COMP3516: Data Analytics for IoT

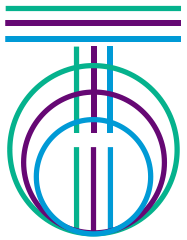
Lecture 2: Wireless for IoT

Chenshu Wu

Department of Computer Science

2026 Spring

香 港 大 學
THE UNIVERSITY OF HONG KONG

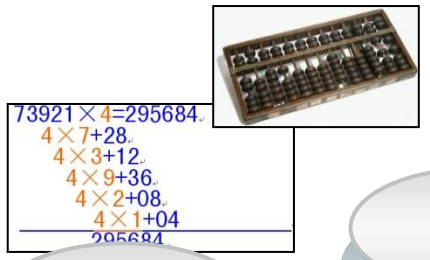


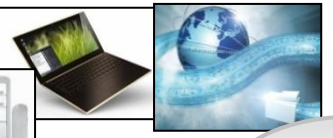
HKU AIoT LAB
香港大學人工智能物联网實驗室

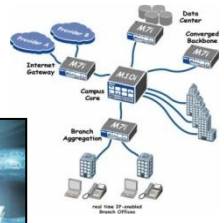
Content

- Internet
- Wireless Networks
- Wireless Sensor Networks
- LoRa Communication
- Other IoT Wireless Protocols
  - ZigBee, Bluetooth, VLC, WiFi…

Computing as Science







1946 First Computer

1965 High Performance Computing

1980 Personal Computer

1995 **Internet**

2010 Smart Planet/ CPS/Intern et of Things

2020 **AIoT**

Omnipresent connectivity & sensing

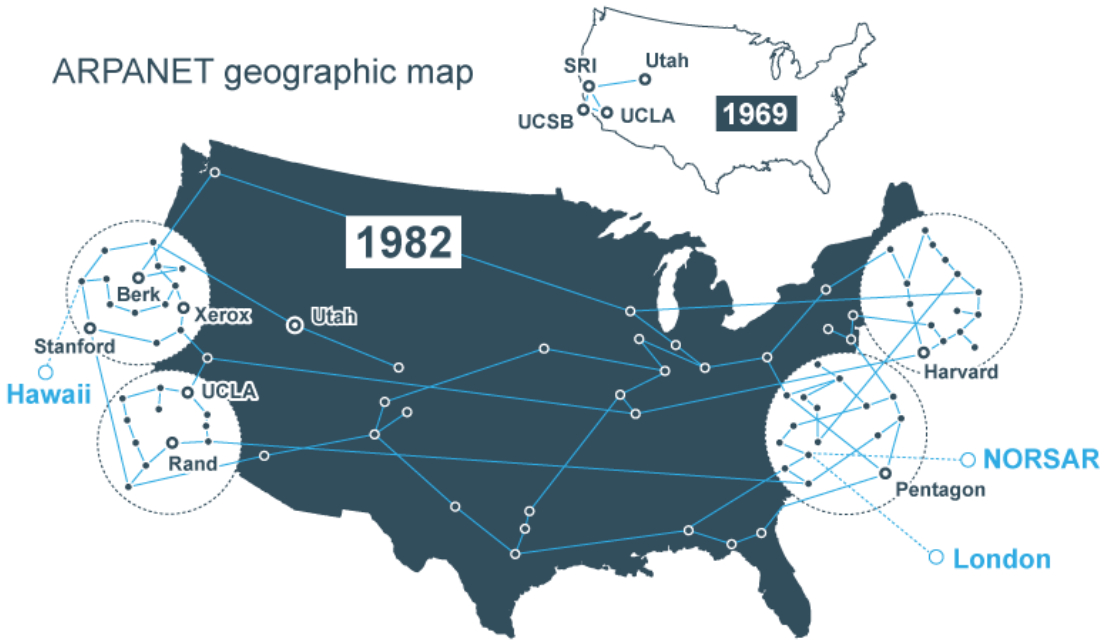
Science → **Internet** → **AI Service**

ARPAnet

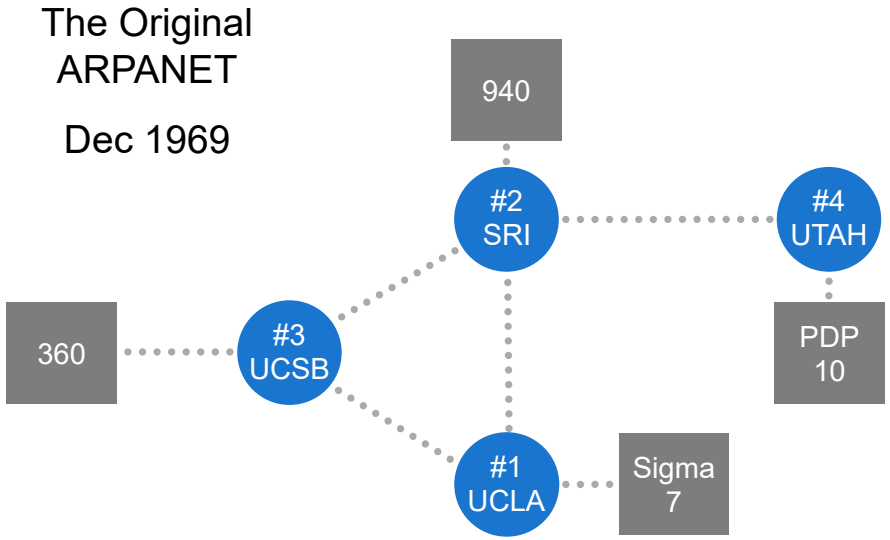
- 1967: ARPAnet conceived by Advanced Research Projects Agency

ARPAnet

- 1969: First ARPAnet node operational
- 1982: TCP/IP is emerged into ARPAnet



Google

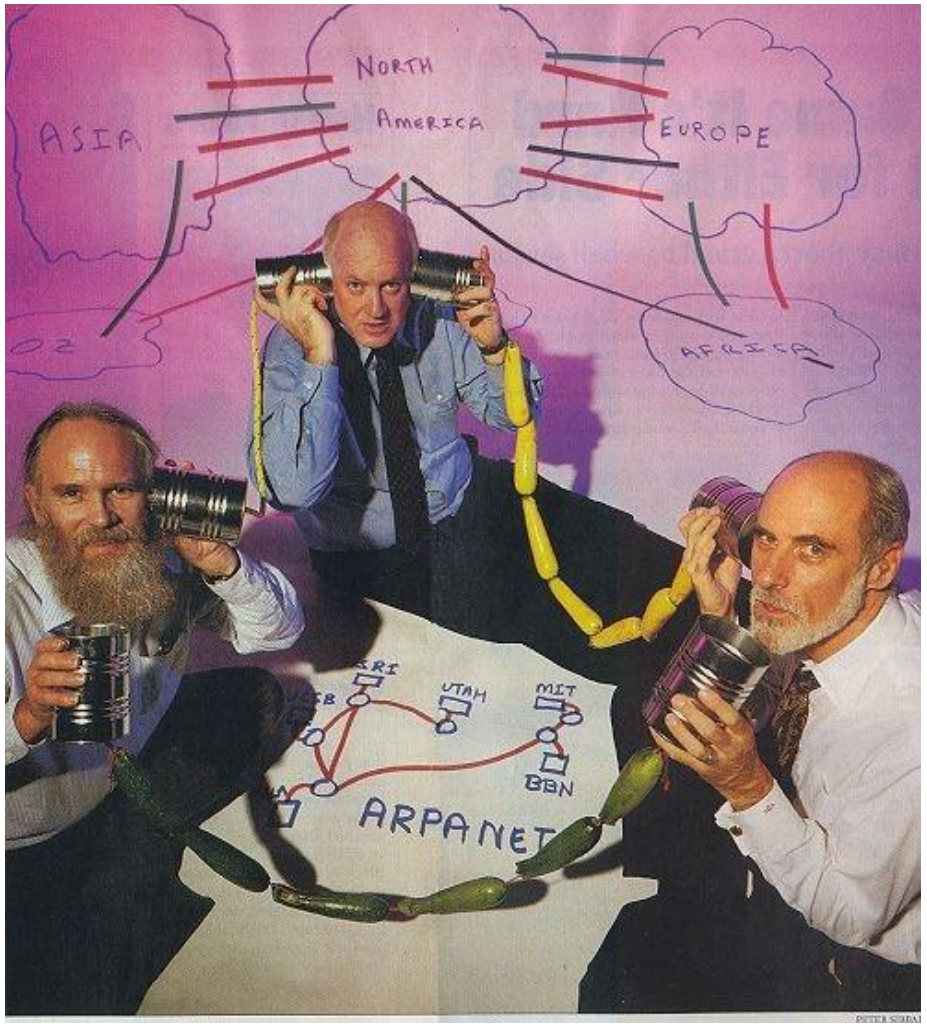


From Vinton Cerf

From Vinton Cerf

25th Anniversary of ARPANET – 1994

Jon Postel, Steve Crocker, Vint Cerf

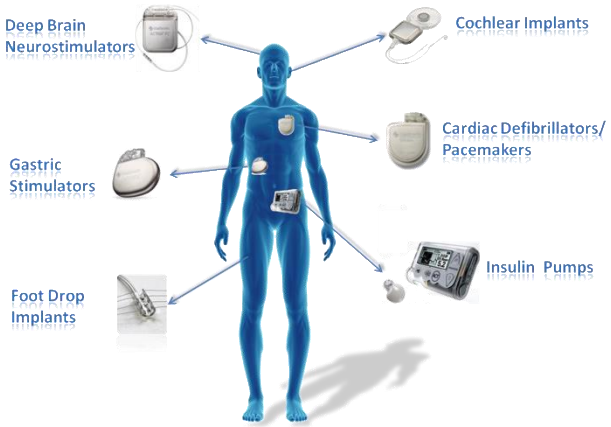


The greatest illusion about network is the feeling that it does not exist.

Wireless Networks Are Every Where

Wireless Homes

Wireless Biomedical Implants



Wireless Wearables

Cellular Networks

Wireless Sensors

UAVs

Wireless Data Centers

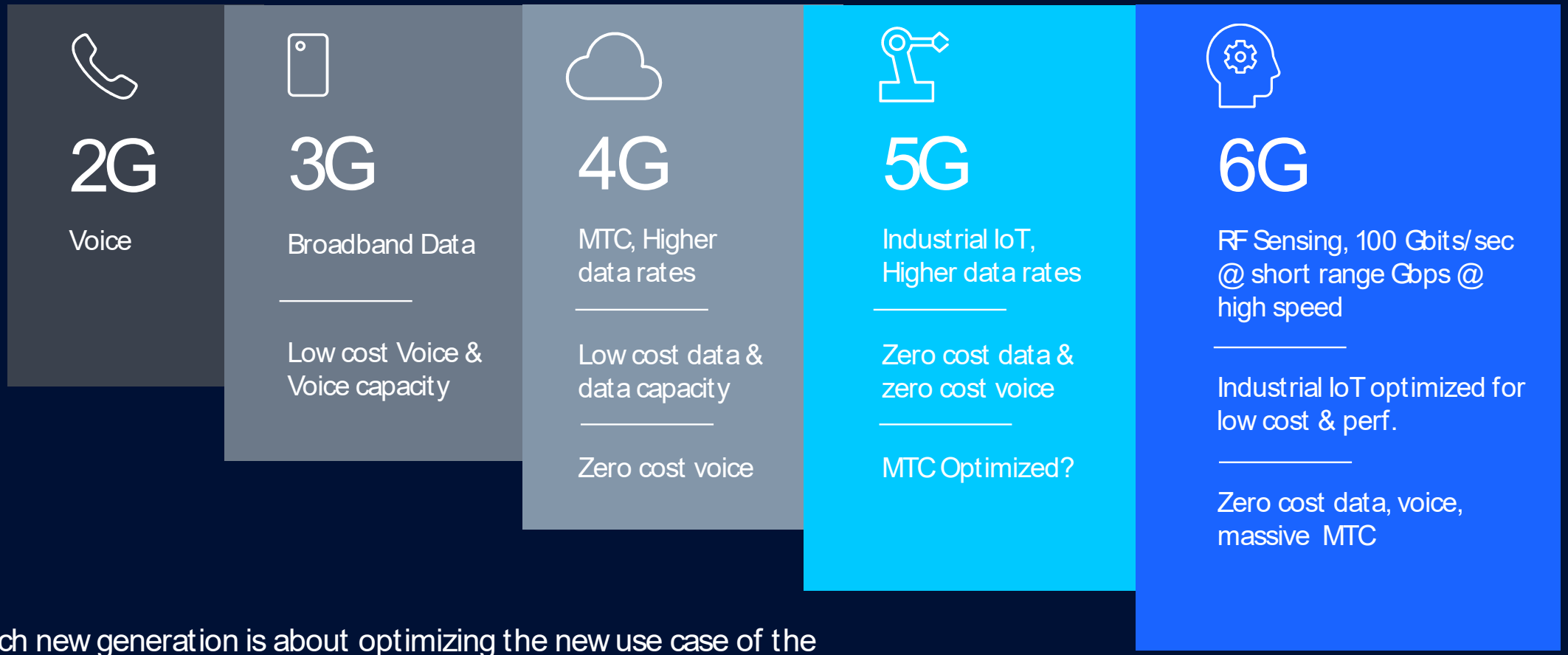
Wireless VR

Wireless Vehicles

Wireless-less?

