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Wireless Options for IoT

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Goals

- Expose the specific requirements of IoT and why traditional wireless technologies fail to meet them.
- Describe the technologies that can be used to build IoT networks.
- Describe LPWAN solutions currently with more traction and those poised to attain it.

IoT nodes can accept:

- Low throughput, in many applications
- Very sparse datagrams
- Delays
- Long Sleeping times

Capacity of a communications channel

$$C = B*\log_2\{1 + [S/(N_o*B)]\}$$

Noise power density, W/Hz

Received signal power, W

Bandwidth, Hz

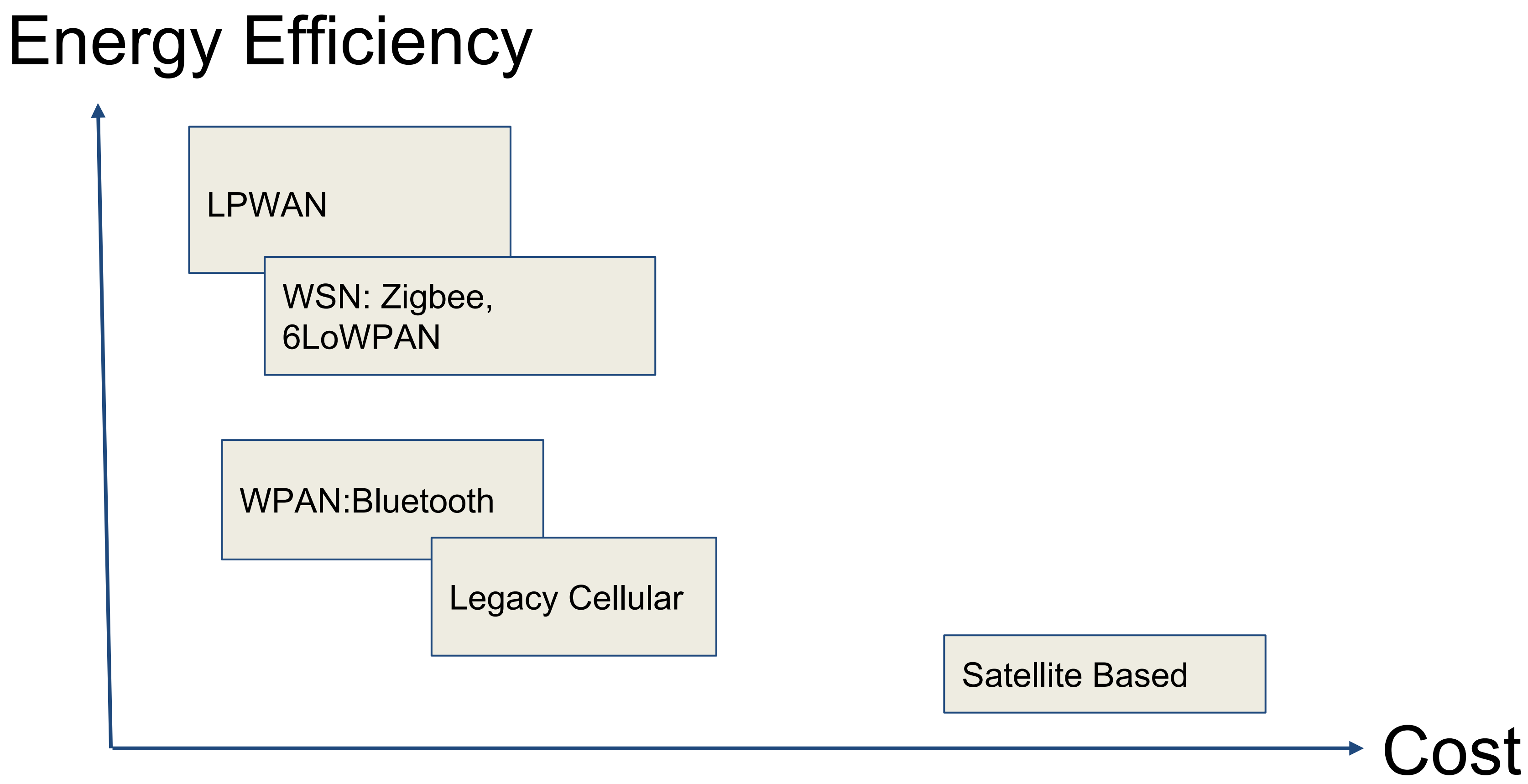
Capacity (maximum throughput), bit-per-second

The maximum range is determined by the energy per bit received, and depends on the effective transmitted power, receiver sensitivity, interference and data rate.

LoRa and Sigfox represent different strategies to achieve long range.

Technology	Sensitivity	Data rate	Spectrum
WiFi (802.11 b,g)	-95 dBm	1-54 Mb/s	Wide Band
Bluetooth	-97 dBm	1-2 Mb/s	Wide Band
BLE	-95 dBm	1 Mb/s	Wide Band
ZigBee	-100 dBm	250 kb/s	100 m
SigFox	-126 dBm	100 b/s	Ultra Narrow Band
LoRa	-149 dBm	18 b/s - 37.5 kb/s	Wide Band
Cellular data (2G,3G)	-104 dBm	Up to 1.4 Mb/s	Narrow Band

Energy efficiency Vs. cost



Some solutions

- RFID
- WiFi
- Bluetooth and BLE (Bluetooth Low Energy)
- Personal Area Networks (PAN)
  - 802.15.4 based
    - ZigBee, 6LoWPAN, Thread
- Cellular based

  extended coverage GSM (EC-GSM)

  enhanced machine type communication (eMTC) also called LTE-M and NB-IoT

RFID

RFID is a very successful application of short distance radio technology. It uses an object (typically referred to as an RFID tag) applied to a product, animal, or person for the purpose of identification and tracking.

The tag maybe passive, in which case it will just modify the signal transmitted to it by a short distance reader or active in which case the reader might be at several meters of distance and beyond LOS.

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RFID :TAGS

- Used in shops to expedite check out, automate inventory control and theft prevention.
- Embedded in passports and in even in animals.
- Maybe read only, like for inventory control applications, or writeable for more advanced ones.
- Have been implanted in humans.

RFID TAGS

RFID tags contain at least 3 parts:

- An antenna for receiving/ transmitting the RF.
- A means to convert the RF into DC power for the integrated circuit.
- An integrated circuit for storing the information and modulating/demodulating the RF carrier, plus non volatile memory and either fix or programmable logic for processing.

RFID System

The reader transmits a coded RF signal to interrogate the tag which responds with its identification and other information.

There are 3 types of RFI systems:

- Active reader, passive tag
  - This is the most common, requires a powerful RF signal
- Active reader, active tag
  - has the greatest range
- Passive reader, active tag

RFID frequencies of operation

Band	Regulation	Range	Data speed
120-150 kHz	Unregulated	10 cm	low
13.56 MHz	ISM	10 cm-1 m	low to moderate
433 MHz	SRD	1-100m	moderate
865-868 MHz	ISM (US)	1-12 m	moderate to high
902-928 MHz	ISM (Europe)	1-12 m	moderate to high
2450/5825 MHz	ISM	1-2 m	High

For details:
ISO/IEC 18000-1:2008 **Radio frequency identification for item management** https://www.iso.org/standard/46145.html

IEEE 802.11 Amendments

Standard	a	b	g	n	ac	ad	af	ah
Year approved	1999	1999	2003	2009	2012	2014	2014	2016
Max data	54 Mb/s	11 Mb/s	54 Mb/s	600 Mb/s	3.2 Gb/s	6.76 Gb/s	426 Mb/s	from 150 kb/s to 347 Mb/s
Frequency band	5 GHz	2.4 GHz	2.4 GHz	2.4/ 5 GHz	5 GHz	60 GHz	54 to 790 MHz	below 1 GHz
Channel width	20 MHz	20 MHz	20 MHz	20/40 MHz	20 to 160 MHz	2160 MHz	6 - 8 MHz	1-2 MHz
RF chains	1X1 SISO	1X1 SISO	1X1 SISO	up to 4X4 MIMO	Up to 8X8 MIMO, MU	1X1 SISO	up to 4X4 MIMO	1X1 SISO

IEEE 802.11 Amendments

- Amendments are modifications (generally enhancements) of an approved standard.
- From time to time amendments are conglomerated in a new version of the standard, referred to by the year of publication.
- Maximum data transfer is higher than the actual throughput experienced by the user because of protocol overhead and the use of half duplex on the channel.
- The max rate can be obtained combining several channels, adjacent or not.

IEEE 802.11 Amendments

The WiFi throughput increase has benefitted from three key technologies:

- Multiple-Input, Multiple-Output (MIMO) RF chains
- Orthogonal Frequency Division Multiplexing (OFDM)
- Higher order modulation schemes.

