Redes de Computadores (RCOMP)

Theoretical-Practical (TP) Lesson 02

2017/2018

- Networking active devices.
- Hubs and repeaters.
- Switches and bridges.
- Routers.
- LAN Ethernet networks (802.3).
- LAN wireless networks (802.11).

Networking active devices

Active network devices are all kind of devices that emit and receive signals transporting data. We can define two categories of active devices:

- **End nodes** – emit and receive the useful end-user's data. They are the workstations and the servers. A network printer or other kind of network user shared device can always be categorized as a server.
- **Network infrastructure devices** – they are part of the network and ensure it accomplishes its main mission **delivering end nodes data** through the network. Some of the most important infrastructure devices are called intermediate nodes, **they receive and then retransmit what they have received**. Often, infrastructure devices use specific protocols to exchange control information between them and helping them accomplishing their missions. Under these protocols point view, these nodes act as end nodes but they don't handle end-users data.

Yet another possible classification of active network devices relates to the OSI layer they work in. Of course, to work in a given layer a device must also work on all layers below that, so we refer to the highest layer a device works with.

OSI layer one active devices

Layer one specifies physical medium, connectors, signals line coding and modulation. The highest level concept these devices deals with is, symbols or bits. There are devices that do not use anything above that, they are usually called repeaters and are mainly used to amplify signals, possibly copying them from one cable to several other cables (device ports).

Amplifying a signal will increase the reach, however, when a signal is amplified, existing noise is also.

A bit more sophisticated repeater overcomes this issue be operating with symbols or bits, in this case when the signal is received in a device port, the symbol is extracted. Then the symbol is used to create a brand new signal to be emitted, possibly in several output ports.

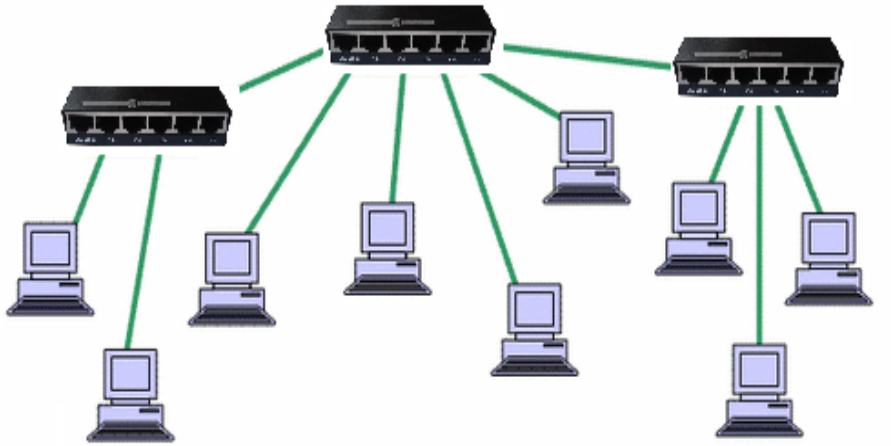
Another advantage of this type of repeater is that there is no signal type dependency between different ports. If layer 2 symbols structures (packets) are identical as well as data rates, these devices will be able for instance to interconnect a copper cable with a optical fiber cable.

When these devices have only two ports they are usually called repeaters, if they have several ports they are called hubs or repeating hubs.

Repeating hubs and collisions

Repeating hubs are active devices with two (in that case called repeaters) or more port cable connections. They listen for a signal in all ports, once one is received they copy it to all ports (including the one from where it was received). The emitted signal may be an amplified version of the received signal or may be a new signal created from the received symbol.

They can even be interconnected to extend the network (image), however they have severe limitations. The signal is spread to every network cable, so a single signal emission from any node will make the whole network busy and unusable for other nodes' emission.



Although having a star topology, it’s a shared medium network, from many points of view equivalent to a bus topology. At layer 2 a medium access control (MAC) protocol must in enforced, otherwise collisions will occur when two nodes emit a signal at the same time. A collision means two or more signals are mixed on the transmission medium and all data is lost.

OSI layer 2 active devices

OSI layer two introduces new concepts: packet (PDU) and node address. Each packet has a well defined structure, including address information on the header (PCI). Layer two packets are usually called **frames**.

Intermediate nodes operating at layer 2, therefore retransmit frames and not signals or individual symbols. They can also use node address information to emit received frames only on the port the destination node address is connected to.

