

Guidelines on using the DEI Networking Laboratory. Shielded and unshielded twisted pairs copper cables. CAT6 copper patches wiring. Ethernet technology. IPv4 basic addressing. IPv4 connectivity testing with ICMP echo messages. Mounting copper CAT6 patch panels and sockets.

1. Guidelines on using the DEI Networking Laboratory

The DEI Networking Laboratory has three open racks, with working desks on both sides. **There are a total of six working desks next to the racks, the class should be divided into up to six teams.**

Each rack holds in the upper positions four similar sets of two devices as shown in Figure 1. Each of the four sets has a Cisco Catalyst 2950 switch (with dark green panel), and below it, a Cisco 2811 router.

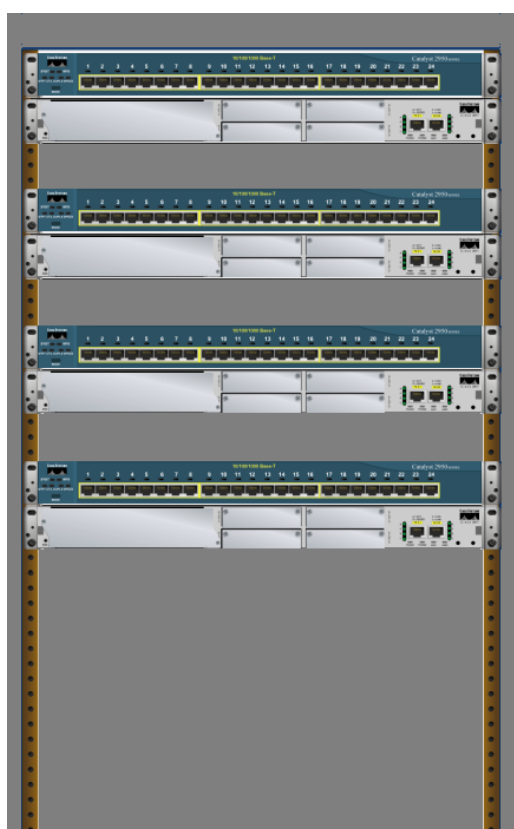


Figure 1 - Upper part of the racks

There is a free U unit spacing between each set.

These Cisco Catalyst 2950 switches don't have a power button, you must plug or unplug the power cable at the rear panel on the right side of the device.

WARNING: These Cisco Catalyst 2950 switches are rather old, and its 10/100 Mbps Ethernet copper ports (10baseT/100baseTX) **are not Auto MDI-X**.

Later in Section 2.5 we will learn that because these ports are not Auto MDI-X, to directly interconnect two of these switches with a copper cable, an old fashion cross-over cable is required.

2. Twisted pairs (TP) copper cables

2.1. Transmission of electrical signals through balanced copper pairs.

In an unbalanced transmission, the electrical signal is sent through a single copper line. The receiver measures the signal relative to an absolute reference (the ground potential).

As we already know, one important issue when using electrical signals is external noise. There is a wide range of external sources for electromagnetic noise, the external electromagnetic noise transforms itself into electrical noise in the copper line. This phenomenon is known as EMI (*Electro Magnetic Interference*).

Because the receiver measures the signal relative to an absolute reference, what it gets is the signal mixed with a lot of external noise (Figure 2).

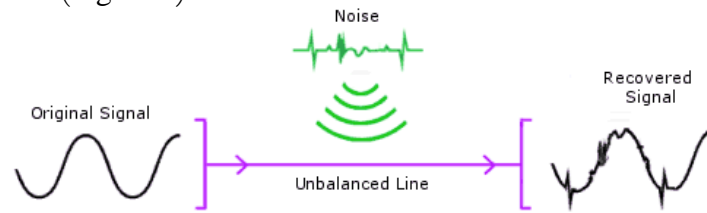


Figure 2- Unbalanced line transmission

(<https://www.belram.be/here-is-what-you-need-to-know-about-balanced-and-unbalanced-cables/>)

Of course, EMI also works the other way around, the signal being sent through the copper line causes electromagnetic radiation that will be regarded as noise by nearby electric signals transmission systems.

Most current copper transmission systems, including local area networks, use *balanced lines with symmetrical differential transmission*.