MIMO is the use of several transceivers and associated antennas (called RF chain) at both the transmitter (Input) and the receiver (Output).
SISO stands for Single Input, Single Output

802.11ah (WiFi HaLow)

- Sub 1 GHz, most commonly 900 MHz
- Low power, long range WiFi, less attenuated by walls and vegetation.
- Up to 1 km range.
- Lower power consumption thanks to sleep mode capabilities.
- 1, 2, 4, 8 and 16 MHz channels.
- Competes with Bluetooth, speed from 100 kb/s to 40 Mb/s.
- Support of Relay AP to further extend coverage.

802.11ah (WiFi HaLow)

•Down sampled 802.11a/g specification to provide up to 26 channels.

•More efficient modulation and coding schemes borrowed from 802.11 ac.

•Relay (AP) capability, an entity that logically consists of a Relay and a client station (STA) which extends the coverage and also allows stations to use higher MCSs (Modulation and Coding Schemes) while reducing the time stations stay in Active mode, therefore improving battery life.

•To limit overhead, the relaying function is bi-directional and limited to two hops only.

Bluetooth

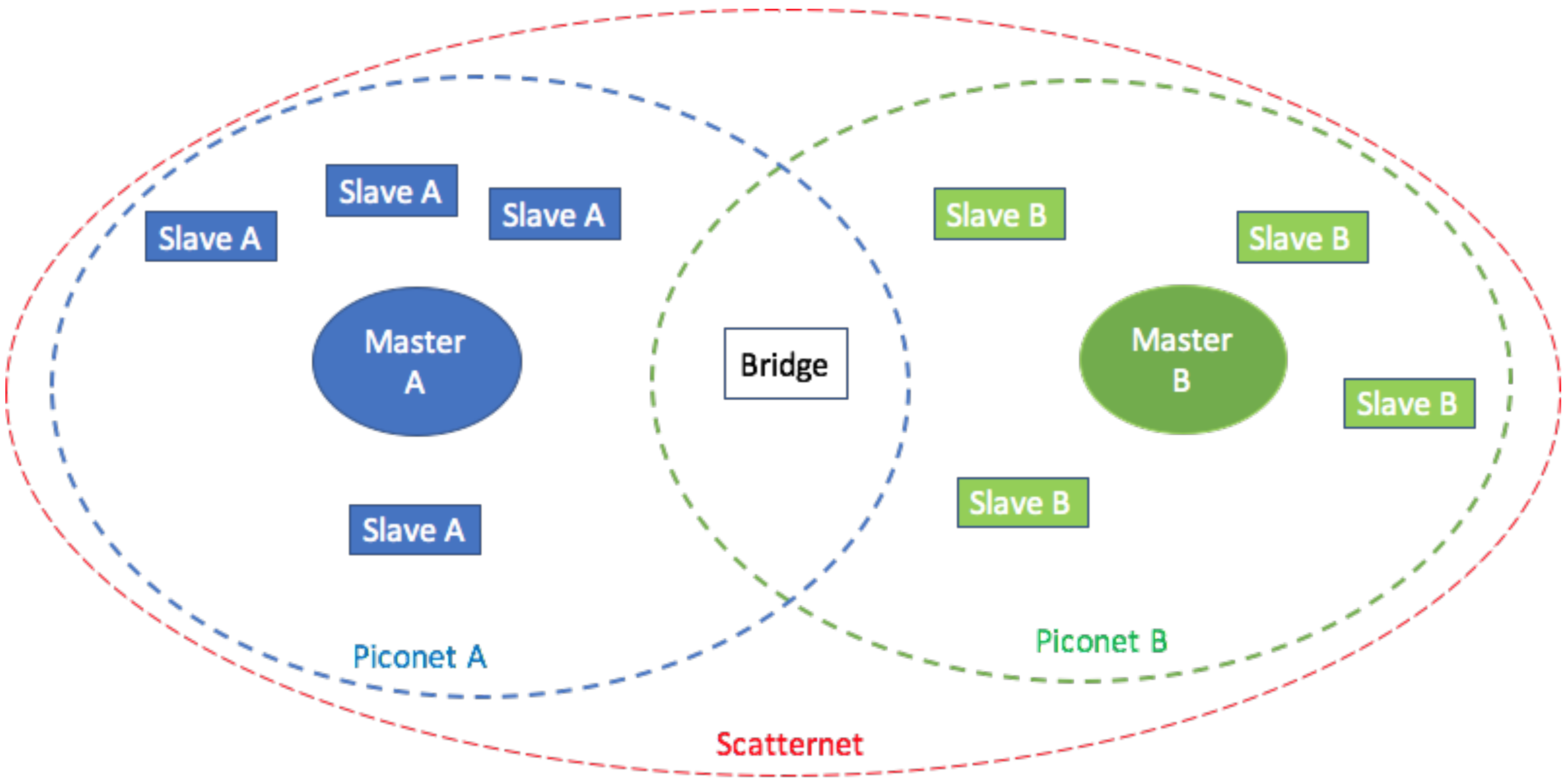
- Based on IEEE 802.15.1
- Smart Mesh.
- 79 channels 1 MHz wide and frequency hopping to combat interference in the crowded 2.4 GHz band.
- Used mainly for speakers, health monitors and other short range applications.

Bluetooth architecture

Master node controls up to 7 active slave nodes and up 255 inactive nodes, forming a *piconet*.

- Several piconets can form a *scatternet* by leveraging bridging nodes associated to more than one *master.*
- *Slaves* must communicate through the master node.

Bluetooth Architecture



Bluetooth Low Energy (BLE) or Smart Bluetooth

- Based on IEEE 802.15.1
- Subset of Bluetooth 4.0, but stemming from an independent Nokia solution.
- Smart Mesh.
- Support for IOS, Android, Windows and GNU/Linux.
- 40 channels 2 MHz wide and frequency hopping to combat interference.
- Used in smartphones, tablets, smart watches, health and fitness monitoring devices.

Bluetooth Low Energy (BLE) or Smart Bluetooth

- Data channels used for bidirectional traffic.
- Beacon mode, where low power, transmit-only sensors periodically transmit in one of three dedicated “advertising channels”.
- BLE compatible receiving devices must periodically listen in each of the tree advertising channels
- Transmitter consumption is 2.9 mW and receiver's is 2.3 mW.

Bluetooth 5

Options that can:

- Double the speed (2 Mbit/s burst) at the expense of range.
- Increase the range up to fourfold at the expense of data rate.
- Increase up to 8 times the data broadcasting capacity of transmissions by increasing the packet lengths.

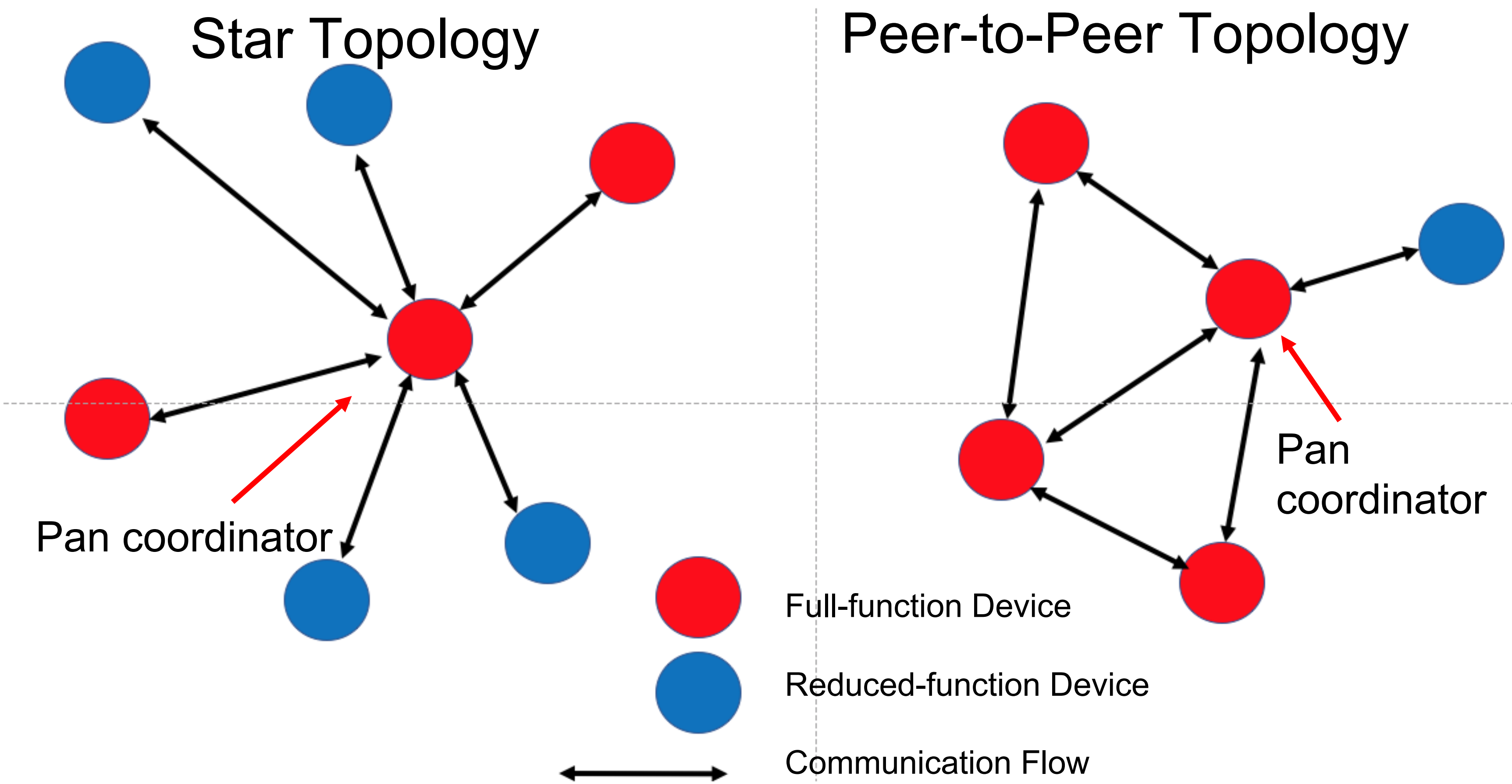
IEEE 802.15.4

Standard for Low-Rate Wireless Personal Area Networks (LR-WPANs)