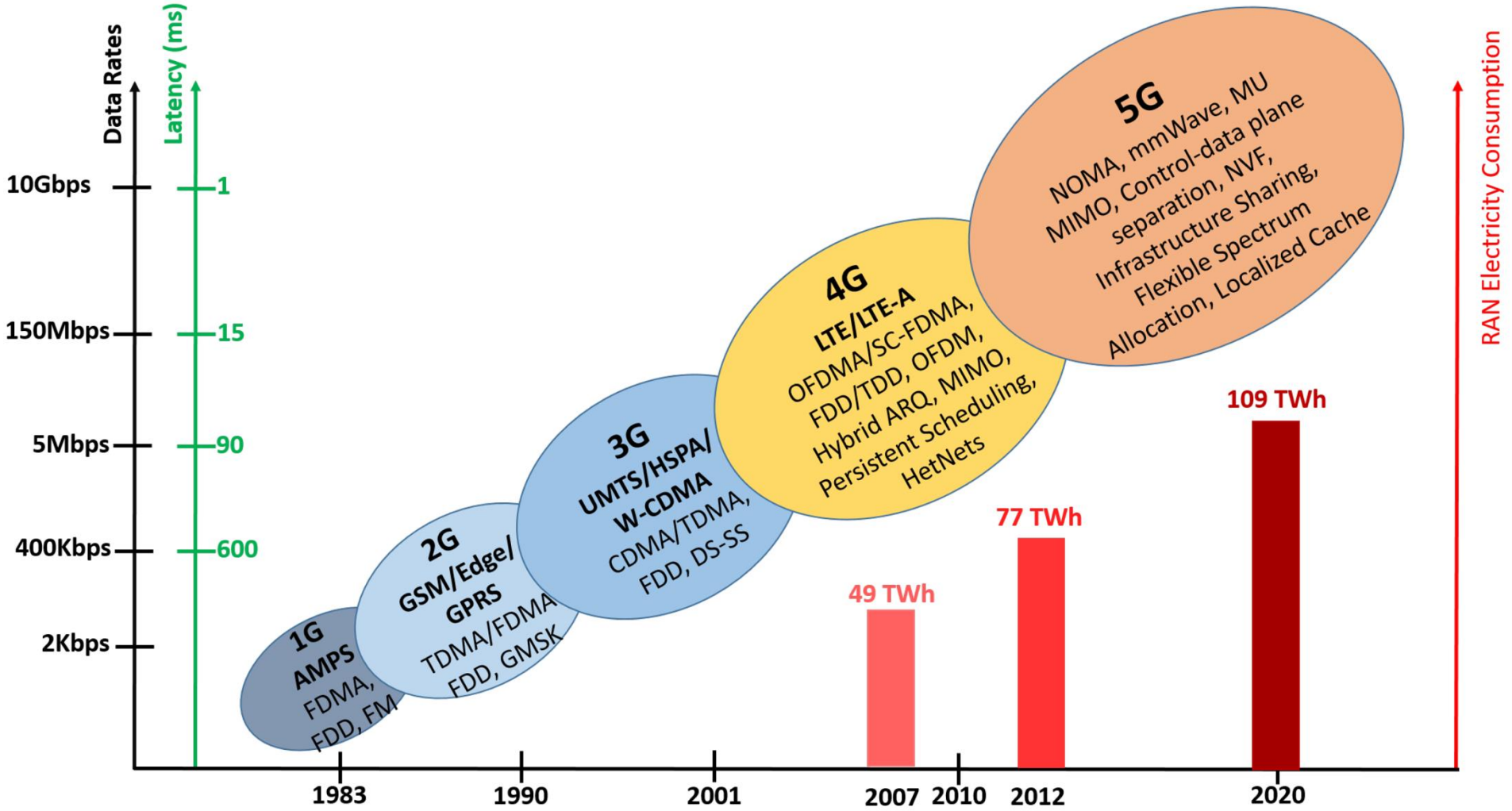
- 10 years ago:
  - Cannot believe that a laptop has no Ethernet port
- Now:
  - Cannot believe that a laptop still has an Ethernet port

The past, present, and future

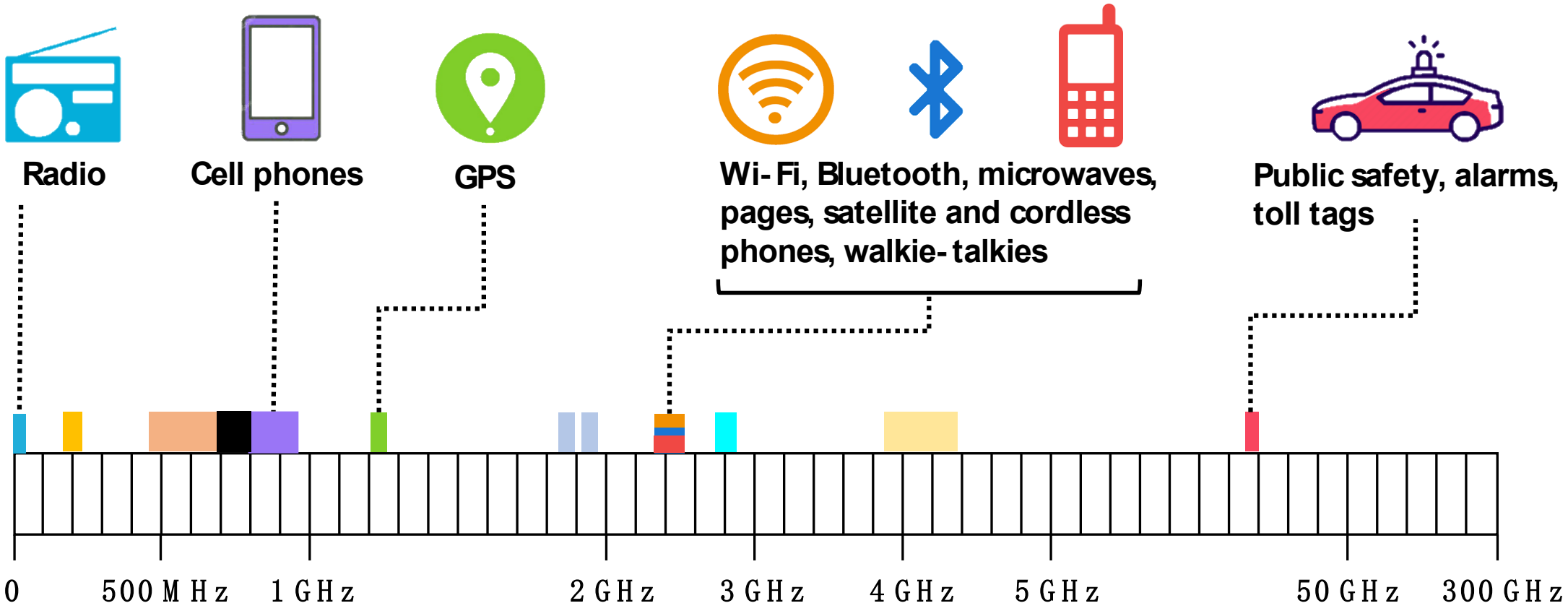


Each new generation is about optimizing the new use case of the previous generation to reduce cost and introduction of new use cases

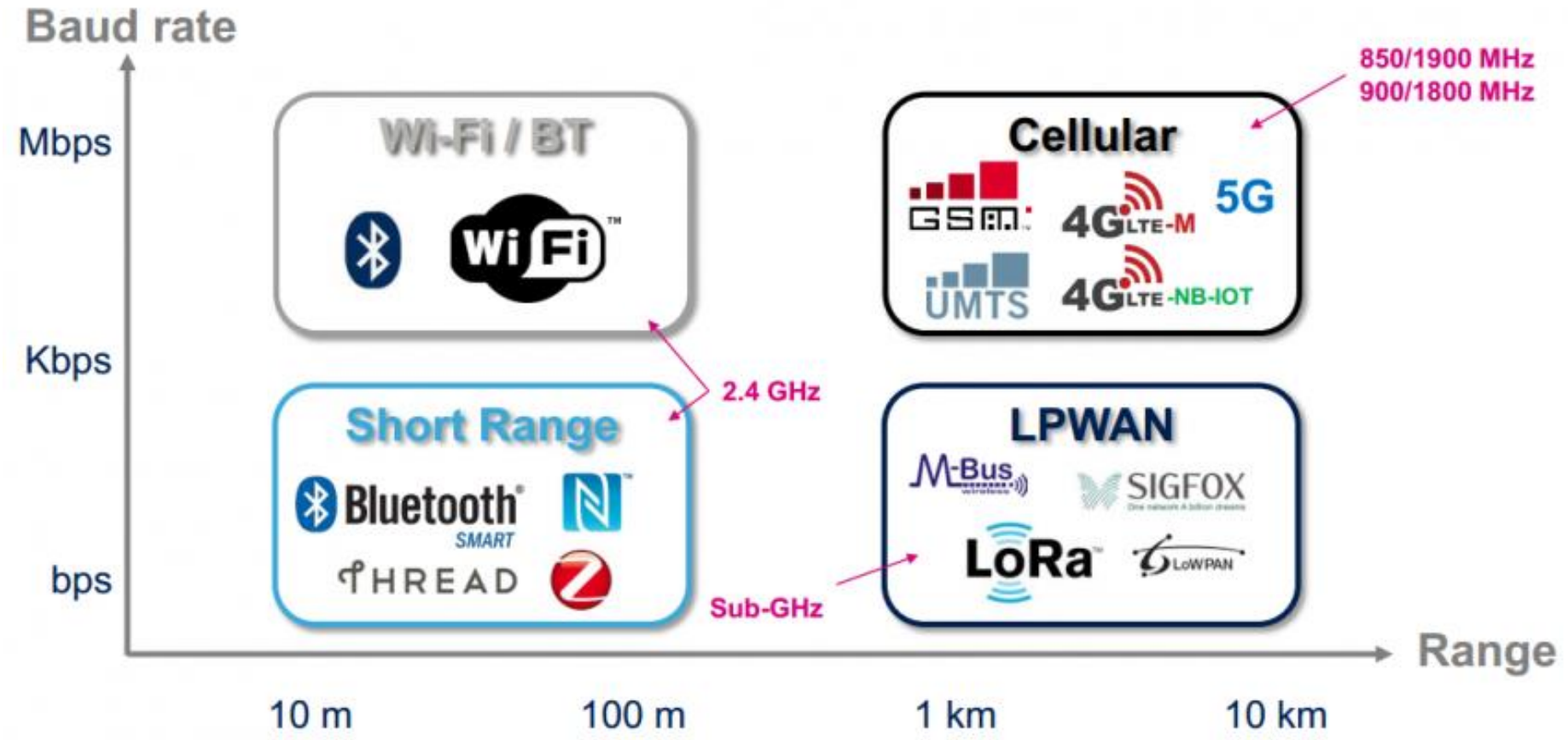
5G: High Frequency; MIMO



Spectrum


Radio
Cell phones
GPS
Wi-Fi, Bluetooth, microwaves, pages, satellite and cordless phones, walkie-talkies
Public safety, alarms, toll tags
0
500 MHz
1 GHz
2 GHz
3 GHz
4 GHz
5 GHz
50 GHz
300 GHz

Range & Data Rate



IoT Technologies

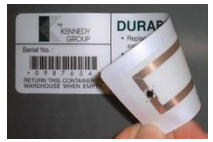
Wi Fi

Bluetooth

ZWAVE

NFC

RFID



ZigBee

Cellular

NB-IoT

LTE-M

sigfox

LoRa

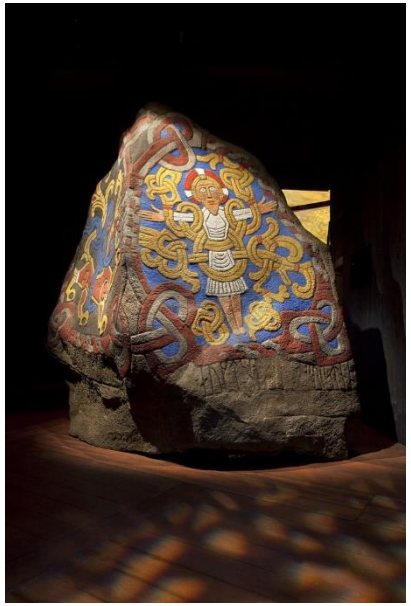
neul

Bluetooth

- Bluetooth is a short-distance wireless technology for Personal Area Networks (PAN).

The Name of Bluetooth

- Business-RF (Intel)
- MC-Link (Ericsson)
- Low Power RF (Nokia)



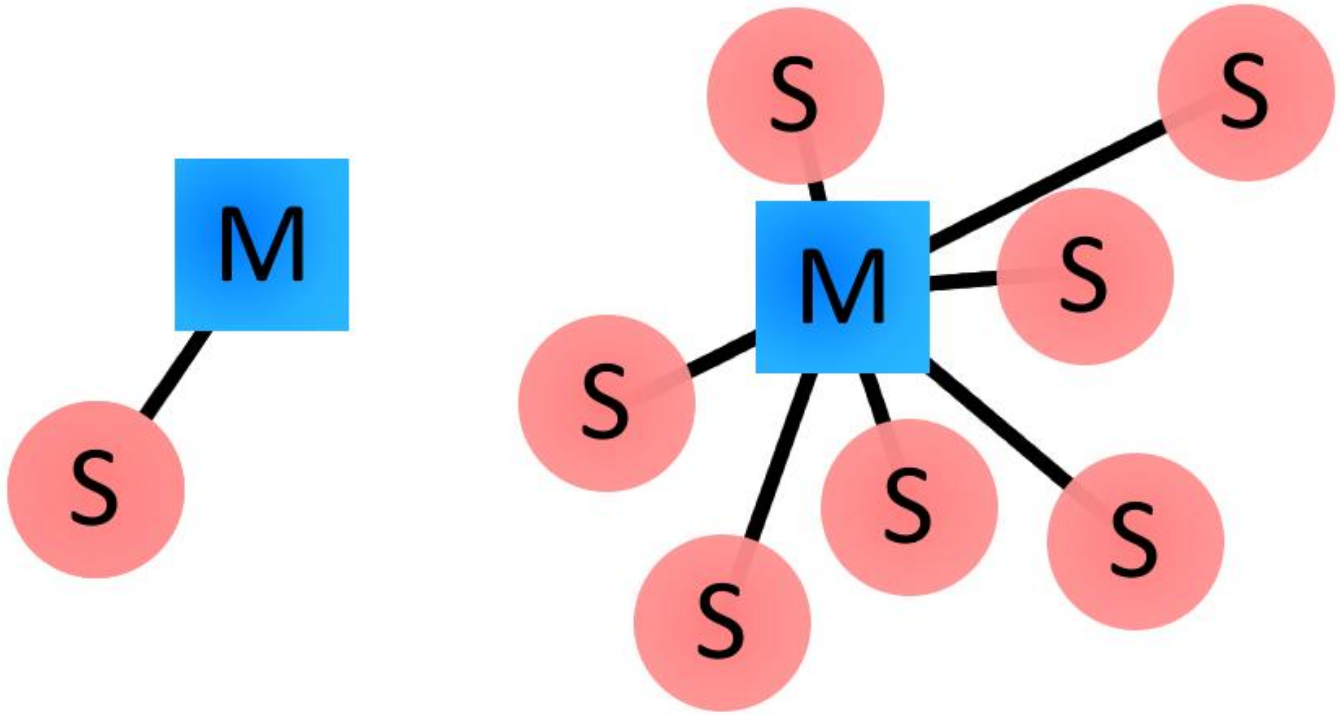
Bluetooth®

- Denmark King: Harold Bluetooth
  - Harald united Denmark and Norway
  - Harald thinks that mobile PC's and cellular phones should seamlessly communicate

