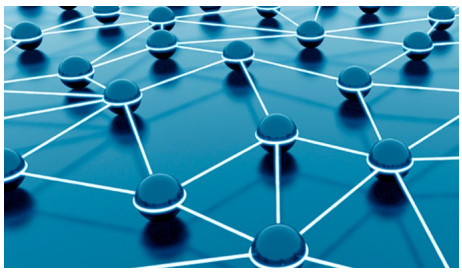
Sistemas de Computação Móvel e Ubíqua

2021/2022

1

Wireless communications

2021/2022



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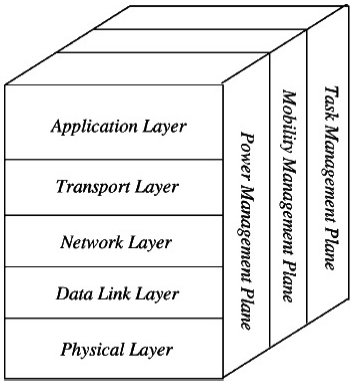
WSN Architecture

Wireless sensor networks follows most common architecture OSI model with five layers:

- application, transport, network, data link and physical.

Three cross layers planes monitor the power, movement, and task distribution among the sensor nodes.

These planes help the sensor nodes coordinate the sensing task and lower the overall power consumption



Wireless Sensor Network Architecture

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Internet of Things (definition)

"*Things* are active participants in business, information and social processes where they are enabled to interact and communicate among themselves and with the environment by exchanging data and information sensed about the environment, while reacting autonomously to the real/physical world events and influencing it by running processes that trigger actions and create services with or without direct human intervention."

H. Sundmaeker, P. Guillemin, P. Friess, S. Woelfflé, Vision and challenges for realising the Internet of Things, Cluster of European Research Projects on the Internet of Things—CERP IoT, 2010.

4

IoT and sensor networks

One of the most important component needed to achieve this is the "**connection** and **communication**".

It enables the remote interaction between devices (artifacts) and also with "the community".

Several possibilities can be used to connect, using wired and wireless links.

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IoT devices (examples)

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Limitations and Difficulties of Wireless Technologies

Wireless is convenient and less expensive deployment.

Limitations and political and technical difficulties can inhibit the use of wireless technologies.

Lack of one industry-wide standard, but lots of standards

Device limitations

- E.g. battery

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Wireless Networks vs. Fixed Networks

Higher loss-rates due to interference

- other EM signals, objects in path (multi-path, scattering)

Limited availability of useful spectrum

- frequencies have to be coordinated, useful frequencies are almost all occupied

Low transmission rates

- local area: 2 – 50 Mbit/s, wide area: 9.6 – 56 Kbit/s

Higher delays, higher jitter

- connection setup time for cellular in the second range, several hundred milliseconds for wireless LAN systems

Lower security, simpler active attacking

- radio interface accessible for everyone
- base station can be simulated, thus attracting calls from mobile phones

Always shared medium

- secure access mechanisms important

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Wireless networks

Ubiquitous data exchange through proximity wireless technologies

- Wireless communication technologies to network “smart” objects.

Energy-optimized solutions

- Minimizing the energy to be spent for communication/computing purposes will be a primary constraint (use of micro solar panels).

Localization and tracking capabilities

- Identify entities, short range wireless communication
- track location and movement of smart objects (e.g. RFID technologies).

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Design Challenges

Wireless channels are a difficult and capacity-limited broadcast communications medium.

Traffic patterns, user locations, and network conditions are constantly changing.

Applications are heterogeneous with hard constraints that must be met by the network.

Energy and delay constraints change design principles across all layers of the protocol stack.