- Little or no Infrastructure, low power.
- Defines the physical (PHY) and the medium access control (MAC) sublayer.
- Targets small, power-efficient, inexpensive solutions for a variety of devices.
- It is used by many upper layer protocols like Zigbee, Thread, Wireless HART, 6LowPAN.

http://ieeexplore.ieee.org/browse/standards/get-program/page/series?id=68

IEEE 802.15.4 Topology



ITU-T G.9959 January 2015

Recommendation for short range narrow-band digital radiocommunication transceivers

Operation mode:

- Always listening (AL)
- Frequently listening (FL)

Optional use of ACK.

Each domain may have up to 232 nodes, identified by the NodeID.

ITU-T G.9959 January 2015

Transmitters operate in one, two or three channels in license-free bands

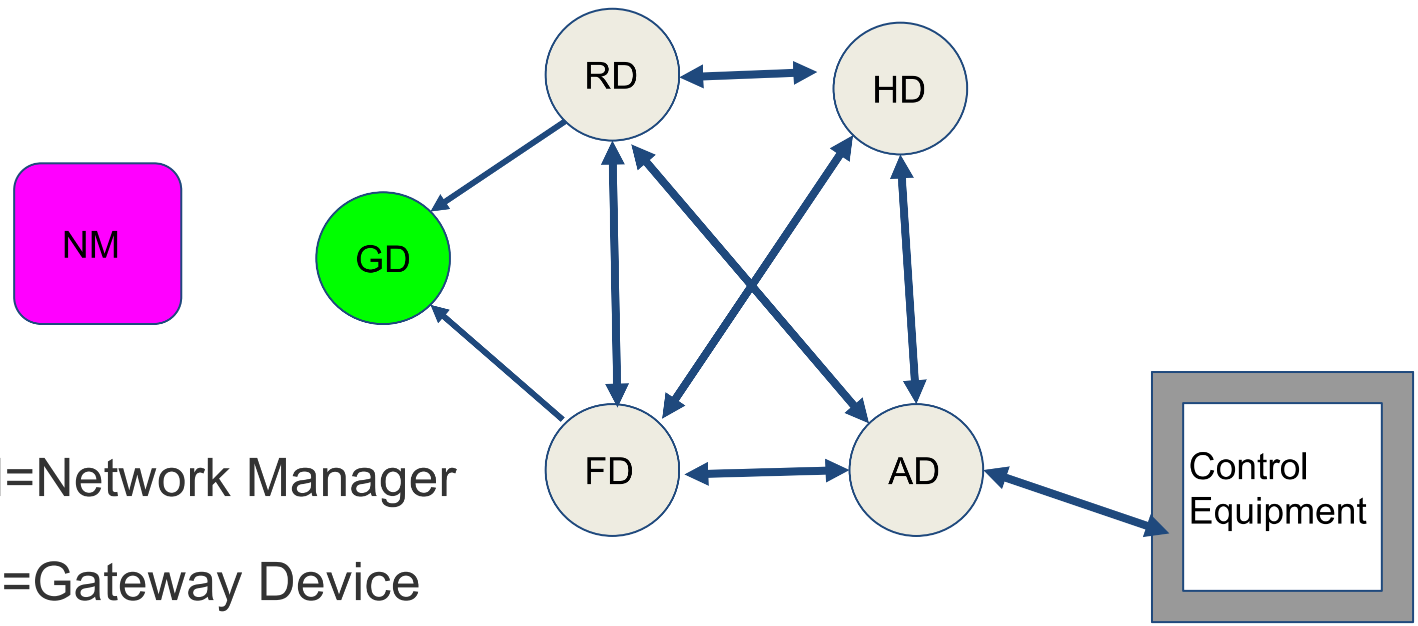
Tasks of Sub 1 GHz PHY:

- Assignment of RF profiles
- Radio activation and deactivation
- Transmission and reception
- Clear channel assessment (CCA)
- Frequency selection
- Link quality assessment

WirelessHART

- For industrial plants, noisy and delay challenged environments. LOS difficult to achieve
- Extension of the wired Hart protocol
- International Electrotechnical Commission (IEC) Standard 62591
- Covers Physical, MAC, Network, Transport and Application layers
- Uses IEEE 802.5.4 PHY but TDMA based MAC
- Network Manager constitute single point of failure
- Nodes serve also as repeaters

WirelessHART



NM=Network Manager

GD=Gateway Device

FD=Field Device

RD=Router Device

AD=Adapter Device

HD=Handheld Device

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ISA 100

Wireless Systems for Industrial Automation: Process Control and related Applications

- PHY from IEEE 802.15.4, 2.4 GHz.
- MAC with TDMA, frequency hopping, CSMA and channel blacklisting.
- End to end secure sessions with PKC
- Supports IpV6 through 6LoWPAN

Zigbee

- Based on IEEE 802.15.4, provides the higher functions up to the application layer for WPAN
- Mesh topology
- Short range, 20 to 250 kbps
- 2.4 GHz, 915 MHz or 868 MHz
- Channels 2 MHz wide with Direct Sequence Spread Spectrum media access
- Zigbee alliance supported by many vendors
- Latest standard Zigbee 3.0 issued Dec 2015

Zigbee

Three specifications targeting different applications

- Zigbee Pro for reliable device to device communication supporting thousands of devices. Green Power feature for energy saving.
- Zigbee RF4CE for simpler, two-way control applications, lower memory requirements, lower cost.
- Zigbee IP for Internet Protocol v6 wireless mesh connecting dozens of different devices.

Z-Wave

- Low-power wireless communication protocol for Home Automation Networks (HAN)
- Mesh operating in the 800-900 MHz range
- Up to 100 m range and 40 kb/s, 1 mW
- Supports IP transport and routing protocols
- Controller and slave nodes
- Source routing managed by controller
- Wide range of device and command classes
- PHY and MAC layers comply with ITU-T G.9959

www.zigbee.org

EnOcean

- Low-power energy-harvesting wireless communication technology.
- Battery-less devices can use different frequencies for short range communication:

  315MHz, 868MHz, 902MHz or 928MHz

- Applications in lighting, heating, ventilation and climate control (HVAC).
- Reduces the required wiring.
- Three networking topologies:

  point-to-point, star and mesh.

- Data rates up to 125 kb/s.

https://www.enocean.com/en

EnOcean

EnOcean alliance with many manufacturers
ISO/IEC 14543-3-10 Standard

https://www.enocean.com/en/technology/

EnOcean energy harvesting

Miniaturized power converters can leverage:

- Turning a light switch on or off .
- Small vibrations within a vehicle.
- Energy derived from the motion of people.
- Ambient luminosity or temperature changes singularly or in combination.

Two main categories of standards

- Cellular based
- Based on LPWAN

3GPP data

	LTE cat 0	LTE cat M1 (eMTC)	LTE cat NB1 (NB IoT)	EC-GPRS	LTE cat 1	GSM 900
DL BW	20 MHz	1.4 MHz	180 kHz	200 kHz	20 MHz	200 kHz
UL BW	20 MHz	1.4 MHz	180 kHz	200 kHz	20 MHz	200 kHz
DL Peak rate	1 Mb/s	1 Mb/s	250 kb/s	10 kb/s	10 Mb/s	22.8 kb/s
UL Peak rate	1 Mb/s	1 Mb/s	250 kb/s (Multitone) 20 kb/s (Single tone)	10 kb/s	5 Mb/s	22.8 kb/s
Duplex	half or full	half or full	half	half	full	full

Low Power Wide Area Network (LPWAN)

Optimized for IoT and Machine to Machine (M2) applications

Trade throughput for coverage (up to several kilometers)

Star or star of stars topology

Low power consumption

Low on board processing power

Emerging Standards

SIGFOX
One network A billion dreams

nwave

LoRa™

LTE-M

NB-LTE

INGENU

WEIGHTLESS

IEEE 802.11ah

DASH7™
ALLIANCE

EC-GSM

ZigBee 3.0

Bluetooth® 4.0

Battery duration

- LoRa, SigFox: up to years

  Devices sleep most of the time, low rate and limited messages per day

- 2G, a few days
- 802.15.4, months
- WiFi, a few days
- Energy scavenging schemes are being pursued
- Inductive powering
- Photovoltaic

Spectrum Usage

- Frequencies allocation country dependent
- Cellular uses costly exclusive licensed spectrum
- Alternatives use ISM bands, without fee payment, but subject to interference

Interference addressed by limiting power and:

- Listen Before Talk (LBT)
- Duty Cycle limitations
- Spatial confinement
    - Use high directivity antennas
    - Frequencies subjected to high attenuation (60GHz)
    - Light communication blocked by walls

Weightless

Weightless-P

Sub 1 GHz spectrum, 12.5 kHz channels, frequency hopping, two way.