Because frames can be received and temporarily stored in memory these devices guarantee a full independence between what is being emitted and received in one port and what is happening in other ports. Devices guaranteeing these features are called **switches** (**bridges** if they have only two ports).

Upgrading from repeating hubs to switches represents a massive improvement for network performance, if each cable connection supports full duplex all nodes can be receiving and emitting a frame at the same time with no chance of collision.

Also, because frames can be stored in memory, interconnection of different type cables does not require the same data rate.

The layer 2 network concept

One important concept on computer networks is the network concept itself. More precisely the layer 2 network concept, in simple words the layer 2 network embraces all nodes reachable using layer 2 frames.

From the layer 2 point of view the layer 2 network is the whole world, there is nothing beyond that, nevertheless it may be just a tiny local area network (LAN). This is why in layer 2 there are no network addresses, only node addresses.

Other important concept around layer 2 networks is the **broadcast address** in local area networks. The broadcast address represents all network nodes, thus in layer 2 it represents all nodes in the layer 2 network. When a frame is sent to the layer 2 broadcast address, a copy of it will be delivered to every node of the layer 2 network, this also denotes the extent of the layer 2 network and is called the **broadcast domain**.

Layer 3 the network concept also exists, but it's not physical related, it's logical, and thus layer 2 networks may not precisely match layer 3 networks, although in most cases they do. One can have several layer 3 networks sharing the same layer 2 network, however, one layer 3 network cannot be distributed by several layer 2 networks.

OSI layer 3 active devices

OSI layer 3 intermediate nodes are called **routers** or gateways. Layer 3 can be viewed as a duplication of layer 2 features: packet and node address. The difference is these features are now decoupled from lower layers, also the network address concept is introduced.

Layer 3 protocols, notably IP (IPv4 or IPv6) defines a new universal packets format and uses any available layer 2 technology to transport them. However, source and destination nodes may not be connected to the same layer two network, this is where routers enter to work. Usually a router is connected to more than one layer 2 network, it receives an IP packet transported by a frame from one layer 2 network, places the same IP packet inside a frame of another layer 2 network and emits it.

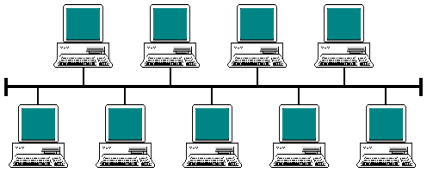
Each layer 3 network will be identified by a network address. In IPv4 and IPv6, the network address is part of each node address, this will make routeing easier because by looking at the node destination address the destination network is identified.

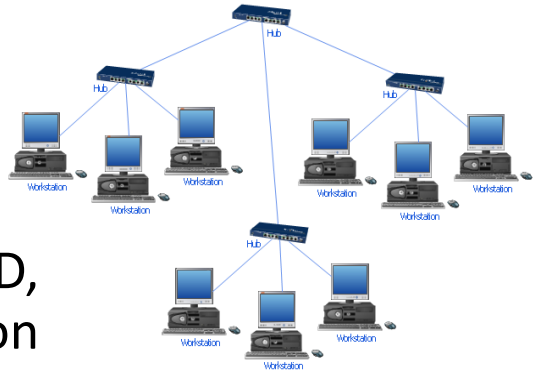
Unlike switches, routers can interconnect totally different layer 2 technologies, including LAN to WAN (Wide Area Networks).

Ethernet networks – 802.3

The dominating layer 2 technology in LAN wired networks is Ethernet. It started by being a shared medium networks, first using a physical bus topology with a shared coaxial cable (10base5 and 10base2) and then repeating hubs in star topology (10baseT).

In either case MAC (Medium Access Control) is required to handle collisions.





The MAC protocol used in Ethernet is called CSMA/CD, meaning Carrier Sense Multiple Access with Collision Detection.

CSMA means, before sending each node must check if the transmission medium is free and wait until it is before sending the packet.

CD means when the node starts emitting a frame it must also listen to see if a collision is occurring, if that happens, it stops sending the frame and sends a JAM instead informing all nodes a collision has happened, next back off and wait a period of time depending on several factors before trying again.

CSMA/CD does not avoid collisions, it focuses on reducing collisions consequences.

CSMA/CD

As more nodes are willing to emit collisions become more likely and thus with heavy traffic the network performance degrades significantly.

The CD proceeding also introduces some issues on frame size and network size, the problem is the collision must be detected before the emitter finishes sending the frame, otherwise it will assume it was successful. This may not happen if the frame is too short because it can be totally emitted (frame transmission time) before it reaches the opposite network extreme (propagation delay).

