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ENEL 492

NETWORK DESIGN PROJECT REPORT

Table of content

1.0 Overview

Many industries are implementing and integrating advanced information and communication technologies in their manufacturing and production processes to better manage the entire automation and control systems. Networking enables easier control, monitoring and integration of different equipment and users. Network solutions should be secure, reliable and meet the real-time traffic requirements of the application. Technologies such as Machine-to-Machine (M2M) communication and Internet of Things (IoT) are becoming trends in current industries and will become a necessity in the near future as the numbers of intelligent devices grow.

In this project, we will design a network for a vehicle assembly plant (AKA Ethernet-to-the-Factory solution). There are four layers of the plant design specifications, such as:

- Enterprise Layer (EL)
- Plant Information Layer (PIL)
- Control Layers (CL)
- Device Layer (DL)

The enterprise building and the plant building are situated in different geographical locations but it is required that both buildings must have the ability to communicate with one another.

1.1 Layout

Enterprise Layout

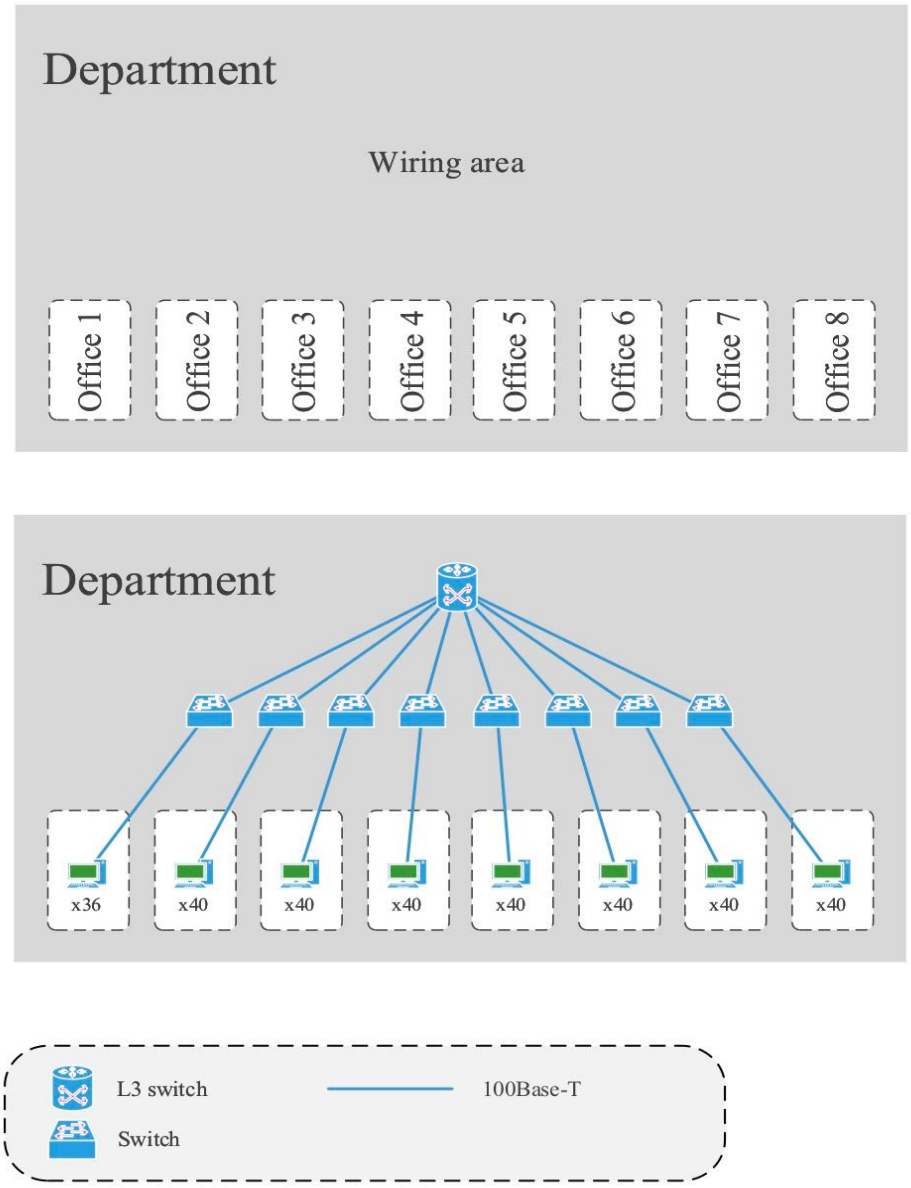


Figure 1: Department mapping

1.2 Hierarchical Network Design

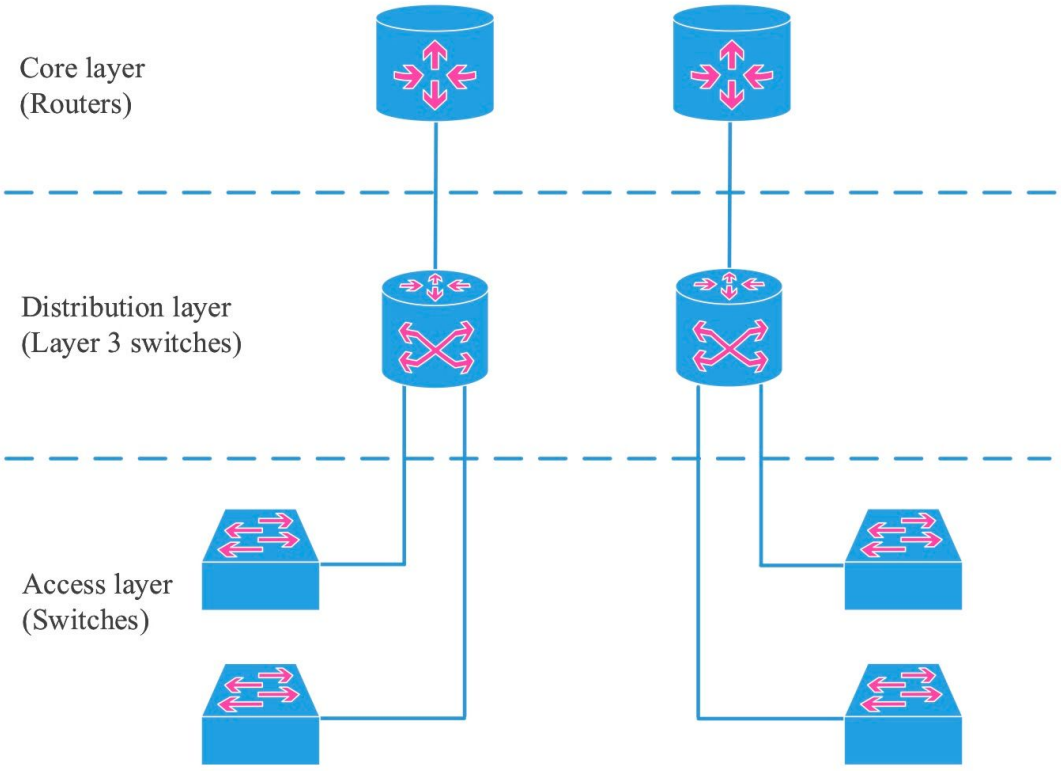


Figure 2: Hierarchical network design