From 200 bps to 100 kbps

Weightless-N is for uplink only

Sub 1 GHz spectrum, 200 Hz channel, 100 b/s

Weightless-W TV White Spaces

TV spectrum, 5 MHz channel, 1 kb/s to 10 M b/s two way.

6LoWPAN

IPv6 over low power wireless personal area networks, concluded working group of IETF

- Defines encapsulation and header compression to send and receive IPv6 packets over IEEE 802.15.4 networks.
- Defines mechanisms for fragmentation and reassembly of IPv6 packets to meet constraints of IoT networks.
- Thread is a royalty-free protocol using 6LoWPAN for IoT.

DASH 7

- Full OSI stack protocol for sensors and actuators (layers 1-7)
- Unlicensed bands at 433 MHz, 868 MHz and 915 MHz
- Asynchronous MAC, command-response
- Highly structured presentation layer
- Up to 2 km range and 167 kb/s data rate
- Low latency, low consumption, mobility support
- AES encryption support
- Open Standard based on ISO/IEC 18000-7

RPMA

Random Phase Multiple Access, backed by Ingenu

- Spread Spectrum technology based on CDMA.
- 172 dB link budget offers the longest range.
- 2.4 GHz band, 1 MHz channel bandwidth.
- Up to 624 kbps UL and 156 kbps DL, slower in mobile applications.
- Reliable message through ack and 128 bit AES.
- Robust to interference and Doppler effects.
- Supports background firmware updates.

Thread

Thread is an open IPv6 based mesh technology for home IoT

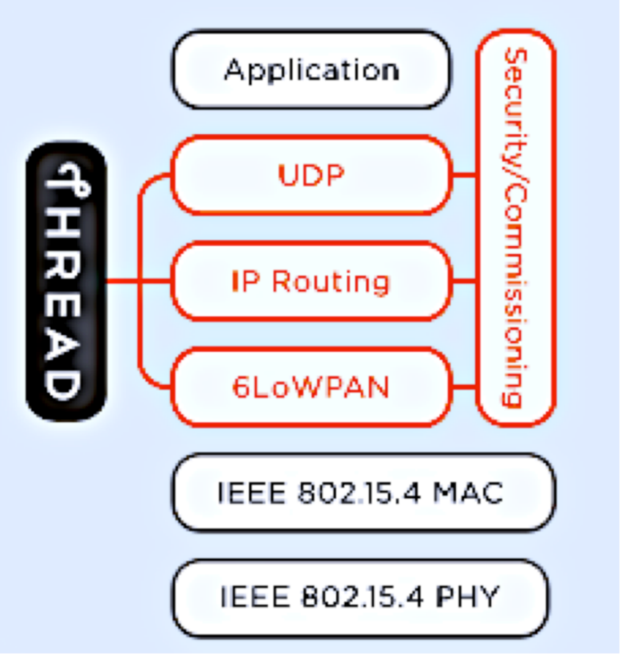
Uses 6LoWPAN and AES encryption.

Supports up to 250 devices.

Self healing network for the home

Low consumption: Sleepy nodes, short messages.

Can use Dotdot application layer as does Zigbee.



Sigfox

- Ultra narrowband technology designed for low throughput and few messages/day.
- Low consumption, low cost
- High receiver sensitivity: -134 dBm at 600 b/s or -142 dBm at 100 b/s on a 100 Hz channel, allows 146 to 162 dB of link budget.
- Each message transmitted 3 times in 3 different frequencies offering resilience to interference.

Sigfox

- Unlicensed frequencies: 868 MHz in Europe, 915 MHz in US.
- Maximum of 140 uplink messages/day with 12 octets payload, 26 octets total with overhead.
- Maximum of 4 downlink messages/day with 8 octets payload.
- Robust modulation: BPSK Uplink, GFSK Downlink.
- Mobility restricted to 6 km/h.
- One hop star topology.

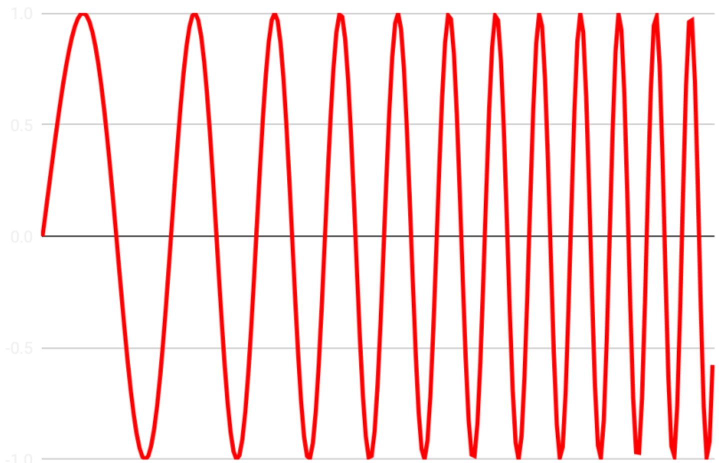
Sigfox

- Partnerships with cellular providers with an aim to worldwide penetration.
- Many network operators worldwide offer Sigfox services on a subscription basis.
- Cloud managed leveraging SDR to offer many services.
- Coarse geolocation capability without GPS.
- Roaming capability.

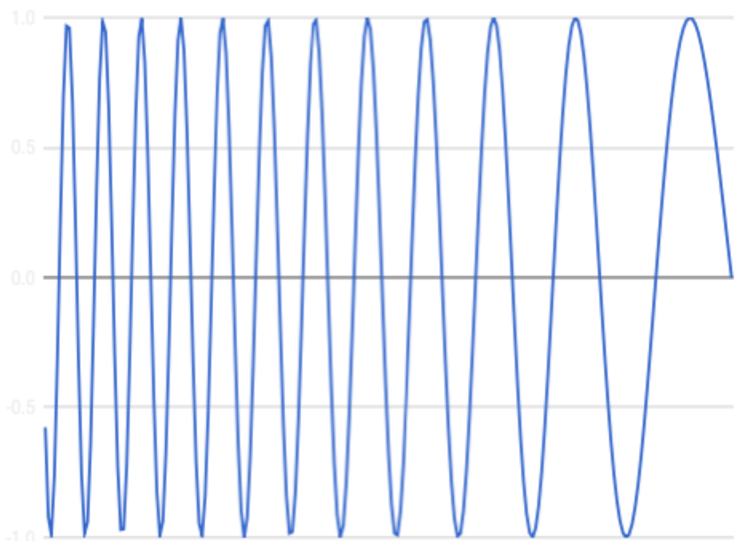
LoRa

- LoRA is a physical layer proprietary scheme for LPWAN based on spread spectrum, trading bandwidth for S/N.
- It achieves long range and deep indoor penetration.
- Uses linearly varying frequency pulses called “chirps” inspired in radar signals.
- Several vendors offer devices built on the chip owned by Semtech.

