FINAL PROJECT

UNIVERSIDAD DISTRITAL
FRANCISCO JOSE DE CALDAS

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Computer networks

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PROBLEM DEFINITION

The construction of the new building in the engineering department of the Universidad Distrital Francisco José de Caldas has begun, and with it, its needed to define, design and implement all kinds of infrastructures to make the building functional, this includes electrical infrastructure, water and sewerage infrastructure, etc. But the one that will be boarded in this paper will be the network infrastructure, that will enable this site to access the Internet, and for that purpose we were asked to analyze and design such a topology.

So, in order to define this infrastructure we need to analyze the dimensions of the new building, the amount of floors, rooms in it, how much people it’s meant to support and what kind of devices are needed to connect to fulfill the needs of the users in the site.

It’s mandatory to have interconnectivity in all the building, not only with cable connections, but with wireless connections too, so we must know the dimensions of the rooms, floors and the distribution of the devices in this spaces in order to know how much network devices we need, how much meters of cables and which types of cables we need to bring this connectivity in all the spaces of the building, so no one will be disconnected in any floor or room of the building.

The topography and architecture must prioritize efficiency and low cost in the design of the topology in general, so the devices, cables and other aspects must be adapted to that goal and for that there must be set some restrictions to establish the boundaries and reach of the project.

OBJECTIVES

Generals:

1. Analyze project information in order to come up with design proposals for the topology of the new building by researching site information, investigating relevant devices and pricing.

   Specifics from 1:

   1.1. Gather detailed information about the project including its scope, requirements, and constraints.
   1.2. Conduct a site survey to understand the physical layout and existing infrastructure of the new building.
   1.3. Research the market for the latest and most relevant devices suitable for the project.
   1.4. Prepare a comprehensive list of potential devices along with their pricing for further analysis.

2. Identify the optimal set of devices and distribution that the topology will have in order to increase efficiency and reduce costs using the information obtained from the preliminary research so that a comparison of prices, features and functionalities can be made and the best options can be chosen.

   Specifics from 2:

   2.1. Evaluate the features and functionalities of the shortlisted devices from the preliminary research.
   2.2. Compare the prices of the shortlisted devices to identify cost-effective options
   2.3. Determine the optimal distribution of devices in the topology to maximize efficiency
   2.4. Select the best devices based on the comparison and distribution analysis.

3. Propose a topology design to be implemented in the new faculty building so that the objective of the project can be met and the connectivity of the building can be achieved using the devices, their distribution and the design of different topologies for the different spaces of the building.

   Specifics from 3:

   3.1. Develop a preliminary design of the topology based on the selected devices and their distribution.
   3.2. Design different topologies for different spaces of the building to ensure optimal connectivity.

3.3. Review and refine the topology design to ensure it meets the project objective.
3.4. Prepare a final proposal of the topology design for the new faculty building.

4. Simulate the design of the proposed topology in order to see its operation and behavior and confirm that the proposal is feasible using the Packet tracer simulation program.

   Specifics from 4:

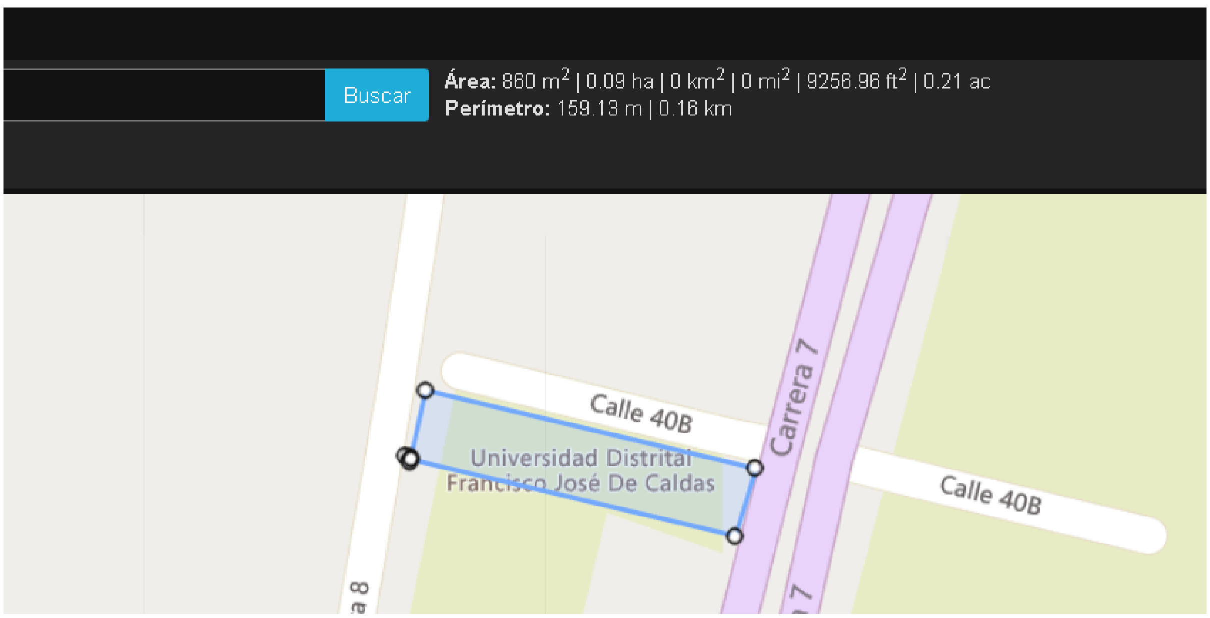
   4.1. Set up the proposed topology design in the Packet Tracer simulation program
   4.2. Run simulations to observe the operation and behavior of the proposed topology.
   4.3. Analyze the simulation results to identify any potential issues or bottlenecks.
   4.4. Confirm the feasibility of the proposal based on the simulation results.