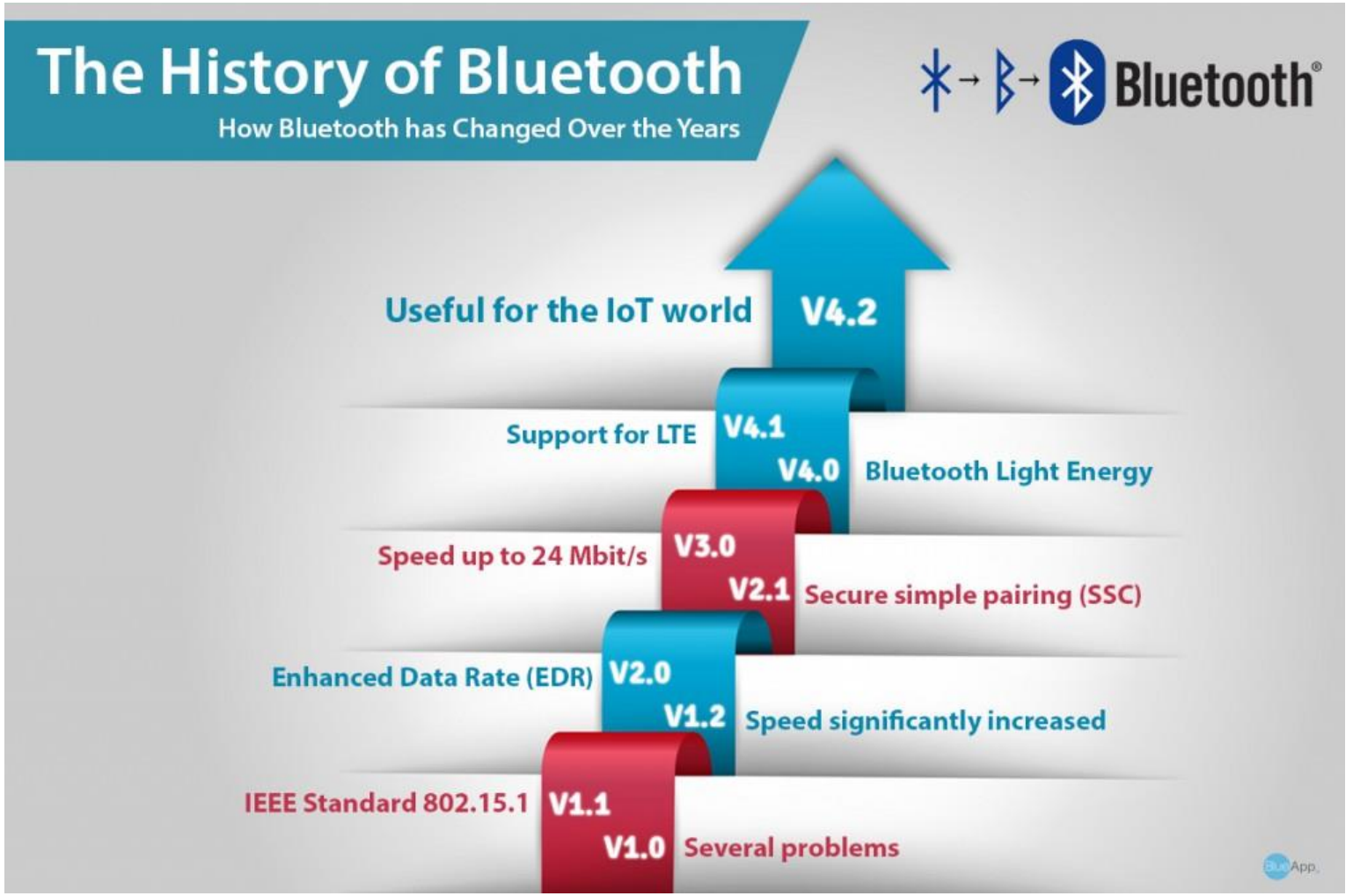
Jim Kardach

Master and Slave Connection

- Two roles: slave and master, one master can support 7 slaves at most.



Bluetooth Evolution



Classic Bluetooth v.s. BLE

Standard	Classic	BLE
Frequency	2.4GHz	2.4GHz
Range	100m	> 100m
Data Rate	1 - 3Mbps	1Mbps
Latency	100ms	6ms
Current Consumption	< 30mA	< 15mA

Bluetooth Devices

Wi-Fi

- Wi-Fi is a generic term that refers to the IEEE 802.11 communications standard for Wireless Local Area Network (WLANs)
- (One of) the most successful wireless communication technologies
  - 30 billions of WiFi-connected devices

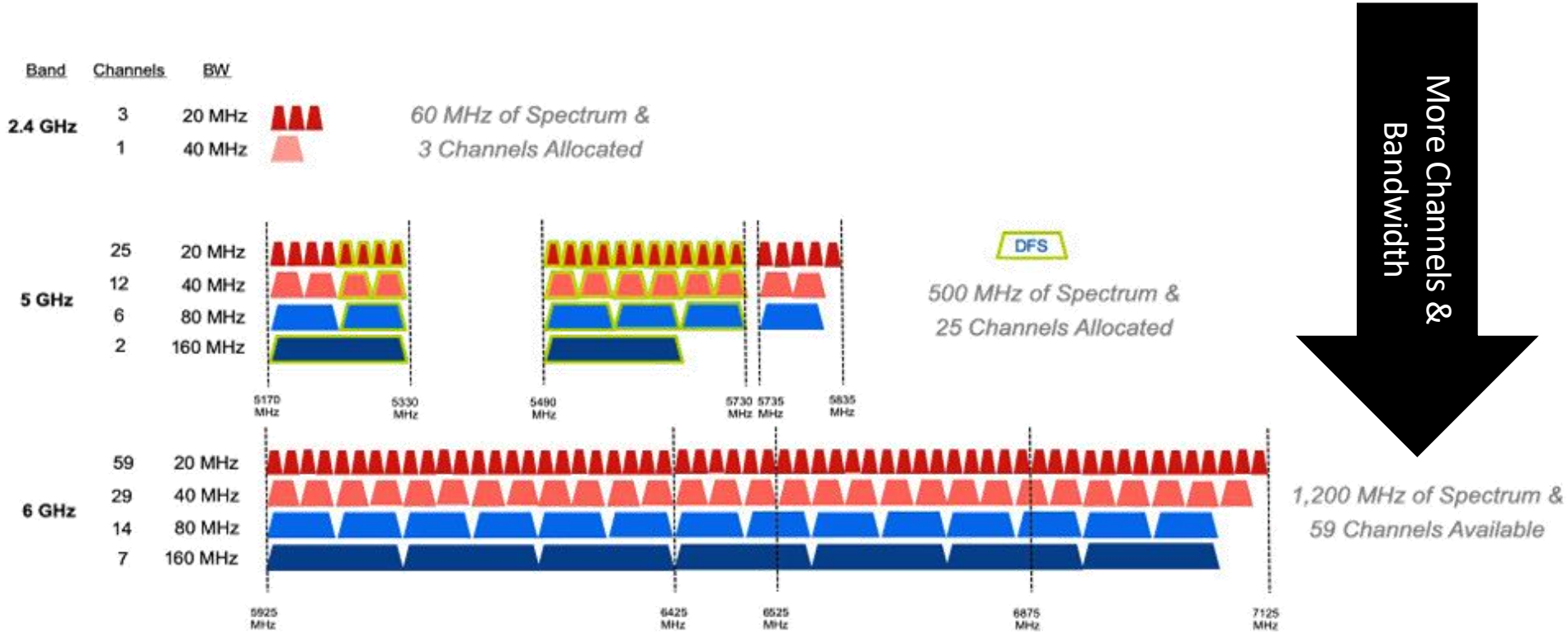
Wi-Fi Devices

Integrating Wi-Fi Smart Applications.

IEEE 802.11 standard

Generation/IEEE Standard	Maximum Linkrate	Adopted	Frequency
Wi-Fi 6 (802.11ax)	600–9608 Mbit/s	2019	2.4/5 GHz 1–6 GHz ISM
Wi-Fi 5 (802.11ac)	433–6933 Mbit/s	2014	5 GHz
Wi-Fi 4 (802.11n)	72–600 Mbit/s	2009	2.4/5 GHz
802.11g	3–54 Mbit/s	2003	2.4 GHz
802.11a	1.5 to 54 Mbit/s	1999	5 GHz
802.11b	1 to 11 Mbit/s	1999	2.4 GHz

WiFi Standards from WiFi 1 to WiFi 6



WiFi 1 — More MIMO Antennas — WiFi 5/6

1994, CSIRO, Australia

- “I certainly had no idea where things would lead. Back then, we set out to do a wireless network at 100 megabits per second. Many people thought we had rocks in our head to try doing such a thing. We thought it really would be big, but now I look back and I'm just blown away at how big it has become.”

John O’Sullivan

As of April 2012, the CSIRO has earned over $430 million in royalties and settlements arising from the use of this patent as part of the 802.11 standards with as much as a billion dollars expected after further lawsuits against other parties.

2002, Zigbee Alliance

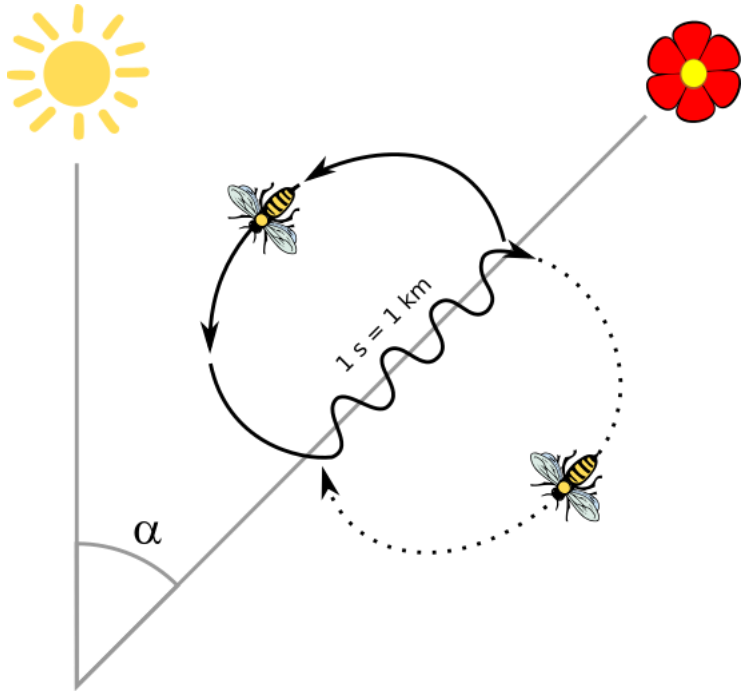
- WiFi
  - High energy consumption
  - High deployment cost
- Bluetooth
  - Limited scenarios
  - Less scalable
- A flexible wireless communication to achieve IOT
  - Low power
  - Low data rate
  - Ad-hoc network

Zigbee

- Zigbee (802.15.4) is a low-power, low data rate, low complexity and ad-hoc communication approach.

Zigbee

- Bee dances in a zig-zag pattern. In this way, it is able to share information, such as the location, distance and direction of a newly discovered food source to its fellow colony members.

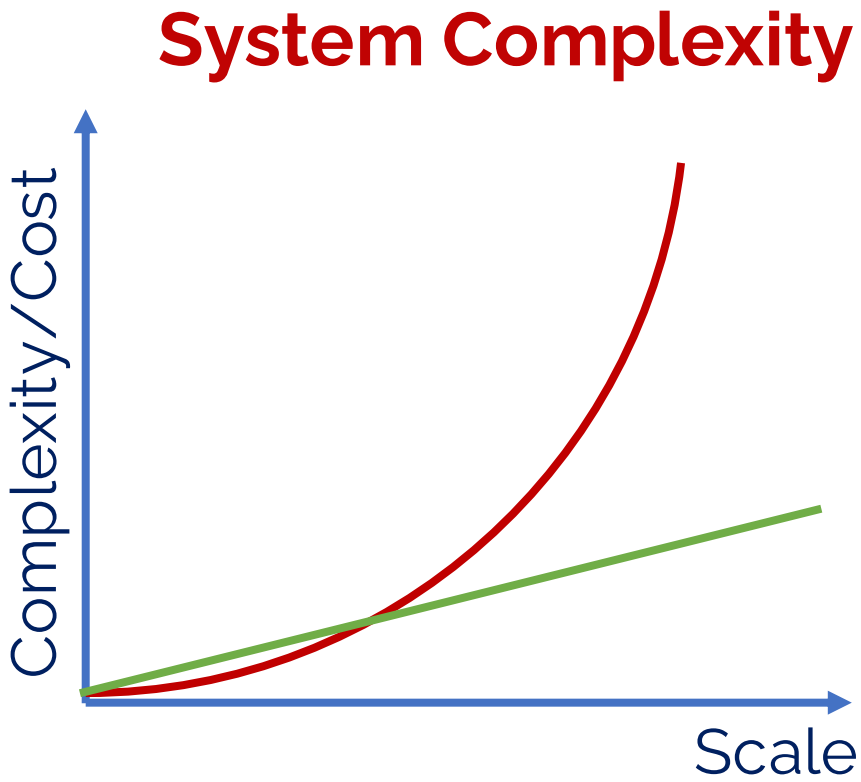


ZigBee

- 2.4GHz(Global), 868 MHz(Europe) and 915MHz(US). Up to 250kb/s, 20kb/s and 40kb/s respectively.
- Range 10-180 meters.
- Low data transmission with 1-100 mW output power.
- At sleep mode, uW level power consumption.