Balanced lines differential transmission means two lines (a pair) are used to transmit a single signal, one line holds the signal, and the other line is used as reference. At the receiver the signal is measured as being the difference between the two lines, the big advantage is that external noise will be the same on both lines, and thus it's eliminated when the receiver measures the difference. Although this removes external noise at the receiver, it does nothing to prevent electromagnetic radiation of the transmitted signal.

In *balanced lines with symmetrical differential transmission*, a symmetrical copy of the signal is placed on the second line (Figure 3). Therefore, each line this produce symmetrical electromagnetic radiation cancelling each other. To make the most of this electromagnetic radiation annulation effect, the two lines are twisted on each other, making what is called a *twisted pair*.

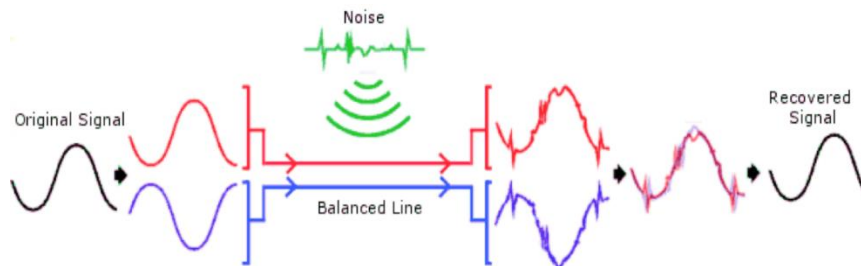


Figure 3 - Balanced lines differential transmission

(<https://www.belram.be/here-is-what-you-need-to-know-about-balanced-and-unbalanced-cables/>)

Figure 4 shows a key electronic circuit on the receiver side, it's called a *differential amplifier*, this device has two inputs, (+) and (-), and outputs the amplified difference between them.

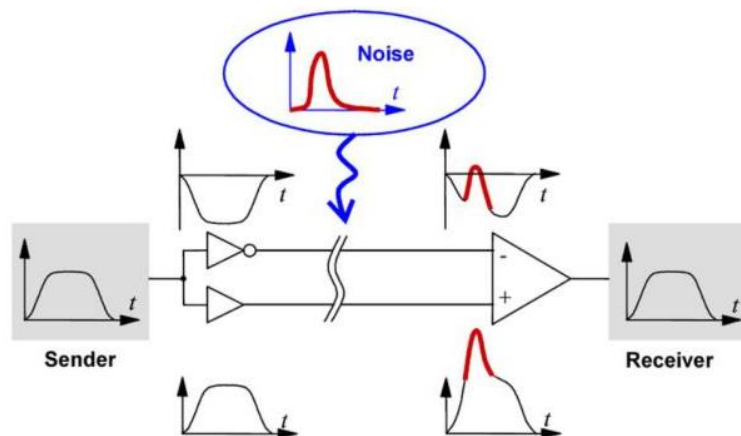


Figure 4 - Balanced lines differential transmission - the differential amplifier

(<https://commons.wikimedia.org/wiki/File:DiffSignaling.png>)

2.2. Shielding

The twisted pairs may be put together in a polyethylene jacket, this is known as UTP (Unshielded Twisted Pairs), however, to minimize the external noise and electromagnetic radiation, the twisted pair cables may also be shielded, this is known as STP (Shielded Twisted Pairs). Electric shielding is achieved by surrounding the pairs with an electric conductor material connected to ground, usually an aluminium foil or a copper mesh, in **Error! Reference source not found.** we can see the cable sections for the possible scenarios.

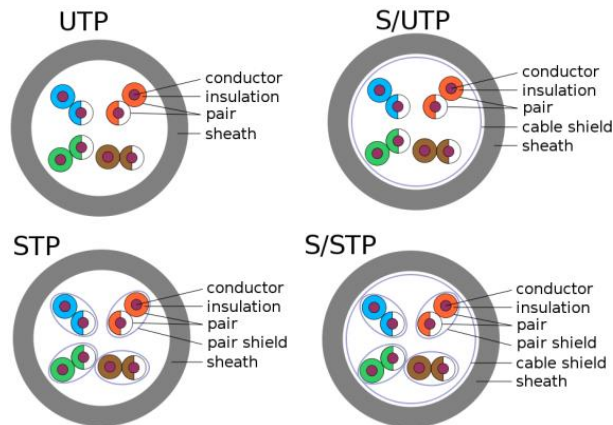


Figure 5 - UTP, S/UTP, STP, and S/STP cable sections

(<https://www.linkedin.com/pulse/shielded-stp-unshielded-utp-twisted-pairs-peter-chipkin/>)

2.3. CAT5E, CAT6 and CAT7 copper cables

Current structured cabling systems standards require at least the use of category 5E (CAT5E) copper cables, however, category 6 (CAT6) or CAT7 are recommended. All these cables have four twisted pairs, making a total of eight connections.

