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Communication technologies in Smart Agriculture

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Jose M. Jiménez (jojiher@dcom.upv.es): He was born in Valencia (Spain) on November 8, 1961. He received his Degree in Computer Science Engineering in 1997 and his University Masters Degree in Corporate Networks and System Integration in 2007, and University Masters Degree in Digital Postproduction from the Polytechnic University of Valencia (Spain) in 2014. He received his Ph.D. in Communication and Cultural Industries from the Polytechnic University of Valencia (Spain) in 2018.

He was Associate Professor from 2005 to 2011 of the Department of Communications at that University, at the Technical School of Telecommunications Engineering. He is Cisco Instructor of different certifications (CCNA, CCNP, Fundamentals Wireless LANs, Network Security, etc.), since the beginning of the 2000s and HP-ATA instructor since 2015. He worked as a network designer and administrator in several enterprises.

He has several scientific papers in international conferences, international journals with JCR. He is currently a researcher at the Research Institute for Integrated Management of Coastal Areas at the Polytechnic University of Valencia, and also at the laboratory of the Institut de Recherche en Informatique, Mathématiques, Automatique et Signal (IRIMAS) at the Universite Haute Alsace (France), focusing her research on algorithms, network communications, security, sensors, and IoT.

He is the author/co-author of multiple publications (including articles in international magazines and book chapters) and participation in congresses. He has participated in more than 30 conferences as a member of the technical committee or organizing committee. She has been the editor of proceedings, panelist, and chair in various congresses. He is Assistant Editor in the journal Network Protocols and Algorithms, and Guest Editor in journal Sensors. Furthermore, he has participated in various national and international research projects.

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- Long Range Wireless Communication Technologies used in Smart Agriculture
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Smart Agriculture

Smart agriculture

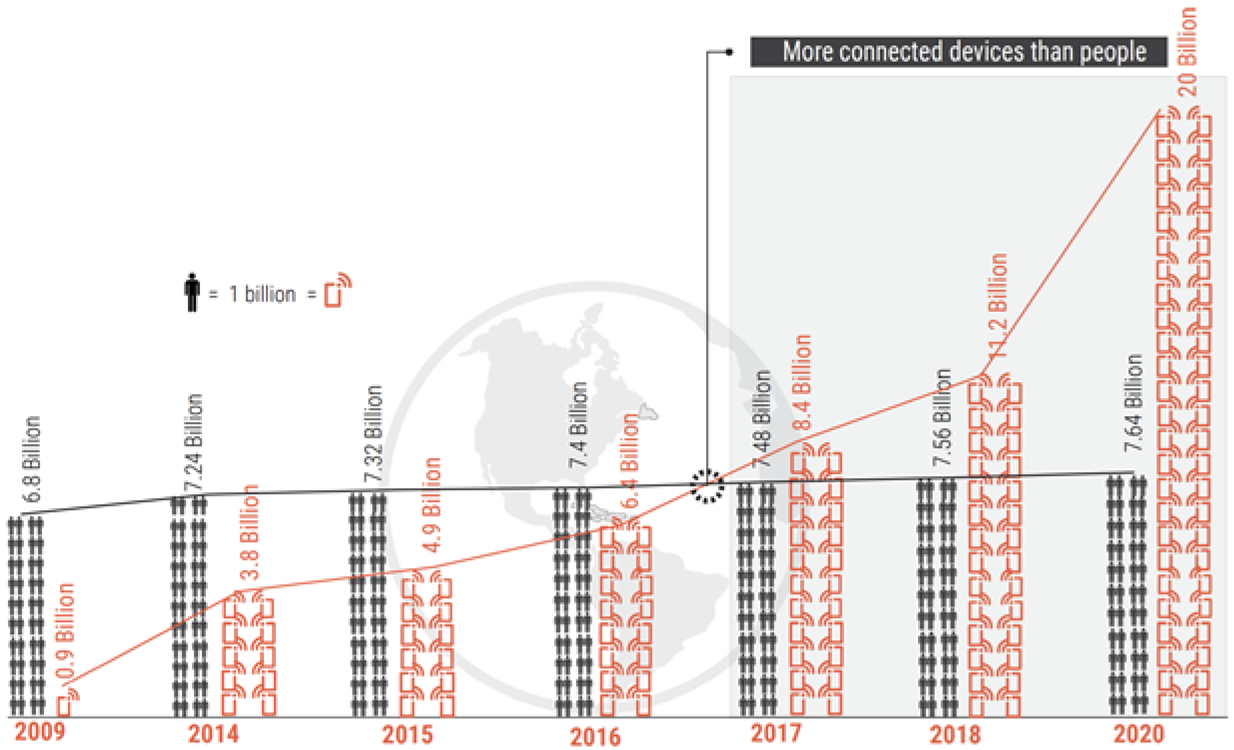
- In the past, the farmer had to stay at the side of the crop at any time, patrol the water, fertilize, and watch the day.

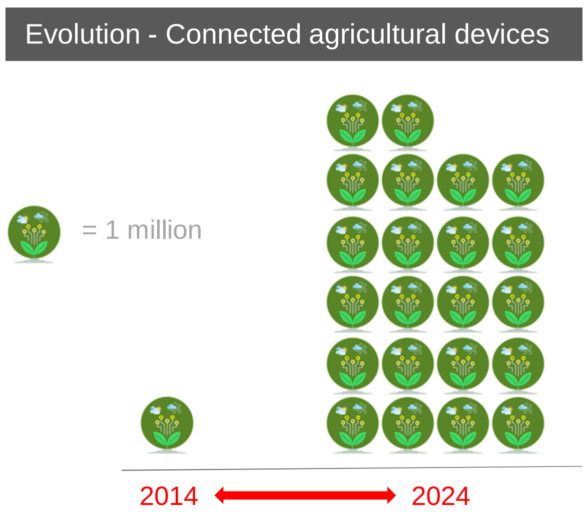
- In order to bring agricultural efficiency with technology, smart farming systems are being developed to help farmers have better control over the cultivation process.

- Now, farmers can use technology in order to reduce labor costs, increase work efficiency, etc.

Smart agriculture

- According to the Machina research report, the number of connected agricultural devices is expected to grow from 13 million at the end of 2014 to 225 million by 2024.





Sources: Gartner/World Bank

Smart agriculture

- Smart Farming is closely related to 3 interconnected technological fields, which are:

  - **Management Information Systems**: Planned systems for collecting, processing, storing, and disseminating data in the form needed to carry out a farm’s operations and functions.

  - **Precision Agriculture**: Management of spatial and temporal variability to improve economic returns following the use of inputs and reduce environmental impact.