To ensure collisions are detected in time, a minimum 64 bytes frame size was defined, depending on the transmission rate this will result in a minimum transmission time and thus a maximum network length can then be established resulting a consistent maximum propagation delay.

The maximum extend of a Ethernet network using CSMA/CD is called the **collision domain**, this represents the zone within the network to which collisions will be confined. If a Ethernet network uses only coaxial buses and repeating hubs the collision domain is the whole network, some Ethernet switches are capable of blocking collisions, but this is not always the case.

Of course routers, operating at layer 3 will always block layer 2 collisions.

Ethernet node addresses

Ethernet networks have evolved in several ways, but somethings were keep unchanged: **the frame format** and the **node address format**.

Each node is identified by a unique 48 bits number (6 bytes), although node addresses are required to be unique only within the layer 2 network, they are globally unique because each manufacturer is assigned a unique 24 bits number (OUI - Organizationally Unique Identifier) to start addresses and manages the remaining 24 bits to produce unique addresses. Ethernet addresses, also known as MAC addresses or physical addresses are usually represented as 6 sets of 8 bits in hexadecimal notation separated by a colon or a hyphen.

Some MAC addresses are reserved for special purposes, for instance all addresses whose first byte (left byte) has the least-significant bit with value one are multicast addresses. A frame with a multicast destination address is supposed to be retransmitted everywhere by layer 2 intermediate nodes.

The layer 2 broadcast address is made of 48 one bits, it's a special case of multicast address that represents all nodes in a layer 2 network. Thus when a frame destination address is FF:FF:FF:FF:FF:FF all nodes will receive a copy of it.

Ethernet frame format

Although several frame formats were initially used, the one that prevails is called Ethernet II or DIX (Digital Intel Xerox). It can carry up to 1500 bytes of data, this is called the **maximum transmission unit** (MTU):

Destination node MAC address (6 bytes)	Source node MAC address (6 bytes)	Payload identifier (E-TYPE) (2 bytes)	**Payload (SDU) (46 up to 1500 bytes) (MTU=1500)**	Frame Check Sequence (FCS) (4 bytes)

Therefore, the total frame length will range from 64 up to 1518 bytes. FCS is used for error detection. Before sending the frame the emitter is required to send the **Ethernet preamble** (not represented in the image above) it's made of 7 bytes with alternate zeros and ones followed by an additional byte called **start frame delimiter** (SFD). The SFD is also made of alternate zeros and ones, but ends with two ones. This alerts receivers of an incoming frame and allows clock synchronization. The inter-packet gap (IPG) must also be respected, it is equivalent to 96 bits.

By keeping the frame format and the node address format unchanged, layer 2 interoperation between different versions is guaranteed, thus initial versions of Ethernet networks using coaxial cable buses can be connected to latest versions running at 10 Gbps over optical fiber.

Ethernet switches – no collisions

It can be said that switches saved Ethernet at a time it was becoming harder for it to compete with other technologies like Token-Ring, 100VG-AnyLAN, and especially ATM. Switches solved the Ethernet main issue: CSMA/CD.

Although externally they are similar to a hub, internally an Ethernet switch is a very high-performance frame processing equipment, main features are:

- At any time, it's capable of receiving a frame on any port (eventually a frame at the same time on all ports).
- At any time, it's capable of emitting a frame on any port (eventually a frame at the same time on all ports).
- It's able to temporarily store frames in memory, this is required to allow different data rates on receiving and emitting ports, it's also required when the output port is busy.
- And, the fundamental feature for any switch: look at the destination node address in the frame header and retransmit the frame only on the port where the destination node is.

The three first features abolish any chance of collision, and therefore CSMA/CD is no longer required, also **because CD is not used full-duplex is now possible**.

Ethernet switches – the MAC table

One key feature of an Ethernet switch is retransmitting frames only on the port the destination node is at. To accomplish this the switch needs to know in which port each node is, that information is stored on the MAC table.

The MAC table is a list of known MAC node addresses, and for each the corresponding switch port. The MAC table is dynamically managed by the switch, when the device boots the MAC table is empty, this means the switch knows nothing about surrounding node addresses and therefore it will retransmit on all ports every frame it receives (except to the incoming port) .

For every frame arriving to the switch, the frame **source node** MAC address is checked and added/refreshed on the MAC table associating to it the port the frame came from.