Each CAT5E (CAT5 Enhanced) twisted pair can cope with signals up to 100 MHz, 1000baseT Ethernet technology can use this type of cable to transmit up to 1 Gbps data rate. CAT6 twisted pairs can cope with up to 250 MHz signals, and CAT6A (CAT6 Augmented) up to 500 MHz, 10GbaseT Ethernet technology uses category 6 cables to transmit up to 10 Gbps data rate.

Category 7 copper cables (CAT7) are S/STP and may be used with signals up to 600 MHz.

2.4. ISO8877 connectors (RJ45) and pairs' colours

TIA/EIA-568 standards require the described copper cables to be terminated with ISO8877 connectors, they are usually known as RJ45 (Registered Jack) or 8P8C (8 position 8 contact).

RJ45 connectors have eight metallic contacts numbered from 1 to 8 that provide electric connection. In addition, they may have a shielding connection to be used for shielded cables. Figure 7 shows male connectors or plugs, Figure 6 show a female connector or jack also known as socket.



Figure 6 – ISO8877 female connector



Figure 7 - ISO8877 male connectors

To make assembly easier, each cable pair is identified by a different colour: green, orange, blue and brown. Each pair assignment to connector pins may follow two alternative standards: 568A or 568B (Figure 8).

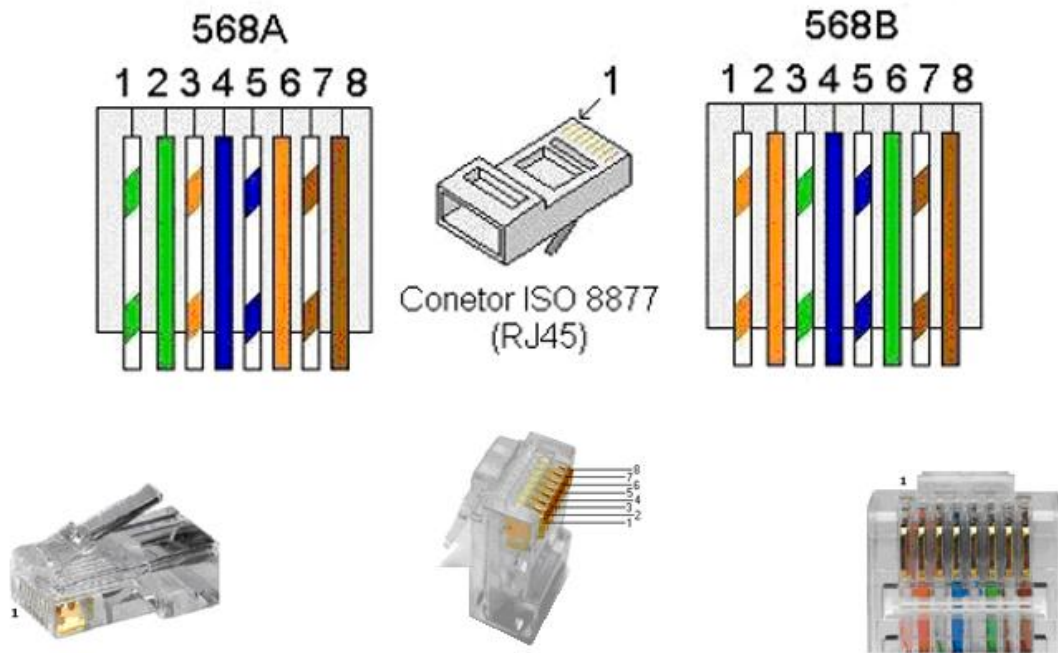


Figure 8 - ISO 8877 male connectors and pairs' colours

The purpose of each pair depends upon the upper layer technology using the cable, the cabling infrastructure should be independent of specific technologies and thus in any cabling infrastructure **one standard must be adopted (568A or 568B) and enforced everywhere in the infrastructure.**