  - **Agricultural automation and robotics**: The process of applying robotics, automatic control and artificial intelligence techniques at all levels of agricultural production

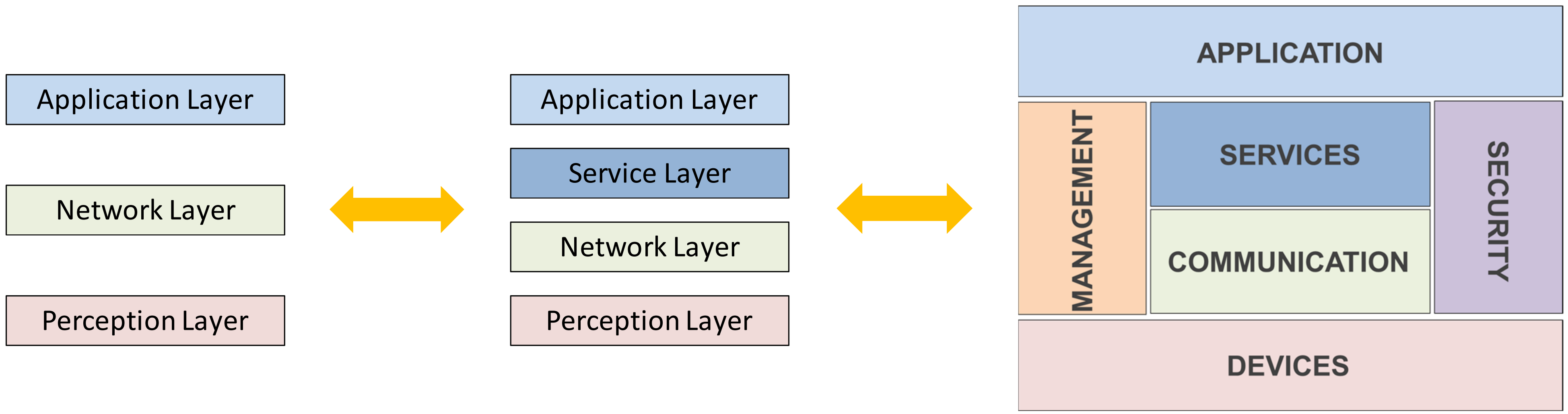
Communication technologies in Smart Agriculture

Benefits derived from the use of Smart Agriculture.

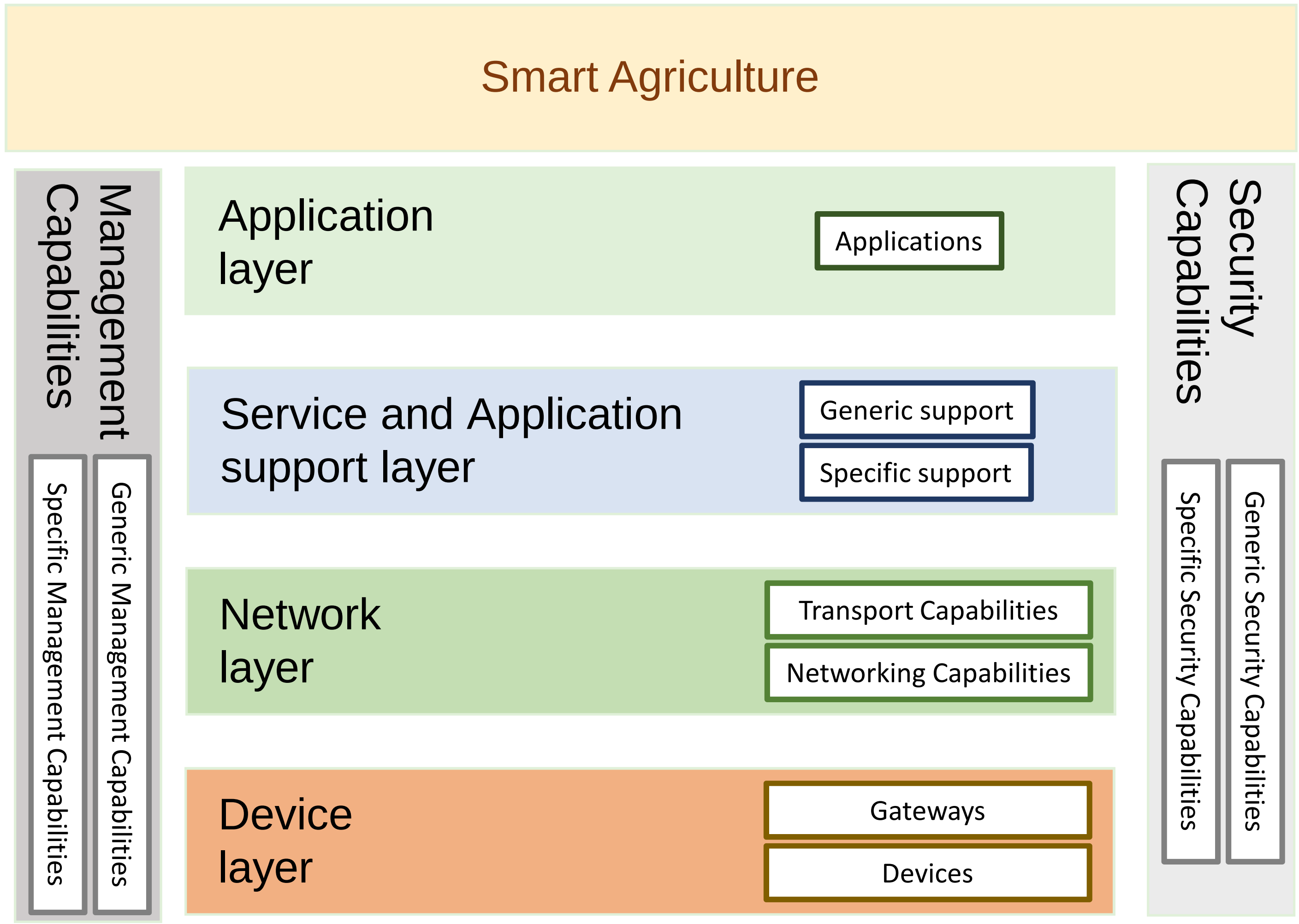
- Community farming
- Safety control and Fraud prevention
- Competitive advantages
- Wealth creation and distributions
- Cost reduction and wastage
- Operational efficiency
- Awareness
- Asset management

Smart Agriculture Architecture

Evolution


Application Layer
Network Layer
Perception Layer
Application Layer
Service Layer
Network Layer
Perception Layer
APPLICATION
MANAGEMENT
SERVICES
COMMUNICATION
SECURITY
DEVICES