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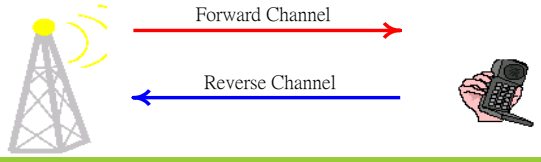
Design Challenges

Classification of mobile radio transmission system
- Simplex: communication in only one direction
- Half-duplex: same radio channel for both transmission and reception (push-to-talk)
- Full-duplex: simultaneous radio transmission and reception (FDD, TDD)

FDD - Frequency Division Duplexing uses two radio channel
- Forward channel: base station to mobile user
- Reverse channel: mobile user to base station

TDD - Time Division Duplexing shares a single radio channel in time.



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Wireless communication

Wireless Communication Technologies

Different electromagnetic signals can be used, with different wavelength and frequency, depending on requirements and deployment environment

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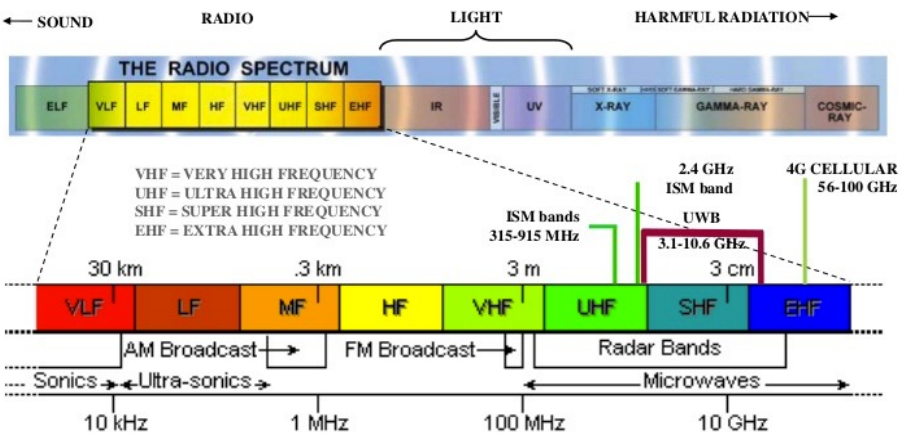
Frequency spectrum



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Frequency spectrum allocation

Frequency	Wavelength	Application
50–60 Hz	6000–5000 km	AC electricity transmission
3–30 kHz	100–10 km	Sub-marine communication
30–300 kHz	10–1 km	Long-wave radio broadcast
180–1600 kHz	1.7 km–188 m	AM radio broadcast
1.8–30 MHz	167–10 m	Shortwave radio
88–108 MHz	3.4–2.7 m	FM broadcast
300–3000 MHz	1–0.1 m	UHF point to point
800–2200 MHz	0.375–0.136 m	Mobile base station
1–60 GHz	0.3–0.005 m	Microwave links
60–300 GHz	0.005–0.001 m	Millimeter-wave links
352, 230, 193 THz	1550, 1300, 850 nm	Fiber-optic links
420–750 THz	714–400 nm	Visible light

Table 2.1: *Applications within the electromagnetic spectrum, arranged by frequency*

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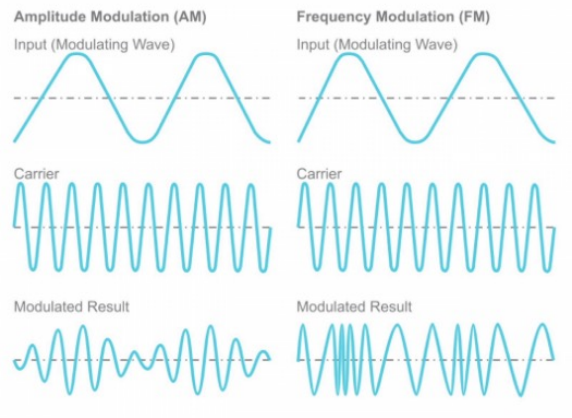
Modulating signals: AM and FM



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Wireless communication

Radio frequency (RF)

- Form of electromagnetic transmission used in wireless communication.
- RF signals ranging 3kHz to 300GHz.
- Ability to go through objects and travel long distances depends on the wavelength, transmitter power, receiver quality, type, size and height of the antenna, etc

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Wireless communication

Microwave Transmission

- Microwave (MW) is a part of this spectrum, comprising the bands between 1 GHz and 300 GHz.
- High frequencies offer wither bandwidth, and can easily carry voice, data, television, telephony or radio signals.
- Radio waves from 30 GHz to 100 GHz are usually strongly attenuated by the Earthly atmosphere and particles contained in it, especially during wet weather.
- The electronic technologies needed in the millimeter wave band (higher frequencies) are also more difficult to utilize.