2.5. Copper pairs usage (historical background)

During several years there were two major dominant technologies using these cables: 10baseT and 100baseTX, Ethernet at 10 Mbps and 100 Mbps. Both these Ethernet implementations use only two pairs, one for sending data (TX) and the other for receiving (RX), thus supporting full duplex (simultaneous transmission in both directions). The signal is emitted in the pair corresponding to connector pins 1 and 2 (TX pair) and received in the pair corresponding to pins 3 and 6 (RX pair). In these standards, only the green and orange pairs were used.

To directly interconnect two 10baseT or 100baseTX nodes through a cable, TX and RX pairs must be swapped. Two types of ports (MDI - Medium Dependent Interface) were established (Table 1).

Table 1 - MDI and MDI-X copper Ethernet ports

MDI ports	RX/TX pairs are not swapped	Used in end nodes like workstations, servers, and routers.
MDI-X ports	RX/TX pairs are swapped	Used in layer two intermediate devices (hubs, switches, and bridges).

On those days, any cable connection was required to be made between an MDI port and an MDI-X port, this is ensured because layer two intermediate devices have MDI-X ports and end devices have MDI ports. However, to be possible to directly interconnect layer two intermediate devices, those intermediate devices were also provided with an MDI port, commonly known as **uplink port**. Often is a shared port (internally a single port with two external connectors, one MDI and another MDI-X), other vendors provided a single port and a small switch to change the port behaviour between MDI and MDI-X.

As last resort, the interconnection of two intermediate layer two devices could also be made between two MDI-X ports by using a specially assembled cable, itself swapping the TX and RX pairs, that is called a

cross-over cable. A cross-over cable is assembled by using different standards (568A/568B) in each cable end. A cross-over cable would also be required to directly interconnect two end devices MDI ports.

Nowadays, almost every Ethernet MDI port is **Auto MDI-X** (aka "auto crossover"), this means it has the ability of automatically detect and negotiate the pairs to be used. Also, the current Ethernet technologies have different uses for each of the four available pairs. So, **cross-over cables are nowadays mostly historical**, and the entire cabling infrastructure should be assembled using the same standard.

3. Practical activity – mounting a copper patch cable

Patch cables, or *patch cords* (Figure 9), are used to connect the active devices (e.g., workstations, servers, switches, and routers) to the cabling system. Copper patch cords may be from **0.5 meters up to 5 meters long** and they have an RJ45 (ISO8877) male connector (plug) assembled on both ends.

Active devices and cabling systems have RJ45 female connectors (also known as **jacks** or **sockets**).

The easiest option is buying a ready to be used patch cord like the one we can see on Figure 9; they are available with several different lengths. Nevertheless, copper patch cords can be mounted with a suitable **RJ45 crimping plier** (Figure 10).



Figure 9 – A copper patch cord

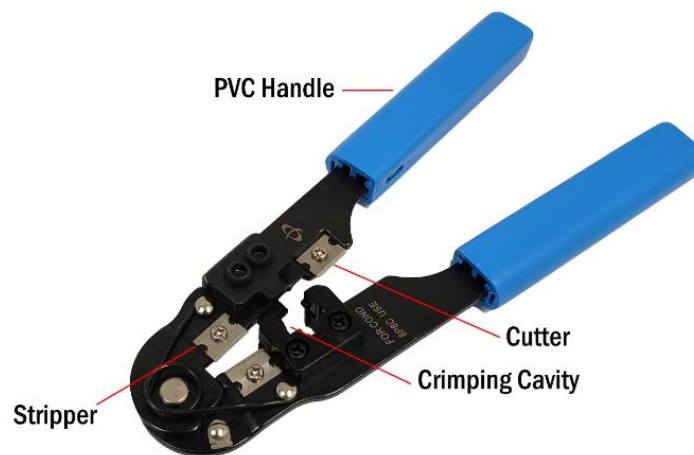


Figure 10 - RJ45 crimping plier

(<https://www.infinitecables.com/products/crimp-tool-for-modular-plugs-rj45-strip-and-cut>)

Before using the plier to crimp the connector to the cable, wires must be prepared. Most common RJ45 crimping pliers provide features for external jacket removal and wire cutting.