Layered Architecture ITU-T



Communication technologies

Communication technologies in Smart Agriculture

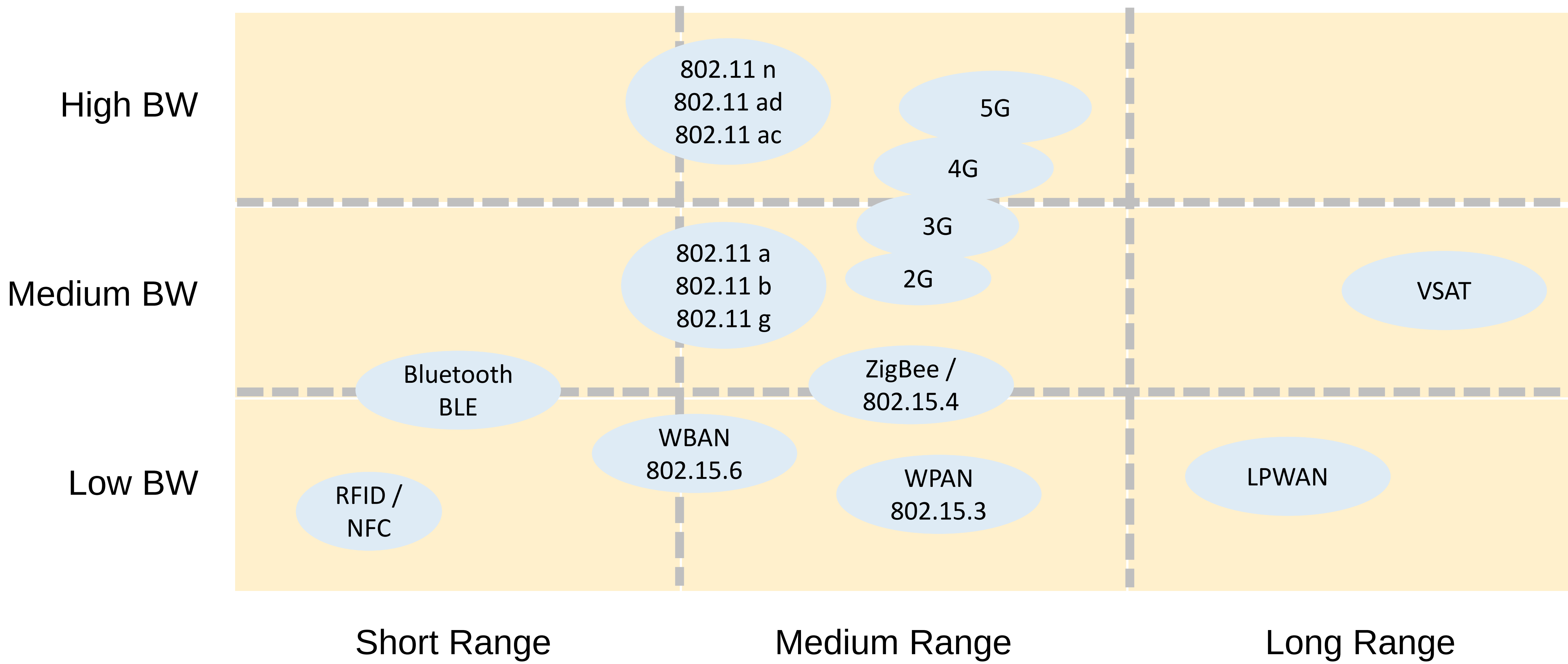
Many wireless communication technologies have been proposed to be applied in a wide variety of applications, such as agriculture, smart cities, industry 4.0, health, tracking, personal devices, etc.

Generally, these technologies are divided into three categories according to the transmission distance:

- Short range wireless communication technologies (≤ 10 m)
- Medium range wireless communication technologies (from 10 m to 100 m)
- Long range wireless communication technologies (≥ 100 m)

Communication technologies in Smart Agriculture

Wireless communication technologies classification in Smart Agriculture



Wireless Communication Technologies used in Smart Agriculture

- **Short range**
  - Bluetooth
  - Bluetooth Low Energy
  - RFID
- **Medium range**
  - Wi-Fi standards
  - ZigBee (IEEE 802.15.4)
- **Long range**
  - Cellular (2G/3G/4G/5G)
  - LPWA (LoRa, NB-IoT, LTE-M, Sigfox)

Main technologies used in IoT for irrigation systems I

Group	Technology	Max. Data rate
Cellular	3G	Upload 7,2 Mbps Download 2 Mbps
	4G / LTE	Upload 150 Mbps Download 50 Mbps
	5G	up to 10 Gbps
Wireless Personal Area Networks	IEEE 802.15.1 – Bluetooth	Up to 3 Mbps
	BLE (Bluetooth Low-Energy)	Up to 2 Mbps
RFDI	RFDI	Up to 640 kbps
Mesh Protocols	Zigbee	Up to 250 kbps
	Z-Wave	Up to 100 kbps
	Thread	Up to 250 kbps

Main technologies used in IoT for irrigation systems II

Group	Technology	Max. Data rate
Low-Power Wide Area Network (LPWAN)	NarrowBand IoT (NB-IoT)	200 kbps
	Long Term Evolution - Machine Type Communication (LTE-M)	Upload peak rate of 5Mbps Download peak rate of 10Mbps
	Sigfox	100 or 600 bps
	LoRa - Low Power Wide Area Network (LoRaWAN)	0.3 to 50 kbps
WiFi	IEEE 802.11a	Up to 54 Mbps
	IEEE 802.11b	Up to 11 Mbps
	IEEE 802.11g	Up to 54 Mbps
	IEEE 802.11n	Up to 600 Mbps
	IEEE 802.11ac	Up to 3,46 Gbps

Short Range Wireless Communication Technologies used in Smart Agriculture

Bluetooth I

Origins

- 1994 by Ericsson as an alternative to cable.
- It uses a **frequency hopping spread spectrum (FHSS) type modulation with 79 frequencies**,
  - Wireless technologies less sensitive to problems derived from noise and interference (better use of frequencies).
  - Transmissions of this modulation difficult to intercept (continuous transmission frequency jumps according to an order only known by transmitter and receiver)
- Bluetooth technology (IEEE 802.15.1), with 2 specifications in its latest version, Bluetooth 4.
  - **Classic Bluetooth**: Devices with high demand for small transmissions. Under this set are grouped all the old Bluetooth specifications.
  - **Bluetooth Low Energy** (BLE): Ideal for applications that require communication of small amounts of data on a one-off or regular basis.
- Communication
  - Specific hardware (baseband module, a radio module and an antenna)
  - The Bluetooth specification intends that all applications are capable of operating with each other. To achieve this interoperability, applications on remote devices must run on an identical protocol stack.

Bluetooth II

- **Common technical characteristics** of Bluetooth are:
  - Communication distance of up to 1 km (straight line without obstacles).
  - 2.4 GHz free frequency use.
  - Highly reliable transmission through redundant transmission channels.
  - Reduced delay time (5-10 ms).
  - Ability to operate in environments with a large number of devices due to its use of frequency.
- **Classic Bluetooth**
  - Fast and cyclical transmission of small data packets.
  - Transmissions of up to 780 kbps.
  - Large number of connected devices in the same radio environment operating without interference.
  - High availability in consumer products.
- **Bluetooth Low Energy**
  - Large number of communication nodes with limited latency requirements.
  - Very low energy consumption.
  - Robustness equal to the Classic Bluetooth specification.
  - Good real-time characteristics, if the number of connected nodes is not high.

Bluetooth III

- **Drawback**:
    - Relatively low data rate
    - High power consumption
    - Always up
    - Relatively short range
    - Vulnerable to outside attacks
    - Very short time to wake up or reconnect.

