Internet as it aims to connect hundreds of billions of things in a matter of few years from now
- IoT is touted as the next (4^{th}) industrial revolution: **Industry 4.0**

Wireless Standards for IoT

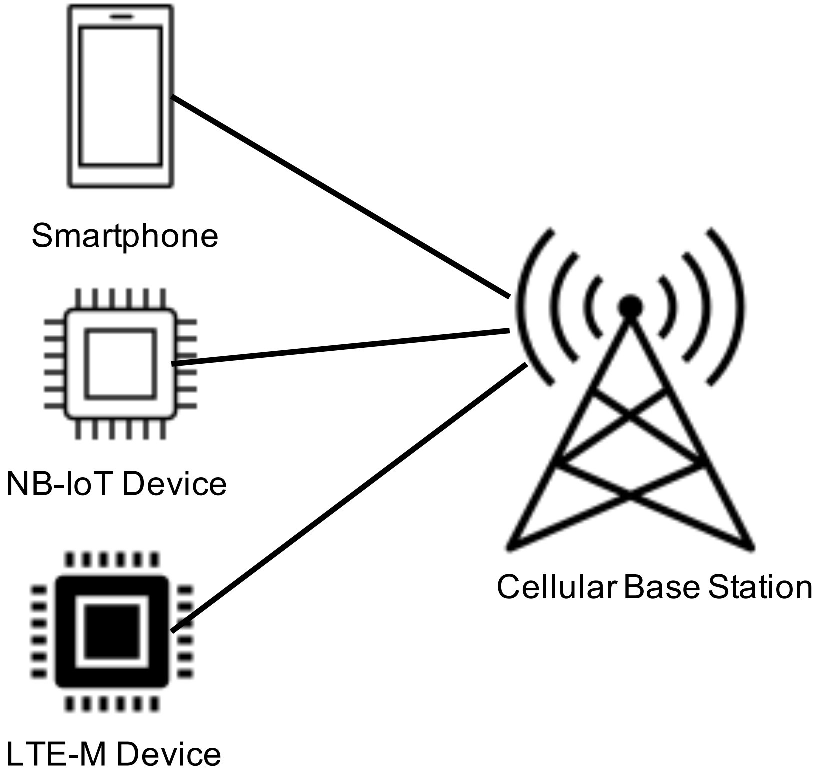


Low Power WAN

- Cellular is the current option for long range (wide area) communication
- Cellular is high power and high data rate technology (*large battery and very short battery life-time*)
- Many IoT applications require long-range communications
  - Sensor data collection, meter reading, …
- IoT requires low power and low data rate (*small battery lasting for years*)
- Significant momentum in standardizing new protocols for this new space (Low Power WAN or LPWAN)
  - New cellular standards for 5G: **NB-IoT** and **LTE-M**
  - New WiFi standards: IEEE 802.11ah
  - New industry-alliance standards: **LoRaWAN**

Cellular LPWAN

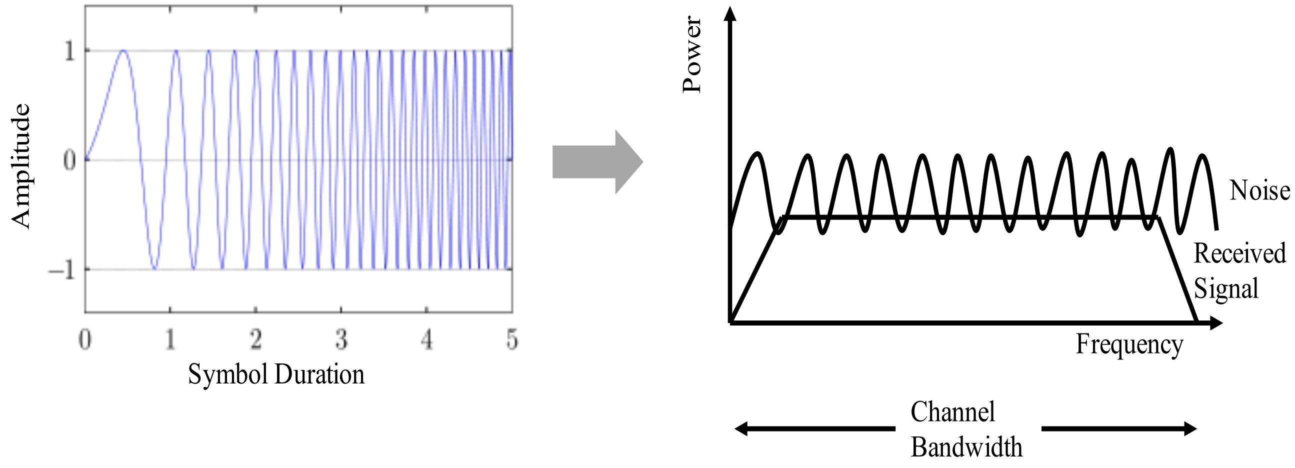
- NB-IoT/LTE-M for low-data rate, intermittent connectivity, low-cost, massive device density
- Massive connectivity can overwhelm a BS with signalling overhead even low data rates; thus, handover etc. not supported with NB-IoT/LTE-M
- NB-IoT: 180kHz gives 28dB enhanced coverage; 128 times retransmission allowed
- LTE-M allows higher bandwidth and higher mobility than NB-IoT
- New equipment class and air interface for NB-IoT/LTE-M to allow the same BS connect both existing and IoT devices