- The external jacket must be removed to an extent that will allow the handling of individual wires of each pair. However, the external jacket is supposed to be inserted into the connector for appropriate crimping, therefore only the required length should be removed.



Figure 11 - UTP cable with the external jacket removed

- **Individual wires jacket removal is not required.**
- All wires must be parallel to each other and in the correct positions for insertion into the connector. You may cut the excessive length of the wires, so they end up with the same size.
- All wires must fully reach the crimping zone of the connector, if one wire is shorter it will be missed by crimping and the electrical contact will fail.



Figure 12 - UTP cable ready to be inserted into an RJ45 connector

Each team will now mount one copper patch cord. Teams should take some minutes to watch the video in Figure 13 before or while doing it.



Figure 13 - Mounting a copper patch cord

<https://www.youtube.com/watch?v=noRk8jYAbSg>

Each patch cord has two ends, as far as there's enough hardware, half the members of a team could deal with one end and the other half with the other end. As training, students are encouraged to perform the cable end preparation several times before crimping the connector. **Crimping is irreversible; if the cable was inadequately prepared the connector will be wasted.**

TO AVOID UNNECESSARY CONNECTORS WASTE, CRIMPING SHOULD BE EXECUTED ONLY AFTER THE TEACHER'S INSPECTION AND APPROVAL

There are two assembly standards: 568A e 568B. Adopting one or another is irrelevant, however once one is adopted it must be used everywhere in the infrastructure. Therefore, in this activity, **the same standard must be used on both ends of the patch cord.**

Once you have mounted your copper patch cord, test it with a copper patch cord cable tester.

Basic copper cable testers like the one in Figure 14 are simple electric continuity testers for each of the eight wire connections and for the shield (if available and connected). Each circuit is tested at a time so any wrong connection or short circuit will be visible.

More sophisticated cable testers are used for cabling certification, they can measure the cable length and signal propagation properties for each pair.



Figure 14 - A simple RJ45/RJ11 patch cord cable tester

4. Practical activity – setting up a private IPv4 network

For this activity the two teams that are next to the same rack will work together and share the network switch located at the top of the rack.

It's a **Cisco Catalyst WS-C2950SX-24**, as shown in Figure 15. It has 24 copper 10baseT/100baseTX ports, and two optical fibre 1000baseSX ports.



Figure 15 - Cisco Catalyst Switch WS-C2950SX-24 (24x10baseT/100baseTX + 2x1000baseSX)

The 10baseT/100baseTX ports of this switch are Auto-Sensing and Auto-Negotiating, but not Auto-MDI-X. Auto-Sensing means that it will automatically activate the port when it detects an active device has been connected to it. Auto-Negotiating means that, when the port is activated, a negotiation protocol with the connected device is started to establish the best options supported by both devices, regarding the transmission rate (in this switch limited to either 10 Mbps or 100 Mbps) and the operation mode, either half-duplex or full-duplex.

4.1. Creating the layer two network

The layer two network is going to be built around the switch shared between the two teams, we are going to create a simple star topology by connecting the personal laptops of the members of the two teams to the switch.

Notice that not all laptops have an Ethernet port, laptops without an Ethernet port can't take part in this activity. If the number of suitable laptops in a team is less than two, then the teams should be merged to ensure that there are at least two operating laptops in each side of the rack/switch.

To connect the laptops to the switch, use the patch cord created in Section 3, and additional patch cords available in the laboratory.

One of the teams near each switch will now power it on: plug in the power cord at the rear, on the right side.

Next, members of the teams on both sides of the rack/switch will connect the laptops through the copper patch cords.

We would then expect to have a link light on both ends (the laptop and the switch port). Each port of the Cisco Catalyst 2950 switch has a light over it, and the light is used for several purposes depending on the mode, we can change the mode by pressing the mode button we can see in Figure 16.

The default/initial mode is STAT (port status), green stands for a successful link, it will blink as Ethernet frames are transmitted through the port. Alternating between green and amber means errors are happening.