Two Big Challenges of WSNs

- Dedicated devices
  - → Wireless & Sensorless Sensing
- Power Supply (battery-powered)
  - Batteryless or Backscatter



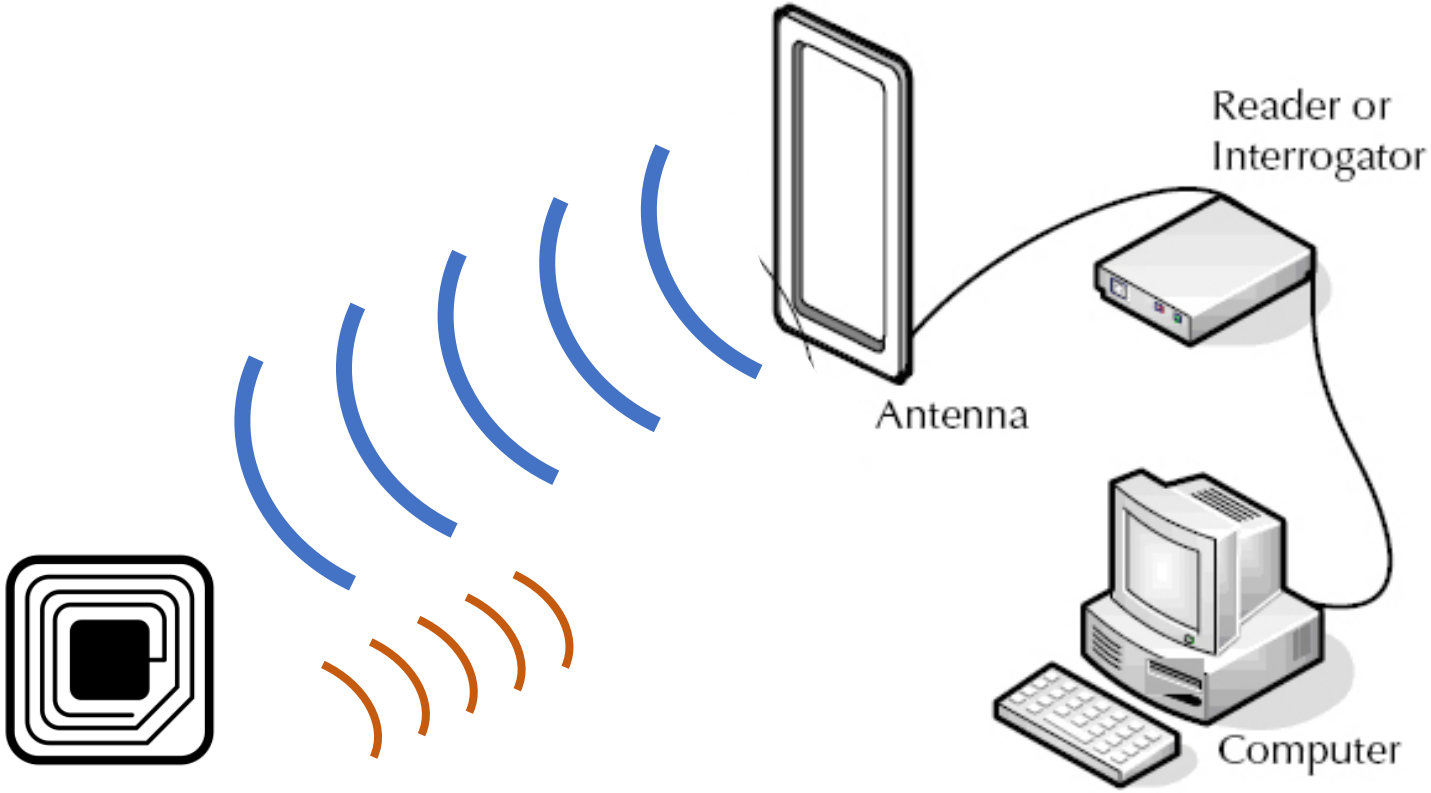
1996, Special Interest Group (SIG) on Short-range Link

- “Power is one of the key attributes. Battery life is life. It’s the life of the product. To ignore that is totally unacceptable. You have to design things to work efficiently, but more importantly, do nothing efficiently.”

Jim Kardach, Mr. Bluetooth

RFID: ”5 cents computing”

- Radio-frequency identification

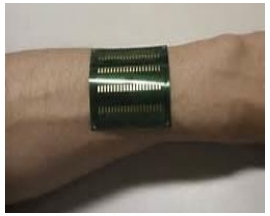


RFID Applications

Obtain the energy with Ambient RF Signals?


Solar Energy


Motion Energy


Thermal Energy


Wind Energy


Bioenergy


Electromagnetic Energy

- **RF energy is everywhere, and always available**


TV Tower


Cell Site


Radio Tower


RFID Reader

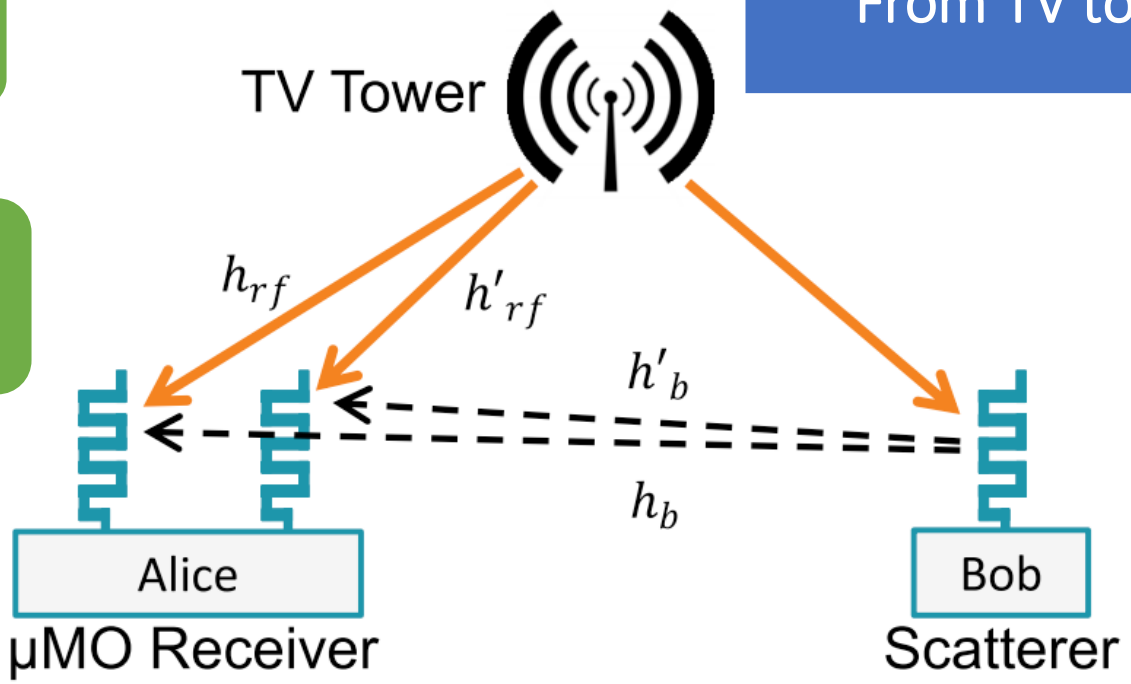

AP

Obtaining the Energy — Ambient Backscatter

Dual Antenna

Data rate: 100 ×
Distance: 10 ×

From TV towers



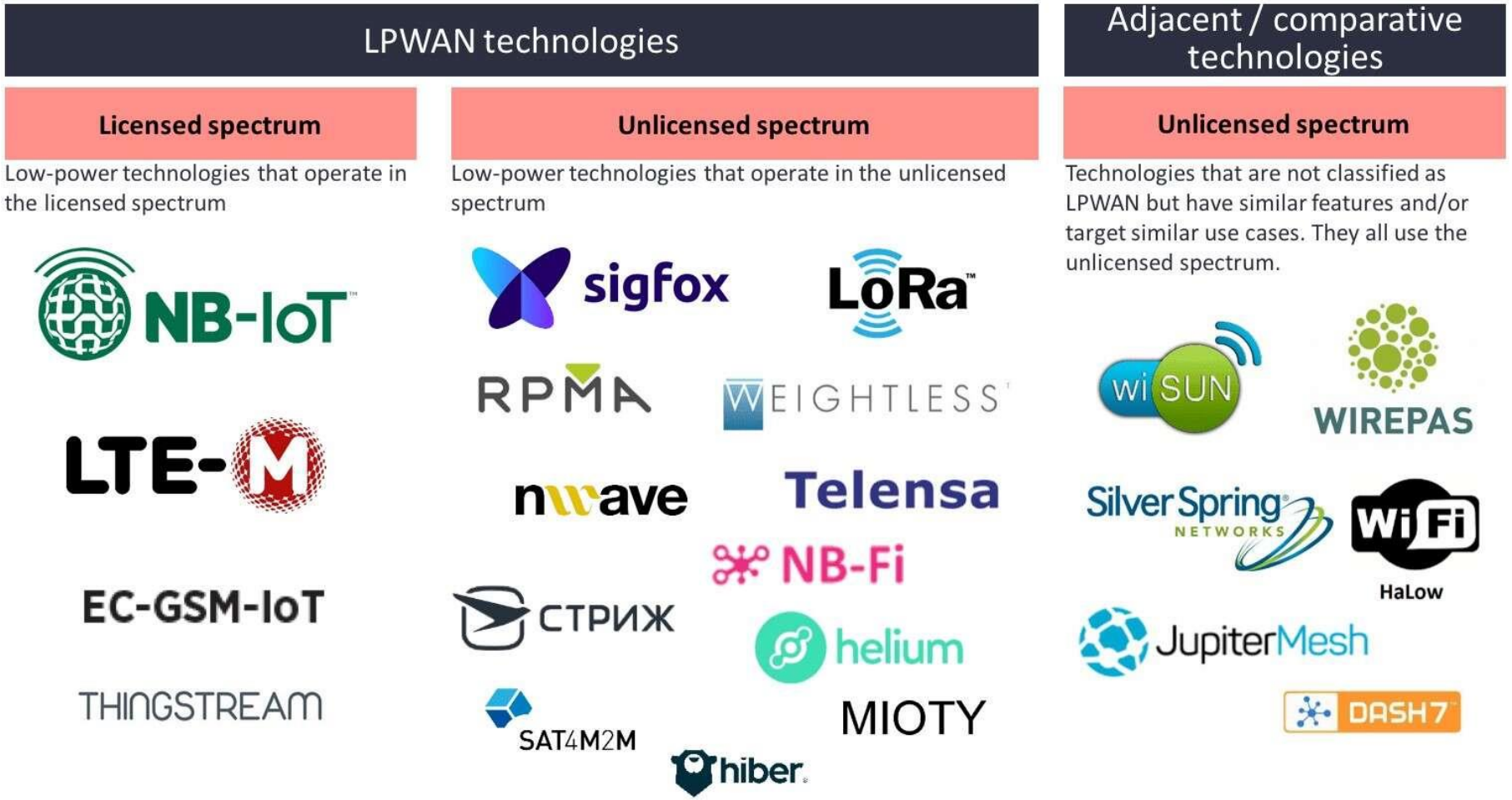
Turbocharging Ambient Backscatter Communication
Aaron N. Parks, Angli Liu, Shyamnath Gollakota, Joshua R. Smith (*University of Washington*), *SIGCOMM 2014*