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Wireless communication

Microwave Transmission

- Microwave transmission requires line of sight in order to work properly.
- These are widely used for long distance.
- Microwave radio transmission is commonly used in point-to-point communication systems on the surface of the Earth, in satellite communications, and in deep space radio communications.
- In order to allow two-way communications two frequencies are used.
- Other parts of the microwave radio band are used for radars, radio navigation systems, sensor systems, and radio astronomy.

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Wireless communication

Wireless Technology for sensor networks and IoT:

- GSM et al.
- Bluetooth
- ZigBee
- Infrared
- WiFi
- LoRa
- Low power RF

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GSM and successors

GSM (Global System for Mobile Communications, originally Groupe Spécial Mobile) is a standard developed by the European Telecommunications Standards Institute (ETSI) to describe the protocols for second-generation digital cellular networks used by mobile devices such as tablets, first deployed in Finland in December 1991.

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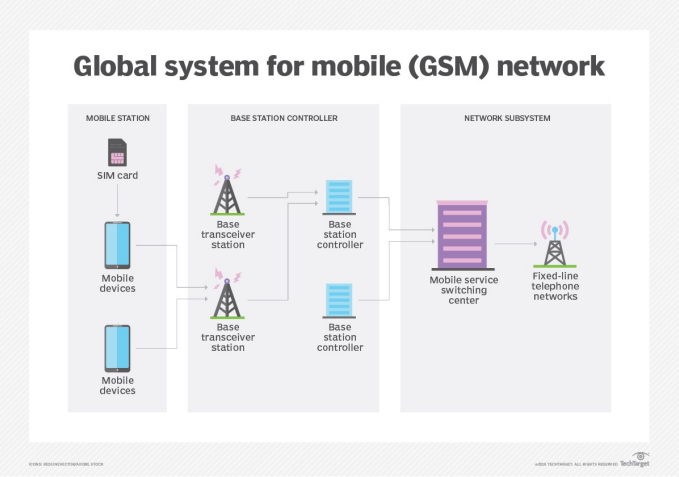
Mobile infrastructure



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GSM and successors

The evolution of 1G to 5G

TYPE	DEPLOYMENT	TECHNOLOGIES AND STANDARDS	FEATURES
1G	Analog telecommunication deployed in the 1980s	■ Advanced Mobile Phone Service (AMPS) ■ Nordic Mobile Telephone (NMT)	Voice calls, NMT for simple integrated data and messaging
2G	Digital cellular deployed in the 1990s	■ Code-division multiple access (CDMA) ■ Global System for Mobile Communications (GSM)/ Enhanced Data rates for GSM Evolution (EDGE) ■ Time-division multiple access (TDMA)	Voice, SMS text messages, low-rate data
3G	First broadband, deployed in 2000	■ CDMA2000 1X/Evolution-Data Optimized (EVDO) ■ Universal Mobile Telecommunications Service (UMTS)/high-speed packet access (HSPA) ■ Worldwide Interoperability for Microwave Access (WiMAX)	Offers speeds from 144 Kbps to 2 Mbps indoors, enabling rich content
4G	Deployed in 2010	■ LTE	100s of Mbps to 1 Gbps with video and streaming capabilities
5G	First deployed in 2018	■ International Telecommunication Union (ITU)/ International Mobile Communications (IMT)-2020 defined technical objectives ■ 3rd Generation Partnership Project (3GPP) is developing 5G specifications	3x higher spectral efficiency than 4G and peak downlink throughputs to peak 20 Gbps

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GSM and arduino

To use Arduino with GSM, you will need a GSM shield

- Usually, to used as a modem or to SMS
- Can also include circuitry for GPS, making it a very good solution when your project needs a precise localization.

