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Experiment 1

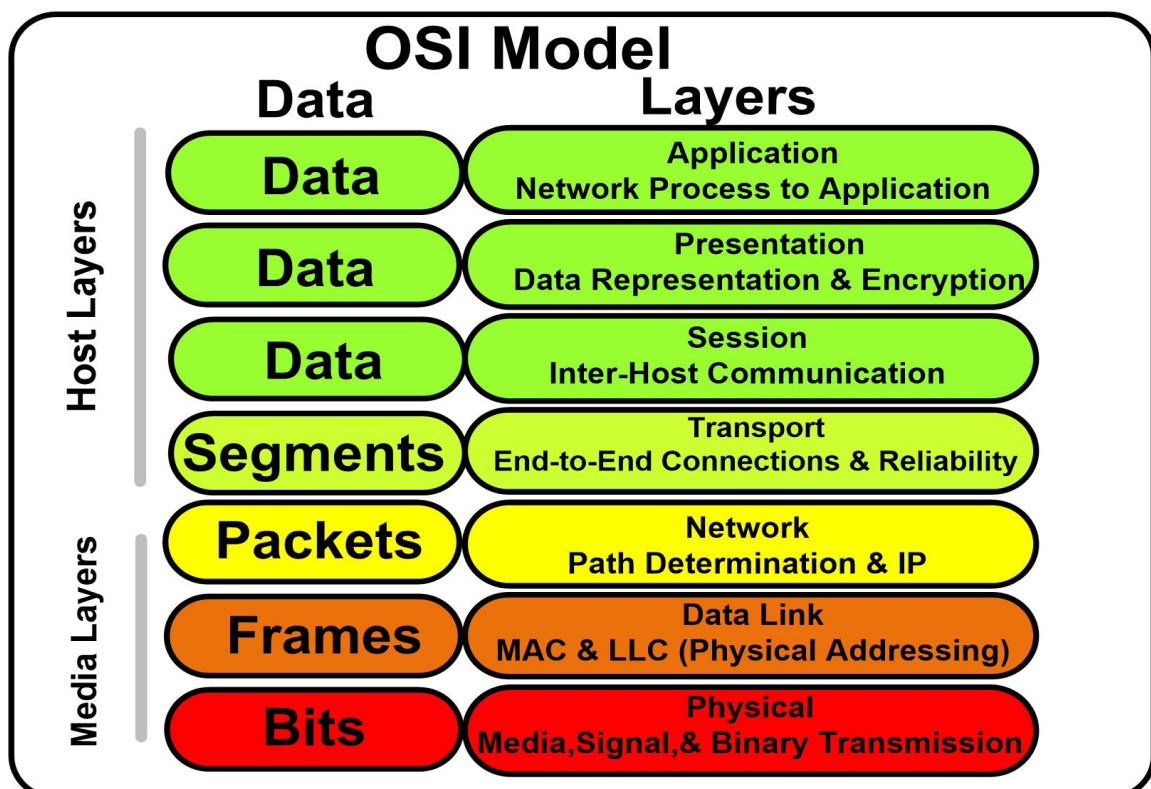
Aim: Study of different types of physical layer wired/wireless connections

1. OSI Model-PHYSICAL LAYER [1 & 2]

The Open Systems Interconnection (OSI) model is a conceptual model created by the International Organization for Standardization which enables diverse communication systems to communicate using standard protocols. In plain English, the OSI provides a standard for different computer systems to be able to communicate with each other.

The OSI model can be seen as a universal language for computer networking. It's based on the concept of splitting up a communication system into seven abstract layers, each one stacked upon the last.

It is a 7 layer architecture with each layer having specific functionality to perform. All these 7 layers work collaboratively to transmit the data from one person to another across the globe.



Physical Layer (Layer 1): [2,3,4]

The lowest layer of the OSI reference model is the physical layer. It is responsible for the actual physical connection between the devices. The physical layer contains information in the form of bits. It is responsible for transmitting individual bits from one node to the next. When receiving data, this layer will get the signal received and convert it into 0s and 1s and send them to the Data Link layer, which will put the frame back together.

The physical layer is aimed at consolidating the hardware requirements of a network to enable the successful transmission of data. Network engineers can define different bit-transmission mechanisms for the physical layer level, including the shapes and types of connectors, cables, and frequencies for each physical medium.

Layer 1 is the first layer of the OSI Model, and therefore, the foundation upon which all higher-level functions are based. It translates the information that receives from the data-link layer (layer 2) into electromagnetic signals (binary data) to send them over the physical medium (wired or wireless media). These signals might consist of either digital signals (electrical pulses) or analog signals (continuous electromagnetic waves).

Examples of protocols that use physical layers include:

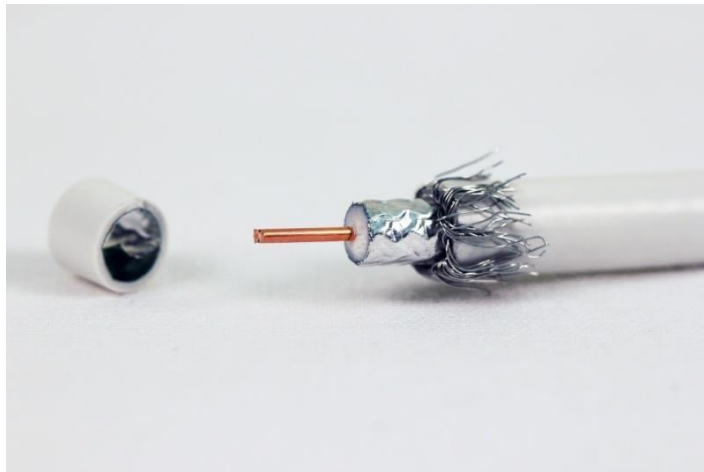
- Digital Subscriber Line.
- Integrated Services Digital Network.
- Infrared Data Association.
- Universal Serial Bus (USB.)
- Bluetooth.
- Controller Area Network.
- Ethernet.