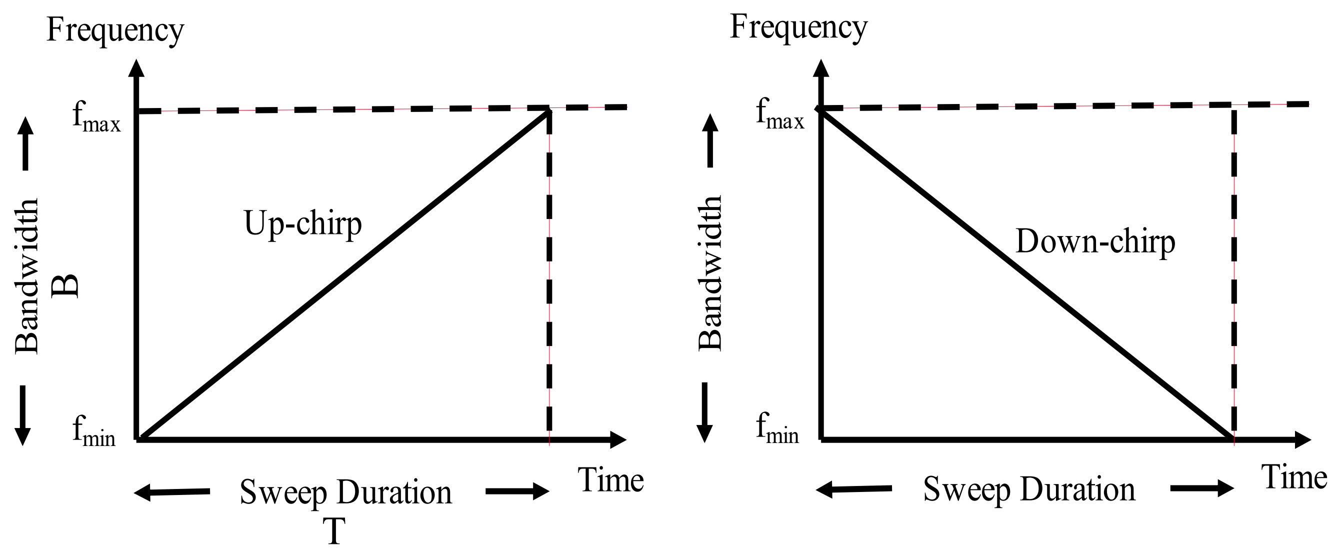
LoRa

- LoRa-LoRaWAN is a rapidly growing IoT communications standard
- Patented PHY technology
- Original company: Cyclos in France; later acquired by Semtech Corp; later formed LoRa alliance: now 500+ members
- Really long range: up to 15km in rural and 5km in urban
- Sub-GHz ISM (license-exempt) band
  - 915 MHz in US. Power limit. No duty cycle limit.
  - 868 MHz in Europe. 1% and 10% duty cycle limit
  - 433 MHz in Asia
- Very narrow channels: 125kHz or 500kHz
- Modulation: Chirp spread spectrum