Medium Range Wireless Communication Technologies used in Smart Agriculture

WiFi I

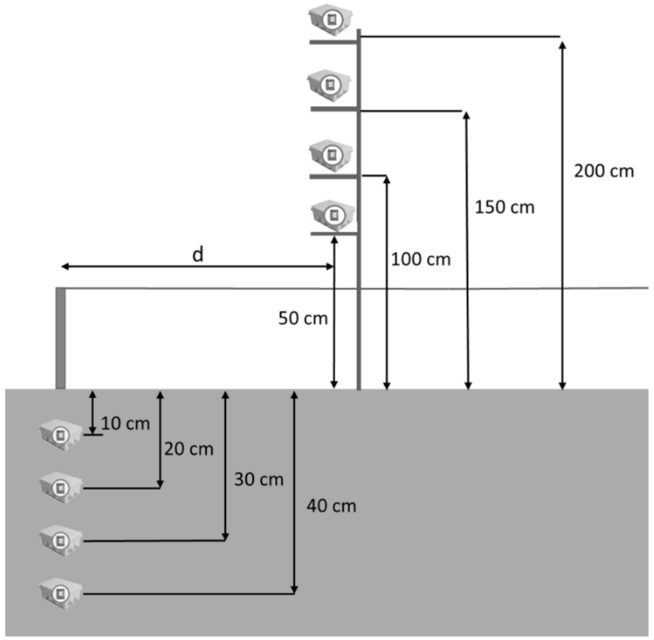
- Most used wireless technology for the exchange of data of all existing wireless networks, both in the industrial sector and in the corporate sector.
- Regulated by the IEEE 802.11 standard in its a / b / g / n / ac versions:
    - Frequency of use in free band, located in 2.4 GHz or 5 GHz.
    - High speeds, depending on the standard, which can reach 3,46 Gbits / s.
    - Fast roaming.
    - Provides mobility in large area networks.
    - High reliability, through the use of MiMo technology (Multiple-input Multiple-output, Multiple input multiple output).
    - Range of action from 50 meters (5 GHz) to 200 (2.4 GHz), although it can be increased if it is in a visible straight line.
    - 23 channels for 5 GHz frequency and 13 channels for 2.4 GHz.
    - High availability of products at very competitive prices.

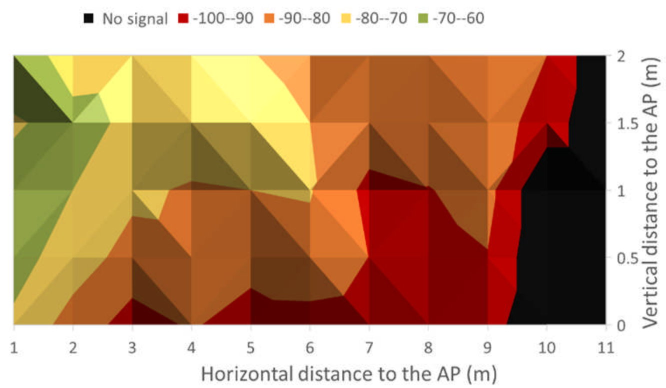
WiFi II

- Drawback
  - Becomes slower with increasing user connections
  - High power consumption
  - Topology has a single paint of failure
  - Vulnerable to attacks
  - Requires large memory capacity and processing power
  - Signals blocked by obstacles
  - Limited to indoor operations

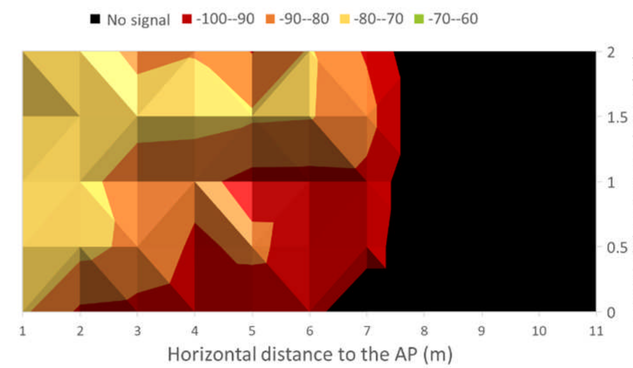
WiFi III

- **Internet of Underground Things (IoUT) and the performance of WiFi low-cost nodes for IoUT Applications**

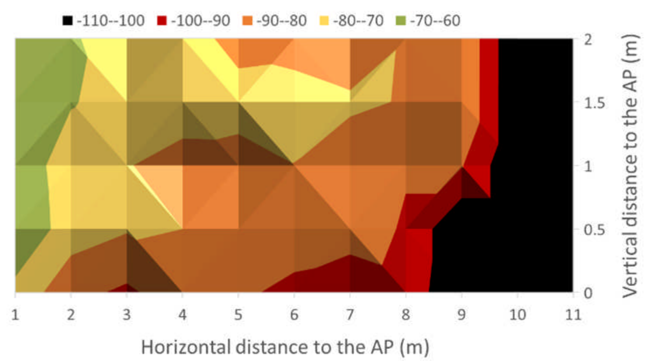




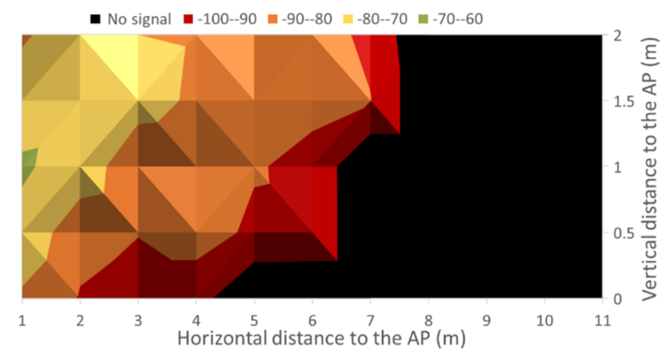
RSSI at 10 cm of depth.



RSSI at 30 cm of depth.



RSSI at 20 cm of depth.



RSSI at 40 cm of depth.

Zigbee

- ZigBee is a wireless protocol, developed by the ZigBee Alliance that adopts the IEEE 802.15.4 standard for the lower layers of the OSI model.
- ZigBee acts on the physical and link layer (access sublayer to the MAC medium), operating directly above these levels.
- Characteristics:
  - Low energy consumption
  - The possibility of using a mesh network topology that provides great robustness to communications, a characteristic that allows Zigbee to be a suitable protocol also for use in industrial environments.
  - Good scalability, ZigBee (up to 65535 nodes distributed in subnets of 255 nodes)
  - Transmission speed is not high (250 kbps)
- Its use in the industry is decided based on the needs of coverage, energy consumption, cost and reliability.

Zigbee

- Drawback
  - No security
  - Short range
  - Low data rates
  - Suffers from compatibility issues with devices from different manufacturers

Long Range Wireless Communication Technologies used in Smart Agriculture

LPWAN technology I

- LPWAN is increasingly gaining popularity in industrial and research communities because of its characteristics:
  - low power
  - long range
  - low-cost communication
- Long-range communication up to 10–40 km in rural zones and 1–5 km in urban zones.
- Highly energy efficient and inexpensive,
- Cost of a radio chipset being less than 2€ and an operating cost of 1€ per device per year.