2. WIRED CONNECTIONS

Wired connections are by far the most common. The main media in use are coaxial cable, twisted pairs and fibre optics. For each of these, specific network technologies or specifications have been designed. The medium must have properties that will ensure a reasonable error performance for a guaranteed distance and rate of data delivery (i.e. speed). It must also support two-way or multiway communications.

1. Coaxial Cable [5]

It has an outer plastic covering containing 2 parallel conductors each having a separate insulated protection cover. Coaxial cable transmits information in two modes: Baseband mode(dedicated cable bandwidth) and Broadband mode(cable bandwidth is split into separate ranges).



Coaxial cable is commonly used by cable operators, telephone companies, and internet providers around the world to convey data, video, and voice communications to customers. It has also been used extensively within homes.

It has been around for a long time as a technology (since the early 20th century) and has many singular advantages for reliable, accurate transmission.

Advantages:

- High Bandwidth
- Better noise Immunity
- Easy to install and expand
- Inexpensive

It also has limitations that will cause it to be replaced in some cases by fiber optic cable, category cable or, sometimes, by wireless signals.

Disadvantages:

- Single cable failure can disrupt the entire network.

Specifications

- Range: Up to 500m
- The transmission speed of coaxial cable is 10Mbps (megabits per second), and they offer 80 times more transmission capacity than twisted pair cables.

Scalability

It is mainly used in LAN

2 Twisted Pair Cable [5]

Twisted pair is a physical media made up of a pair of cables twisted with each other. A twisted pair cable is cheap as compared to other transmission media. Installation of the twisted pair cable is easy, and it is a lightweight cable. The frequency range for twisted pair cable is from 0 to 3.5KHz. It can either be a shielded or unshielded twisted pair.

- Unshielded Twisted Pair Cable

It consists of two insulating copper wires (1mm thick). The wires are twisted together in a helical form to reduce electrical interference from a similar pair. Identification is the reason behind colored plastic insulation. It has high-speed capacity. Bandwidth is low when compared with Coaxial Cable. It provides less protection from interference. The commonly used UTP cables are Cat5, Cat5e, Cat6, Cat6a and Cat7.

Scalability

Higher grades of UTP are used in LAN technologies like Ethernet.

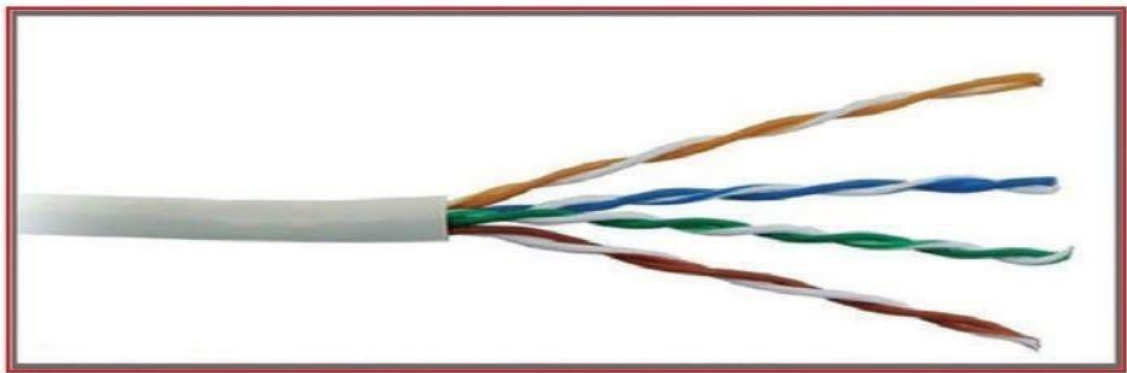


Figure 14.9 Unshielded Twisted Pair Cable

- **Shielded Twisted Pair Cable**

This cable has a metal foil or braided-mesh. Electromagnetic noise penetration is prevented by a metal casing. Shielding also eliminates crosstalk. It is faster than unshielded and coaxial cable.

Advantages:

- ◆ It can be used for Analog or Digital transmission

- ♦ It increases the signaling rate.
- ♦ It eliminates crosstalk.

Disadvantages:

- ♦ It is difficult to manufacture

Specifications:

Range: 100m

Modulation:

It uses line coding technique. Line coding is the process of converting digital data to digital signals. By this technique we convert a sequence of bits to a digital signal. At the sender side digital data are encoded into a digital signal and at the receiver side the digital data are recreated by decoding the digital signal.

Scalability

It is scalable in LAN architecture.



Figure 14.10 Shielded Twisted Pair

3. Fiber Optics Cable [5]

Fiber optic cable, also called as optical fiber cable, is a type of Ethernet cable which consists of one or more optic fibers that are used to transmit data. Fiber optic cable transmits data as pulses of light go through tiny tubes of glass. The transmission capacity of optical fiber cable is 26,000 times higher than that of twisted pair cable.

Fiber optic cable can be divided into single mode fiber (SMF) and multimode fiber (MMF).

Single mode optical fiber has a small core, and only allows one mode of light to propagate at a time.

While multimode fiber cable comes with a larger core and is designed to carry multiple light rays or modes at the same time.

Specifications:

Range: Up to 80km.

Bandwidth up to 4700MHz. Available for home use in speeds up to 2 Gbps (2000 Mbps). Business Internet available in much faster speeds.