Chirps


Amplitude
1
0
−1
0
1
2
3
4
5
Symbol Duration
Power
Noise
Received
Signal
Frequency
Channel
Bandwidth

Up Chirp vs. Down Chirp



- Frequency increases/decreases linearly
- Frequency sweeping speed (k) = B/T Hz/sec

Example

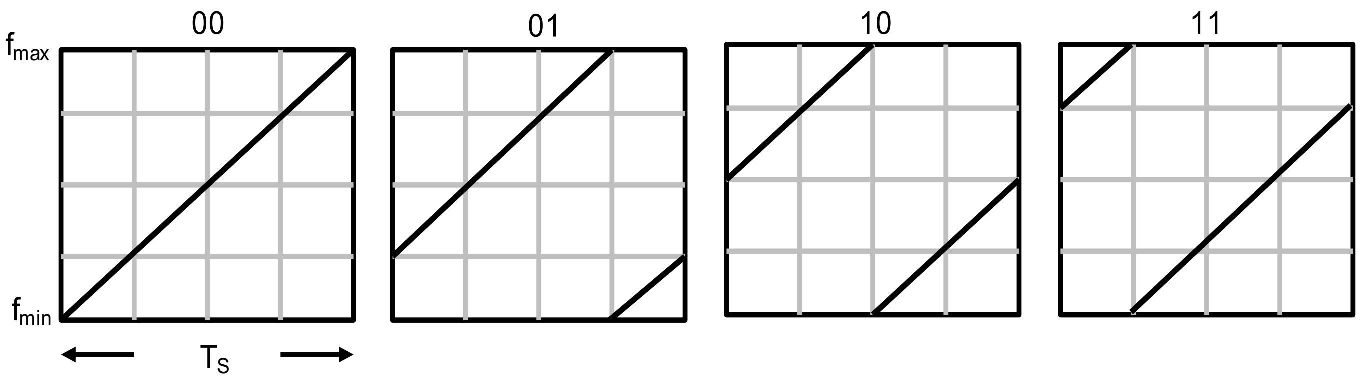
- How long does it take for a 1 MHz/s *linear* chirp to sweep the entire bandwidth of a 500 kHz channel?

$T = \mathrm{B/k} = (500 \times 10^3)/10^6 = 500 \text{ ms}$

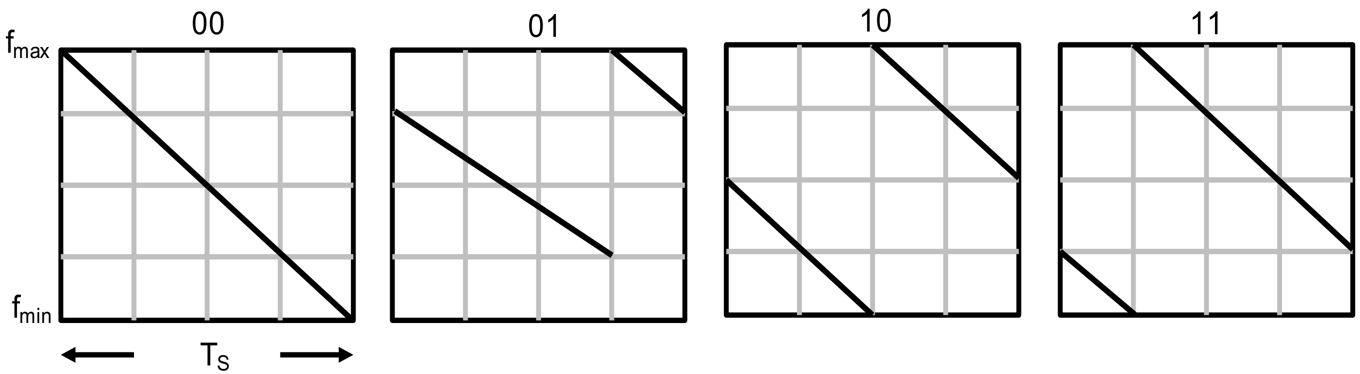
LoRa Modulation with Chirps

- Upchirps for uplink and downchirps for downlink
- 1 chirp = one symbol: symbol duration = chirp duration
- Shifts the starting frequency to modulate a chirp