LoRa modulation

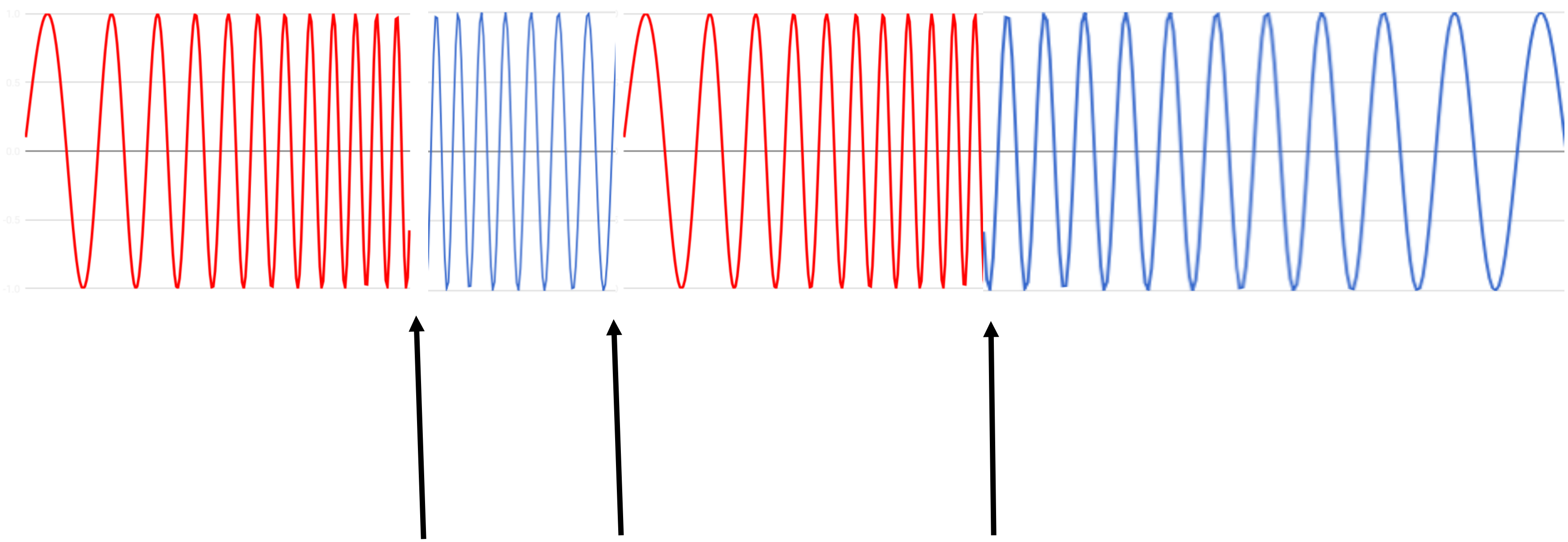


Up-chirp:
sinusoidal signal of linearly increasing frequency



Down-chirp:
sinusoidal of linearly decreasing frequency

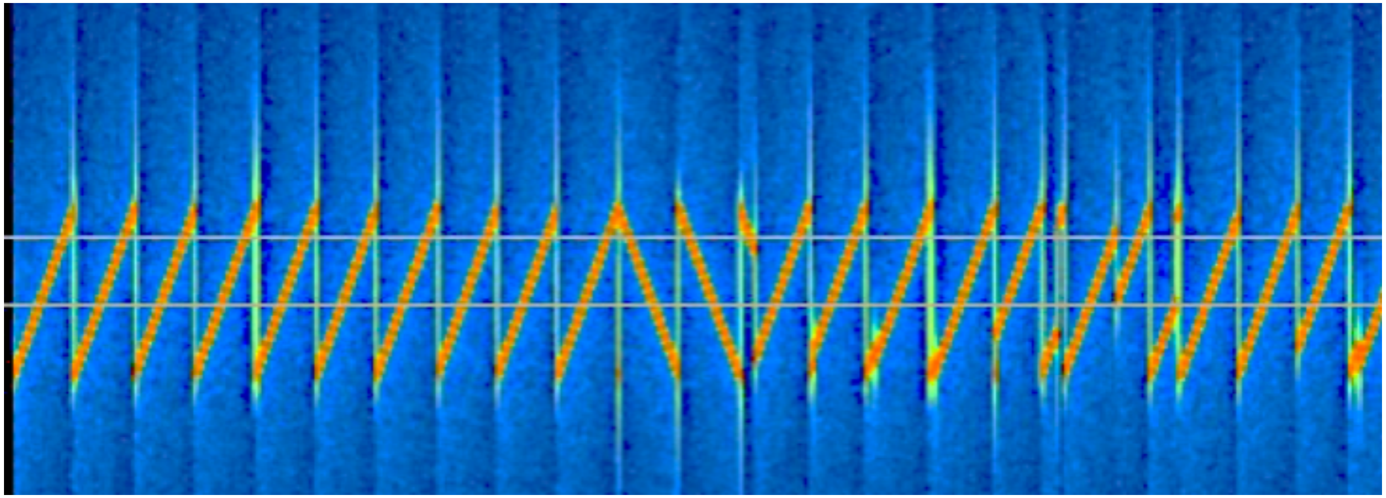
LoRa modulation



Data is conveyed in the transitions from up-chirp to down-chirp and vice versa

Tolerant to frequency drifts

LoRa physical layer



Preamble: at least 10 up-chirps followed by 2.25 down-chirps

Data: Information transmitted by the Instantaneous frequency transitions

Beginning of data

LoRa physical layer

An optional header can be inserted between the preamble and the data. Data can be followed by an optional cyclic redundancy check (CRC) if this is specified in the header.

Parameters of LoRa physical layer

- Bandwidth (BW): 125 KHz, 250 kHz or 500 kHz
- Spreading Factor (SF): 6, 7,8,9,10,11,12
- Coding Rate (CR): 5/4, 6/4, 7/4/ 8/4
- payload size (PL): maximum 255 octets

A LoRa symbol is composed of 2^{SF} chirps

- The number of symbols transmitted depends also on the number of symbols in the preamble and whether a header and CRC are present.

Parameters of LoRa physical layer

- Coding Rate (CR): 5/4, 6/4, 7/4/ 8/4

The coding rate (CR) is the fraction of transmitted bits that actually carry information. So if CR is 4/8 we are transmitting twice as many bits as the ones containing information.

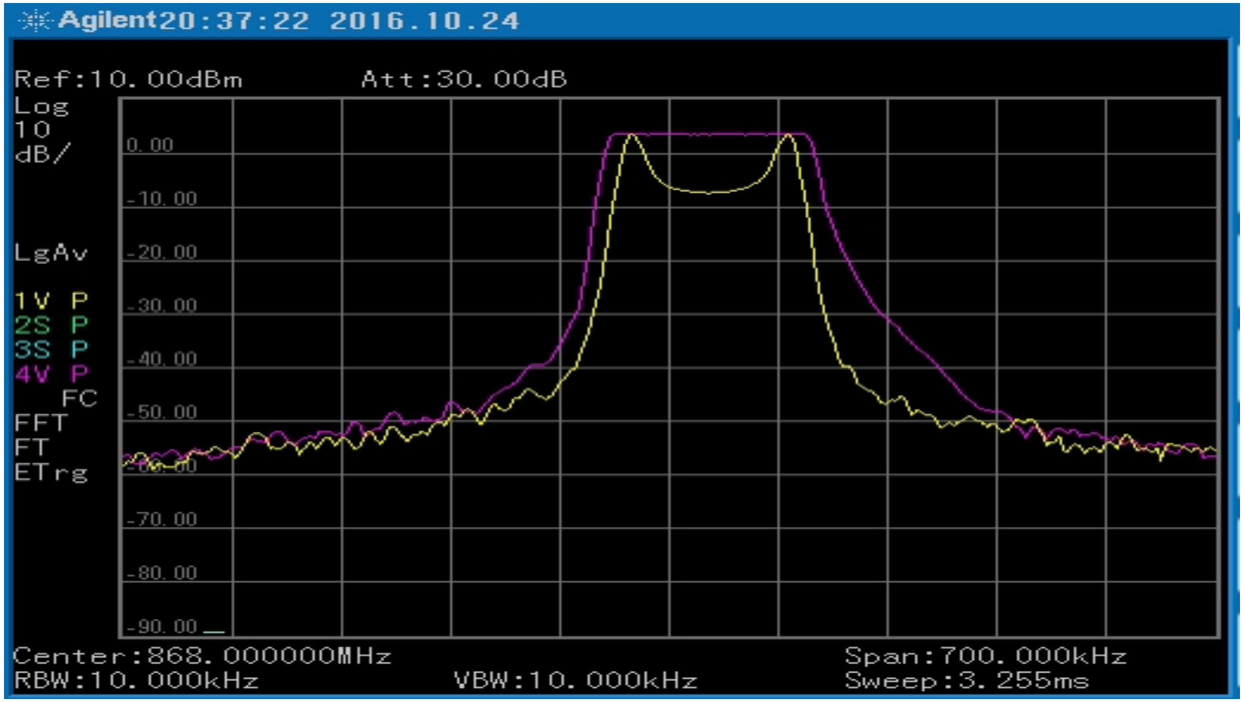
A symbol can encode SF bits of information.

The duration of a symbol is Ts=(2^SF)/BW, so the useful bit rate is Rb=SF*CR/Ts.

Parameters of LoRa physical layer

The BW and SF are constant in a given LoRa frame, but the SF can be changed to accommodate different channel conditions on subsequent frames.