Later when a frame is received the frame **destination node** MAC address is looked for in the MAC table, if found the frame is retransmitted only on the associated switch port, otherwise it's retransmitted on all ports (except for the incoming port). Though in case of a multicast address, the frame is retransmitted on all existing ports (including de incoming port).

Each entry in the MAC table has a time to live of about 5 seconds, if not refreshed before it will be deleted.

Ethernet switches – store & forward

Totally receiving a frame in a port before starting to retransmit it on another port is called store & forward, this operation mode has several advantages:

- the receiving port may operate at a different data rate than the emitting port.
- collisions are not propagated because they are detected during the frame reception, therefore the receive operation will fail and there is nothing to retransmit, also if several frames are to be emitted in a single port they can wait in a queue until the port is free, so no collision will occur here as well.
- transmission errors are blocked because after receiving the entire frame error checking (FCS) by the switch is possible.

The store & forward mode has, however, one disadvantage: **latency**. There will always be a delay corresponding to the transmission time, this depends on data rate and frame size.

Other operation modes are available to overcome this, sophisticated switches can operate in several modes depending on conditions, some lower cost switches may not support store & forward and operate only on alternative modes.

Ethernet switches - cut-through and fragment free

The **cut-through mode** provides the lowest latency, as soon as the first 6 bytes of the frame are received (destination node MAC address) the output port is immediately determined and retransmission starts, consequently, **the latency will be the time to receive 6 bytes** and not the time to receive the entire frame. Of course, data rates must be the same, collisions are propagated, also collisions may occur if the output port is busy and finally FCS errors cannot be blocked.

An additional operation mode exists: **fragment free**. In fragment free mode the switch always receives the first 64 bytes of the frame before starting to retransmit. Due to Ethernet CSMA/CD fundamentals, all collisions must occur within these first 64 bytes, so in fragment free mode collisions are not propagated, the switch latency is now the time required to receive the first 64 bytes of the frame. However, data rates must be equal and collisions may occur if the output port is busy. Also, FCS errors cannot be blocked, that requires the whole frame to be received and when that happens a significant part of the frame has already been transmitted.

As stated before, sophisticated switches may support several modes and apply the best one depending on the context.

Ethernet – OSI layer one

All Ethernet networks share the same layer 2 implementation, but they can use several different types of layer 1. There is a naming convention for Ethernet layer one implementations: **Data-RateSignal-TypeCable-Type**

Data-Rate – specifies the nominal data rate in Mbps, for instance 10 for 10 Mbps and 100 for 100 Mbps (Fast Ethernet), above 1000 Mbps (Gigabit Ethernet) the G letter is used for rates in Gbps, for instance 10G for 10 Gbps.

Signal-Type – defines if a digital (base) or an analogic (broad) signal is used, current implementations only use only digital signals (base), the old 10broad36 implementation is now obsolete.

Cable-Type – on coaxial cable bus topologies this is a numerical digit specifying the bus length in hundreds of meters, for instance 10base2 and 10base5 for 200 meters (180 meters in reality) and 500 meters long buses. Once the star topology was introduced, **Cable-Type** is now used to specify the cable type using letters, **T** means copper twisted pairs, **F** and **S** for multimode optical fibers and **L** for monomode optical fibers. The **X** letter is sometimes used to represent full-duplex support. In CSMA/CD mode full-duplex is not usually supported because receiving is dedicated to collision detection. Other letters and digits may be used with specific meanings.

Ethernet – physical medium

Using this naming convention, the main historical physical mediums used by Ethernet networks are:

Name	Required cable type	Description
10base5	Thick coaxial cable	Shared bus up to 500 meters long
10base2	Thin coaxial cable	Shared bus up to 180 meters long
10baseT	Copper CAT3	Uses 2 twisted pairs for 10 Mbps data rate, may run on half-duplex or full-duplex if nodes support it.
10baseF	Multimode optical fiber	Uses 2 optical fibers up to 2000 meters long in full-duplex.
100baseTX	Copper CAT5	Uses 2 twisted pairs for 100 Mbps data rate in full-duplex.
100baseFX	Multimode optical fiber	Uses 2 optical fibers up to 400 meters long in half-duplex CSMA/CD mode or up to 2000 meters in full-duplex.
100baseSX	Multimode optical fiber	Uses 2 optical fibers up to 300 meters long in full-duplex, compatible with 10baseF.