4-ary modulation
4 different shifts
$\mathrm{Log}_2(4) = 2$ bits per symbol or chirp
For non-zero shift, chirp is ‘broken’ into 2 pieces



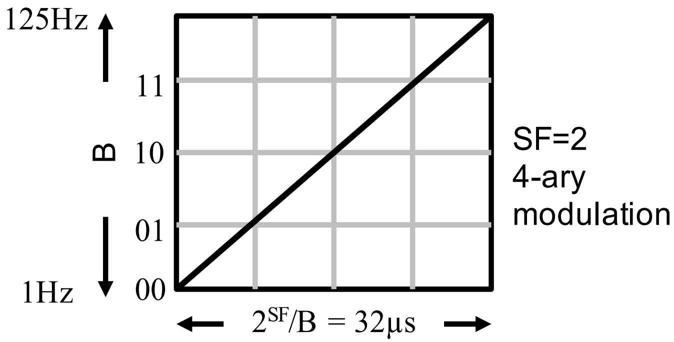
(a) Upchirps

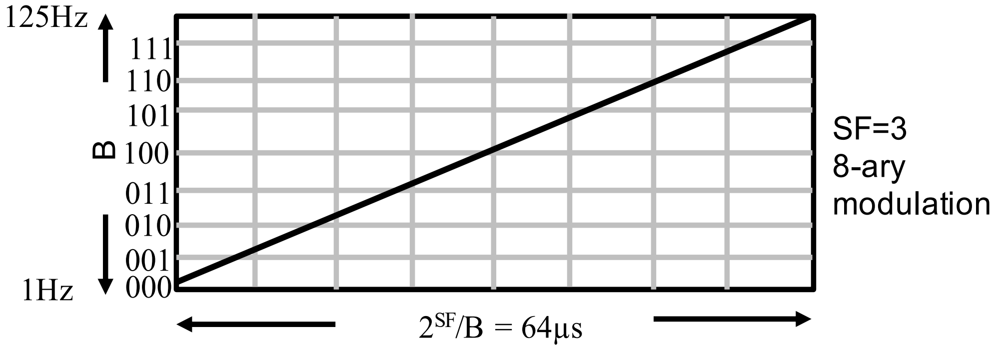


(b) Downchirps

Spreading Factor (SF)

- SF, an integer, controls the modulation order and the symbol duration
- SF bits per symbol; Modulation order (M) = 2^{SF} ; SF = $Log_2(M)$
- Symbol/chirp duration = $2^{SF}/B$
- Increasing SF by 1 would double the modulation order and also double the symbol duration
- Orthogonality: two transmitters with different SF would not interfere even using the same channel/frequency





Example

How long a LoRa transmitter would take to transmit one symbol over a 125kHz channel if it was configured with SF=10?

Solution:

$Ts = 2^{SF}/B = 2^{10}/125 \text{ ms} = 8.192 \text{ ms}$

LoRa Data Rate

- In contrast to most wireless networks, data rates for LoRa decreases with increasing SF, i.e., increasing the number of bits per symbol does not increase data rate because the symbol duration is also increased exponentially

$$Data\ rate\ =\ bits\ per\ symbol\ x\ symbol\ rate\ x\ coding\ rate\ =\ SF\ x\ \frac{B}{2^{SF}}\ x\ CR\ bps.$$

Where B is in Hz and CR is the FEC ratio between actual data bits and the total encoded bits

- CR options: 4/5, 4/6, 4/7, or 4/8
- SF is the control knob to trade-off between range and data rate
- SF options: 7, 8, 9, 10, 11,or 12

Example

A LoRa sensor is allocated a 125kHz uplink channel. What would be its effective data rate if it is forced to use a spreading factor of 10 and 50% redundancy for forward error correction?