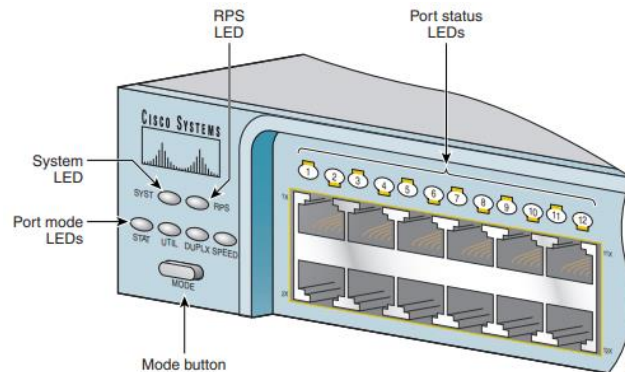


Figure 16 - Cisco Catalyst 2950 panel details

(Catalyst 2950 Switch Hardware Installation Guide, August 2004)

By pressing the mode button, you can change the mode. Change to DUPLX mode (port duplex-mode), if the port is operating in half-duplex the light will be off, if operating in full-duplex the light will be green.

Change to SPEED mode (port speed), for 10/100 Mbps ports, if the port is operating at 10 Mbps (10baseT) the light will be off, if operating at 100 Mbps (100baseTX) the light will be green.

4.2. Creating the layer three network (IPv4)

The layer two Ethernet network role is exchanging Ethernet frames between the nodes connected to it; however, we haven't yet tested that in our network.

The best way to test if the Ethernet network is working, is checking if it can do what is mostly expected from it nowadays, and that is transporting IP packets (as payload of the Ethernet frames).

Once we have an IPv4 network (layer three) operating over the Ethernet network (layer two), then we can use the Internet Control Message Protocol (ICMP) and undertake the ping test. The ping command sends an **ICMP echo request** to a destination IP address, and waits for an **ICMP echo reply**, in other words it performs a **round-trip communication test**.

Creating the IPv4 network is just a matter of establishing the IP configuration of the end nodes. To better understand how IPv4 addresses work, we are going to create two IPv4 networks over the same Ethernet network.

In the following activity, in each enrolled laptop, the student will change the IPv4 configuration of the local Ethernet interface, how exactly this is done depends on the laptop's operating system.

The team on the left side of the rack/switch is going to create the IPv4 network **192.168.100.0/24** (255.255.255.0 network mask). To its laptops will assign the addresses **192.168.100.1, 192.168.100.2, 192.168.100.3, ..., 192.168.100.254.**

The team on the right side of the rack/switch is going to create the IPv4 network **192.168.101.0/24** (255.255.255.0 network mask). To its laptops will assign the addresses **192.168.101.1, 192.168.101.2, 192.168.101.3, ..., 192.168.101.254.**

Both teams should now test the IPv4 connectivity with other nodes. At the command line of the laptops, use the ping command:

```
ping 192.168.100.1
ping 192.168.100.2
...
ping 192.168.101.1
ping 192.168.101.2
...
```

Important: personal computer firewalls may block incoming ICMP echo requests, for a successful test the target personal computer may be required to temporarily disable the firewall.

The expected results are the ping tests within the same team (same IPv4 network) are successful, between different teams (different IPv4 networks) will fail.

Notice that this happens despite all nodes being connected to the same layer two Ethernet network.

**However, it all depends on the network prefix-length
(network mask)**

In every enrolled laptop, let's reduce the network prefix-length from 24 bits to 16 bits (255.255.0.0 network mask instead of 255.255.255.0), without changing the IP address itself.

This has the major impact of putting all laptops on the same IPv4 network, the network is now 192.168.0.0/16.

Repeat the ping tests, now they should be successful for all laptops connected to the switch.

```
ping 192.168.100.1
ping 192.168.100.2
...
ping 192.168.101.1
ping 192.168.101.2
...
```

4.3. ARP tables

We have now tested that our Ethernet network is fulfilling its role of transporting IPv4 packets inside Ethernet frames. Nevertheless, the way nodes are addressed in an Ethernet network (48-bits addresses) and the way nodes are addressed in an IPv4 network (32-bits addresses) is totally different and unrelated.

The issue is, to send an IPv4 packet to a given IPv4 destination address, the IP packet is placed inside an Ethernet frame, and the destination address of the Ethernet frame is required to be the Ethernet address of the node where the IPv4 packet is to be delivered.