PROJECT DEVELOPMENT

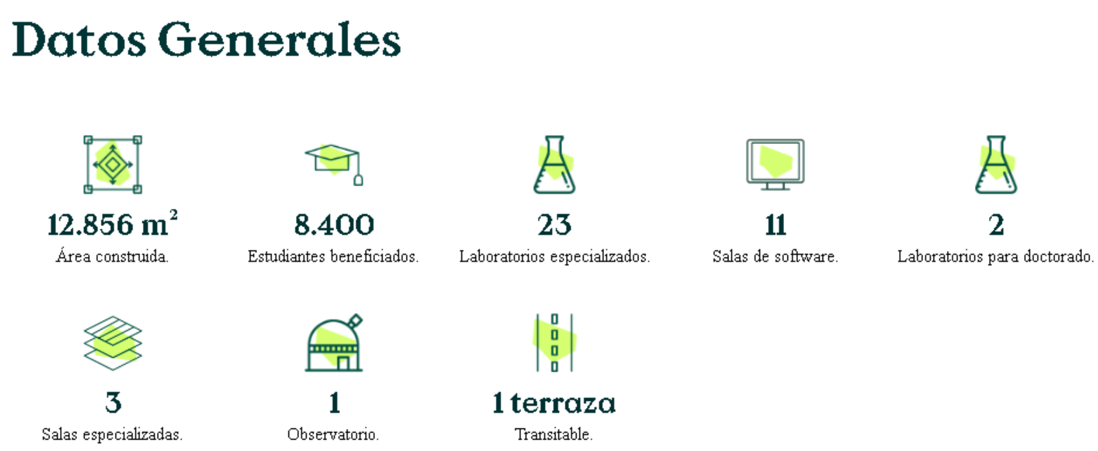
Information about the project:

Note: The packet tracer file and the presentation can be found in the next repository: https://github.com/Skyrus1203/Final-project-Computer-networks.git

The building has 15 floors and, according to the construction company, will have 12,856 square meters which, when divided between floors, we obtain a value of about 857.6 square meters. In turn, if we estimate the area that the building will cover in a map tool, we see that the space occupied by a single floor would be around 860 square meters, so we will take this last value as a guess to have an approximate area of each floor.



The new building will have 23 specialized laboratories, 11 software rooms, three doctoral rooms, two doctoral laboratories, a study and consultation room, a multipurpose room and an astronomical observatory. There will also be a relaxation and socialization room, a terrace where students can socialize and 11 wellness areas.



Devices research:

In this section we will focus on Cisco devices, for reasons of practicality when simulating the design that will be used for the topology of the new building, since the Packet Tracer software is from Cisco, in addition to Cisco provides a wide range of options which are easily consultable on their website and their prices although they are somewhat high, are not the most expensive on the market. So we will divide this section into the devices that we may need such as routers, switches and endpoints and we will look at the different options that Cisco offers to put together a catalog of options from which we will choose the products that best suit the objective of the project.

Routers:

For the routers section we will have to subdivide it in two: Edge routers to connect the WAN with the LAN and the normal routers to handle the internal connections.

For the edge routers we have three potential candidates offered by Cisco, below is a comparative table between the three:

	NCS 5001	NCS 5002	NCS 5011
Features			
Product Description	MPLS aggregation router for metro aggregation, MPLS Enabled TOR/Leaf Architectures	MPLS aggregation router for metro aggregation, MPLS Enabled TOR/Leaf Architectures	MPLS aggregation router for metro aggregation, MPLS Enabled TOR/Leaf Architectures
Target Deployments	Enterprise, Over-The-Top (OTT), and Service Provider data center networking architectures	Enterprise, Over-The-Top (OTT), and Service Provider data center networking architectures	Enterprise, Over-The-Top (OTT), and Service Provider data center networking architectures
Slots per Chassis	Fixed	Fixed	Fixed
Rack Size	1 RU	2 RU	2 RU
Max Capacity	800 Gbps	1.2 Tbps	3.2 Tbps
Size (H x W x D)	1.72 x 17.44 x 19.3 inches (4.3688 x 44.2976 x 49.022 cm)	3.38 x 17.44 x 19.3 inches (8.5852 x 44.2976 x 49.022 cm)	1.72 x 17.3 x 22.5 inches (4.3688 x 43.942 x 57.15 cm)
Weight	20.5 lb (9.29kg)	33 lb (14.96kg)	22.2 lb (10.06 kg)
Power	1+1 redundant AC or DC Typical: 200 W Max: 275W	1+1 redundant AC or DC Typical: 300W Max: 500W	1+1 redundant AC or DC Typical: 228W Max: 508W
Fans	1+1 redundant	1+1 redundant	3+1 redundant
Airflow	Front to Back Back to Front	Front to Back Back to Front	Front to Back Back to Front
Software	IOS XR	IOS XR	IOS XR
System Memory	16 GB DRAM	16 GB DRAM	16 GB DRAM
Storage	Embedded USB (eUSB) storage (32GB)	Embedded USB (eUSB) storage (32GB)	64 GB mSATA
Processor	Intel IVB Gladden 4 core processor @ 2.5GHz	Intel IVB Gladden 4 core processor @ 2.5GHz	Intel IvyBridge 4 core processor @ 1.8GHz