Solution:

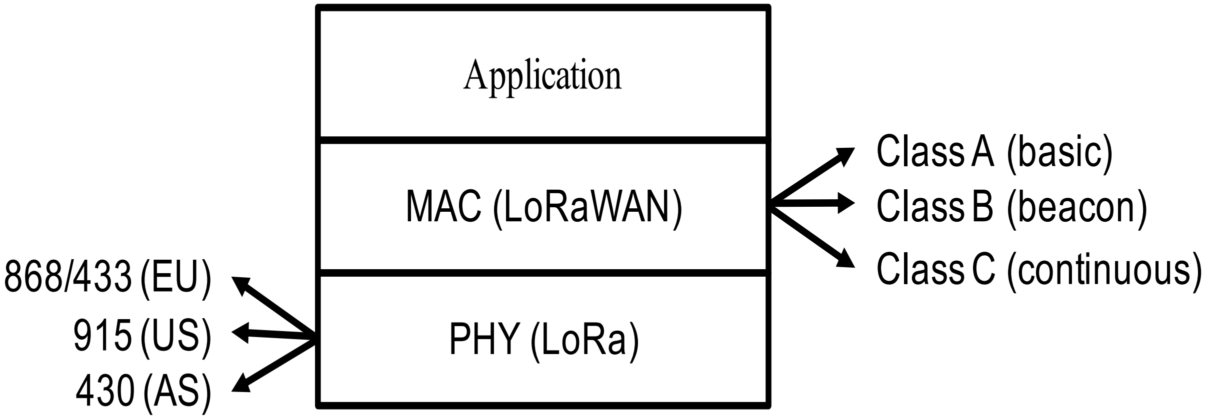
SF=10; 2^{SF}=1024; CR=0.5
Symbol rate = $B/2^{SF}$ sym/s = 125,000/1024 sym/s
Effective data rate = 10 x 125000/1024 x 0.5 = ~610 bps

LoRa Energy Consumption

- SF affects energy consumption of LoRa messages
- Energy consumed = transmission power x message air-time
- Shorter SF would consume less energy (higher data rate and hence shorter message air-time), and vice-versa
- LoRa implements adaptive data rate to select the minimum possible SF depending on the channel
- Devices closer to the BS (LoRa gateway) would use shorter SF and enjoy longer battery life compared to the ones far away from the BS