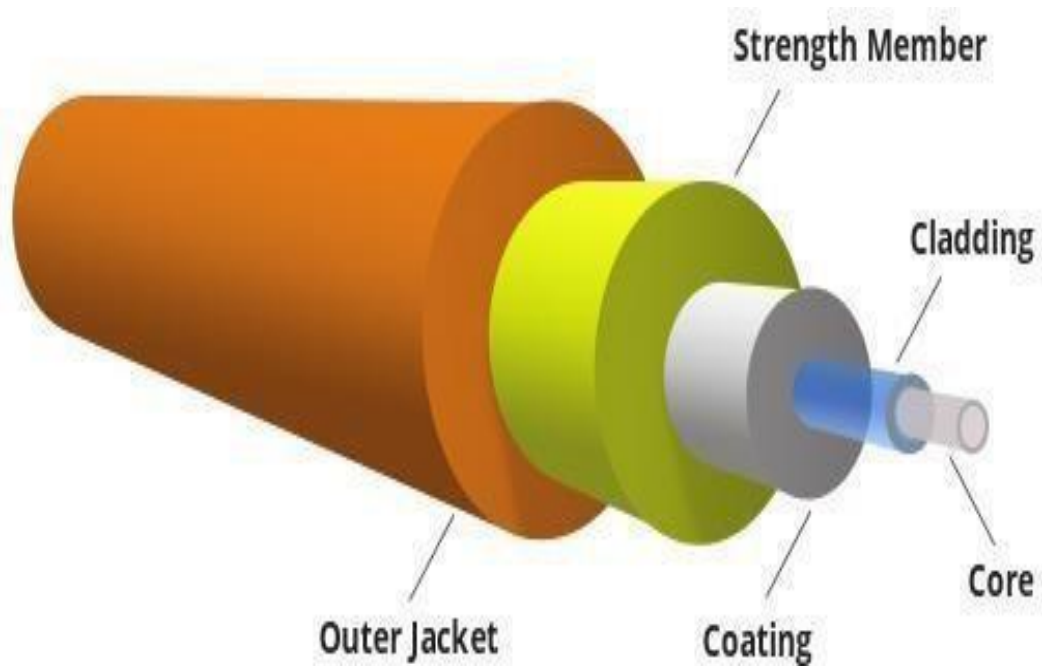
Modulation:

An optical modulator is a device which is used to modulate a beam of light. Depending on the parameter of a light beam which is manipulated, modulators may be categorized into amplitude modulators, phase modulators, polarization modulators etc. Often the easiest way to obtain modulation of intensity of a light beam, is to modulate the current driving the light source, e.g. a laser diode. This sort of modulation is called direct modulation, as opposed to the external modulation performed by a light modulator. For this reason light modulators are, e.g. in fiber optic communications, called external light modulators.

Scalability

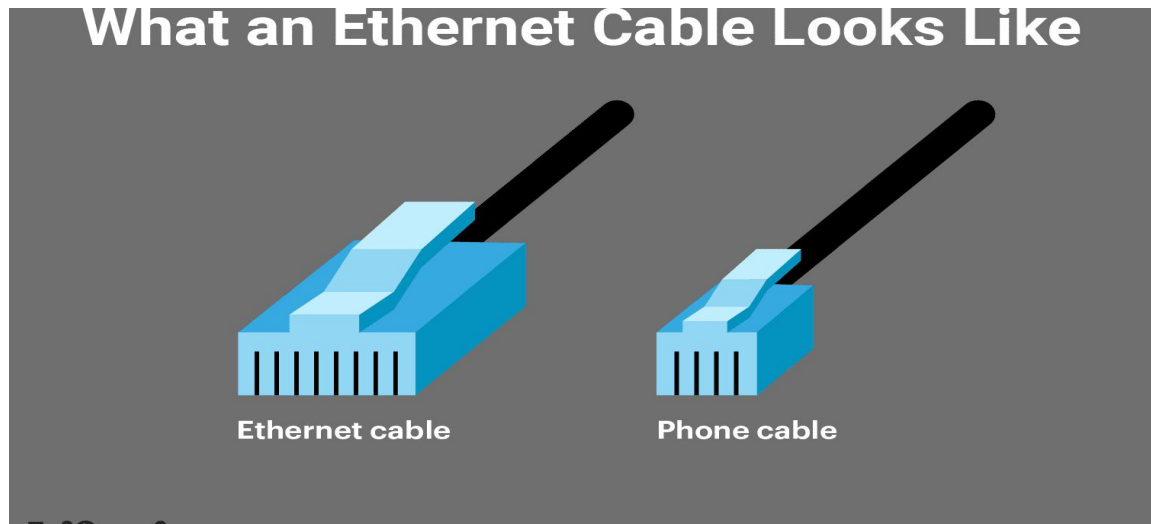
It is scalable in CAN architecture.

Schematic View



2.1 ETHERNET [6, 7]

The Ethernet physical layer is the physical layer functionality of the Ethernet family of computer network standards. The physical layer defines the electrical or optical properties of the physical connection between a device and the network or between network devices. It is complemented by the MAC layer and the logical link layer.



The Ethernet physical layer has evolved over its existence starting in 1980 and encompasses multiple physical media interfaces and several orders of magnitude of speed from 1 Mbit/s to 400 Gbit/s. The physical medium ranges from bulky coaxial cable to twisted pair and optical fiber with a standardized reach of up to 40 km. In general, network protocol stack software will work similarly on all physical layers.

Specifications:

Range

Over deployed multimode cabling ethernet supports ranges of between 240 m and 300 m with 400/500 MHz·km modal bandwidth. It also supports 10 km over single-mode fiber.