Nowadays, almost every Ethernet end node device supports rates up to 1 Gbps, called Gigabit Ethernet. When ordering new hardware, Gigabit Ethernet is currently the minimum requirement.

Ethernet – Gigabit Ethernet

Name	Required cable type	Description
1000baseT	Copper CAT5	Uses 4 twisted pairs to transmit simultaneously in both direction, support full-duplex. Each pair is used simultaneously for sending and receiving, echo cancellation is used to remove the signal being emitted from the signal being received.
1000baseTX	Cooper CAT6	Uses 2 twisted pairs to transmit in full-duplex, not commercially implemented.
1000baseSX	Multimode optical fiber	Uses 2 optical fibers up to 550 meters long, full-duplex.
1000baseLX	Multimode or monomode optical fiber	Uses 2 optical fibers to transmit in full-duplex, up to 550 meters (multimode) or up to 2,000 meters (monomode).
1000baseLX10	Monomode optical fiber	Uses 2 optical fibers to transmit in full-duplex, up to 10,000 meters.
1000baseBX10	Monomode optical fiber	Uses a single fiber to transmit in full-duplex, up to 10,000 meters. Uses different wavelength signals for each direction.

Copper technologies (10baseT, 100baseTX, 1000baseT, and 1000baseTX) use auto-negotiation to determine counterpart capabilities and use the best possible mode regarding the transmission rate and full-duplex.

Ethernet – 10 Gigabit Ethernet

The most important 10 Gigabit Ethernet implementations are:

Name	Required cable type	Description
10GbaseT	Copper CAT6 or CAT6A	CAT6A or CAT7 cable is required to reach the cable maximum length of 100 meters. CAT6 cables can also be used up to 55 meters length. Uses 4 twisted pairs to transmit in both directions in full-duplex using echo cancelation.
10GbaseSR	Multimode optical fiber	Uses 2 optical fibers to transmit in full-duplex, maximum cable length depends on the fiber used, from 25 up to 400 meters.
10GbaseLR	Monomode optical fiber	Uses 2 optical fibers up to 10,000 meters long, full-duplex.

Copper technology 10GbaseT also uses auto-negotiation, so it can be connected to 10baseT, 100baseTX, 1000baseT, and 1000baseTX counterparts.

10GbaseT was designed to be able to use older CAT6 cabling systems as far as cable length is less than 55 meters, for instance inside a datacenter.

There is a wide variety of other high rate Ethernet physical mediums, many require special non-standard cabling systems.

Ethernet – above 10 Gbps

Higher data rate Ethernet physical mediums require special cabling systems, especially on copper.

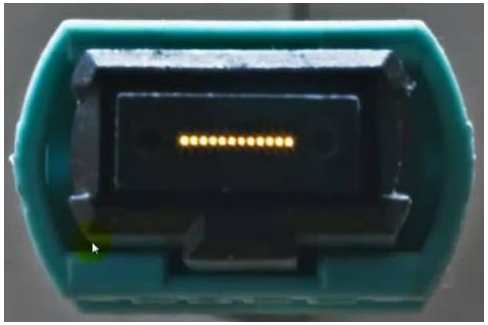
Name	Required cable type	Description
40GbaseT 25GbaseT	Copper CAT8	Up to 30 meters cable length. Uses 4 twisted pairs to transmit in both directions in full-duplex.
40GbaseSR4 100GbaseSR4	Multimode optical fiber	Uses 8 optical fibers to transmit in full-duplex, maximum cable length depends on the fiber used, up to 300 meters.
40GbaseLR4 100GbaseLR4	Monomode optical fiber	Uses 8 optical fibers up to 10,000 meters long, full-duplex (four fibers for each direction).
100GbaseSR10	Multimode optical fiber	Uses 20 optical fibers, full-duplex. Maximum cable length depends on the fiber used, up to 300 meters.
100GbaseLR10	Monomode optical fiber	Uses 20 optical fibers up to 10,000 meters long, full-duplex (ten fibers for each direction).