The ARP protocol is used to solve this issue and dynamically create the ARP table with equivalencies between IPv4 addresses and Ethernet addresses.

At the command line of your laptop, enter "arp -a" to see your current ARP table. Interpret your ARP tables contents.

5. Practical activity – mounting a copper patch panel

A structured cabling system is a hierarchical set of cables interconnection points known as cross-connects or distributors (Figure 17).

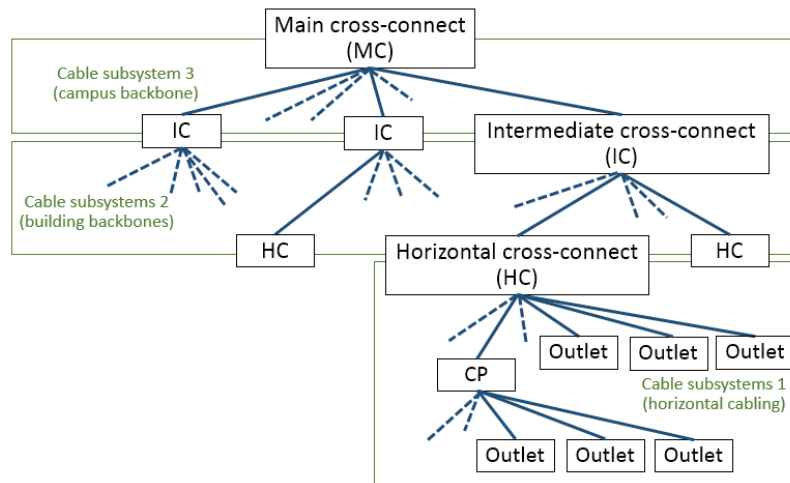


Figure 17 - Structured cabling system

The structured cabling system is made of **passive equipment only: cables, connectors, and suitable mechanical supports**. Every cable is ended by either two patch panels, one on each edge, or, for horizontal cabling, a patch panel on one edge and a work area outlet on the other edge (Figure 18).

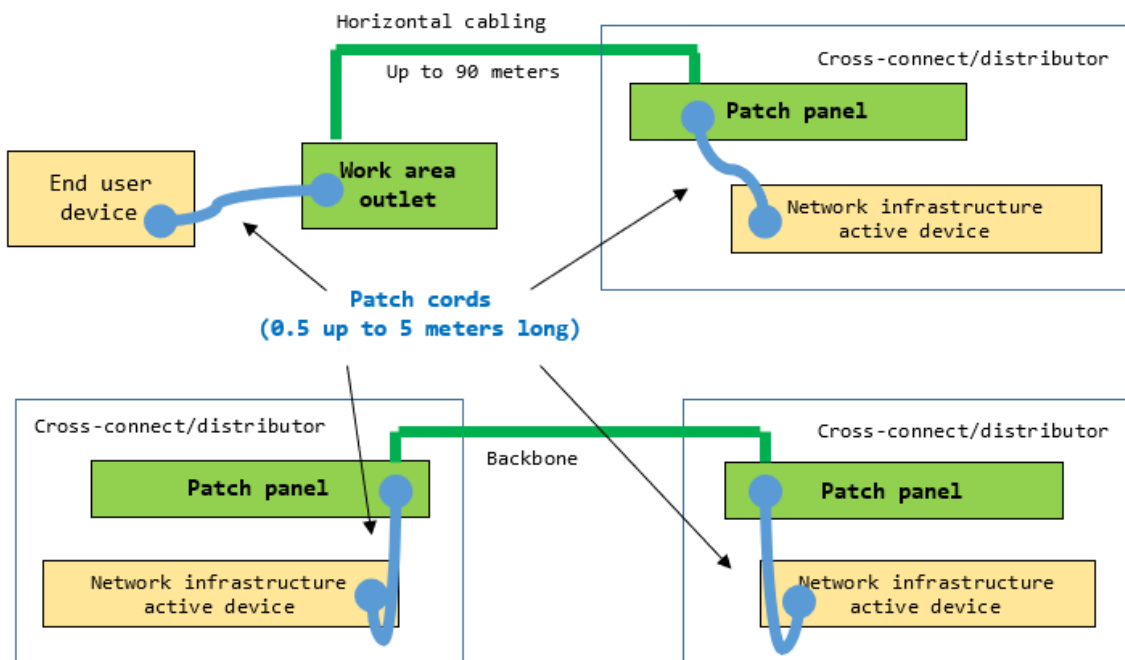


Figure 18 - The two active-device to active-device cabling scenarios in structured cabling

Patch cords (from half a meter long, up to 5 meters long) are used to connect active devices to the cabling system. Within the same distributor, active devices may be directly interconnected by a patch cord, otherwise, they are interconnected through the structured cabling system as shown in Figure 18.