LPWAN technology II

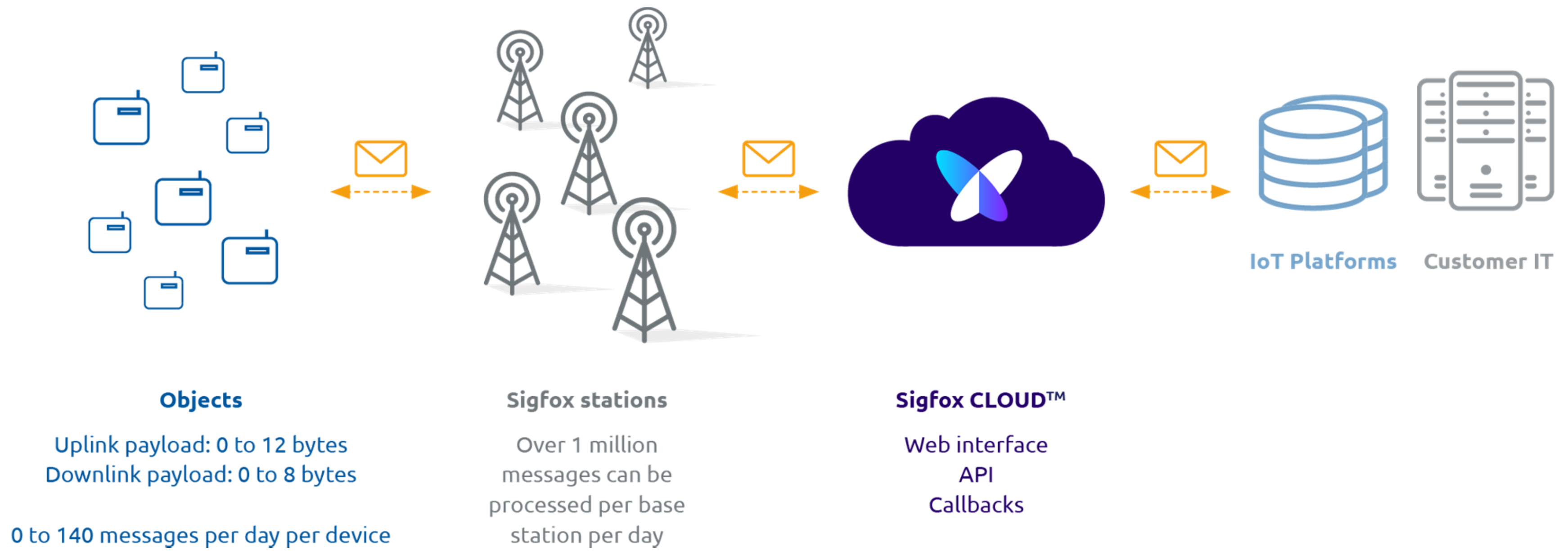
- LPWAN is highly suitable for IoT applications.
- Only need to transmit tiny amounts of data in long range.
- Many LPWAN technologies have arisen in the licensed as well as unlicensed frequency bandwidth.
- Sigfox, LoRa, and NB-IoT are today’s leading the lasts proposed solutions.

Sigfox I

- Sigfox is an LPWAN network operator that offers an end-to-end IoT connectivity solution based on its patented technologies.
- Proprietary base stations equipped with cognitive software-defined radios and connect them to the back end servers using an IP-based network.
- The end devices connected to these base stations using binary phase-shift keying(BPSK) modulation in an ultra-narrow band (100 Hz) sub-GHZ ISM band carrier.
- Sigfox uses unlicensed ISM bands, for example, 868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia.
- By employing the ultra-narrow band, Sigfox uses the frequency bandwidth efficiently and experiences very low noise levels, leading to very low power consumption, high receiver sensitivity, and low-cost antenna design at the expense of maximum throughput of only 100 bps.

Sigfox II

- Sigfox is a public network based on a star network architecture. A device is not attached to a specific base station unlike cellular protocols. The broadcasted message is received by any base station in the range, 3 in average.



https://www.avnet.com/wps/portal/ebv/solutions/iot/sigfox/

Sigfox III

Very long range

- Low bit rate and simple radio modulation enable a 163.3 dB budget link leading to long-range communications.

High network capacity

- The small footprint of Ultra Narrow Band (UNB) enables more simultaneous signals within the operation band. In addition, the objects are not attached to a specific base station.
- They broadcast their messages which are received by any base station in the range (3 in average).
- There is no need for message acknowledgement. UNB modulation, spatial diversity coupled with the time and frequency diversity of the radio frames repetitions lead to a high capacity of the Sigfox network.

High resilience to interferers

- UNB intrinsic ruggedness coupled with spatial diversity of the base stations offer great anti-jamming capabilities. UNB is extremely robust in an environment with other spread spectrum signals. UNB is the best choice to operate on the public ISM band.

Sigfox IV

Drawbacks

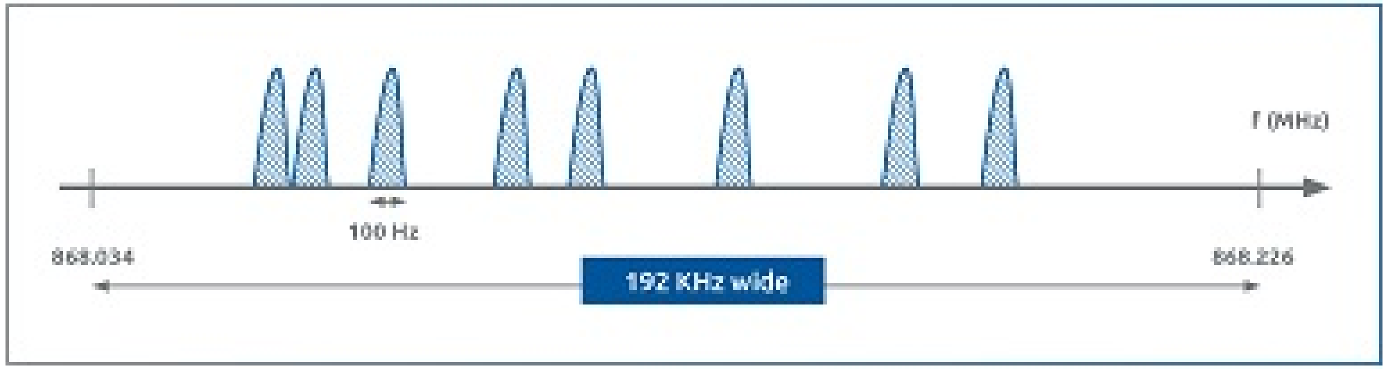
- CSMA/CA or other such techniques for collision detection/avoidance are not being used in Sigfox.
- There are duty cycle limitations in Europe and PSD spectrum radiation limitations in Japan.
- The narrow band spectrum emitted by single Sigfox end device cause strong interference to nearby existing wideband system. More such Sigfox devices will further enhance the interference.
- Sigfox supports one way communication without acknowledgement. This necessitates multiple transmissions if server does not receive data without errors. Due to this power consumption will increase which depends on number of retransmissions.
- Due to low data rate support, it can not be used for high data rate applications.
- Sigfox system works well in fixed location. There are issues such as interference and frequency inaccuracies in the mobility environments.

Sigfox V

Sigfox radio technology overview

- Sigfox uses 200 kHz of the publicly available and unlicensed bands to exchange radio messages over the air (868 to 869 MHz and 902 to 928 MHz depending on regions).

- Sigfox uses Ultra Narrow Band (UNB) technology combined with DBPSK and GFSK modulation. Each message is 100 Hz wide and transferred at 100 or 600 bits per second data rate depending on the region.