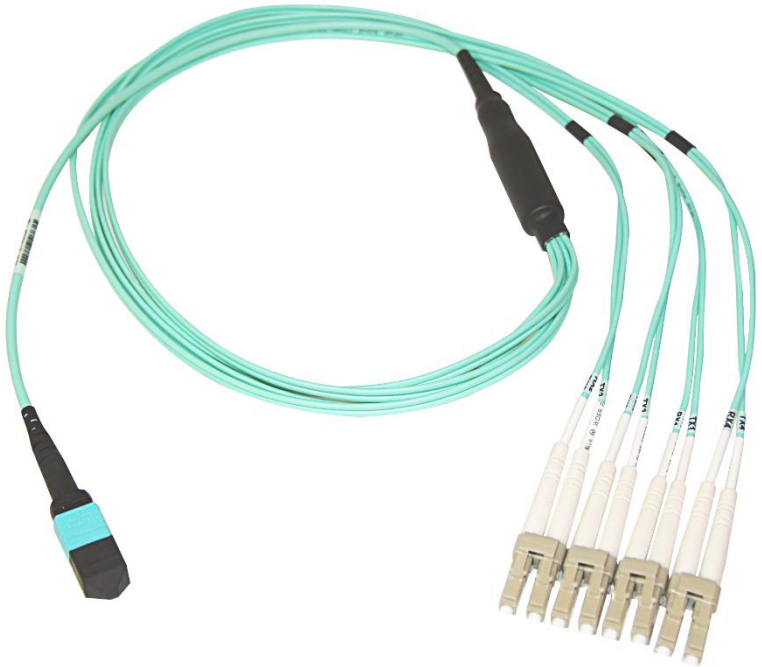
Even higher data rates Ethernet physical mediums are to be supported, standards are being established for 200 Gbps, 400 Gbps and 1 Tbps (Terabit Ethernet). Ethernet devices working above 10 Gbps are commercially available, but still not very common.

MPO (Multi-fiber Push On) connectors

For layer one technologies requiring several optical fibers, high density connectors must be used. A MPO connector, also known as MTP (specific vendor name), can provide up to 72 optical fiber connections, but usually are used with 12 or 24 connected fibers, and thus supporting 40GbaseSR4/100GbaseSR4/40GbaseLR4/100GbaseLR4 on the first case and 100GbaseSX10/100GbaseLX10 on the second case.

Also pre-mounted patch cords are available (images below).





Power over Ethernet (PoE)

Power over Ethernet allows passing electrical power to devices through CAT5 or better twisted-pairs copper cables. The main use for PoE is for devices that are far from telecommunications enclosures, where there may be no power outlet available.

Common PoE powered devices are wireless access points and video cameras. If the device supports PoE power (usually as an alternative), installing a local power outlet can then be avoided. For that purpose a compatible power injection device must be used, this can be a special Ethernet switch or a dedicated device usually called **power injector** (images).

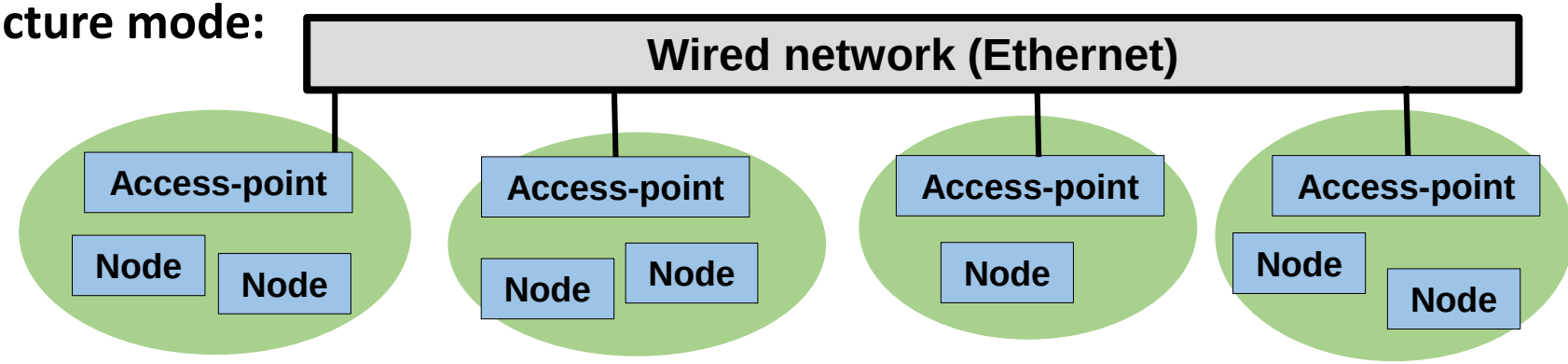
Compatibility between the PoE powered device and the power injection device must be checked. There are several standards using different voltages, maximum current and different twisted pairs.