https://www.youtube.com/watch?v=gX9cbxLSOkE&t=26s

https://www.youtube.com/watch?v=YK2j6VV7sZ0

LPWAN: Low Power Wide Area Network

High-level overview of current LPWAN technologies



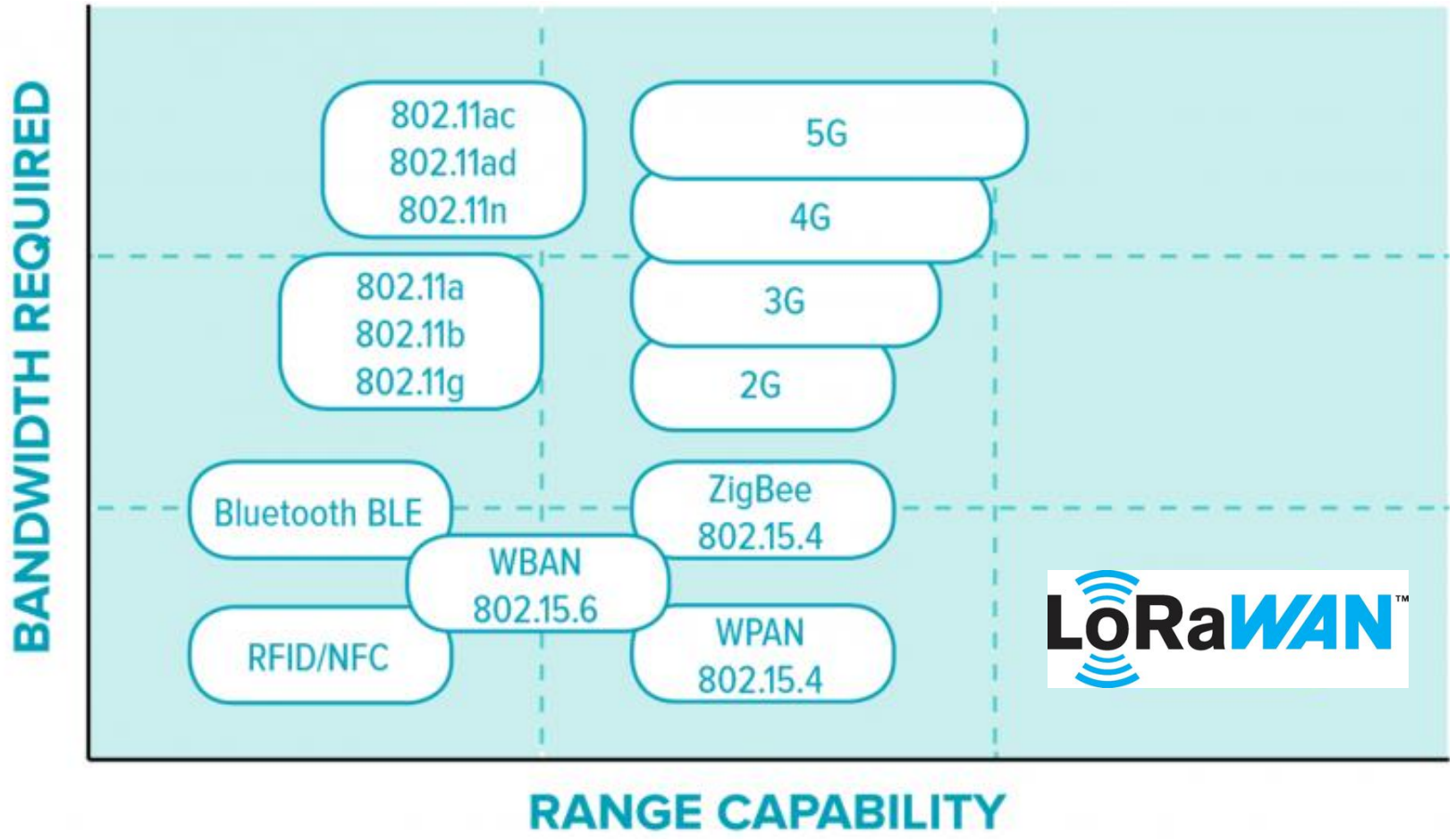
Source: IoT Analytics LPWAN Market Report 2018 - 2023

Communication

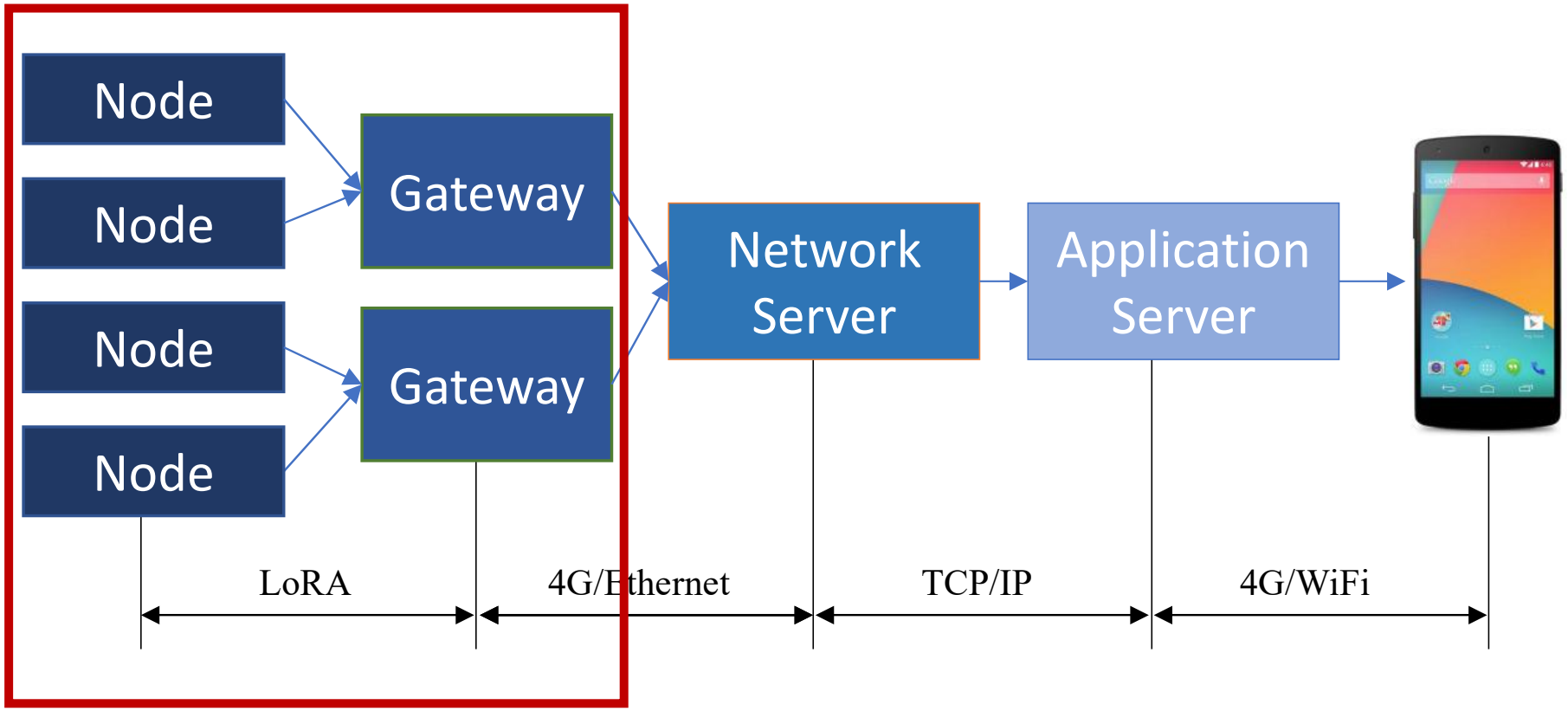
- A general view: Sending/Receiving an agreed set of symbols

- What is the computer's version of this?

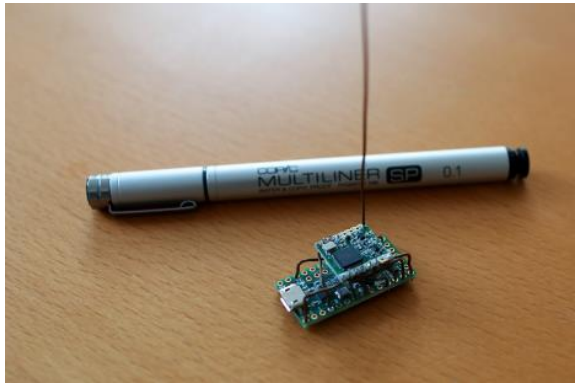
LPWAN: Low Power Wide Area Network



LPWAN: Low Power Wide Area Network



LoRa (Long Range)



LoRa Node

LoRa Gateway

LoRa (Long Range)

Key Features of LoRa Technology

Long Range
Connects devices up to 30 miles apart in rural areas and penetrates dense urban or deep indoor environments

Low Power
Requires minimal energy, with prolonged battery lifetime of up to 10 years, minimizing battery replacement costs

Secure
Features end-to-end AES128 encryption, mutual authentication, integrity protection, and confidentiality

Standardized
Offers device interoperability and global availability of LoRaWAN networks for speedy deployment of IoT applications anywhere

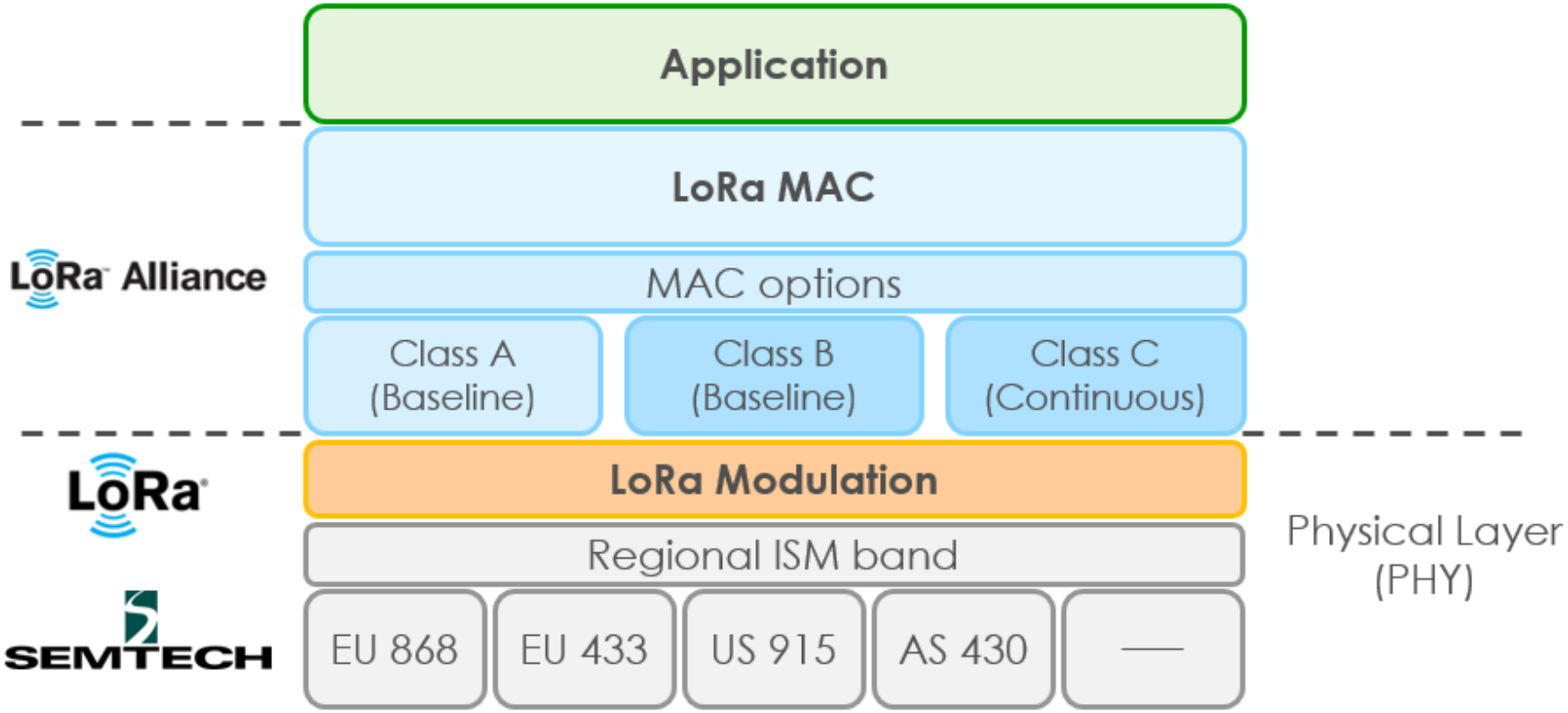
Geolocation
Enables GPS-free tracking applications, offering unique low power benefits untouched by other technologies

Mobile
Maintains communication with devices in motion without strain on power consumption

High Capacity
Supports millions of messages per base station, meeting the needs of public network operators serving large markets

Low Cost
Reduces infrastructure investment, battery replacement expense, and ultimately operating expenses

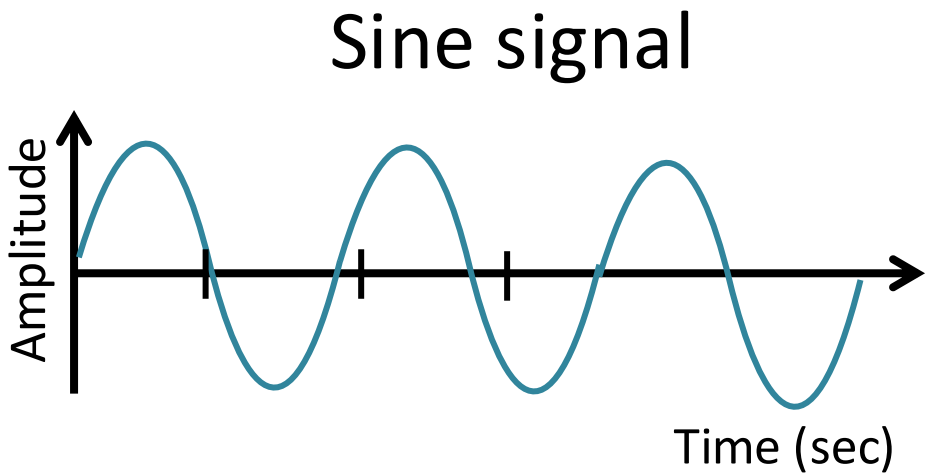
LoRa Stack

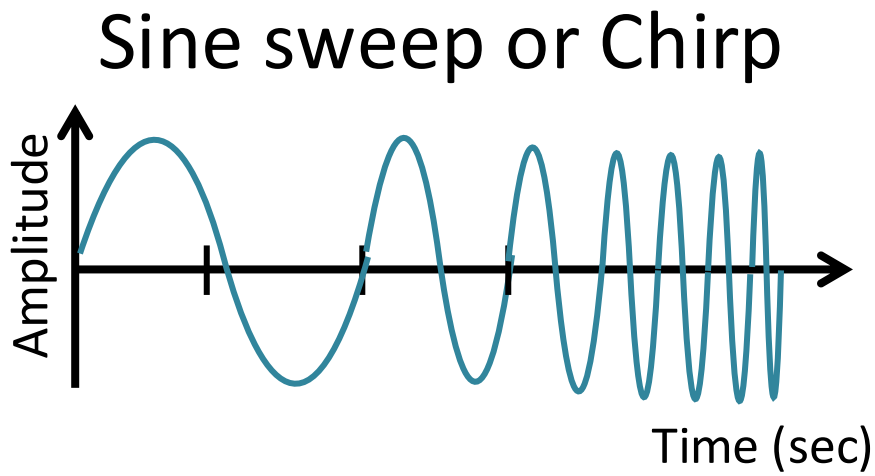

Application
LoRa MAC
LoRa Alliance
MAC options
Class A (Baseline)
Class B (Baseline)
Class C (Continuous)
LoRa
LoRa Modulation
Regional ISM band
SEMTECH
EU 868
EU 433
US 915
AS 430
—
Physical Layer (PHY)