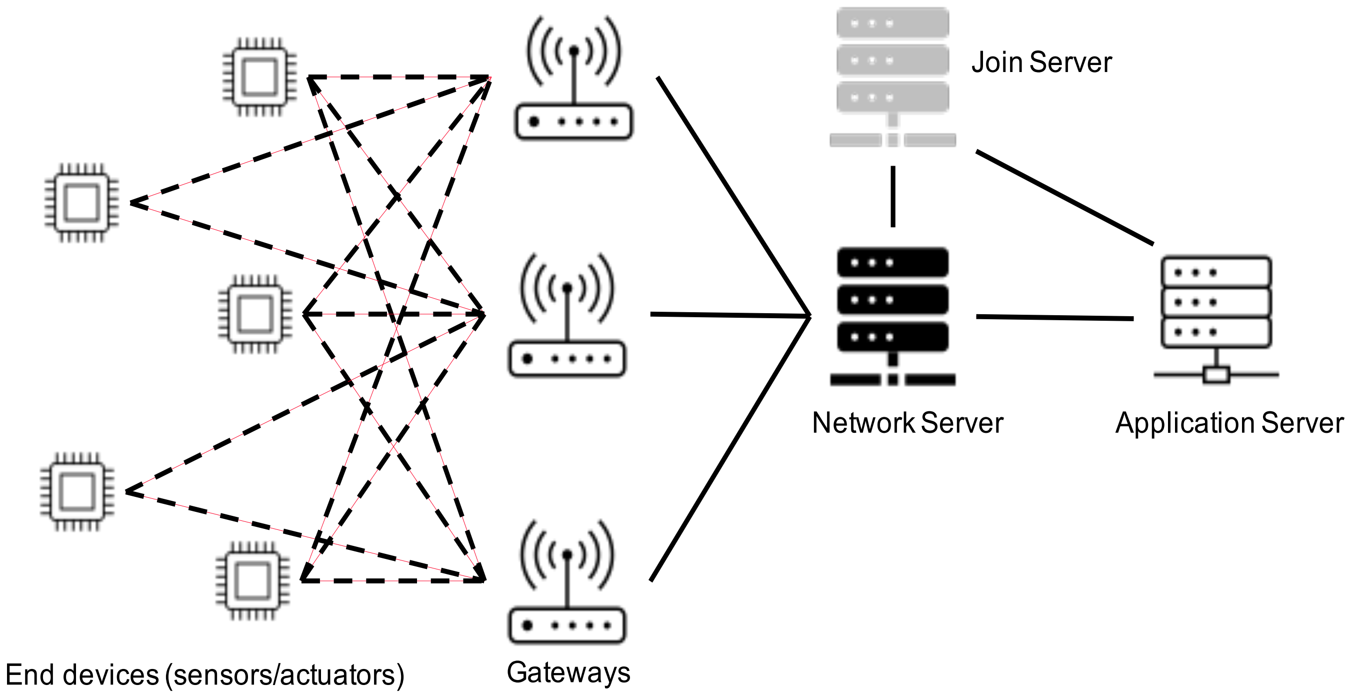
LoRaWAN: protocol stack

- LoRa (PHY) is patented
- LoRaWAN (MAC) is open source



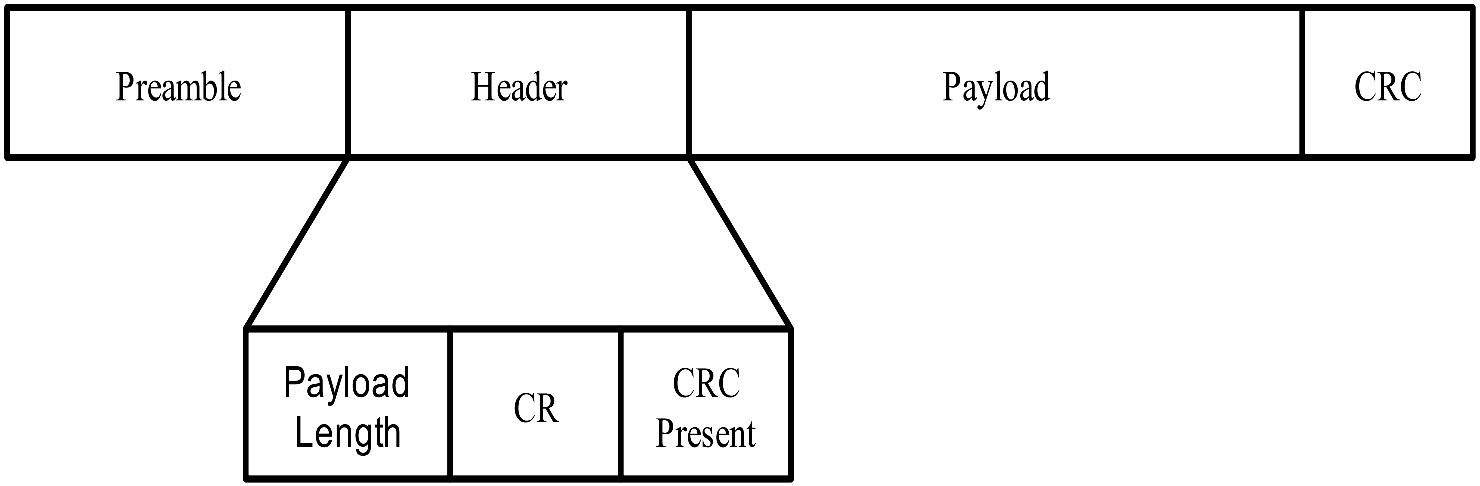
LoRaWAN End-to-end Network

- LoRa gatways operate at PHY layer
- Network server runs the MAC protocol



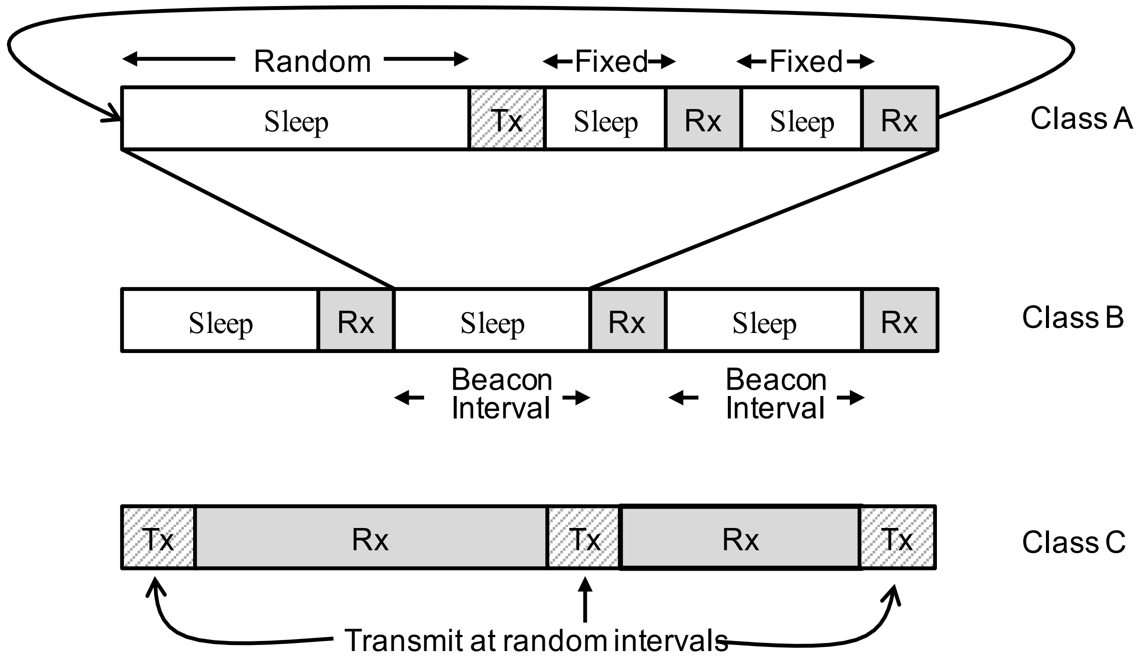
LoRa Packet Format

- Preamble: few upchirps followed by a few down chirps; synchronises clocks at transmitter and receiver
- Header is optional: automated configuration of payload length, coding rate, use of CRC
- Header would consume more energy; manual configuration at start of each session would eliminate the need for the header



LoRa Device Classes

- **Class A**: Uplink transmission followed by 2 short downlink; sleeps most of the time; lowest traffic and lowest energy consumption. Pure Aloha (contention-based) for channel access, performs well under light traffic, but under saturated traffic efficiency = 18.4% =1/2e
- **Class B**: Class A + extra receive window at scheduled time following the beacon from Gateway; suits devices that require more frequent communication from the server, e.g., sensors with actuation functions as well
- **Class C**: Can receive anytime (unless transmitting). Almost always awake and typically connected to the grid.



LoRa-LoRaWAN: Summary

1. LoRa is designed to work with narrow bandwidth channels, long symbols, and low data rates; data rate is sacrificed for longer range.