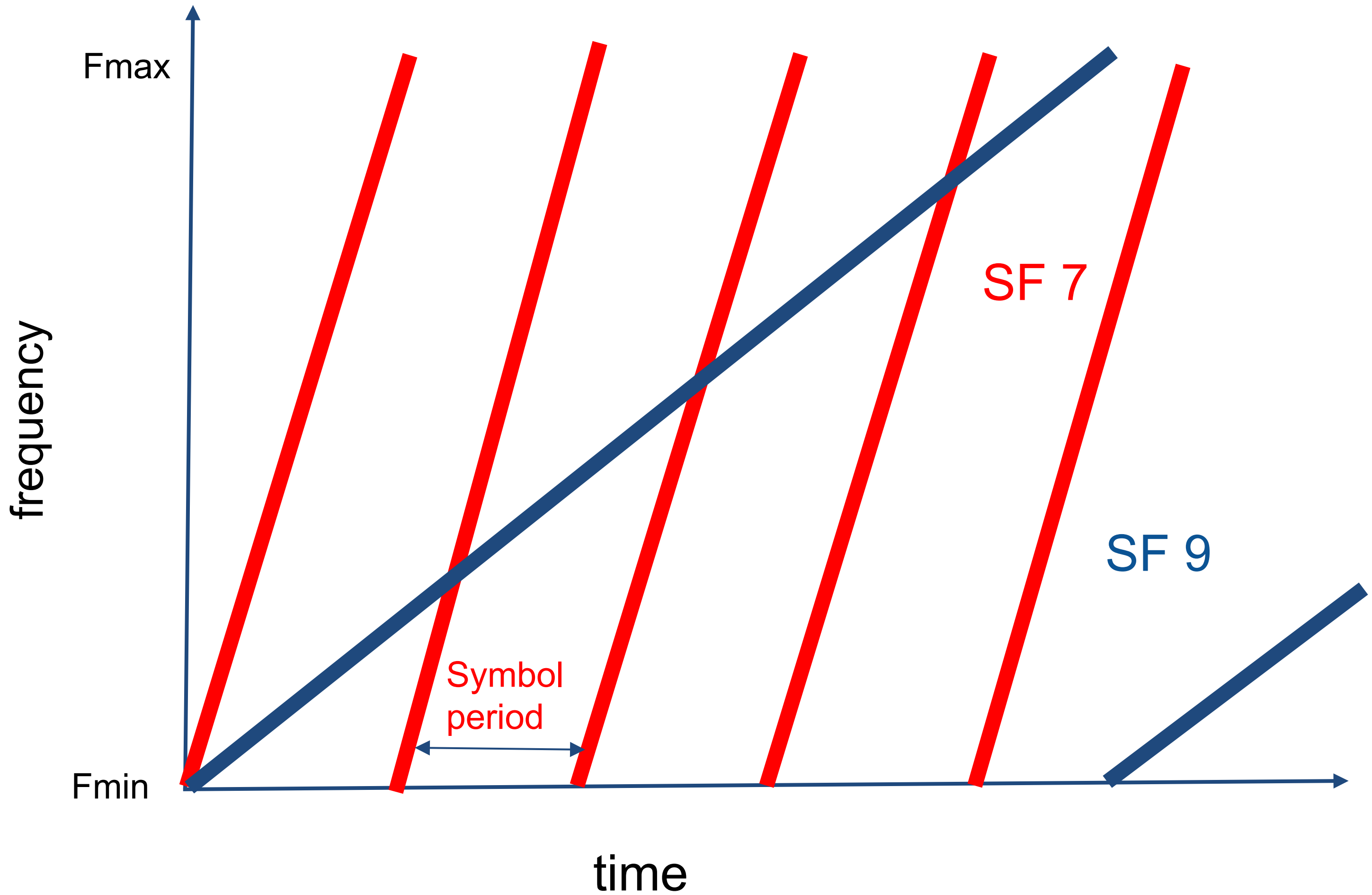
LoRa and FSK spectra



Flat top LoRa spectrum implies a more efficient spectrum usage as compared with the two peaked FSK.

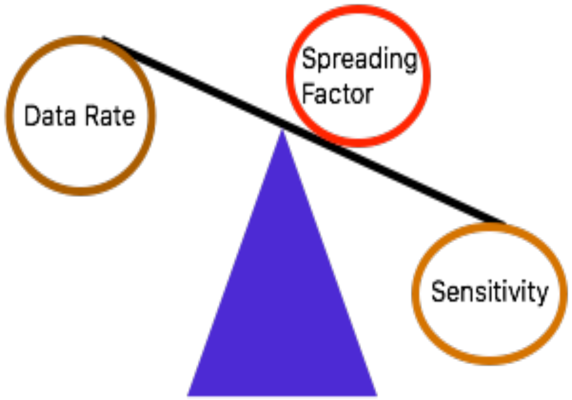
Output power is the same, bandwidth is 125 kHz

Spreading Factors and duration



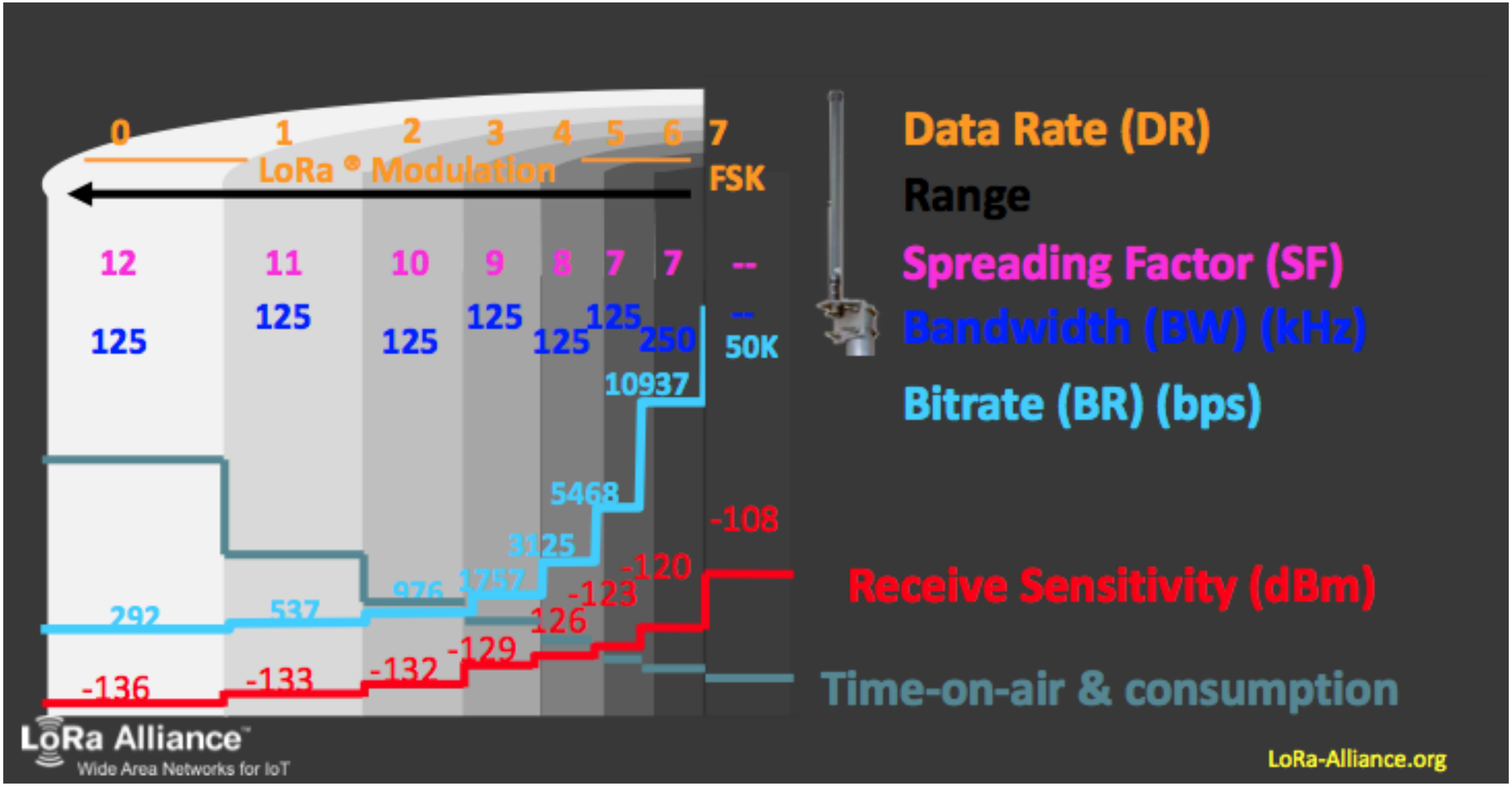
Adaptive Data Rate (ADR) at 125 kHz BW

Sprd. Factor	S/N dB	bit rate bit/s	ms per ten byte packet
7	-7.5	5469	56
8	-10	3125	103
9	-12.5	1758	205
10	-15	977	371
11	-17.5	537	741
12	-20	292	1483

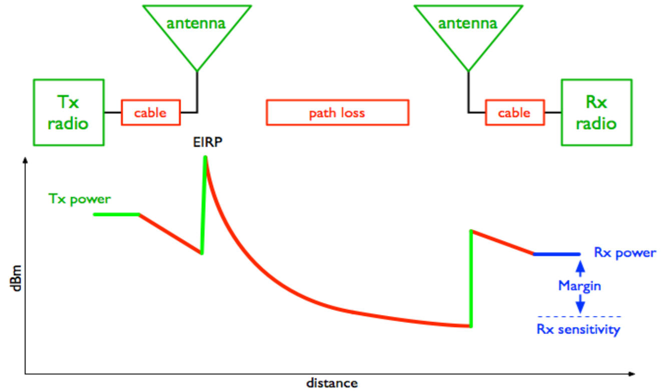


Sensitivity is proportional to S/N

LoRa parameters interaction



LoRa link budget



Tx=14 dBm

BW = 125 kHz, S/N = -20 (for SF 12)