Scalability:

Ethernet is a family of computer networking technologies commonly used in local area networks (LAN), metropolitan area networks (MAN), and wide area networks(WAN). Ethernet is currently the most widely used technology in enterprise networking. Unfortunately, it is widely acknowledged that Ethernet does not have the scalability to meet the emerging networking needs of large enterprises. Ethernet does not scale well to large networks. The flat MAC address space, whilst having obvious benefits for the user and administrator, is the primary cause of this poor scalability. Ethernet exhibits scalability issues on networks of more than a few thousand devices, such as costly and energy-dense address table logic and storms of broadcast traffic. Ethernet's inability to handle networks containing loops also presents a scalability problem.

Schematic View:

The ESP32 Ethernet PHY interface is shown in the schematic below. It mainly consists of three sections:

- The PHY chip or interface
- The 50 MHz oscillator
- Jack and magnetics

Universal Serial Bus (USB) is an industry standard that establishes specifications for cables and connectors and protocols for connection, communication and power supply (interfacing) between computers, peripherals and other computers. A broad variety of USB hardware exists, including several different connectors, of which USB-C is the most recent.

The diagram illustrates the pin configurations for two types of USB connectors. On the left, the 'Standard A' connector is shown with four pins labeled from right to left: 1 (+), 2 (D-), 3 (D+), and 4 (-). On the right, the 'Standard B' connector is shown with four pins labeled from right to left: 3 (D+), 4 (-), 1 (D-), and 2 (+). The central text 'USB' is prominently displayed above the connectors.

Released in 1996, the USB standard is currently maintained by the USB Implementers Forum (USB-IF). There have been four generations of USB specifications: USB 1.x, USB 2.0, USB 3.x and USB4.

Specifications

- **Range:**

1. The USB 1.1 standard specifies that a standard cable can have a maximum length of 5 meters (16 ft 5 in) with devices operating at full speed (12 Mbit/s), and a maximum length of 3 meters (9 ft 10 in) with devices operating at low speed (1.5 Mbit/s).
2. USB 2.0 provides for a maximum cable length of 5 meters (16 ft 5 in) for devices running at high speed (480 Mbit/s).
3. The USB 3.0 standard does not directly specify a maximum cable length, requiring only that all cables meet an electrical specification: for copper cabling with AWG 26 wires, the maximum practical length is 3 meters (9 ft 10 in).

- **Modulation :**

1. At the input, the device communicates via MIDI and USB protocols. At the output is tension. Its value is managed by pulse-width modulation.
2. Pulse-width modulation (PWM) is used for controlling the amplitude of digital signals in order to control devices and applications requiring power or electricity. It essentially controls the amount of power, from the perspective of the voltage component, that is given to a device by cycling the on-and-off phases of a digital signal quickly and varying the width of the "on" phase or duty cycle.

- **Other specifications :**

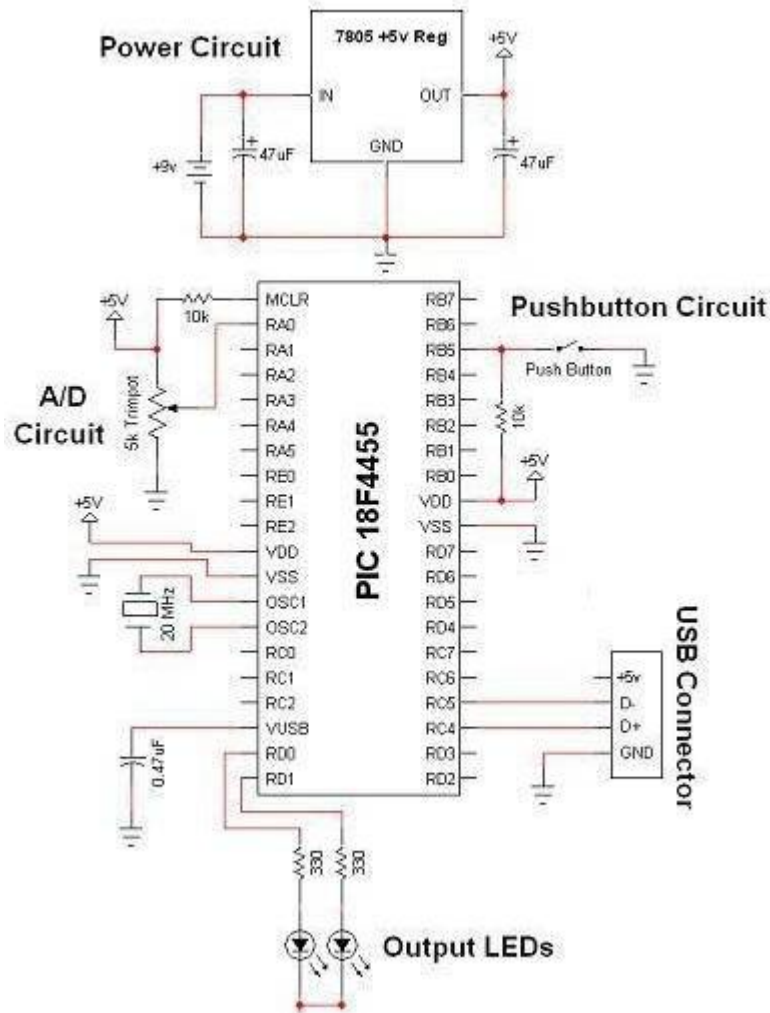
1. Two important aspects of USB are its support capability and total bandwidth. It is capable of supporting 127 devices and has a total bandwidth of 12 Mbit per second which is equal to 1.5 MB per second. Working of a 12 Mbit (full speed device) or a 1.5 Mbit (low-speed device) depends on the total bandwidth of the USB.
2. USB 2.0 has a maximum signaling rate of 480 Mbit/s and USB 3.0 has a usable data rate of up to 4 Gbit/s (500 MB/s).