2. LoRa modulation is a variation of chirp spread spectrum where the modulation order as well as the frequency sweeping speed of the chirp is modulated by an integer variable called spreading factor (SF).
3. For a given bandwidth B Hz and spreading factor SF, modulation order = 2^{SF} and symbol duration = $2^{SF}/B$ sec. As a result, contrary to typical wireless communications, increasing the modulation order actually decreases the data rate in LoRa.
4. For a given bandwidth, the larger the SF, the longer the symbol duration and longer the range at the expense of reduced data rates.
5. Orthogonality of the SF enables transmission of multiple LoRa chirps at the same frequency channel and at the same time slot.
6. There are 6 valid SF values in LoRa: 7 to 12.
7. LoRa data contains either all upchirps or all downchirps depending on the direction of communication (uplink vs. downlink); upchirps and downchirps are never mixed within the same LoRa packet except for the preamble field.
8. LoRa end devices broadcast to all gateways within range. The gateway with the best connectivity replies back.
9. LoRa gateways are only PHY-layer devices; all MAC processing is done at the network server.
10. LoRa supports 3 classes of devices. Class A devices can sleep most of the time to conserve energy but allow most restricted access from the network. Class B devices can be accessed more frequently by the network at the expense of higher energy consumption. Class C devices are usually powered by the mains; they never sleep and hence can be reached by the network at any time without delay.