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WiFi (Wireless Fidelity)

WiFi is primarily a local area networking (LAN) technology designed to provide in-building broadband coverage.

It is based on IEEE 802.11 specification.

Medium range (around 100m).

Operates in frequencies of 2.4GHz and 5GHz.

Higher frequencies allow for the signal to carry more data

WiFi networks are contention-based TDD systems, where the access point and the mobile stations all vie for use of the same channel.

Time division duplex (TDD) refers to duplex communication links where uplink is separated from downlink by the allocation of different time slots in the same frequency band.

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WiFi Standards

- 802.11: 2 Mbps (1997)
- 802.11a: 54 Mbps – 5 GHz
- 802.11b: 11 Mbps – 2.4 GHz
- 802.11g: 54 Mbps – 2.4 GHz
- 802.11n: 300 Mbps – 2.4 and 5 GHz
- 802.11ac: 1300 Mbps on 5 GHz plus to 450 Mbps on 2.4 GHz
- 802.11ax: 600 Mbps to 9680 Mbps (2.4 GHz, 5 GHz and 6 GHz)
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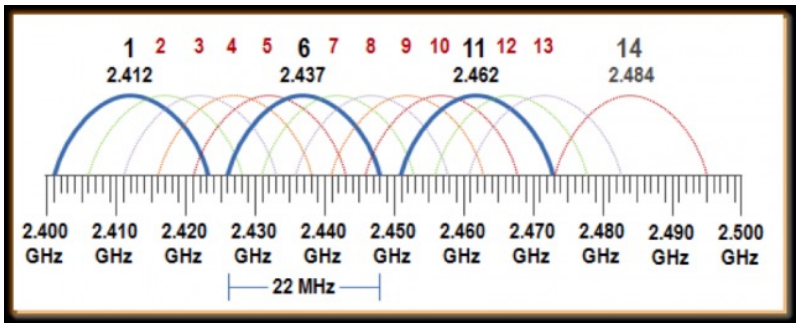
WiFi Channels 2.4 GHz



Source: http://boundless.aerohive.com/experts/wi-fi-back-to-basics--24-ghz-channel-planning.html

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WiFi Channels 2.4 GHz

WiFi Channel Overlap

The channels used for WiFi are separated by 5 MHz in most cases and have a bandwidth of 22 MHz.

As a result channels overlap and it can be seen that it is possible to find a maximum of three non-overlapping channels.

Therefore if there are adjacent pieces of WLAN equipment that need to work on non-interfering channels, there is only a possibility of three.

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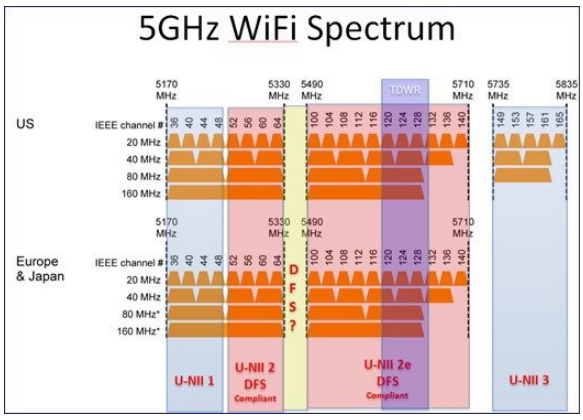
WiFi Channels 5 GHz



http://www.cisco.com/c/en/us/td/docs/wireless/controller/technotes/8-1/HDX-DG/b_hdx_dg_final/high_density_experience_features_in_release_8_1.html

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WiFi - ESP8266 and ESP32

Some microcontrollers (like ESP32) includes WiFi radio with TCP/IP stack

ESP8266 is a cheap WiFi microcontroller with a full WiFi, can also work as a modem for other microcontrollers

- Very popular.
- Most of the low cost modules are not breadboard friendly, don't have an onboard 500mA 3.3V regulator or level shifting

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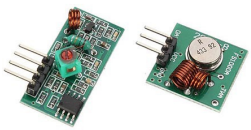
Radio RF transceivers

When your project do not have many communication requirements.