802.11 wireless local area networks (WLAN)

Also known as Wi-Fi, 802.11 is made of several standards. There is one sophisticated layer two that can use several alternative radio waves based layer one implementations.

Radio waves are analogical signals by nature and thus digital modulation techniques must be used to transmit data at layer one.

Although direct radio communication between end nodes is possible (ad-hoc mode), to provide **secure and solid coverage** an infrastructure of centralizing radio devices called **Wireless Access Points (WAP)** are required, this is called the **infrastructure mode:**



An access point, also know as base-station, is a layer two active device, first of all, it operates as a frame switch, retransmitting frames. Because each access point has a wired connection (Ethernet) it will not only retransmit frames between wireless nodes but also between wired nodes (Ethernet) and wireless nodes.

Wireless Access Points and Cells

In infrastructure mode, wireless nodes out of direct radio reach can yet communicate with each other by using local access points which in turn communicate with each other through the wired Ethernet network. Interconnection of access points could also be wireless, however, performance would deteriorate significantly.

Each access point is responsible for managing an area of radio coverage around it called a **cell**. Due to power legal restrictions, the maximum effective reach of the signal is less than 30 meters, thus the cell diameter is around 50 meters.

A cell can be imagined as being a sphere centered on the access point with around 30 meters radius, that would be roughly true on empty space. Nevertheless, Wi-Fi is intended for indoors space, here the scenario is rather different, microwave radio signals propagation is blocked by solid objects. Walls, beams, columns, and slabs have a significant impact on the real reach for the signal. Slabs are particularly thick and solid, they attenuate significantly the signal between different floors.

When an infrastructure of access points is planned, all these propagation issues must be taken into account if an efficient Wi-Fi coverage of the area is desired.

Association and roaming – BSS and ESS

When wireless workstations are within radio reach of an access point they may associate to the cell. Association to a cell is controlled and authorized by the access point, typically it depends on authentication, usually based on a unique pre-shared secret key (PSK) or user password authentication over central authentication services like RADIUS.

Each access point (and corresponding cell) is called **Basic Service Set** (BSS) and identified by a unique **Basic Service Set Identifier** (BSSID), in reality, this is the MAC address of the access point. Cells are also identified by the **Service Set Identifier** (SSID), this is an up to 32 bytes sequence that is usually interpreted as a human readable string. Unlike the BSSID, the SSID is not unique for each cell. Access points that are part of the same infrastructure should share the same SSID, thus the whole infrastructure can be seen as one by wireless workstations, this infrastructure is called the **Extended Service Set** (ESS).

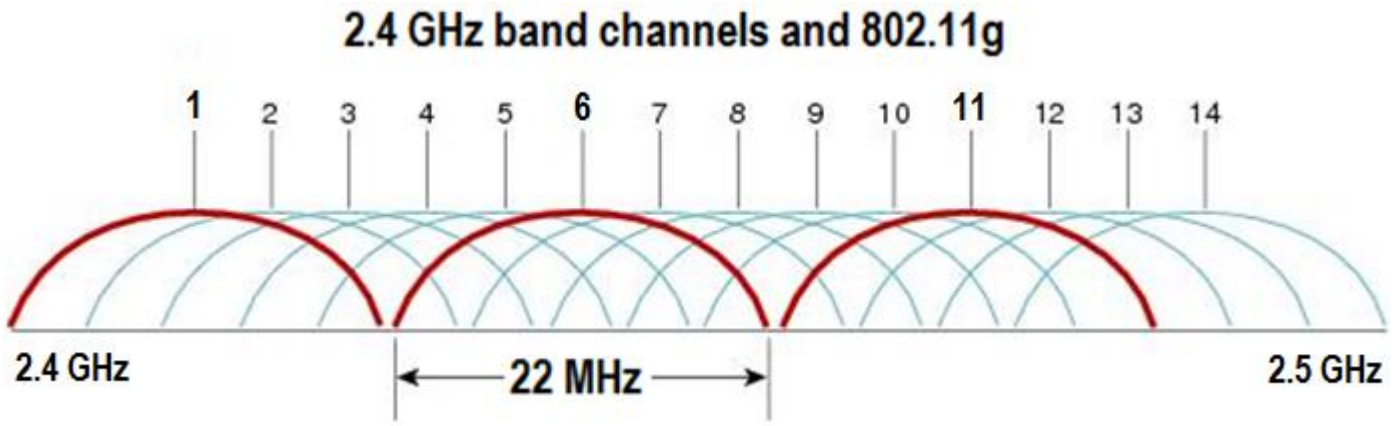
Wireless access points belonging to the same infrastructure (same SSID) support roaming of clients between cells: once the client is associated to a cell that association is can be automatically and transparently transferred to a neighbour cell. Thanks to roaming, wireless clients circulating within the infrastructure are kept connected although they are transferred from cell to cell.