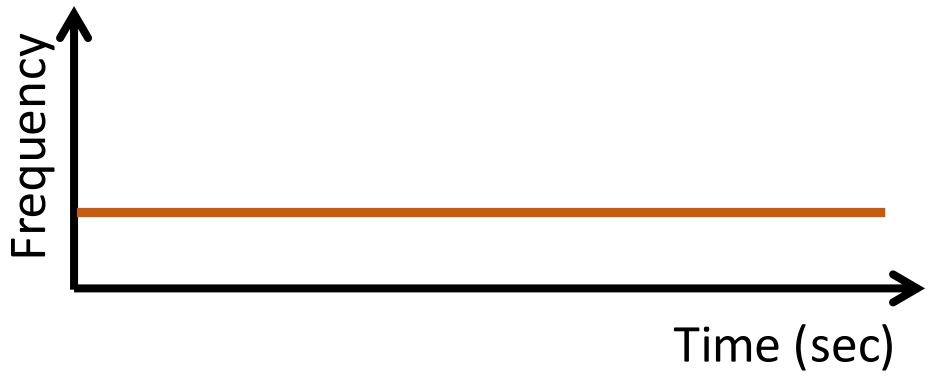
LoRa Communication

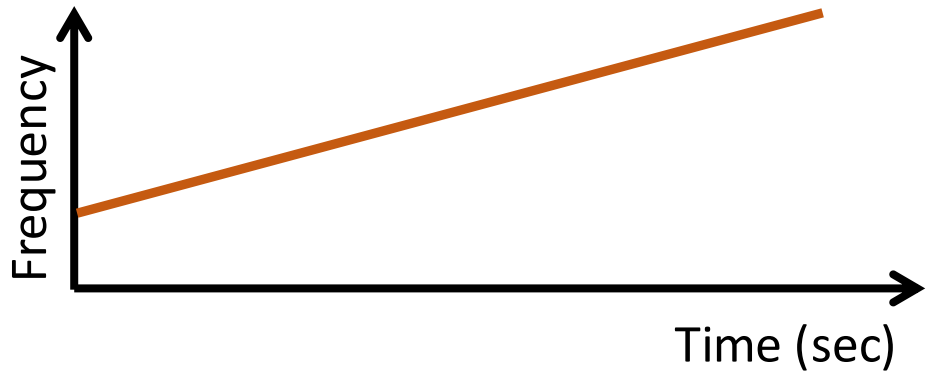
- Utilizes unlicensed ISM bands
  - Promises kilometers of communication distances
  - And years of battery life
- Use Chirp Spread Spectrum (CSS)
  - Robust to interference, multipath, and Doppler effects
  - High channel capacity: simultaneous transmissions on a single channel

LoRa: Chirp Spread Spectrum (CSS)

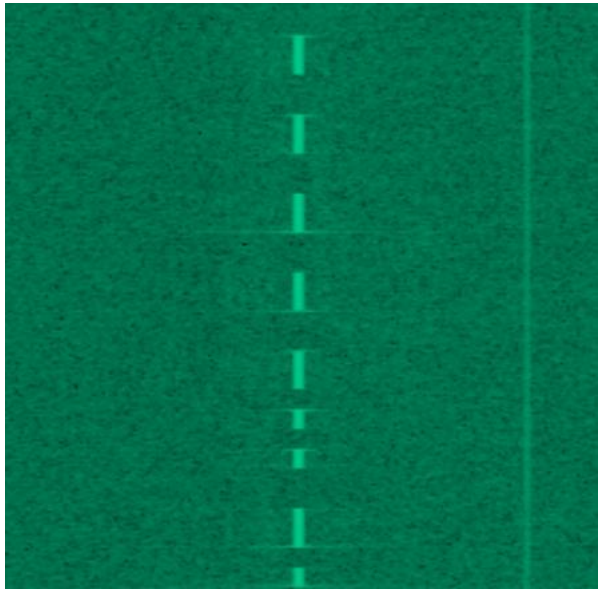




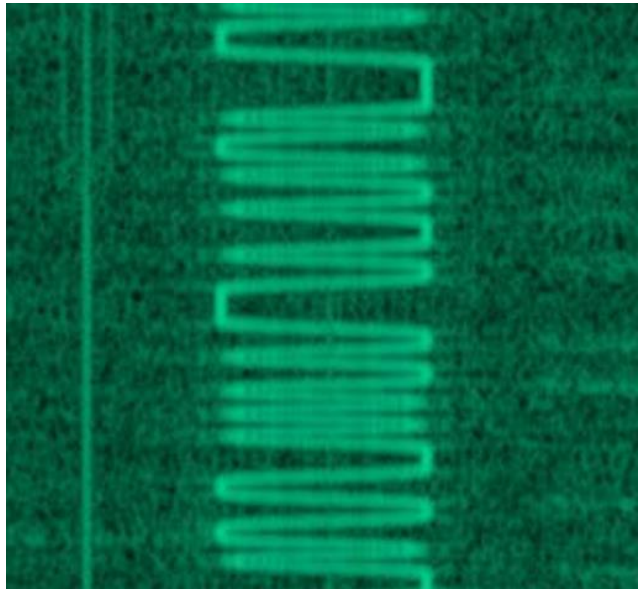




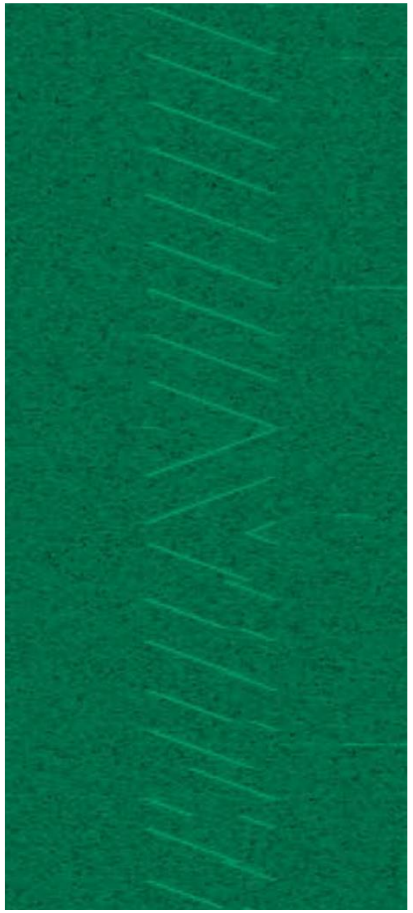
Modulation



On-Off Keying!



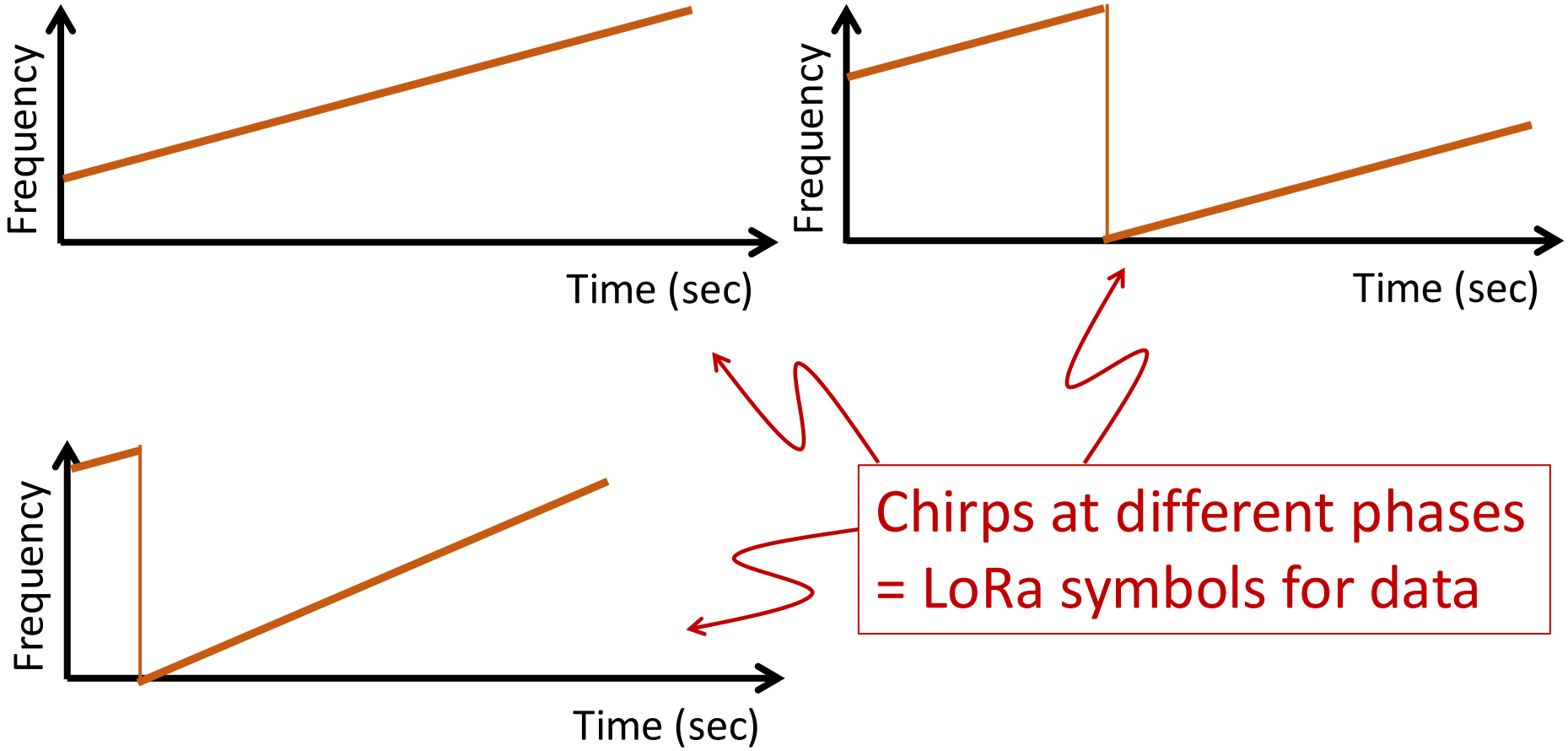
Frequency-shift Keying!

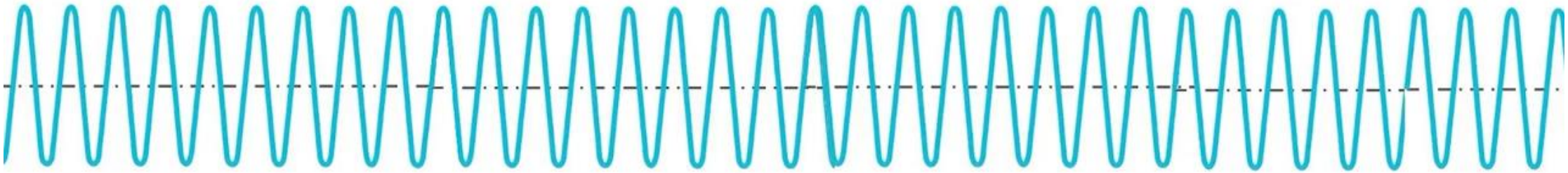


LoRa!

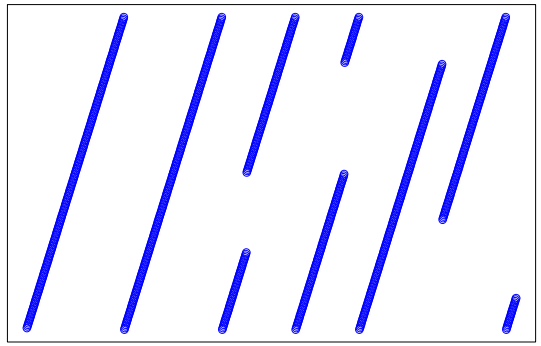
Source: MaD Knight

LoRa: CSS Communication

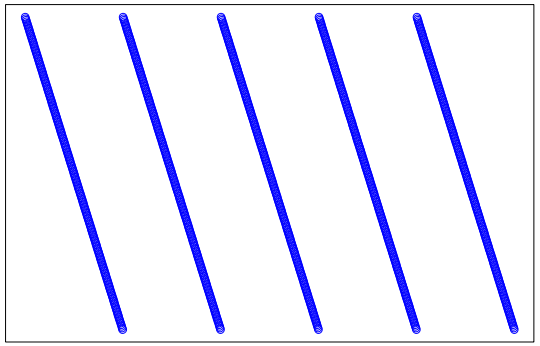




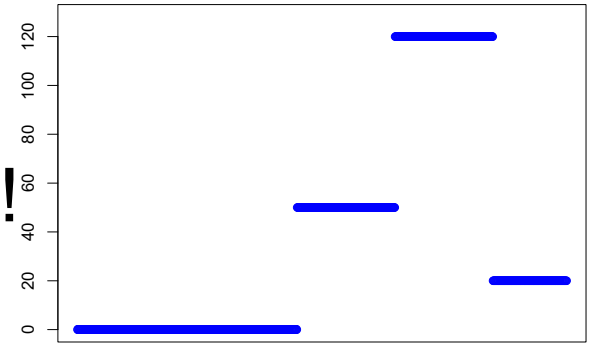
LoRa Demodulation



x!