Usually low cost, low range and low data rate applications

Use license-free frequencies like 433MHz



Example of a module for Arduino DRF1278F.

(LoRa - Long Range)

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LoRa

LoRa frequency bands:

- 868MHz (Europe), 915MHz (Australia and North America), …
- Enables long-range transmissions with low power consumption
- Covers the physical layer (LoRaWAN - Long Range Wide Area Network, cover the upper layers).
- Can achieve data rates between 0.3kbit/s and 27kbit/s

https://lora-alliance.org/about-lorawan/

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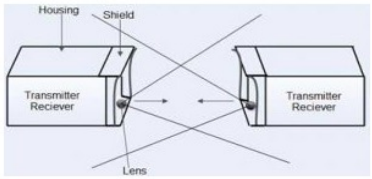
Wireless communication

Infrared Transmission

- Infrared radiations are electromagnetic radiations with longer wavelengths than visible light.
- Usually used for short-range communications. These signals do not pass through solid objects.



Infrared Transmission

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Infrared communication

- Short distance
- Requires two devices to be in line of sight.
- There should be no opaque obstacle between the devices.
- Easy and low cost to implement.
- Two common types of IR technologies: TV Remote (TVR); and the IrDA (Infrared Data Association) standard protocol.

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Infrared communication

The lowest cost wireless connection technology is TVR. The trade-off with this technology is between distance and bit-rate. Usually, this interface is also unidirectional.

IrDA if a bidirectional, higher data bandwidth is required in application.

IrDA standard has been defined by the IrDA industry-based group, that has developed communication standards that are well suited for low-cost, short-range, point-to-point infrared channels.

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Bluetooth

Bluetooth Technology

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Bluetooth

Invented by telecom vendor Ericsson in 1994

Was originally conceived as a wireless alternative to RS-232 data cables.

Bluetooth communications protocol primarily designed for low-power consumption, with a short range based on low-cost transceiver microchips in each device.

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Bluetooth

Bluetooth is a wireless technology standard (IEEE 802.15.1) for exchanging data over short distances

- using short-wavelength UHF radio waves from 2400 MHz to 2485 MHz) from fixed and mobile devices, and for building personal area networks (PANs).
- Every Bluetooth device has a unique 48-bit address (MAC).
  - The most-significant half (24 bits) of the address is an organization unique identifier (OUI), which identifies the manufacturer. The lower 24-bits are the more unique part of the address.

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Bluetooth

The transmit power, and therefore range, of a Bluetooth module is defined by its power class. There are three defined classes of power:

Class Number	Max Output Power (dBm)	Max Output Power (mW)	Max Range
Class 1	20 dBm	100 mW	100 m
Class 2	4 dBm	2.5 mW	10 m
Class 3	0 dBm	1 mW	10 cm

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Bluetooth Low Energy (BLE)

Bluetooth is one of the most used wireless protocols in IoT specifications, especially with the introduction of Bluetooth Low Energy extension, also known as **iBeacon**.

The advantage of BLE is its extremely low power consumption, which helps the making of full battery powered boards with a long working time.

Another feature, is the possibility to embed the management protocol directly at kernel level without requesting any intervention by the users.

- This facilitates the setup of a **mesh network** of Bluetooth devices with lower latency and higher range respect to standard Bluetooth.

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Bluetooth Low Energy (BLE)

- BLE sacrifices range (50m instead of 100m) and data throughput (0.27 Mbps instead of 0.7-2.1 Mbps) for a significant savings in power consumption.
- BLE is aimed at peripheral devices which operate on batteries, and don't require high data rates, or constant data transmission.