Scalability:

USB's are used in Personal Area Network(PAN).

Schematic View

Hardware design for USB is actually quite minimal, which is a big plus for us. However, what you quickly find out with USB is that the easy hardware design means the communication and control software is very complex, we'll see more about that in the theory and software sections. The main devices used in the circuit are the PIC 18F4455, USB Connector, and LM7805.



2.3 Power Lines



Power Line communication (PLC) is Layer-1 (Physical Layer) technology which uses power cables to transmit data signals. In PLC, modulated data is sent over the cables. The receiver on the other end de-modulates and interprets the data. Because power lines are widely deployed, PLC can make all powered devices controlled and monitored. PLC works in half-duplex.

There are two types of PLC:

- Narrow band PLC
- Broadband PLC

Narrow band PLC provides lower data rates up to 100s of kbps, as they work at lower frequencies (3-5000 kHz). They can be spread over several kilometers.

Broadband PLC provides higher data rates up to 100s of Mbps and works at higher frequencies (1.8 – 250 MHz). They cannot be as much extended as Narrowband PLC.

3. WIRELESS CONNECTIONS

Computer networks that are not connected by cables are called wireless networks. They generally use radio waves for communication between the network nodes. They allow devices to be connected to the network while roaming around within the network coverage.

3.1 BLUETOOTH [10,11]

Bluetooth is a wireless technology standard used for exchanging data between fixed and mobile devices over short distances using short-wavelength UHF radio waves in the industrial, scientific and medical radio bands, from 2.402 GHz to 2.480 GHz, and building personal area networks (PANs). It was originally conceived as a wireless alternative to RS-232 data cables.

The IEEE standardized Bluetooth as IEEE 802.15.1, but no longer maintains the standard. The Bluetooth SIG oversees development of the specification, manages the qualification program, and protects the trademarks. A manufacturer must meet Bluetooth SIG standards to market it as a Bluetooth device. A network of patents apply to the technology, which are licensed to individual qualifying devices

Specifications:

Bluetooth operates at frequencies between 2.402 and 2.480 GHz, or 2.400 and 2.4835 GHz including guard bands 2 MHz wide at the bottom end and 3.5 MHz wide at the top. This is in the globally unlicensed (but not unregulated) industrial, scientific and medical (ISM) 2.4 GHz short-range radio frequency band.

	BLUETOOTH V2.1	BLUETOOTH 4.0 (LE)	BLUETOOTH 5 (LE)
Range	Up to 100 m	Up to 100 m	Up to 400 m
Max range (free field)	Around 100 m (class 2 outdoors)	Around 100 m (outdoors)	Around 1,000m (outdoors)
Frequency	2.402 – 2.481 GHz	2.402 – 2.481 GHz	2.402 - 2.481 GHz
Max data rate	1- 3 Mbit/s	1 Mbit/s	2 Mbit/s
Application Throughput	0.7-2.1 Mbit/s	Up to 305 kbit/s	Up to 1,360 kbit/s
Topologies	Point-to-point, scatternet	Point-to-point, mesh network	Point-to-point, mesh network
Network Standard	IEEE 802.15.1	IEEE 802.15.1	IEEE 802.15.1

- Modulation

The format originally chosen for Bluetooth in version 1 was Gaussian frequency shift keying, GFSK, however with the requirement for higher data rates two forms of phase shift keying were introduced for Bluetooth 2 to provide the Enhanced Data Rate, EDR capability.

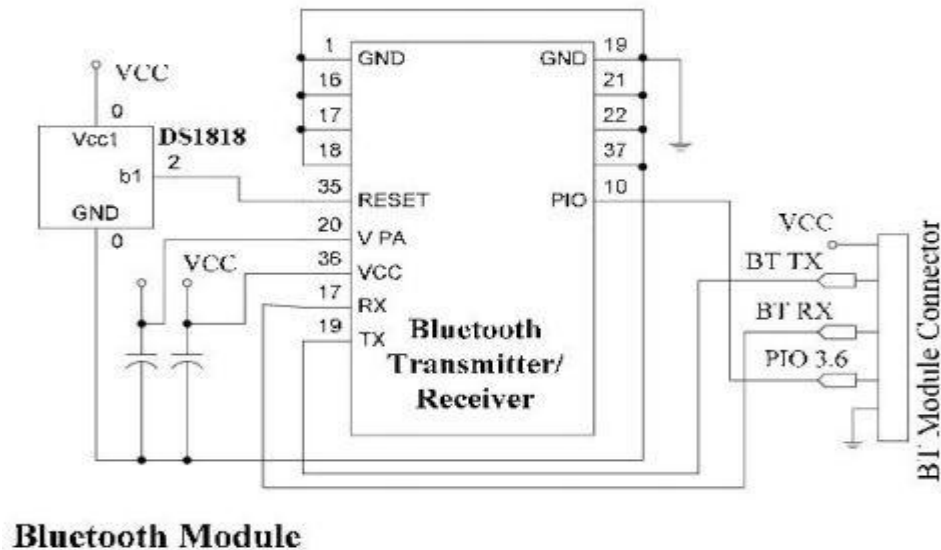
The enhanced data rate capability for Bluetooth modulation is implemented as an additional capability so that the system remains backwards compatible. The Bluetooth modulation schemes and the general format do not lend themselves to carrying higher data rates. For Bluetooth 3, the higher data rates are not achieved by changing the format of the Bluetooth modulation, but by working cooperatively with an IEEE 802.11g physical layer. In this way data rates of up to around 25 Mbps can be achieved.