Wiring copper cables to patch panels and network sockets is a simple operation, and unlike with plugs crimping, is reversible. In Figure 19 we can see the how the wires are inserted into slots at the back of the patch panel or network socket.

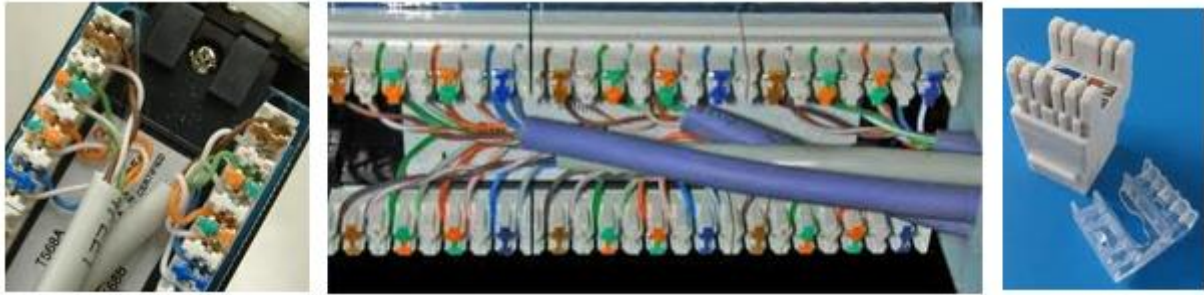


Figure 19 - The back of copper patch panels (left and centre) and a socket (right)

There are several different tools known as **Punch Down Tool** designed to insert the wires into the slots. The wires are forced between two metallic tabs that will drill the plastic insulation cover and establish electrical contact.

A simple **wire stripper** that may be also used as **punch down toll** is presented in Figure 20, these models are often offered together with the crimping plier.

There are more sophisticated **punch down tolls**, like the one used in the Figure 21 video, which cuts the excess wire when inserting it into the slot.



Figure 20 - Wire stripper / simple punch down tool

Each team will now wire a UTP cable to a copper patch panel on one end, and if available wire a network socket on the other end of the cable. Take some minutes to see the video in Figure 21 before proceeding.



Figure 21 - Video about mounting a copper patch panel

<https://www.youtube.com/watch?v=D8PnNuDbkAw>

- The team may test the wiring with the cable tester (and two approved patch cords).
- The team may test the wiring by integrating the assembled set (patch panel and network socket) in the network created in Section 4.
- Ask the teacher for comments on the team's job.

When done, the group should remove the cable from both the patch panel and the outlet and cut out the cable ends.

Of course, for optical fibre cabling, comparable but specific patch panels must be used instead, check the video in Figure 22.

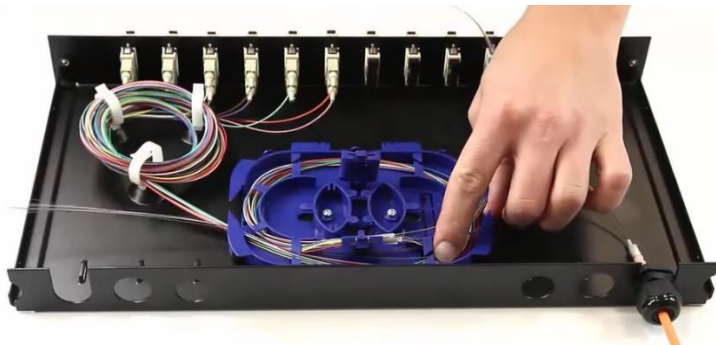


Figure 22 - Inside an optical fibre patch panel

<https://www.youtube.com/watch?v=X-01PWzfpes>