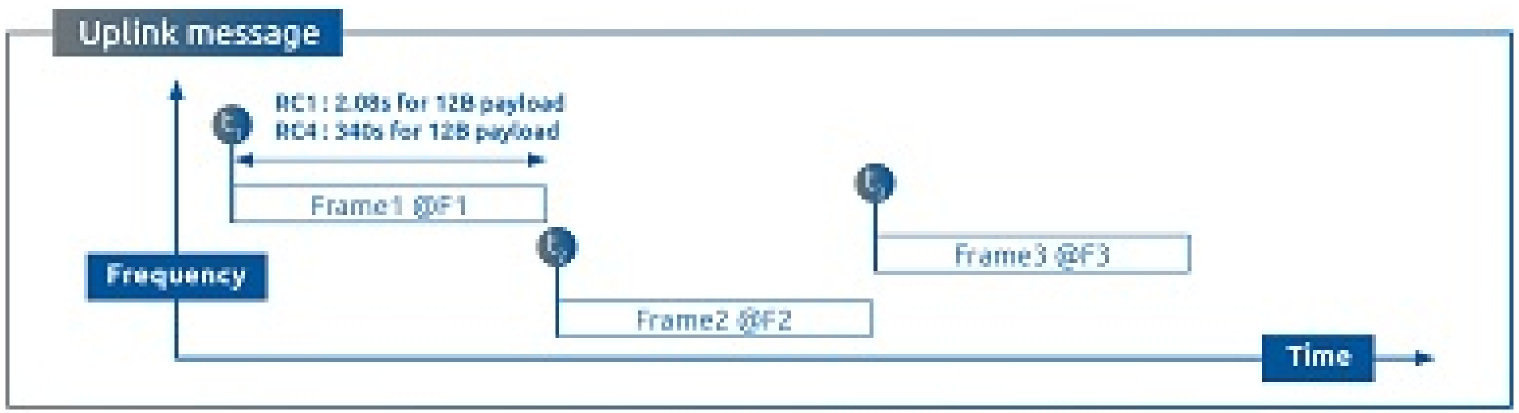


https://www.avnet.com/wps/portal/ebv/solutions/iot/sigfox/

Sigfox VI

Random access to the radio frequency resource

- The transmission is unsynchronized between the devices and the network.
- They broadcast each message 3 times on 3 different frequencies (frequency hopping).
- The base stations monitor the spectrum and look for UNB signals to demodulate.



https://www.avnet.com/wps/portal/ebv/solutions/iot/sigfox/

Sigfox VII

Small messages

- Sigfox has tailored a lightweight protocol to handle small messages.
- An uplink message has a maximum 12-bytes payload and a downlink of 8 bytes.
- For a 12 bytes data payload, a Sigfox frame will use 26 bytes in total.

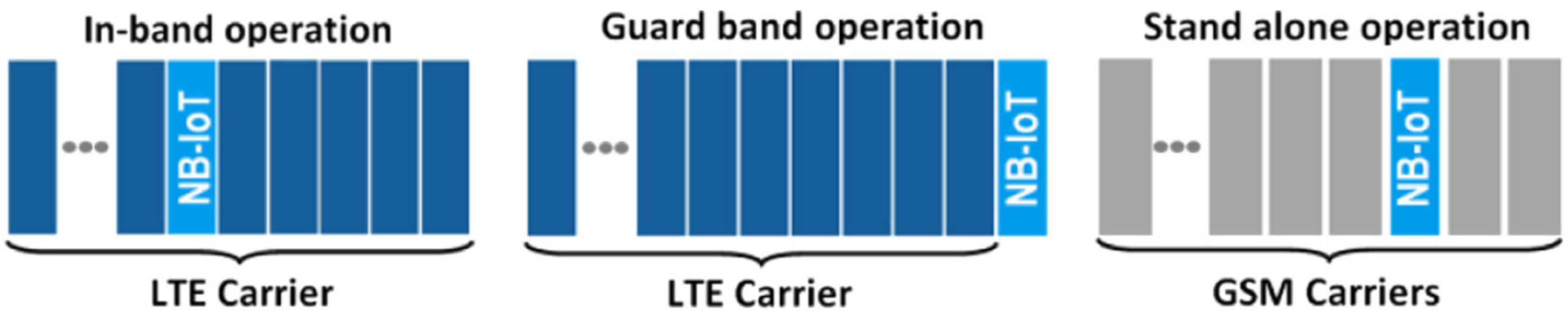
https://www.avnet.com/wps/portal/ebv/solutions/iot/sigfox/

NB-IoT I

- NB-IoT uses licensed spectrum bands, so there is no interference with other technologies,
- Robustness of communications, not dependent on the number of devices in the vicinity.
- Many of the frequency bands reserved for NB-IoT are in the 700 and 800 MHz range → easy penetration into buildings and basements, making the technology able to operate in a greater number of scenarios.
- Low consumption orientation based on cellular telephone networks is LTE Cat M1.
- Transmission speeds up to 375 kb/s.

NB-IoT II

- NB-IoT is a Narrow Band IoT technology is specified in Release 13 of the 3GPP in June 2016.
- NB-IoT can coexistwith GSM (global system for mobile communications) and LTE(long-term evolution) under licensed frequency bands (e.g., 700 MHz, 800 MHz, and 900 MHz).
- It is placed at the frequency band width of 200 KHz, which corresponds to one resource block in GSM and LTE transmission.



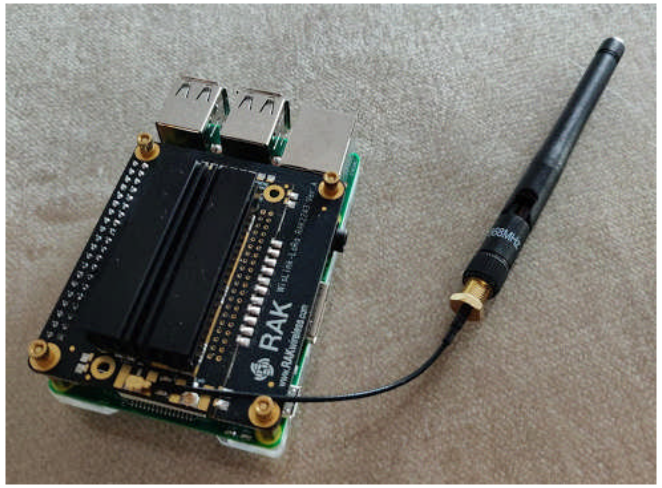
Mekki, K., Bajic, E., Chaxel, F., & Meyer, F. (2019). A comparative study of LPWAN technologies for large-scale IoT deployment. *ICT express*, *5*(1), 1-7

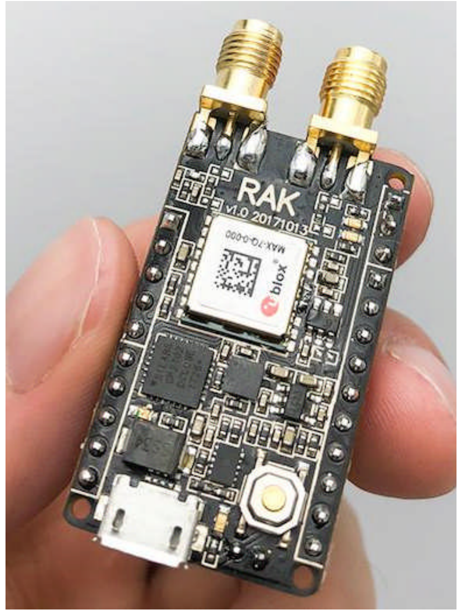
LoRa ≠ LoRaWAN I

- LoRa is Semtech's proprietary type of radio frequency modulation.
- Its main advantages are:
  - High tolerance to interference.
  - High sensitivity to receive data (-168dB)
  - Based on chirp modulation
  - Low power consumption (up to 10 years with battery)
  - Long range: 10 to 20 km
  - Low data transfer (up to 255 bytes)
  - Point to point connection
  - Working frequencies: 915Mhz America, 868 Europe, 433 Asia
- It is the ideal technology for long distance connections and for IoT networks that can be used in smart cities, places with little cellular coverage or private sensor or actuator networks, which is why LoRaWAN was born.