Scalability :

Bluetooth uses short-range radio waves. Uses in a WPAN include, for example, Bluetooth devices such as keyboards, pointing devices, audio headsets, printers may connect to smartwatches, cell phones, or computers. A Bluetooth WPAN is also called a piconet, and is composed of up to 8 active devices in a master-slave relationship (a very large number of additional devices can be connected in "parked" mode). The first Bluetooth device in the piconet is the master, and all other devices are slaves that communicate with the master. A piconet typically has a range of 10 metres (33 ft), although ranges of up to 100 metres (330 ft) can be reached under ideal circumstances. Long-range Bluetooth routers with augmented antenna arrays connect Bluetooth devices up to 1,000 feet.

Schematic View:

The Bluetooth Module is a low-power embedded Bluetooth v2.0+EDR module with a built-in high-output antenna. The module is a fully Bluetooth compliant device for data communication with a transmission power of up to +8dBm and receiver sensibility of down to -83dBm combined with low power consumption. The Bluetooth Module delivers opportunities for rapid ad-hoc connections and the possibility of automatic, unconscious, connections between WPCOMs. The complete circuit diagram of the Bluetooth Module is given in the figure.



3.2 Wireless Fidelity-WIFI [12]

Wi-Fi is a family of wireless network protocols, based on the IEEE 802.11 family of standards, which are commonly used for local area networking of devices and Internet access. Wi-Fi uses multiple parts of the IEEE 802 protocol family and is designed to interwork seamlessly with its wired sibling Ethernet. Compatible devices can network through wireless access points to each other as well as to wired devices and the Internet.

Wi-Fi stations communicate by sending each other data packets: blocks of data individually sent and delivered over radio. As with all radio, this is done by the modulating and demodulation of carrier waves. Different versions of Wi-Fi use different techniques, 802.11b uses DSSS on a single carrier,

whereas 802.11a, Wi-Fi 4, 5 and 6 use multiple carriers on slightly different frequencies within the channel (OFDM).

Specifications:

Wi-Fi generations			
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
Wi-Fi 3 (802.11g)	3–54 Mbit/s	2003	2.4 GHz
Wi-Fi 2 (802.11a)	1.5 to 54 Mbit/s	1999	5 GHz
Wi-Fi 1 (802.11b)	1 to 11 Mbit/s	1999	2.4 GHz

● Range

A wireless network's range can vary wildly depending on the type of network. A standard home network using one wireless router can serve a single-family dwelling, but often not much more.

Business networks with grids of access points can serve large office buildings, and wireless hotspots spanning several square miles have been built in some cities.

Wi-Fi can be used on several types of devices like personal computers, video game console, smart phones, digital camera, tablet computers etc. You can use Wi-Fi to create a hotspot within the range of 20 meters (66 feet).

● Modulation

WiFi systems use two primary radio transmission techniques.

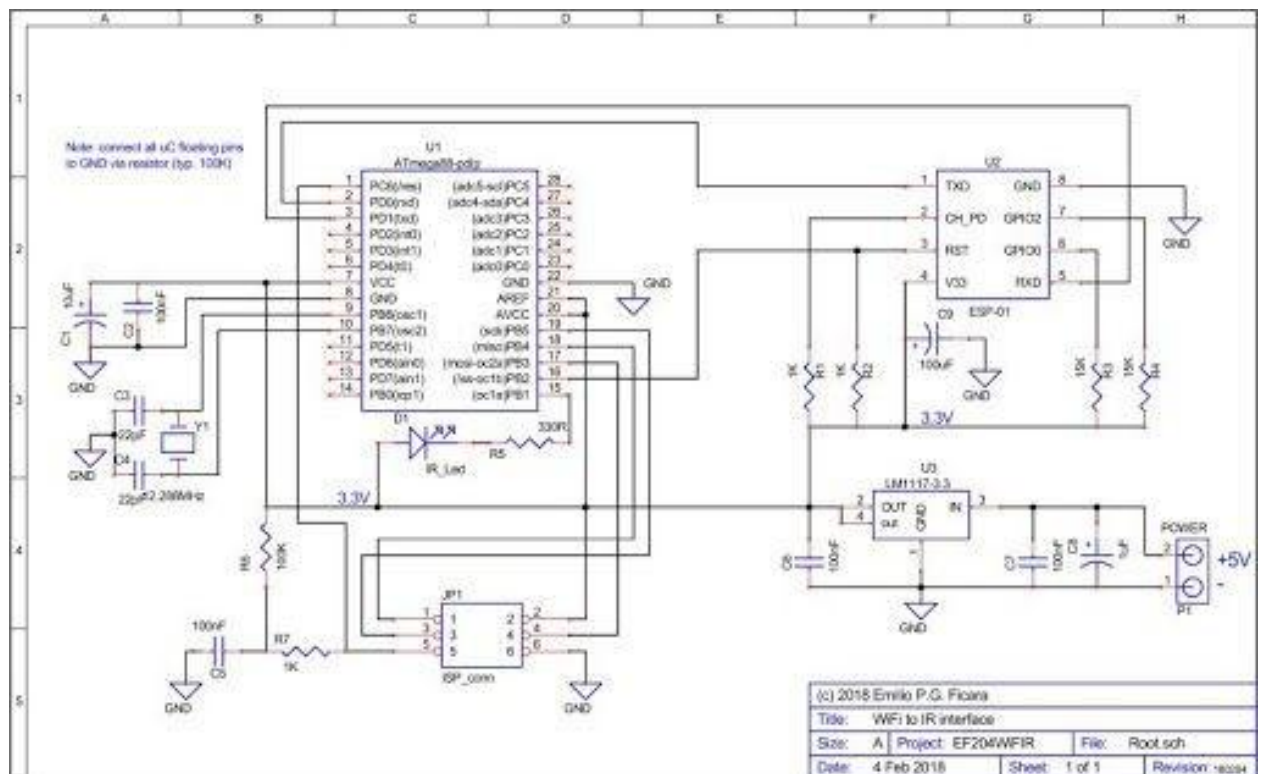
The bit stream is processed with a special coding and then modulated using Quadrature Phase Shift Keying (QPSK). ... 802.11a and g (≤ 54 Mbps) – The 802.11a and g systems use 64-channel orthogonal frequency division multiplexing (OFDM).