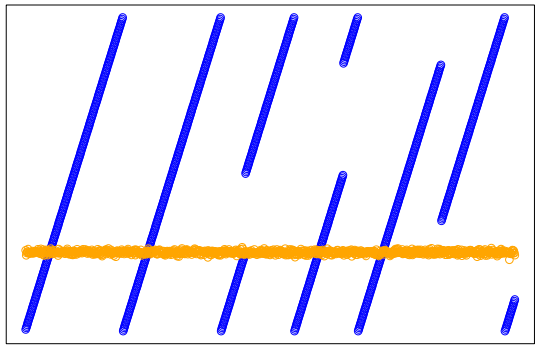
=!



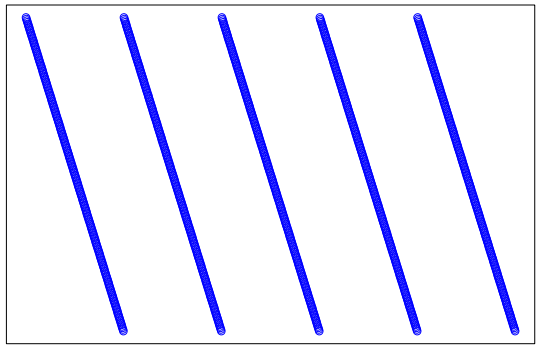
Received Lora signal!

Inverse chirp!

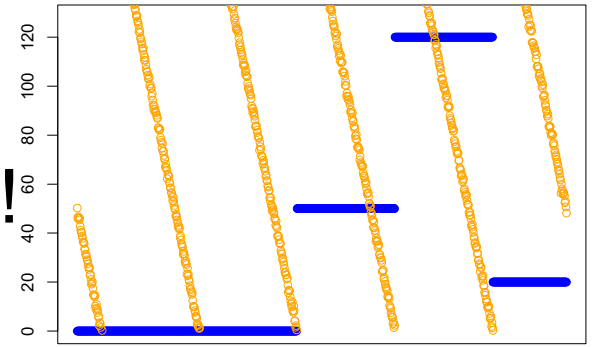
Decoded symbols!



x!



=!

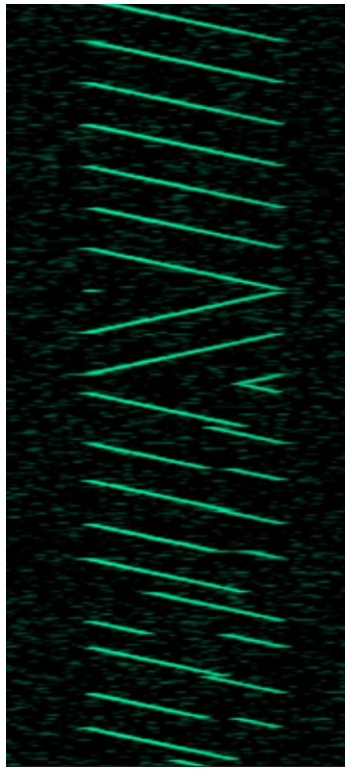


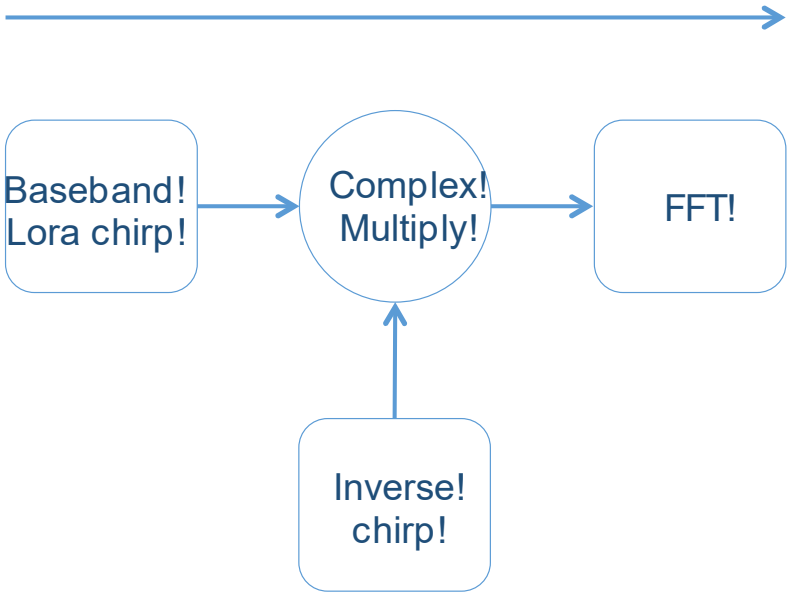
Received Lora signal !
Narrowband interferer!

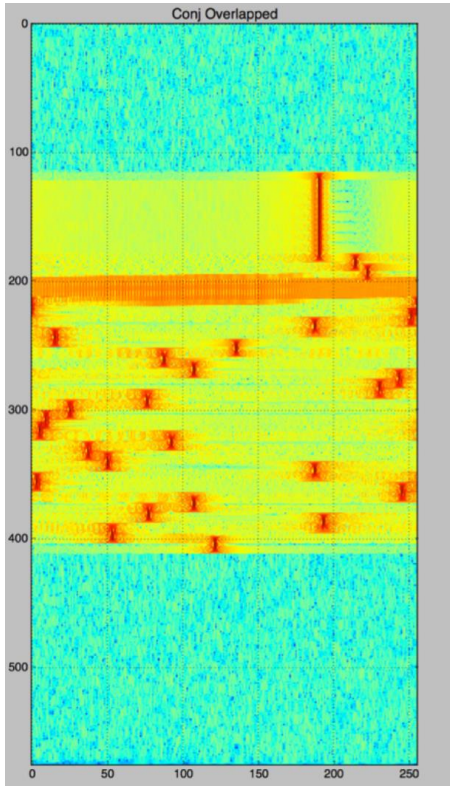
Inverse chirp!

Decoded symbols!

LoRa Demodulation

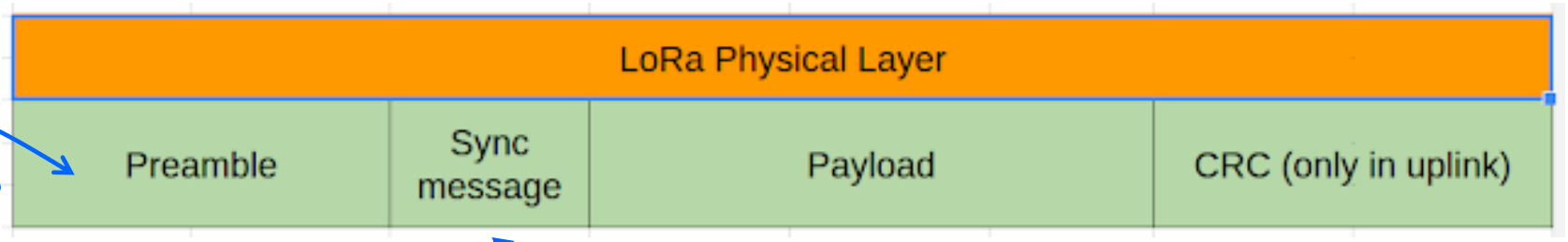




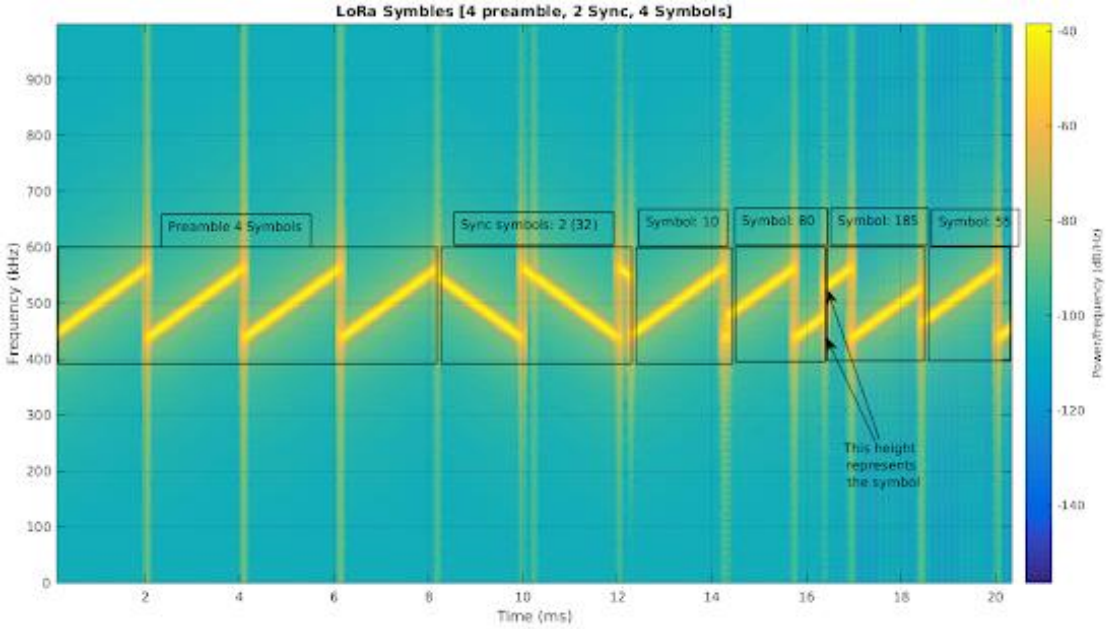


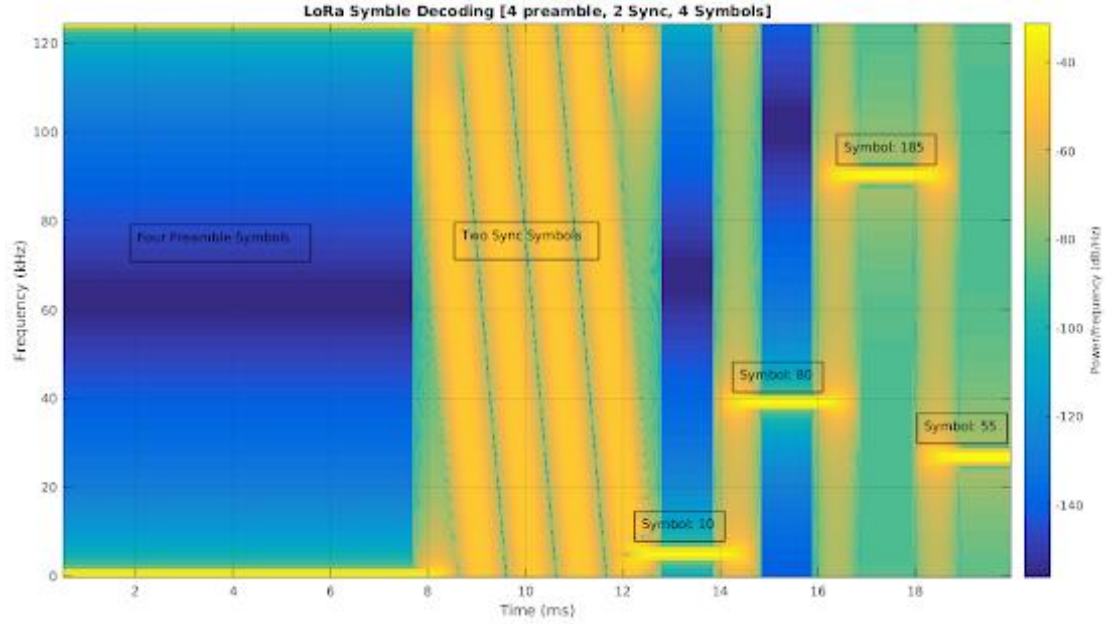
LoRa Decoding

Used to detect the LoRa signals

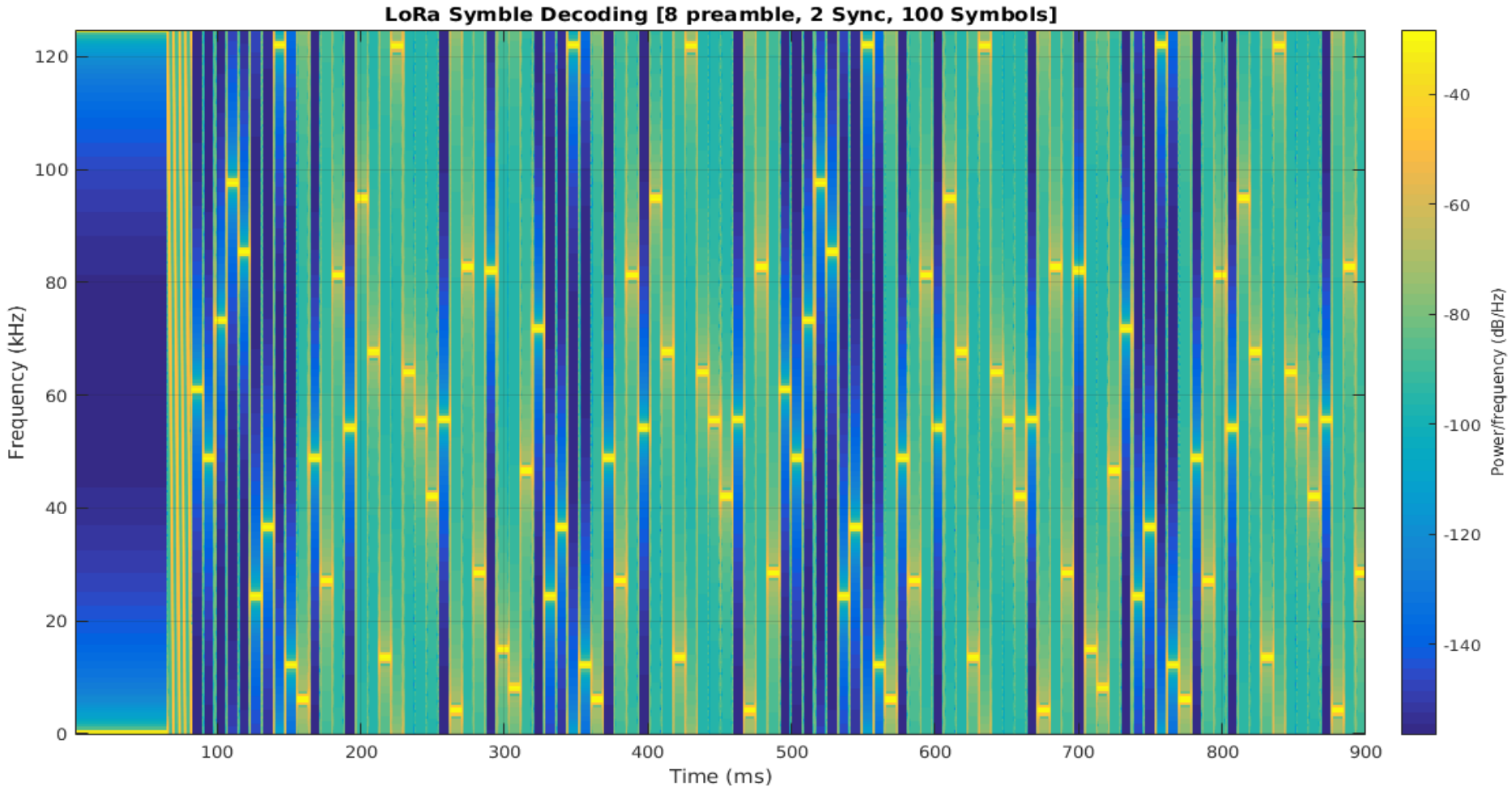


Used to detect the starting of the LoRa Payload.