802.11 - channels

Different frequency radio signals don't interfere with each other, however when data is modulated on a signal its frequency shifts up and down, therefore adequate band wide channels are required to avoid interference between near frequency signals.

Two main frequency ranges are used in 802.11 networks: the **2.4 GHz band** and the **5 GHz band**. Each band is divided into different channels with central frequencies spaced by around 5 MHz, accordingly, the band wide of this channels is also 5 MHz.

Each layer one standard in 802.11 uses this channels in different ways, for instance, **802.11g** uses channels 1 to 14 of the 2.4 GHz band, still, when a signal is modulated with 802.11g standard its frequency shifts and a **22 MHz** band wide is required, this means near channels will interfere with each other.



802.11 – 5 GHz band channels

When designing an infrastructure of access points, radio coverage areas of neighbour cells will overlap, thus channels must be selected to avoid radio interference between them. On the previous image, we can see channels 1, 6 and 11 do not interfere in 802.11g, we can also see there are no non-interfering options for more than three channels.

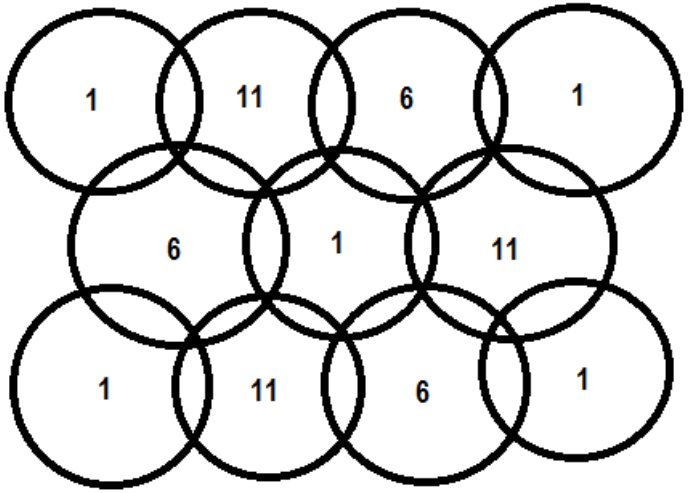
Propagation through solid material also depends on the signal frequency, the higher the signal frequency is the higher the attenuation will be. For instance, unlike in the 2.4 GHz band, signals on the 5 GHz band will be almost totally eliminated when crossing slabs between floors. In the 5 GHz band, cells tend to be more confined by walls and other physical obstacles.

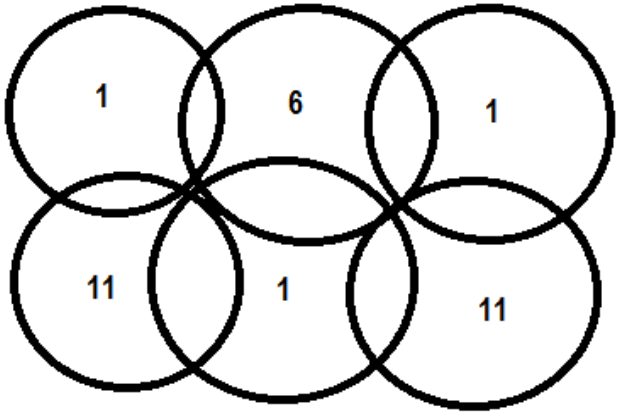
Also, in the 5 GHz band, the number of available channels is much higher, most of them are reserved for Dynamic Frequency Selection (DFS). DFS means channels are not manually set, instead, each access point automatically selects one to avoid overlapping with near cells.

From all this comes that selecting channels for each access point in the 5 GHz band is not an issue. On the 2.4 GHz band, however, some planning is required.

802.11 – selecting 2.4 GHz band channels

On the 2.4 GHz band neighbour cells channel selection is particularly complex because only three non-overlapping channels exist, thus avoiding interference requires a careful physical positioning of each access-point and adequate channels selection.





With a multiple floors building this turns into a three-dimensional problem.