Assume Noise Figure = 6 dB

Sensitivity = -174 +10 $\log_{10}$ (BW) +NF + S/N =

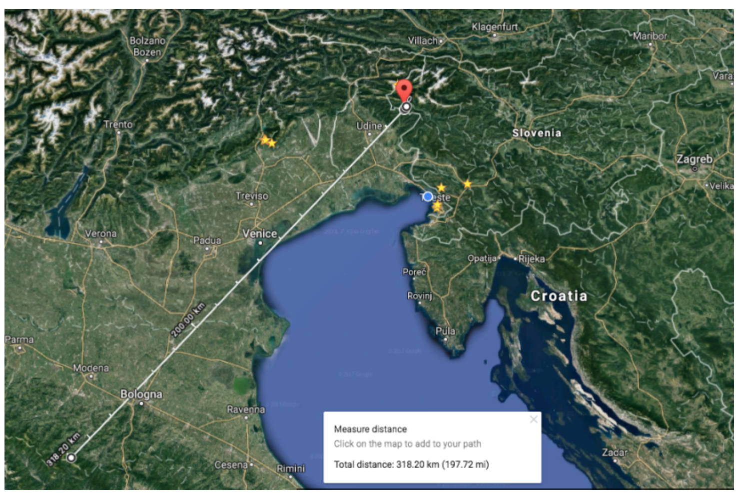
-174+51+6-20= -137 dBm

Link budget for Europe: 14+137 = 151 dB

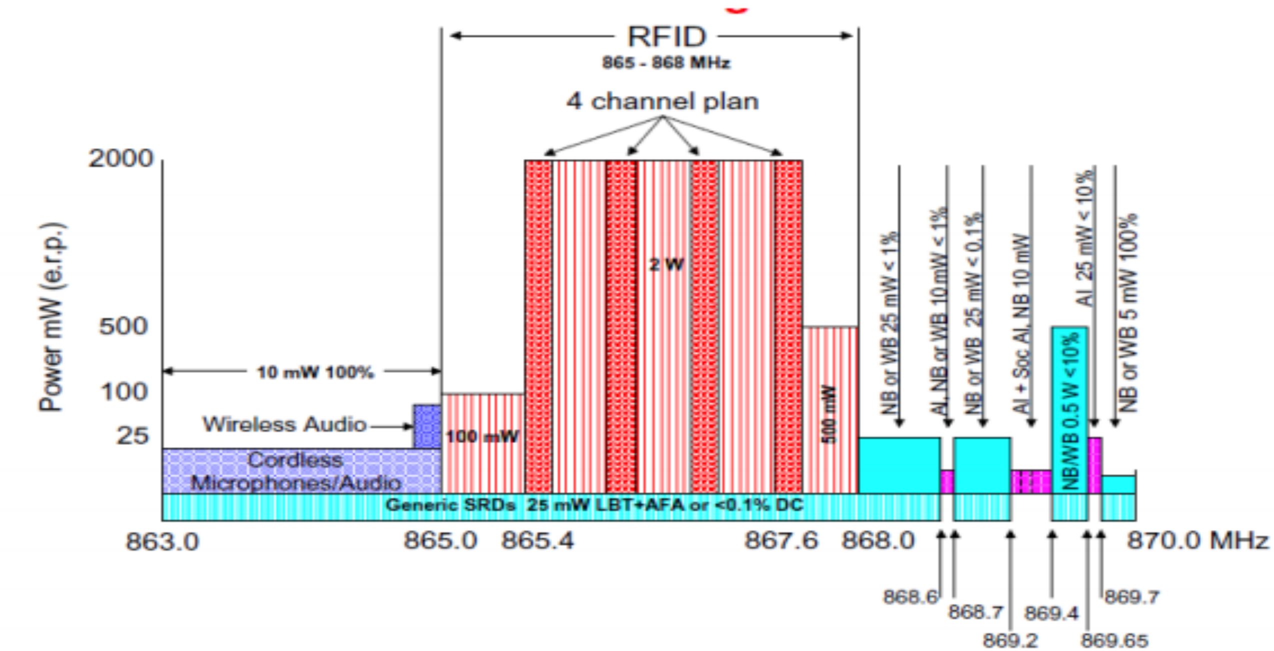
In US, up to -157 dB in the 900 MHz band

Range

- LoRa and SigFox: many kilometers
- 2G, typically 3 km, maximum 30 km
- 802.15.4 less than 100 m
- WiFi, typically 100 m, much higher values attainable with high gain antennas



Short Range Devices and LoRa spectrum access



G1: 868,000 MHz to 868,600 MHz with 25 mW EIRP (14 dBm) and 1 % duty cycle.
G2: 868,700 MHz to 869,200 MHz with 25 mW EIRP (14 dBm) and 0,1 % duty cycle.
G3: 869,400 MHz to 869,650 MHz with 500 mW EIRP (27 dBm) and 10 % duty cycle.

http://www.etsi.org/deliver/etsi_tr/103000_103099/103055/01.01.01_60/tr_103055v010101p.pdf

LoRa spectrum usage

Europe: 863 to 868 MHz and 434 MHz

Duty cycle limitations: 0.1%, 1% and 10%

Max EIRP: 14 dBm, 27 dBM in G3 sub-band

US: 902 to 928 MHz

400 ms max dwell time per channel (SF 7 to SF 10 at 125 kHz)

Max EIRP: 21 dBm on 125 kHz, 26 dBm on 500 kHz channel

LoRa duty cycle example

A device in Europe transmits a 0.75 s long frame at 868.3 MHz in the G1 (868 to 868.6 MHz) sub-band.

The whole sub-band (868 – 868.6) will be unavailable for 73.25 seconds, but the same device can hop to another sub-band meanwhile.

In US, the device would be violating the 400 ms maximum dwell time.