Scalability :

Compared to cell phones and similar technology, Wi-Fi transmitters are low power devices. In general, the maximum amount of power that a Wi-Fi device can transmit is limited by local regulations, such as FCC Part 15 in the US. Equivalent isotropically radiated power (EIRP) in the European Union is limited to 20 dBm (100 mW).

To reach requirements for wireless LAN applications, Wi-Fi has higher power consumption compared to some other standards designed to support wireless personal area network (PAN) applications. For example, Bluetooth provides a much shorter propagation range between 1 and 100m[74] and so in general have a lower power consumption. Other low-power technologies such as ZigBee have fairly long range, but much lower data rate. The high power consumption of Wi-Fi makes battery life in some mobile devices a concern.

Schematic View:



ESP8266 has powerful on-board processing and storage capabilities that

allow it to be integrated with the sensors and other application-specific devices through its GPIOs with minimal development up-front and minimal loading during runtime. Its high degree of on-chip integration allows for minimal external circuitry, and the entire solution, including the front-end module, is designed to occupy minimal PCB area. ESP8266 Serial Wifi Wireless Transceiver Module is suitable for Uno, Mega 2560, and Nano.

3.3 ZIGBEE [13]

Zigbee is an IEEE 802.15.4-based specification for a suite of high-level communication protocols used to create personal area networks with small, low-power digital radios, such as for home automation, medical device data collection, and other low-power low-bandwidth needs, designed for small scale projects which need wireless connection. Hence, Zigbee is a low-power, low data rate, and close proximity (i.e., personal area) wireless ad hoc network.

Specification:

- **Range**

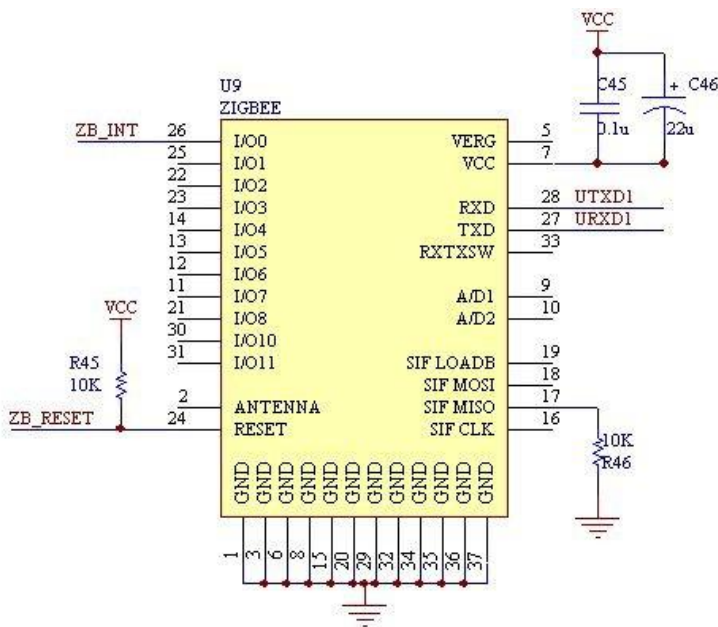
Its low power consumption limits transmission distances to 10–100 meters line-of-sight, depending on power output and environmental characteristics. Zigbee devices can transmit data over long distances by passing data through a mesh network of intermediate devices to reach more distant ones. Zigbee is typically used in low data rate applications that require long battery life and secure networking (Zigbee networks are secured by 128 bit symmetric encryption keys.) Zigbee has a defined rate of 250 kbit/s, best suited for intermittent data transmissions from a sensor or input device.

Scalability:

The technology defined by the Zigbee specification is intended to be simpler and less expensive than other wireless personal area networks (WPANs), such as Bluetooth or more general wireless networking such as Wi-Fi. Applications include wireless light switches, home energy monitors, traffic

management systems, and other consumer and industrial equipment that require short-range low-rate wireless data transfer.

Schematic:



3.4 CELLULAR NETWORK [14,15]

A cellular network or mobile network is a communication network where the last link is wireless. The network is distributed over land areas called "cells", each served by at least one fixed location transceiver, but more normally, three cell sites or base transceiver stations.



Cellular networks offer a number of desirable features:

1. More capacity than a single large transmitter, since the same frequency can be used for multiple links as long as they are in different cells
2. Mobile devices use less power than with a single transmitter or satellite since the cell towers are closer
3. Larger coverage area than a single terrestrial transmitter, since additional cell towers can be added indefinitely and are not limited by the horizon

Specifications

Range: In cities, each cell site may have a range of up to approximately $\frac{1}{2}$ mile (0.80 km), while in rural areas, the range could be as much as 5 miles (8.0 km). It is possible that in clear open areas, a user may receive signals from a cell site 25 miles (40 km) away.