LoRa ≠ LoRaWAN II

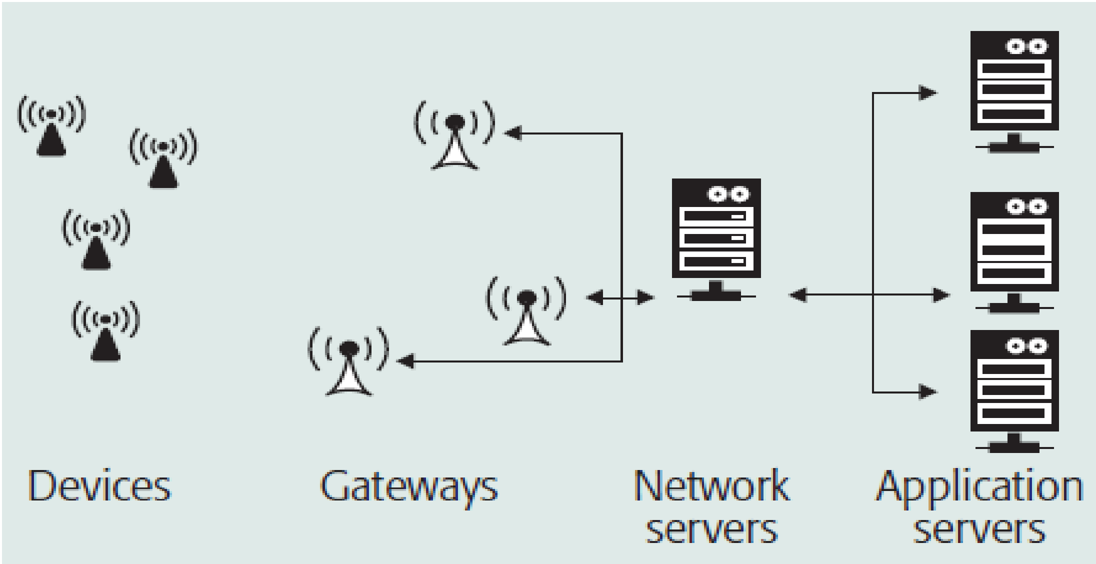
- According to Semtech, the key features of this technology are:
  - Low cost (in terms of investment in infrastructure, operating expenses and end devices), standardization (allowing interoperability),
  - Low power (prolongs battery life up to 10 years),
  - Long range (deep penetration in dense urban / inland regions and up to 30 miles in rural areas),
  - Geolocation (geolocation without GPS without requiring additional power), Security (advanced end-to-end AES encryption standard, AES, encryption),
  - High capacity (support of many devices per LoRaWAN gateway).





LoRa ≠ LoRaWAN III

- Unlike other IoT technologies, LoRaWAN does not use a mesh network architecture.
- Although mesh networking may be useful to increase the communication range, it also affects the device battery life due to the forwarding of messages. LoRaWAN uses a star topology
- LoRaWAN allows end devices to have bidirectional communications, although they are asymmetric, since uplink transmissions (from end devices to gateways) are strongly favored.



LoRa ≠ LoRaWAN III

Drawbacks

- Only point to point (no mesh) connection
- Using of gateways may cause bottlenecks and become single points of failure
- Operates in un-licensed band
- Support for variable frame length reduces predictability
- Low bandwidth support
- Suffers from near/far problem
- Relatively high packet loss rates during congestion times
- All gateway nodes are tuned to the same frequencies reducing the ability to control them individually

LoRa ≠ LoRaWAN IV

- LoRa is a proprietary spread spectrum modulation scheme which is based on chirp spread spectrum (CSS).
- Some of the key properties of this modulation are scalable bandwidth, constant envelope, low power, high robustness, multipath and fading resistant, Doppler resistant, long-range capability, enhanced network capacity, and geolocation capabilities.
- Using different spreading factors (SFs), the developer may trade data rate for coverage or energy consumption. The spreading factor is

$$SF = \log_2\left(\frac{R_C}{R_S}\right)$$

RS and *RC* are the symbol and chip rates

LoRa ≠ LoRaWAN V

- The usage of a high SF decreases the data rate but increases the maximum distance between the transmitter and the receiver, and vice versa.

- Since transmissions using different SFs are orthogonal, it is possible to receive multiple frames simultaneously.

- LoRa error correction reduces the bit rate by a factor rate code = 4/ (4+CR), where code rate (CR) is an integer value between 1 and 4.

$$Rb = SF \times \frac{\frac{4}{4+CR}}{\frac{2^{SF}}{BW}}$$

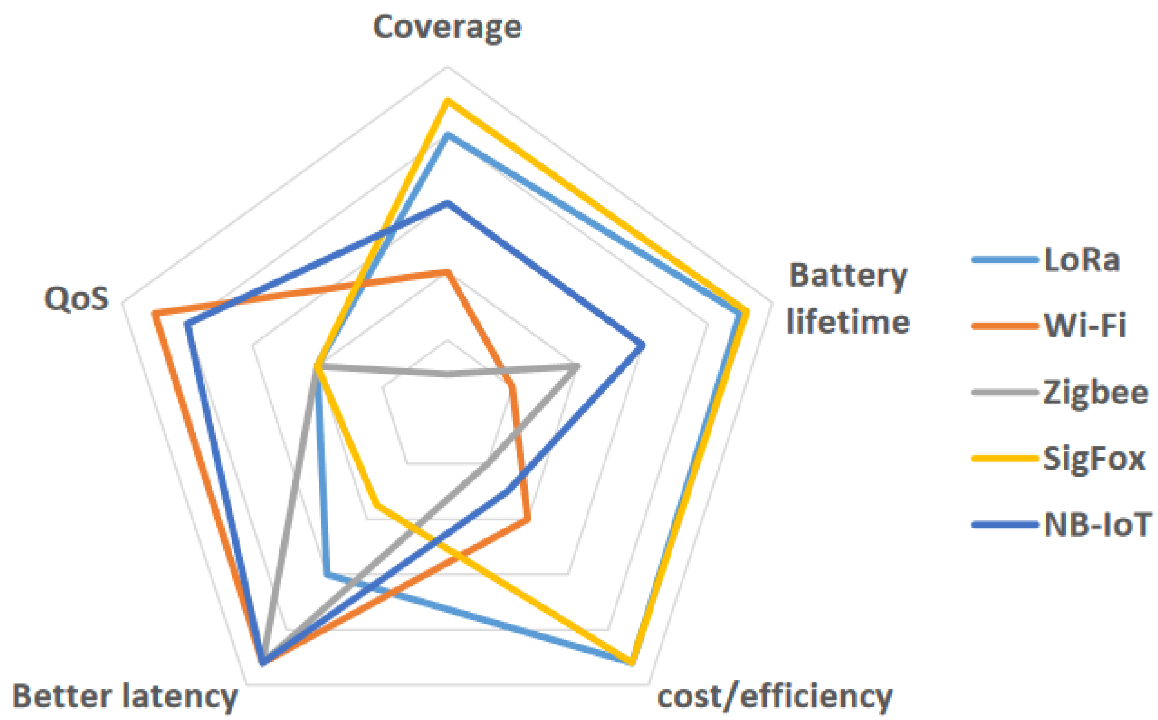
- Since SFs vary from 7 to 12, and frames sent with different SFs can be decoded simultaneously, the maximum aggregated bit rate (assuming BW = 500 kHz and CR = 1) is 43 kb/s.