Analyzing the specifications of each edge router, it was concluded that for capacity issues the NCS 5011 router is the most suitable since it will be able to support more traffic.

With this in mind, if we search for the price of this border router we found that it has a cost of 5715 USD or 22’676.360 COP

For the internal Routers we must choose between the Catalyst series 8000 and the ISR series 1000, being the last ones much cheaper than the Catalyst 8000, so in order to know which one choose, here is a comparison between both:

Feature	ISR 1161X-8P	Catalyst 8300-1N1S-6T	Catalyst 8300-1N1S-4T2X	ISR 1100X-6G
Rack vs. desktop	Rack and desktop	Rack	Rack	Rack or Desktop
Height	1.65 in/41.9 mm	1.73 in/43.9 mm	1.73 in/43.9 mm	1.1in/ 28mm
Width	10.8 in/274.3 mm	17.25 in/438.15 mm	17.25 in/438.15 mm	10.20in/ 259mm
Depth	7.85 in/199.4 mm	16.25 in/412.75 mm	16.25 in/412.75 mm	7in/ 178mm
Weight	3.7 lb/1.7 kg	20 lb/9.1 kg	20 lb/9.1 kg	2.69lb/ 1.21kg
Noise (dB)	Noiseless (~ 0dB)	49 dBa/71 dBa	49 dBa/71 dBa	Noiseless (~ 0dB)
Fanless	Yes	No	No	Yes
Security				
Hardware VPN acceleration	No	Yes	Yes	Yes
Intrusion prevention/detection	Yes (X PID only)	Yes	Yes	Yes
URL Filtering	Yes (X PID only, SD-WAN and SD-Routing only)	Yes (SD-WAN)	Yes (SD-WAN)	Yes
Advanced Malware Protection	Yes (X PID only, SD-WAN and SD-Routing only)	Yes (SD-WAN)	Yes (SD-WAN)	Yes
Secure Service Edge (Cisco Secure Access)	Yes	Yes	Yes	Yes
WAN MACsec	No	Yes	Yes	No
LAN MACsec	No	Yes	Yes	No

SSL VPN	No	No	No	No
DMVPN	Yes	Yes	Yes	No
FlexVPN	Yes	Yes	Yes	No
GETVPN	Yes	Yes	Yes	No
Site-to-Site VPN	Yes	Yes	Yes	Yes
NAT	Yes	Yes	Yes	Yes
CGN	No	No	No	No
Zone-based firewall	Yes	Yes	Yes	No
LAN				
Built-in GE switchports	8	No	No	4 (Can be used as LAN or WAN)
mGig switchports	No	Yes	Yes	No
Flexports (L2 to L3 conversion)	2	Yes	Yes	No
802.11ax wireless (Wi-Fi6)	No	No	No	No
Layer 3 switch module	No	Yes	Yes	No
Maximum switched Ethernet ports	8	22	22	4 (Can be used as LAN or WAN)
Maximum switched Ethernet LAN ports with POE	4PoE/ 2PoE+	20 (PoE/PoE+/ UPoE)	20 (PoE/PoE+/UPoE)	No
Network interface modules (NIM)	No	1	1	No
Enhanced services modules (SM-X)	No	1	1	No
Network Services				
SD-WAN	Cisco SD-WAN	Cisco SD-WAN	Cisco SD-WAN	Viptela OS (Upto 20.9) & IOS XE SD-WAN
IPv6 support	Yes	Yes	Yes	Yes
SD-Access	Yes	Yes	Yes	No
SD-Routing	Yes	Yes	Yes	No
Application Quality of Experience (AppQoE)	TCP Optimization	Yes	Yes	TCP Optimization
Application Visibility and Control	Yes	Yes	Yes	Yes
IOS high availability	No	No	No	No
Segment routing (MPLS)	Yes	Yes	Yes	No
Segment routing (SRv6)	No	Yes	Yes	No
Multicast routing protocols	Yes	Yes	Yes	Yes
Overlay Transport Virtualization (OTV)	Yes	Yes	Yes	No

Ethernet VPN (EVPN)	EVPNoMPLS is supported	Yes	Yes	No
Key Features				
Target deployments	Branch, MSP, SMB	Medium/Large Branch	Large Branch	Branch, MSP, SMB
Encryption throughput (Internet MIX)	800 Mpbs	Up to 1.9 Gbps	Up to 6.5 Gbps	970 Mbps

Analyzing the specifications of each edge router, as with the edge router, capacity will be prioritized so ISR 1000 models will be discarded. However, the Catalyst 8300-1N1S-4T2X has a higher capacity and in terms of cost is a good option if we compare its specifications with the other 8300 model. This has a price of 9013 USD or 35’760.384 COP

Switches:

For the switches we have that in the official page of Cisco, the Catalyst 9400 Series has the purpose to serve for enterprise-class midsize and large campus access networks, and the Catalyst 9200 its for small branches and midsize campuses, so they fits with the needs of the project, so now we must choose between the devices of this series, which one is the better option.