Modulation: It uses QAM modulation technique. QAM (quadrature amplitude modulation) is a method of combining two amplitude-modulated (AM) signals into a single channel, thereby doubling the effective bandwidth. QAM is used with pulse amplitude modulation (PAM) in digital systems, especially in wireless applications

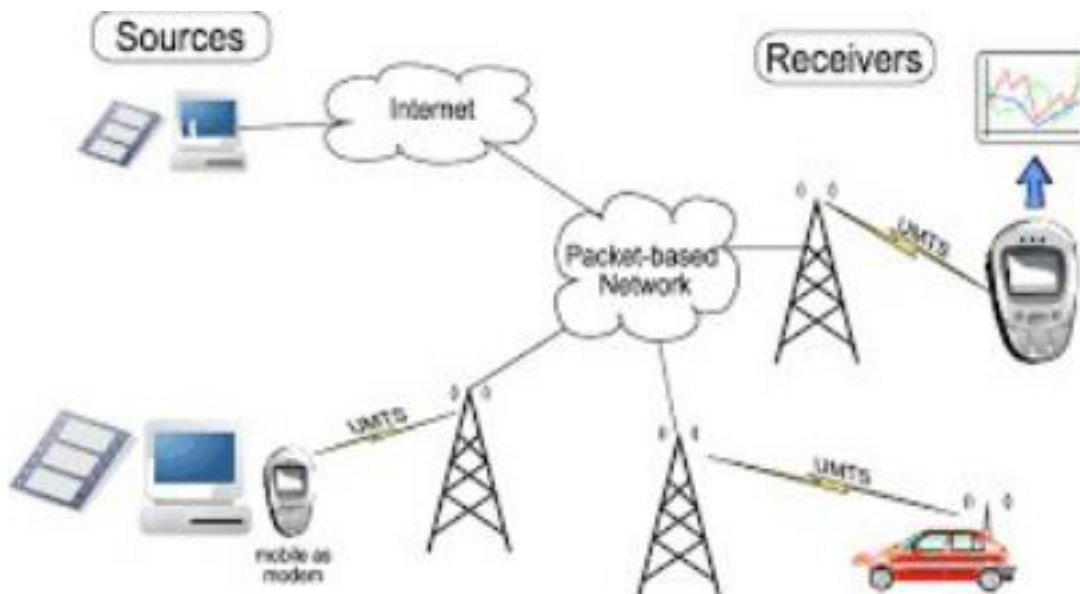
Signaling: Cellular signalling networks are formed when different cell signalling pathways interact and are detected by a combination of experimental and computational methods.

Scalability

Cellular systems use several radio communications technologies. The systems divide the region covered into multiple geographic areas. Each area has a low- power transmitter or radio relay antenna device to relay calls from one area to the next area.

The most common example of a cellular network is a mobile phone (cell phone) network. A mobile phone is a portable telephone which receives or makes calls through a cell site (base station) or transmitting tower. Radio waves are used to transfer signals to and from the cell phone.

Schematic Diagram



5G[16,17]

5G is the 5th generation mobile network. It is a new global wireless standard after 1G, 2G, 3G, and 4G networks. 5G enables a new kind of network that is designed to connect virtually everyone and everything together including machines, objects, and devices.

5G wireless technology is meant to deliver higher multi-Gbps peak data speeds, ultra low latency, more reliability, massive network capacity, increased availability, and a more uniform user experience to more users. Higher performance and improved efficiency empower new user experiences and connects new industries.

Specifications:

Speed:

5G is designed to deliver peak data rates up to 20 Gbps based on IMT-2020 requirements. 5G can also deliver much lower latency for a more immediate response and can provide an overall more uniform user experience so that the data rates stay consistently high—even when users are moving around. And the new 5G NR mobile network is backed up by a Gigabit LTE coverage foundation, which can provide ubiquitous Gigabit-class connectivity.

Latency:

In 5G, the "air latency" in equipment shipping in 2019 is 8–12 milliseconds. The latency to the server must be added to the "air latency" for most comparisons. Verizon reports the latency on its 5G early deployment is 30 ms: Edge Servers close to the towers can reduce latency to 10–20 ms; 1–4 ms will be extremely rare for years outside the lab.

Scalability:

Smart cities could use 5G in a variety of ways to transform the lives of people living in them—primarily providing greater efficiencies like more connectivity between people and things, higher data speeds, and lower latency than ever before in areas like automotive safety, infrastructure, VR, and entertainment

3.5 WiMax[18]

WiMAX is one of the hottest broadband wireless technologies around today. WiMAX systems are expected to deliver broadband access services to residential and enterprise customers in an economical way.

Loosely, WiMax is a standardized wireless version of Ethernet intended primarily as an alternative to wire technologies (such as Cable Modems, DSL and T1/E1 links) to provide broadband access to customer premises.

More strictly, WiMAX is an industry trade organization formed by leading communications, component, and equipment companies to promote and certify compatibility and interoperability of broadband wireless access equipment that conforms to the IEEE 802.16 and ETSI HIPERMAN standards.

WiMAX would operate similar to WiFi, but at higher speeds over greater distances and for a greater number of users. WiMAX has the ability to provide service even in areas that are difficult for wired infrastructure to reach and the ability to overcome the physical limitations of traditional wired infrastructure.

WiMAX was formed in April 2001, in anticipation of the publication of the original 10-66 GHz IEEE 802.16 specifications. WiMAX is to 802.16 as the WiFi Alliance is to 802.11.

WiMAX can provide two forms of wireless service –

- Non-line-of-sight – service is a WiFi sort of service. Here a small antenna on your computer connects to the WiMAX tower. In this mode, WiMAX uses a lower frequency range -- 2 GHz to 11 GHz (similar to WiFi).
- Line-of-sight – service, where a fixed dish antenna points straight at the WiMAX tower from a rooftop or pole. The line-of-sight connection is stronger and more stable, so it's able to send a lot of data with fewer errors. Line-of-sight transmissions use higher frequencies, with ranges reaching a possible 66 GHz.

Conclusion:

From this experiment, I learned about the Physical Layer, the types of Wired and Wireless Connections. For each of these connections, I studied their specification, their scalability in the various network architecture, and their schematic view.

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