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Bluetooth - module

HC-05 Bluetooth module

HC-05 module is a Bluetooth SPP (Serial Port Protocol) module, designed for transparent wireless serial connection setup.

You can use it simply for a serial port replacement to establish connection between computer and peripheral devices.

Two modes master and slave.

Running in slave role: Pair with BT dongle and master module.

Coupled Mode: Two modules will establish communication automatically when powered.

PC hosted mode: Pair the module with Bluetooth dongle directly as virtual serial.

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Bluetooth

When two Bluetooth devices want to “talk” to each other, they need to pair.

Paring allows devices to establish a full duplex communication.

Communication between Bluetooth devices happens over short-range, ad-hoc networks known as piconets that can link up to eight devices.

When a network is established, one device takes the role of the master while all the other devices act as slaves.

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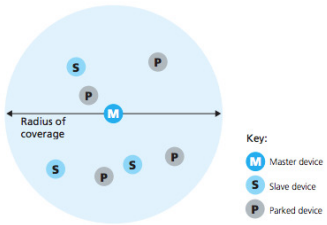
Personal area networks: Bluetooth



Devices organizes into a piconet of up to 8 active devices.

- One device designated as the master is the device that initiates data exchange. Its clock determines time in the piconet.
- Remain devices act as slaves, that respond to the master.
- Up to 255 parked devices (status changed by the master)

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Bluetooth

The master device acts as a hub, and slave devices communicate through the master device in order to communicate with each other.

Piconets are established dynamically and automatically as Bluetooth devices enter and leave radio proximity.

Another important characteristic of Bluetooth technology is its use of frequency hopping to reduce the impact of interference.

Frequency Hopping Spread Spectrum (FHSS): is a method used to rapidly switch transmitting radio signals among several frequency channels.

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Personal area networks: Bluetooth

- IEEE 802.15.1 network operates over a short range at low power.
- Operates in the 2.4 GHz band.
- TDM with time slots of 625 microseconds.
- 79 channels (1MHz each).
- Channel hopping (frequency-hopping spread spectrum (FHSS).
- Rates up to 4 Mbps.
- Ad-hoc network.

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Bluetooth
Adaptive Frequency Hopping (AFH)

Frequency Hopping is a technique where when a link is formed the devices are synchronized to change channels together many times a second.

The pattern of channels used is called the hop sequence and is unique for each link.

Since the devices spend only small amounts of time on a particular channel and because the hop sequence is different for each link the possibility of interference is minimized.

https://www.design-reuse.com/articles/5715/adaptive-frequency-hopping-for-reduced-interference-between-bluetooth-and-wireless-lan.html

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Bluetooth
Adaptive Frequency Hopping (AFH)

Adaptive Frequency Hopping allows Bluetooth to adapt to the environment by identifying fixed sources of interference and excluding them from the list of available channels.

This process of re-mapping also involves reducing the number of channels to be used by Bluetooth.

The Bluetooth Specification does not dictate how bad channels are to be identified, a process commonly referred to as “Channel Assessment”, so developers implementing AFH are faced with the task of selecting the most appropriate method for each particular solution.

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Bluetooth
Adaptive frequency hopping (AFH)

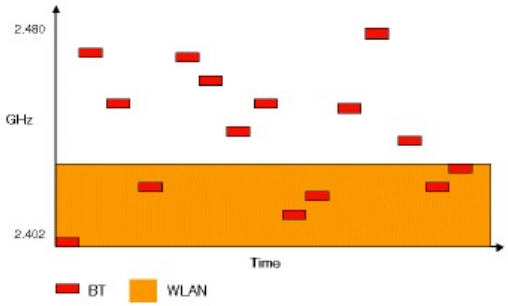

Figure 2.1 -- Collisions resulting from random frequency hopping Adapting to the environment

https://www.design-reuse.com/articles/5715/adaptive-frequency-hopping-for-reduced-interference-between-bluetooth-and-wireless-lan.html

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Bluetooth
Adaptive Frequency Hopping (AFH)