Comparison technologies

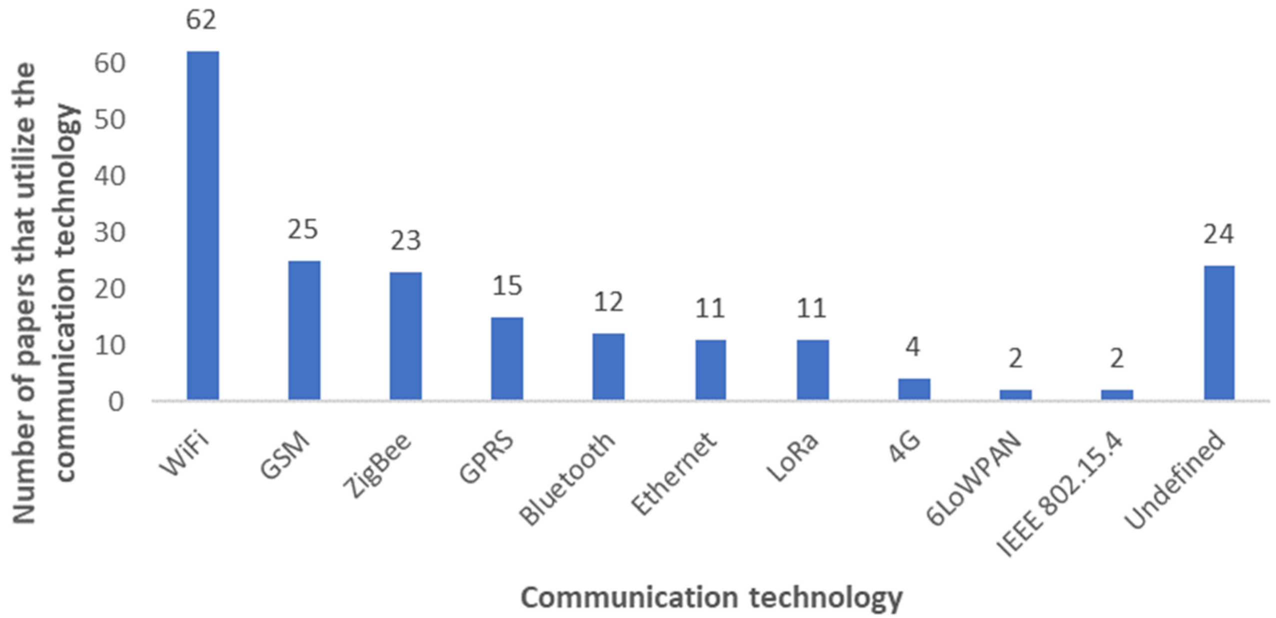
Communication technologies in Smart Agriculture

	LoRa	Wifi	ZigBee	SigFox	NB-IoT
Frequency	868 MHz (EU); 915 MHz (USA); 433 MHz (Asia)	2.4 GHz and 5 GHz	868 MHz (EU); 915 MHz (USA); 433 MHz (Asia); 2.4 GHz	868 MHz (EU); 915 MHz (USA), 433 MHz (Asia)	Depends on the frequency licensed to LTE
Standard	IEEE802.15.4g, LoRa Alliance	IEEE802.11	IEEE802.15.4	SigFox (Owner)	3GPP Standard
Coverage	5 km (urban),20 km (rural)	50 m (indoor), 40 km (outdoor, as a function of the visibility)	10–100 m	10 km (urban), 40 km (rural)	1 km (urban), 10 km (rural)
Modulation	LoRa, FSK, GFSK	BPSK, QPSK, 16 QAM, 64 QAM, 256 QAM, 1024 QAM	BPSK, OQPSK	BPSK, GFSK	QPSK, OFDM (DL, SC-FDMA (UL)
Power consumption	Low	High	Medium-Low	Low	Low
Theoretical Data Transfer Rate	22 kbps (LoRa), 100 kbps (GFSK)	2.4 Gbps (IEEE802.11 ax, 2 streams with 1024 QAM)	250 kbps at 2.4 GHz, 20 kbps at 868 MHz, 40 kbps at 915 MHz	100 bps	10 Mbps
Price of end devices	3–5 €	3–5 €	2–5 €	>2 €	>20 €
Price of Gateway/ Base Station	100 € Gateway/ >1000 € Base station	20–600 € Gateway	40–1000 € Gateway	4000 € Base station	15000 € Base station

- Many factors should be considered when choosing the appropriate technology for an Smart Agriculture application including quality of service, battery life, latency, scalability, payload length, coverage, range, deployment, and cost. In the following.



Communication technologies in Smart Agriculture



Communication technologies employed to implement IoT irrigation systems.

Source
IoT-Based Smart Irrigation Systems: An Overview on the Recent Trends on Sensors and IoT Systems for Irrigation in Precision Agriculture

Related Papers

Related Papers

- Laura Garcia, Lorena Parra, Jose M. Jimenez, Jaime Lloret, P Lorenz, IoT-Based Smart Irrigation Systems: An Overview on the Recent Trends on Sensors and IoT Systems for Irrigation in Precision Agriculture, Sensors 2020, 20(4), 1042; https://doi.org/10.3390/s20041042
- Laura García, Lorena Parra, Jose M. Jimenez, Jaime Lloret, Abdelhafid Abouaissa, Pascal Lorenz, Internet of Underground Things ESP8266 WiFi Coverage Study, The Eighth International Conference on Communications, Computation, Networks and Technologies (INNOV 2019), November 24, 2019 to November 28, 2019 - Valencia, Spain
- L García, J Jimenez, Jose M., Lloret, P Lorenz, WiFi and LoRa Energy Consumption Comparison in IoT ESP 32/ SX1278 Devices, The Eighth International Conference on Smart Cities, Systems, Devices and Technologies (SMART 2019), July 28, 2019 to August 02, 2019 – Nice, France
- García L., Parra L., Jimenez J.M., Lloret J., Lorenz P. (2020) Estimation of the Best Measuring Time for the Environmental Parameters of a Low-Cost Meteorology Monitoring System. In: Ezziyyani M. (eds) Advanced Intelligent Systems for Sustainable Development (AI2SD'2019). AI2SD 2019. Lecture Notes in Networks and Systems, vol 92. Springer, Cham. https://doi.org/10.1007/978-3-030-33103-0_14

Related Papers

- Jose M. Jimenez, Laura Garcia, Miran Taha, Lorena Parra, Jaime Lloret, Pascal Lorenz, Comprehensive security framework of an Intelligent Wastewater Purification System for Irrigation, The Twelfth International Conference on Communication Theory, Reliability, and Quality of Service (CTRQ 2019) March 24, 2019 to March 28, 2019 - Valencia, Spain
- García-García, L.; Jimenez, JM.; Abdullah, MTA.; Lloret, J. (2018). Wireless Technologies for IoT in Smart Cities. Network Protocols and Algorithms. 10(1):23-64. doi:10.5296/npa.v10i1.12798

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