Cisco Catalyst 9200 Series switches are designed for simple branch/midmarket fixed enterprise access deployments.

With its family pedigree, Catalyst 9200 Series offers simplicity without compromise – it is secure, always on and provides a new level in IT simplicity.

- Delivers 160 Gbps stacking bandwidth.
- Flexible uplinks: 1 Gbps, 10 Gbps, 25 Gbps. Fixed (C9200L), and modular (C9200) options.
- Downlinks: 1 Gbps, Cisco Multigigabit copper, perpetual PoE+.
- Supports cold patching, MACsec-128 encryption, and FRU redundant platinum-rated power supplies and fans options.
- Fanless compact models (C9200CX).
- AC and HVDC power supply options (C9200CX)
- Meraki cloud monitoring option.

Cisco Catalyst 9300 Series switches are our leading fixed enterprise access switching platform.

Ideal access switch for business-critical branch and campus environments where scale and an extra degree of security, resiliency and programmability is needed.

- Delivers up to 8 chassis with 1 Tbps stacking bandwidth capacity.
- Flexible uplinks: Cisco Multigigabit, 100 Gbps, 40 Gbps, 25 Gbps, 10 Gbps and 1Gbps. Fixed (C9300L/C9300LM) and modular (C9300X and C9300) options.
- Flexible downlinks: Cisco 10G Multigigabit, 5 Gbps, 2.5 Gbps, or 1 Gbps copper, or 25 Gbps, 10 Gbps or 1 Gbps fiber. Perpetual Cisco 90W UPOE+, Cisco UPOE and PoE+ options.
- Supports ETA, AVB, IPsec, Cisco Umbrella cloud security, MACsec-256 encryption, 100G IPsec in hardware, embedded wireless controller and wire sensor, ThousandEyes Enterprise Agent, Cisco Spaces, MACsec, application hosting including ASAc firewall, Docker containers, hot patching, NSF/SSO, redundant power and fans.
- Meraki cloud monitoring and management option.

Cisco Catalyst 9400 Series switches are our leading modular enterprise access/aggregation switching platform. Ideal for business critical Enterprise campus access and distribution.

- Delivers up to 480 Gbps/slot, 9 Tbps/chassis.
- Flexible uplinks: 100, 40, 25, 10 and 1 Gbps.
- Flexible downlinks: 10G Multigigabit, 5 Gbps, 1 Gbps copper, 1 Gbps (SFP), 10 Gbps (SFP+),25 Gbps (SFP28), 40 Gbps (QSFP+), 100 Gbps (QSFP28) Cisco 90W UPOE+, Cisco UPOE and PoE+.
- Supports ETA, AVB, MACsec-256 encryption, MACsec encryption over EoMPLS, 100G IPsec in hardware TrustSec, ThousandEyes Enterprise Agent, Cisco Spaces, application hosting including Docker containers, StackWise® Virtual for core/ aggregation placement, ISSU, NSF/ SSO, hot patching, uplink resiliency.

Analyzing the specifications of each switch, in terms of capacity the Catalyst 9300 switch is the best of the three, and among the options of this model, the Catalyst 9300 with 24-port 1G copper with modular uplinks will be considered as an option for cost reduction reasons. It has a price of 5167 USD or $20’500.821 COP

Access points:

In terms of access points Cisco gives us the option to choose the Cisco Catalyst 9100, that adjust to the requirement of extra connectivity and scalability:

Cisco Catalyst 9100

Cisco Catalyst 9100 access points are adaptive, fast, intelligent and secure. Not only do they adhere to Wi-Fi 6/6E (802.11ax) but they go beyond the standard.

These access points allow for more flexibility and scalability needed to handle the extra devices connected to the network and the data that they will generate.

The Catalyst 9100 APs deliver:

- Three to four times the performance than 802.11 ac.
- Reliable performance—always connected, always dependable—even in challenging environments.
- Up to 50% reduced latency to provide better performance for applications that use high voice and video.
- Increased density and connect more devices (especially IoT) at higher throughputs.
- Meraki Cloud Management option for Catalyst 9166, 9164 and 9162 access points.

In terms of capacity, the Cisco catalyst 9130 is the best option, so we will use this device, which has a cost of 1761 USD or 6’987.022 COP

Cables:

Based on the assumption that, as this is an engineering-focused building, in which there are specialized rooms that require a reliable connection without dispensing with speed, category 6A Ethernet cables are taken as candidates.