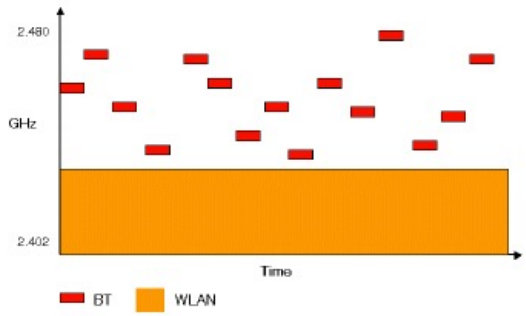

Figure 2.2 -- Collisions avoided using Adaptive Frequency Hopping

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ZigBee

- Specification for a suite of high-level communication protocols used to create personal area networks (WPAN) built from small, low-power digital radios.
- Based on IEEE 802.15.4 standard.
- Though its low power consumption limits transmission distances to 10–100 meters, ZigBee devices can transmit data over long distances by passing data through a mesh network of intermediate devices to reach more distant ones (multi-hop).

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ZigBee

- ZigBee is typically used in low data rate applications that require long battery life and secure networking (support 128 bit encryption): home automation, healthcare, industrial control applications with short range and low bitrate.
- ZigBee has a defined rate of 250 Kbit/s, best suited for intermittent data transmissions from a sensor or input device.
- ZigBee uses the 2.4 GHz ISM frequency band and has 16 channels.
- Multi-level security (supports AES-128 security).
- Addressing space of up to 64 bit IEEE address devices.

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ZigBee

The Xbee shield allows an Arduino board to communicate wirelessly using ZigBee.

The module can communicate up to 30 meters indoors or 100 meters outdoors (with line-of-sight).

It can be used as a serial/USB replacement, or you can put it into a command mode and configure it for a variety of broadcast and mesh networking options.

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ZigBee – Characteristics

- Low cost
- Low power consumption
- Low data rate
- Relatively short transmissions range
- Scalability
- Reliability
- Flexible protocol design suitable for many applications

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ZigBee – Device types

Uses notion of "logical devices" in a Personal Area Network (PAN):

ZigBee Coordinator Only one coordinator exists in each ZigBee PAN. Its function is to store information about the network and to determine the optimum transmission path between any two points of the network.

- Is responsible for initializing, maintaining and managing the network.

ZigBee Route (Full function device), for controlling the message routing between nodes (Router, Repeater). Act as an intermediate repeater that passes data from other devices.

ZigBee end-device, acts has the end point of the network. Also called Reduced Function Device. This device contains a minimal amount of functionality to enable it to talk to its parent node (either the coordinator or a router); it cannot relay data directly from other devices.

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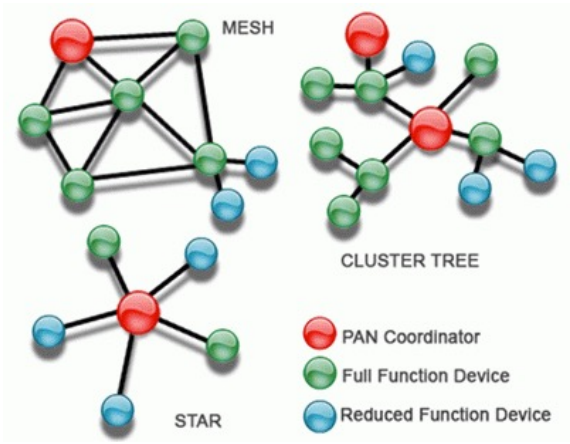
ZigBee - topologies