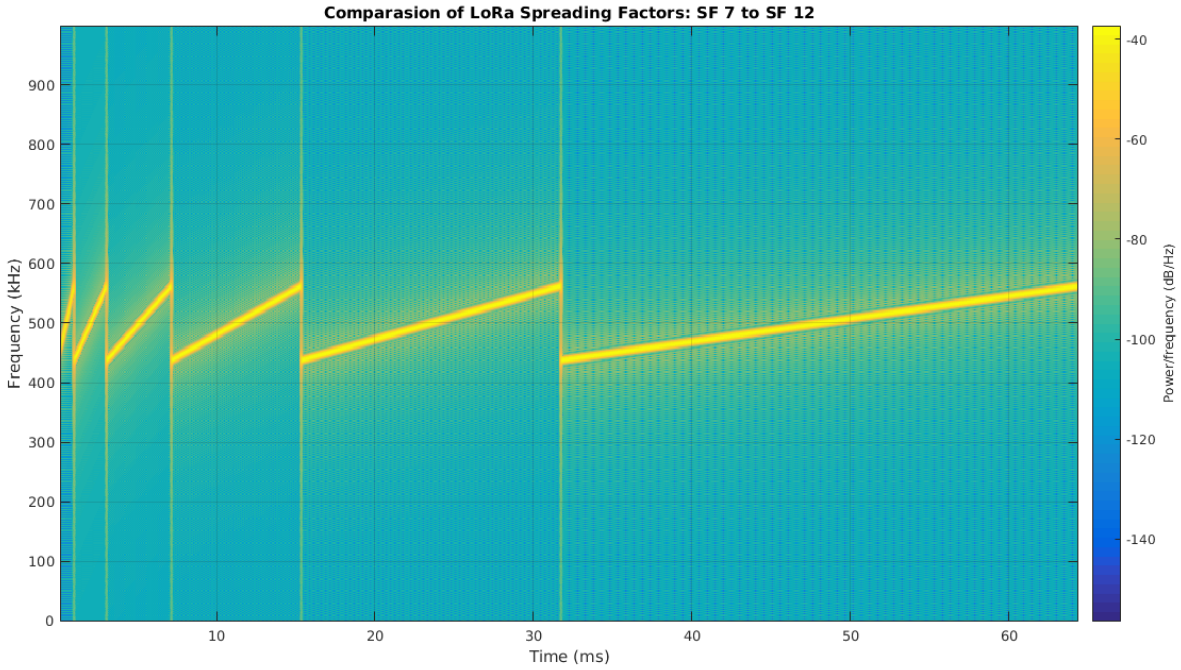


An example of 100 symbols

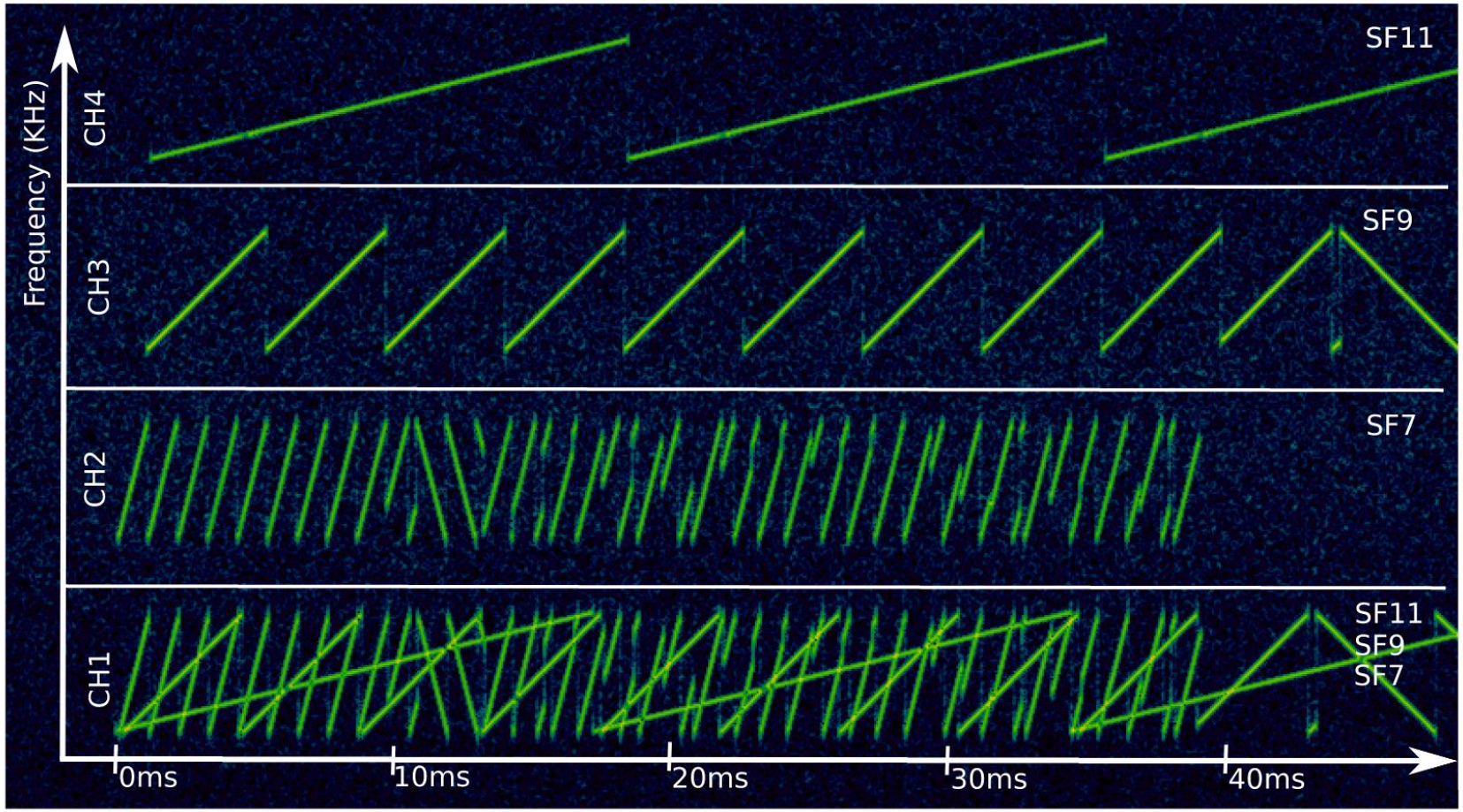


LoRa Spreading Factor (SF)

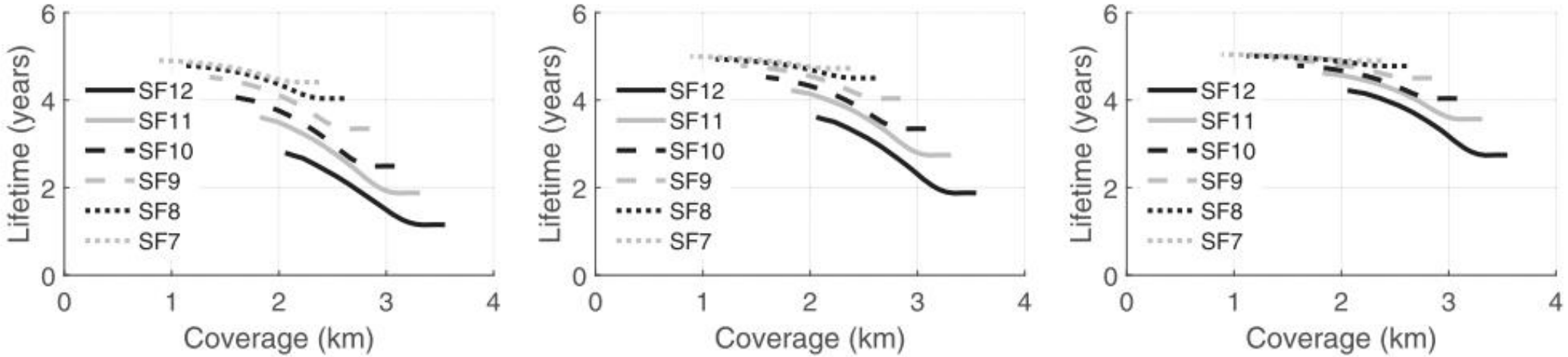
- SF determines the speed of a chirp.
- The speed of a single chirp equals approximately 2^SF.
- LoRa uses SF of 7 to 12
  - (Given fixed bw and coding rate) Lower SF -> faster chirps, higher data rates, lower power, shorter range, lower Rx sensitivity (higher min SNR)
  - Doubling the bandwidth also doubles the bit rate for a fixed SF and coding rate.



Concurrent transmission of LoRa



LoRa Performance in Reality



(a) Inter-packet delay of 15 minutes.

(b) Inter-packet delay of 30 minutes.

(c) Inter-packet delay of 60 minutes.

Fig. 17. Lifetime and coverage of all settings for PRR of 0.7 in NLoS environment. The skyline of all curves in each figure is the optimal settings for the given inter-packet delay.

Jansen C. Liando, Amalinda Gamage, Agustinus W. Tengourtius, and Mo Li. 2019. Known and Unknown Facts of LoRa: Experiences from a Large-scale Measurement Study. ACM Trans. Sen. Netw. 15, 2, Article 16 (May 2019). https://doi.org/10.1145/3293534

Shannon-Hartley theorem

- Shannon-Hartley theorem for channel capacity:

$$C = B * log_2\left(1 + \frac{S}{N}\right) \Rightarrow \frac{C}{B} \propto \frac{S}{N}$$

Where:

C = channel capacity (bit/s)
B = channel bandwidth (Hz)
S = average received signal power (Watts)
N = average noise or interference power (Watts)
S/N = signal to noise ratio (SNR) expressed as a linear power ratio

Wireless for Low-Altitude Economy?

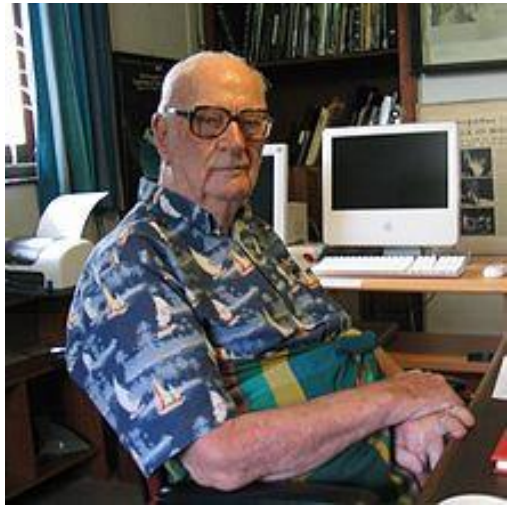
Wireless Sensing

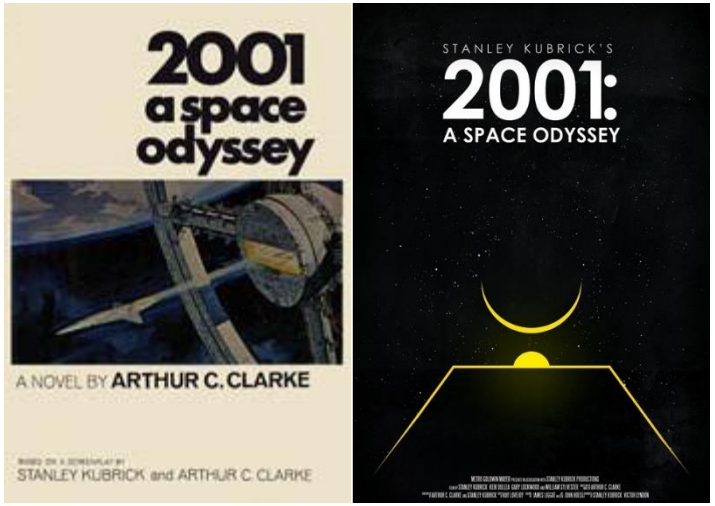
- The next big thing for WiFi is not about communication or networking…
- It is about sensing!
- The world's largest sensing network!
- IEEE P802.11bf - TASK GROUP BF (WLAN SENSING)

Integrated Sensing and Communication

- Clarke's Law #3: Any sufficiently advanced technology is indistinguishable from magic.

- Clarke's Law #1: When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible, he is very probably wrong.





Summary

- Why do we learn wireless networks?
  - Understand how the things we use everyday work
  - Learn about underlying technologies for IoT data acquisition and transportation
  - Gain knowledge for various design choices for IoT systems
    - What wireless solutions to choose?
    - Data kept at local (the IoT/Edge) or on cloud? How much?
  - Warm up for wireless sensing

One more reason...

Questions?

- Thank you!