CATEGORÍA	VELOCIDAD	FRECUENCIA	VELOCIDAD DE DESCARGA
ETHERNET CAT 5	100 Mbps	100 MHz	15,5 MB/s
ETHERNET CAT 5E	1.000 Mbps	100 MHz	150,5 MB/s
ETHERNET CAT 6	1.000 Mbps	250 MHz	150,5 MB/s
ETHERNET CAT 6A	10.000 Mbps	500 MHz	1.250 MB/s ó 1,25 GB/s
ETHERNET CAT 7	10.000 Mbps	600 MHz	1,25 GB/s
ETHERNET CAT 7A	10.000 Mbps	1.000 MHz	1,25 GB/s
ETHERNET CAT 8	40.000 Mbps	2.000 MHz	5 GB/s

They have a cost of 4700COP/meter.

Design proposal:

Having the information about the building we now be able to define which spaces require wired Internet connection and which spaces can be supplied with wireless service:

Cable connection:

- 11 Software rooms
- 3 PhD rooms
- 2 doctoral laboratories
- Multiple classroom (1 host for computer equipment for projection)
- Astronomical observatory

Wireless connection:

- Multiple classroom (Wireless connection for attendees).
- Study and consultation room
- Rest and socializing room
- Terrace
- 11 wellness areas
- X number of classrooms
- Corridors and common areas

Now, we proceed to make a rough estimate of the number of meters of cable needed to make the necessary connections:

It can be assumed that each floor could measure 4 meters in height, multiplying by 15 floors would give us 60 meters on the vertical axis, taking the above approximation of the area of 860 square meters per floor, we have for each floor, a horizontal distance of about 30 meters per floor. Depending on the floor you are on the vertical distance will vary, but the horizontal distance should be the same, however all these distance estimates are just enough for a cable to cover a certain distance, so we must give it some slack. This added to the lack of information on the distribution of the rooms on the different floors makes it very difficult to estimate the number of meters of cable needed and therefore, the cost of acquiring the cabling, but we can make an approximation.

Taking as an average meter of cable required to reach each device about 100 meters of cable, an estimate of 25 pc's per computer room (understanding as computer room the list of rooms and spaces listed above that require cable connection) we have that:

$$\#rooms = 11 + 3 + 2 + 1 + 1 = 18$$

So if we multiply the number of pc's by the number of rooms:

$$\#Conections = 18 \cdot 25 = 450$$

It should be noted that switches, servers and routers should also be counted, however, since we do not have an exact number of these devices, an estimate should be made, therefore we will take as a rule to use a router for each subnet and an end router for WAN-LAN trancision, a switch for every 25 users, and if we take into account to allocate at least two software rooms as a network laboratory, there would be two servers in addition to the others that are allocated, therefore, in addition to the two network rooms we could guess another two for other purposes having a total of 4 servers, thus:

$$\#Routers = \#subnetworks = \#floors + border\ router = 15\ + 1\ = 16$$

$$\#Switches = \frac{450}{24} \approx 19$$

$$\#Servers = 4$$

$$\#Conections = 450 + 16 + 18 + 4 = 488$$

Thus, multiplying the number of connections by the meters of cable we have:

$$TotalMeters = 488 \cdot 100 = 48800\, m$$

And finally, taking as a reference the meter of Ethernet cable category 6A at an average cost of 4700COP/meter, we have:

$$Cabling\ price = 48800\ \cdot 4700 =\ 229'360.000$$

Now that we have the total cost of the cables, we can find the total cost of the switches, which are:

$$Switches\ price = 20500821 * 19 = 389'515.599\ COP$$

For the routers price we have that there will be one router per floor to manage one sub-net per floor, so the total price is (counting the edge router):

$$Routers\ price = (35760384\ *15) + 22676360 = 559'082.120\ COP$$

Finally for the access points, we have that taking into account the infrastructure and the reliability of the connection, we will have two access points per floor, so that for the building we will have a total of 30 access points, so their price would be as follows:

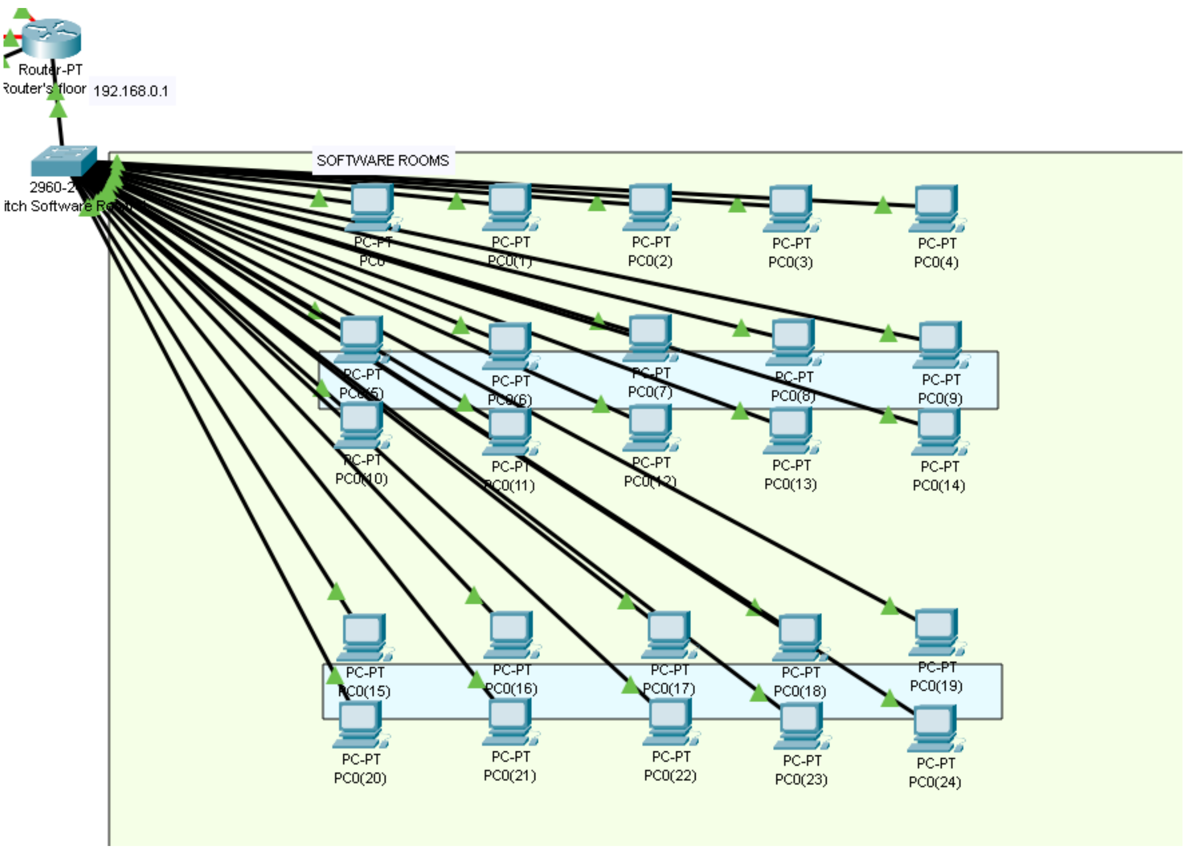
$$Access\ points\ price = 6987055 * 30 = 209'610.660\ COP$$

So the total price of the project only counting the network devices cost is:

$$Project\ cost\ (only\ devices) = 1.387'568.379\ COP$$

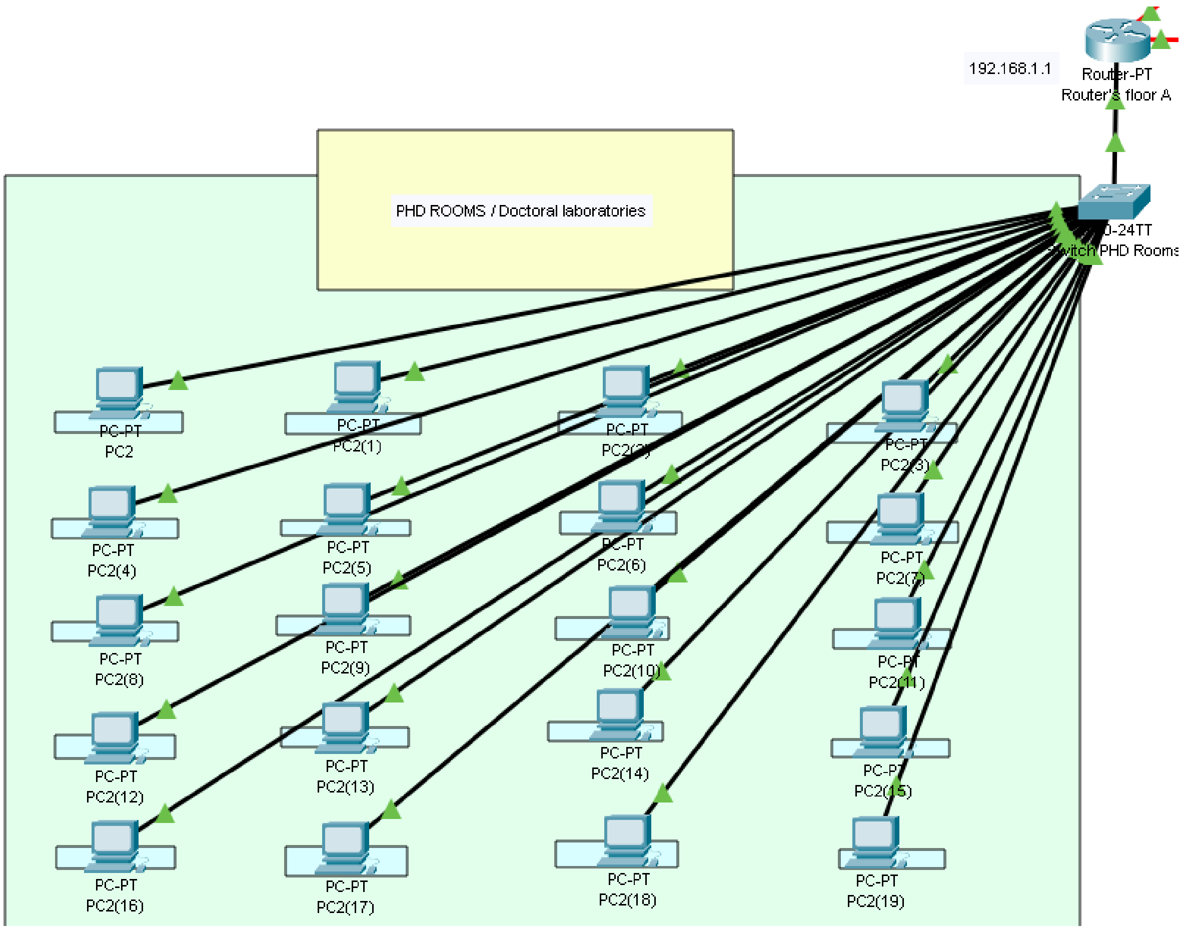
DESINGS AND SIMULATION

First lets take a look into the design of the software rooms:

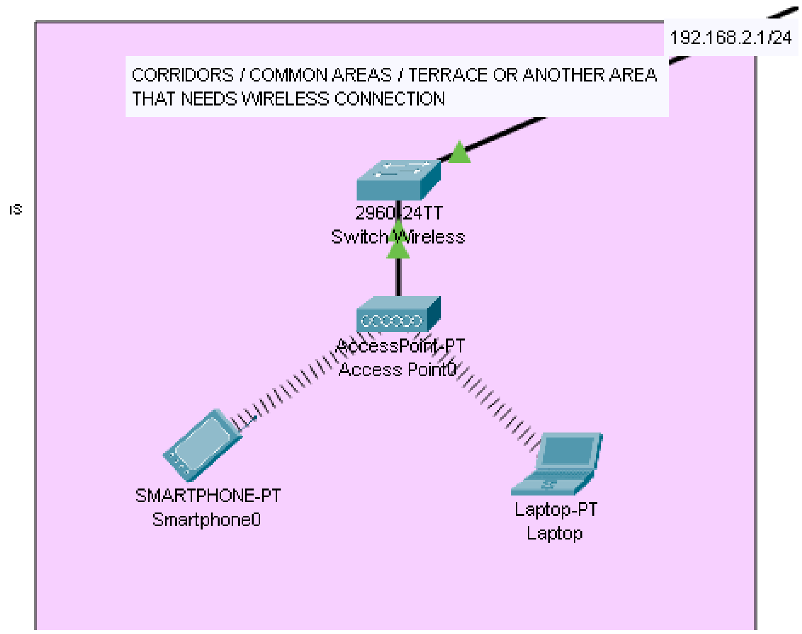


First we have the router of the floor that is connected to the switch in charge to distribute connection up to 25 users, in this case the Software room blueprint that we showcase in the packet tracer Model, here we connected all the 25 devices to the switch with cables of copper, this structure will be reproduced in every software room that we need, a router per floor, a switch per room or set of users and the final devices connected to it.

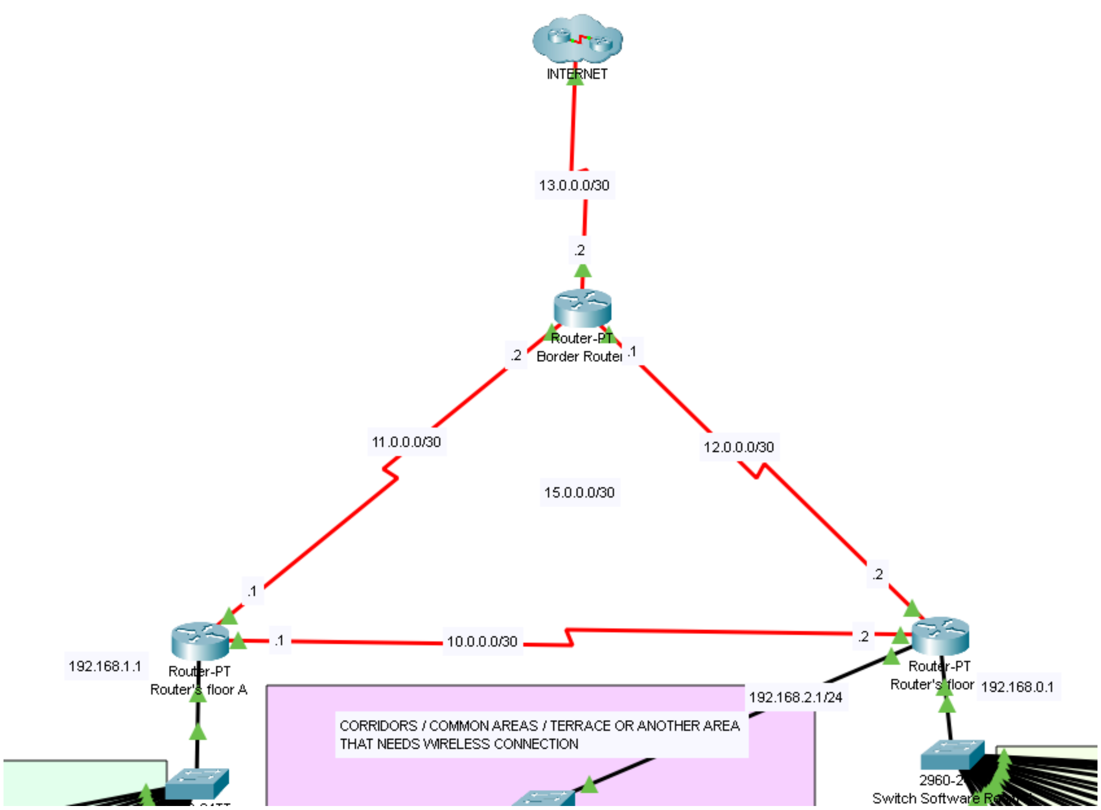
For example the PHD Rooms and doctoral labs, even if they have a different distribution of devices, the logic will be the same:



Here we have a different distribution of the devices, and in the analysis we stated that we use 100 meters of cables to have a slack in this topic, so the cabling will be distributed outside the walls, in every topology, this in order to prevent issues with preserving the physical infrastructure if it becomes an issue to have in count.

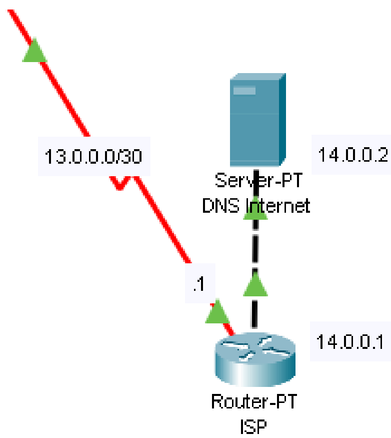


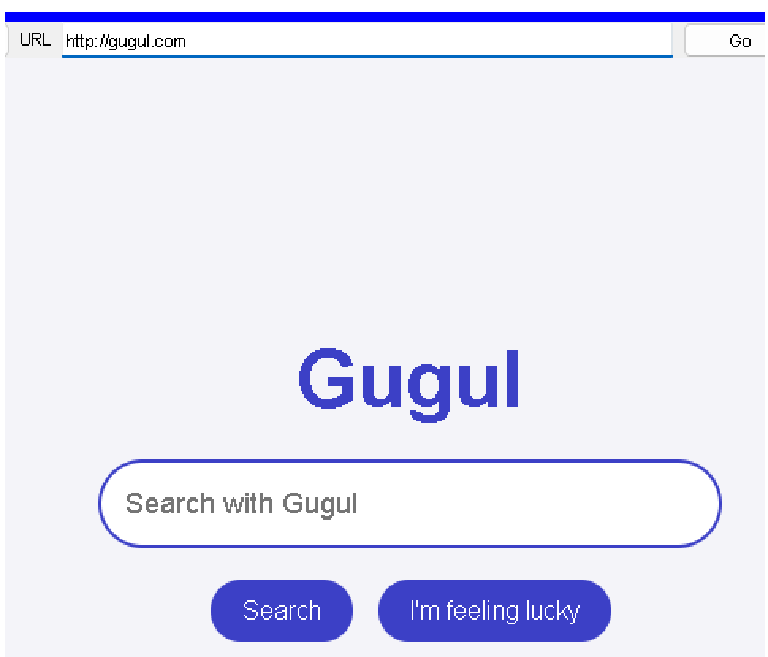
There will be two access points per floor, so here we showcase how they will work in a free space where is required a wireless connection, so it is tested with both smartphones and laptop to show how it will work in a simulated environment.



Finally we have the representation of the border router and it connections with the Floor routers (in this case 2, for the simulation), so we have that the proposed topology for this infrastructure will be the Star type topology, whose central node will be the edge router that will connect the university LAN to the WAN. This will ensure higher performance and efficient communication between nodes.

In the simulation the internet is being represented as a server with a DNS service that has an HTML with the representation of a Browser, and in the packet tracer file, every end device can reach this server and open the navigator, all this was did via dynamic routing using RIP version 2, and the floor routers have embedded a DHCP protocol for every room.





CONCLUSSIONS:

The project to design and implement a network topology for the new building has been successfully completed. We have achieved all the general and specific objectives set at the beginning of the project.

We started by analyzing the project information and conducting a thorough site survey to understand the physical layout and existing infrastructure of the new building. This allowed us to come up with design proposals for the topology of the new building. We researched the market for the latest and most relevant devices suitable for the project and prepared a comprehensive list of potential devices along with their pricing for further analysis.

Next, we evaluated the features and functionalities of the shortlisted devices and compared their prices to identify the most cost-effective and efficient options. This led us to select the best devices based on the comparison and distribution analysis.

With the optimal set of devices identified, we developed a detailed design of the topology, including the optimal distribution of devices to maximize efficiency. We designed different topologies for different spaces of the building to ensure optimal connectivity. The final proposal of the topology design was prepared and presented for the new faculty building.

Finally, we simulated the proposed topology to observe its operation and behavior. The simulation results confirmed the feasibility of the proposal and ensured that the design met the project objective of achieving the connectivity of the building.

In conclusion, the project has been a success. We have designed and implemented a network topology that is efficient, cost-effective, and meets the connectivity needs of the new building.

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