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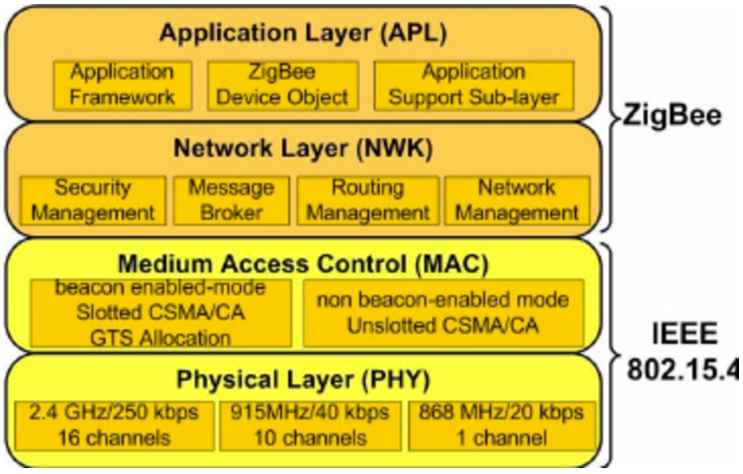
ZigBee Layers



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ZigBee vs Bluetooth

Bluetooth targets medium data rate continuous duty

- 1 Mbps.
- Larger packets over small network.
- File transfer, streaming telecom radio.
- Ad-hoc networks.

ZigBee targets low data rate, low duty cycle

- 250 Kbps (60-115 Kbps typical data transfer).
- Smaller packets over large network.
- More sophisticates networking, mostly static networks with many infrequently used devices .
- Long battery life (weeks to months).

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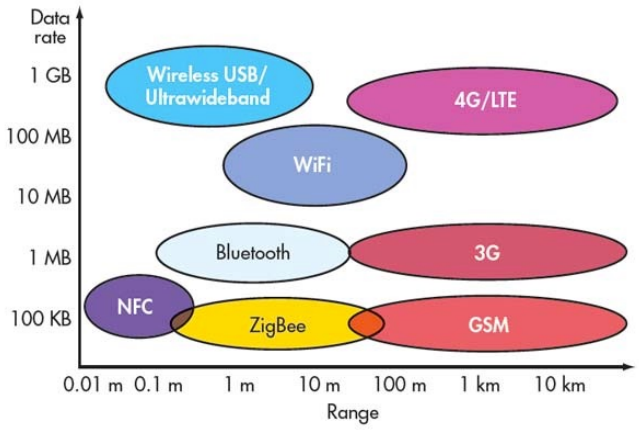
ZigBee vs Bluetooth



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Wireless - Compare

Name	Bluetooth Classic	Bluetooth 4.0 Low Energy (BLE)	ZigBee	WiFi
IEEE Standard	802.15.1	802.15.1	802.15.4	802.11 (a, b, g, n)
Frequency (GHz)	2.4	2.4	0.868, 0.915, 2.4	2.4 and 5
Maximum raw bit rate (Mbps)	1-3	1	0.250	11 (b), 54 (g), 600 (n)
Typical data throughput (Mbps)	0.7-2.1	0.27	0.2	7 (b), 25 (g), 150 (n)
Maximum (Outdoor) Range (Meters)	10 (class 2), 100 (class 1)	50	10-100	100-250
Relative Power Consumption	Medium	Very low	Very low	High
Example Battery Life	Days	Months to years	Months to years	Hours
Network Size	7	Undefined	64,000+	255

https://learn.sparkfun.com/tutorials/bluetooth-basics

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Bibliography

- "Internet of Things (IoT): a vision, architectural elements, and future directions", Jayavardhana Gubbi, Rajkumar Buyya, Slaven Marusic Marimuthu Palaniswami, Future Generation Computer Systems 29 (2013) 1945-1660
- "Internet of things: Vision application and research challenges", Daniele Miorandi, Sabrina Sicari, Francesco De Pellegrini, Imrich Chlamtac, Ad Hoc Networks 10 (2012) 1497 – 1516

- https://www.slideshare.net/pantechsolutions/basics-of-rf
- https://en.wikipedia.org/wiki/Zigbee
- https://www.design-reuse.com/articles/5715/adaptive-frequency-hopping-for-reduced-interference-between-bluetooth-and-wireless-lan.html
- https://en.wikipedia.org/wiki/Bluetooth_Low_Energy

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