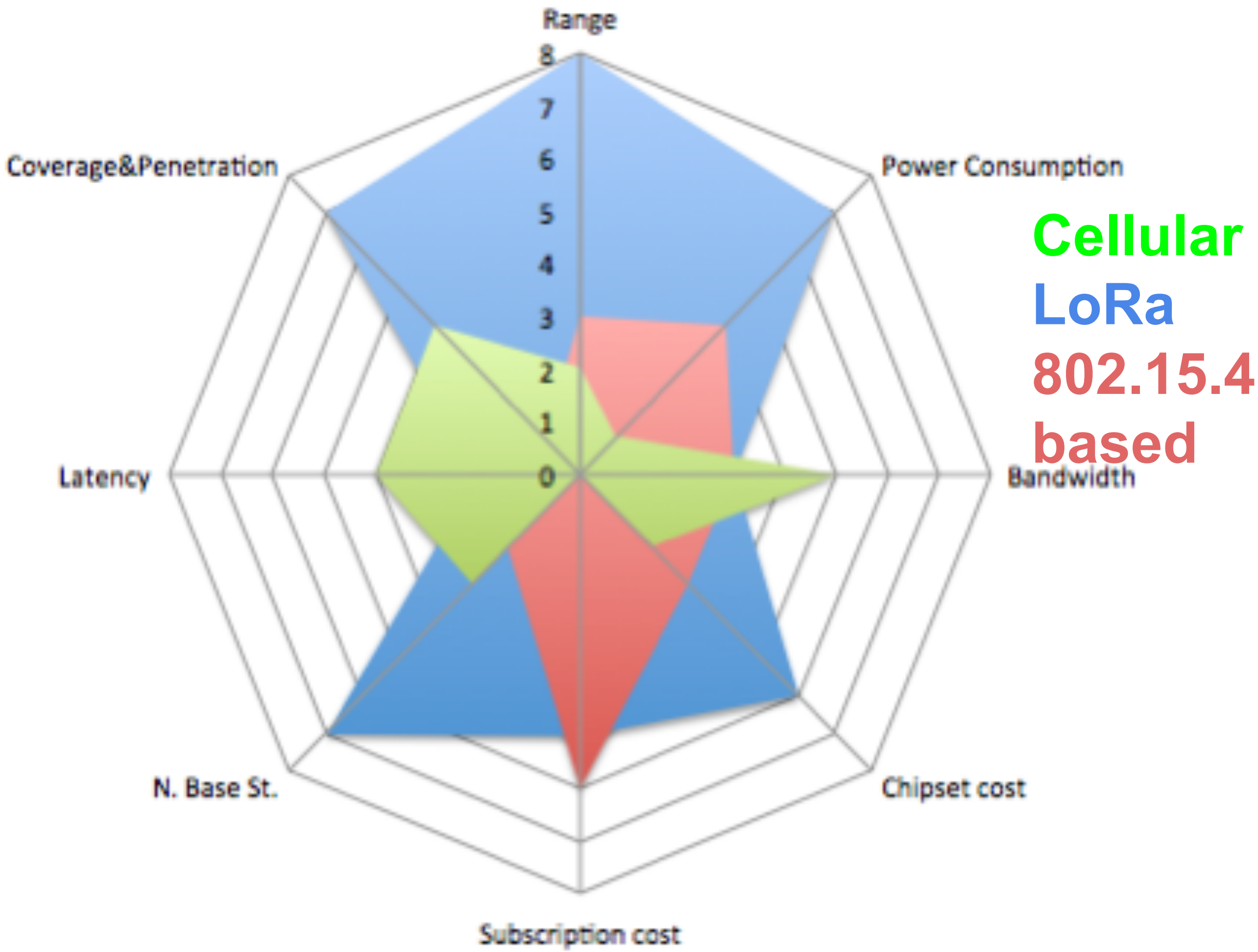
Effect of LoRa SF on consumption

You can change the values in columns A, B, C, D and H to suit your particular case.									
	SF 7	SF 7	SF 7	SF 7	SF 7	SF 7	SF 12	SF12	SF 12
	Active T, ms	#of times/h	current, mA	mA/h	mA/year	battery %	Active T, ms	mA/year	battery %
Transmit	70	12	38	0.0088666	77.67	18	1650	1,800.83	83.99
Receive	10	12	15	0.0005	4.38	1	165	71.09	3.32
Receive 2	70	12	15	0.0035	30.66	6	70	30.16	1.41
Temperature	20	12	15	0.001	8.76	2	20	8.62	0.40
Humidity	20	12	15	0.001	8.76	2	20	8.62	0.40
CO2	60	12	130	0.026	227.76	48	60	224.03	10.45
sleep	1000	3600	0.004	0.004	35.04	8	10	0.34	0.02
battery	1000	3600	0.004	0.004	35.04	8	10	0.34	0.02
			Sum	0.0488666	428.07		2005	2,144.02	
Years of duration with a 3.6 V	800	mA.h battery =			1.87				0.37

Chirp Spread Spectrum advantages

- Great link budget, low power transmission
- Resistant to multipath and other interference
- Orthogonality of spreading factors
- Simplified electronic for receiver synchronization
- Robust against Doppler shift (apt for mobile applications)

Comparison of LPWAN solutions



LoRa and LoRaWAN

LoRa is strictly physical layer, and is proprietary. Chip manufacturers include Semtech and Hope RF.

LoRaWAN is an open standard promoted by the LoRa Alliance that adds the MAC, networking and application layers that provide required functionalities like managing medium access, security and so on.

Satellites for IoT

- Satellite communications have been very successful for broadcasting applications and also for two way communications, but the associated costs have precluded them to find extensive usage in IoT.
- The situation is beginning to change, so it is worth to briefly describe the technology involved.

Satellites for IoT

There are three mayor categories for communications satellites:

- Geostationary (GEO), orbiting the Earth in an Equatorial plane at 36000 km.
- Medium Earth Orbit (MEO), with different orbits at around 20000 km.
- Low Earth Orbit (LEO), at altitudes between 600 and 800 km.

We can also consider High Altitude Platforms (HAPS) at much less distance from the earth, but they are not yet commercially available.

Satellites for IoT

The satellite is essentially a repeater up in the sky, so an Earth station connected to the terrestrial network normally by fiber optic will function as the gateway for all the traffic.

- Gateway communicate with the satellite using the uplink RF channel.
- The satellite can detect this signal, amplify, change frequency and beam it back to earth, in what is known as the "bent-pipe" technology, or:
- It can regenerate the signal thus emulating a Base Station in the sky.

Satellites for IoT

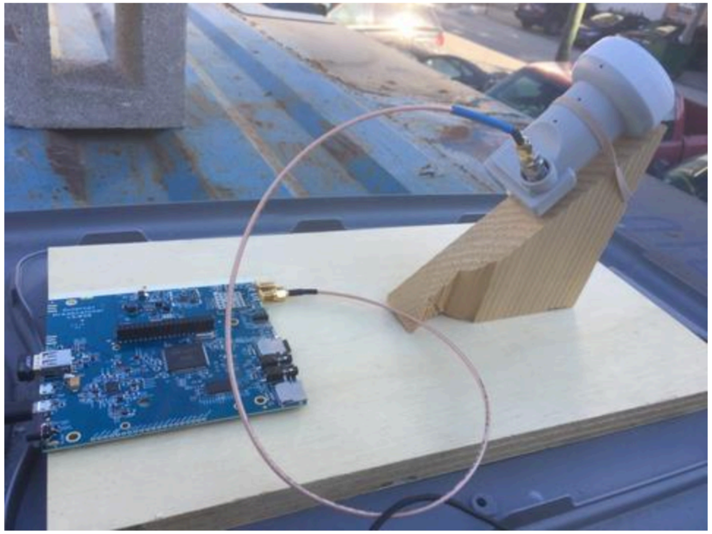
Satellites can be used to communicate the IoT gateway to the respective server, and a number of vendors are currently offering this kind of service.

- The novelty lies in the possibility of a direct link from an end-device to a Gateway up in the sky.
- Several solutions have been proposed and trials made but no commercial service is yet available.
- We will examine the technical details with a couple of examples.

Satellites for IoT

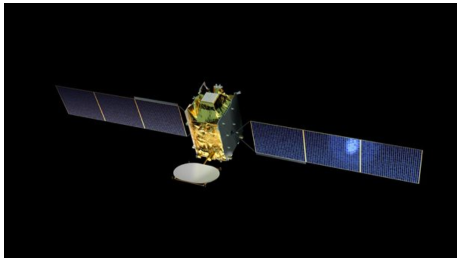
As an example of what can be achieved:
LoRa World Record: 71,572 km to Space and Back
https://store.outernet.is/blogs/the-official-outernet-blog/world-record

- The uplink used a 5 m parabolic antenna transmitting at 11.9 GHz to a GEO satellite which amplified the received signal to output 90 W back to earth
- The receiver was a the modest antenna shown:



LoRa offers improved co-channel interference and lower S/N requirements.
Download bitrates will be around 30 kbps,

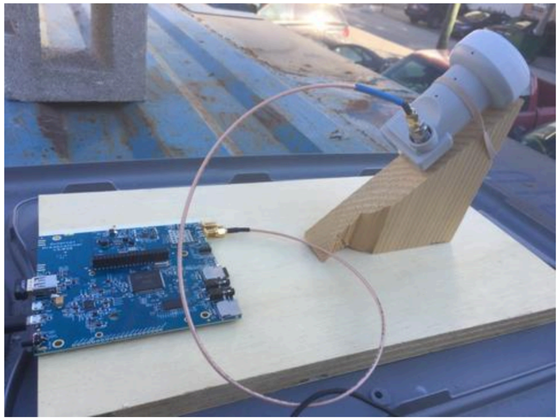
Satellites for IoT



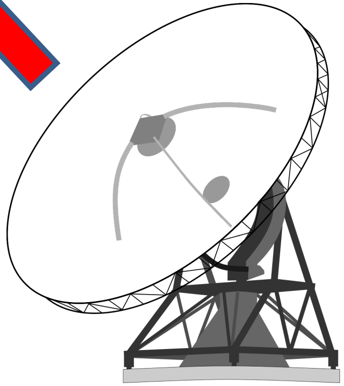
Downlink 12 GHz

Uplink 12 GHz

5 m dish



This example is of the “bent-pipe” type satellite link



Link calculations

Downlink from the satellite to the LoRa board:

$$L_{fs} = 92.4 + 20*\log(D) + 20*\log(f)$$

$$L_{fs} = 92.4 + 20*\log(35786) + 20*\log(11.9) = 205 \text{ dB}$$

The 90 W amplifier output corresponds to 49.54 dBm

So, the receiver signal strength is 49.54 -205= -155.46 dBm

Note that the reverse link would not work! Why?

Satellites for IoT

Another example:
https://www.semtech.com/company/press/semtech-and-lacuna-receiving-messages-from-space

- Lacuna Space uses a constellation of polar low-earth orbiting satellites to receive messages from sensors integrated with LoRa radios.
- At about 500 km above the ground, the satellites circle over the poles every 100 minutes and as the earth revolves below them, they cover the globe.
- The satellites store the messages for a short period of time until they pass over the network of ground stations.

Link calculations

Upnlink from the LoRa end-device to the LEO:

$$L_{fs} = 92.4 + 20*\log(D) + 20*\log(f)$$

$L_{fs} = 92.4 + 20*\log(500) + 20*\log(0.868) = 145.9$ dB

Assuming a 14 dBm EIRP for the TX, the satellite antenna will receive a signal of 14 -145.9 = -131.9 dBm

Which can be detected even with a < 0 dBi antenna.

Note that this is a delay tolerant network (DTN), and the number of ground stations needed will depend on the application's latency requirements.

Conclusions

- IoT requires specific standards.
- Legacy cellular technologies not efficient.
- Cellular based on Release 13 address most of the shortcomings but the cost is high and availability limited.
- WiFi , Zigbee and BLE have limited range.
- Several vendors offer alternatives.
- LoRa and SigFox are widely used worldwide for long distance but with limited data rate.