- **Core layer:** This layer provides fast and reliable transportation between devices in the distribution layer located in different network region.
    - Routers
- **Distribution layer:** This layer is an aggregation point for all the devices in the access layer that provides management of the routing, filtering and quality of service policies.
    - Layer 3 switches
- **Access layer:** This layer provides access for end-stations (host computers) and servers to connect to the network.
    - Switches

1.3 Enterprise Layer (EL)

Requirements:

Devices	Size per department
PCs	306
Printers	10
Total	**316**

The enterprise layer consists of 5 different departments which are housed in a 3 storey building. These departments are: Marketing, Sales, Management, Engineering and IT. Each department consists of 306 end user computers and 10 network printers. This layer connects to the internet.

There are various topologies that can be implemented to network design of this layer. The topologies to be considered are bus, mesh, partial mesh, ring, star or ring topology. In terms of decision-making, each topology is analyzed taking efficiency, cost, reliability and simplicity into consideration.

	Bus	Mesh	Partial mesh	Ring	Star	Tree
Efficiency	✓	✓	✓		✓	✓
Low cost	✓		✓	✓	⁇	
Reliability		✓	✓			✓
Simplicity	✓	⁇	⁇	⁇	✓	

Note: ⁇ represents maybe

From the analysis provided above, we see that the bus, partial mesh and star topology happen to be the best choice to be implemented in the design.

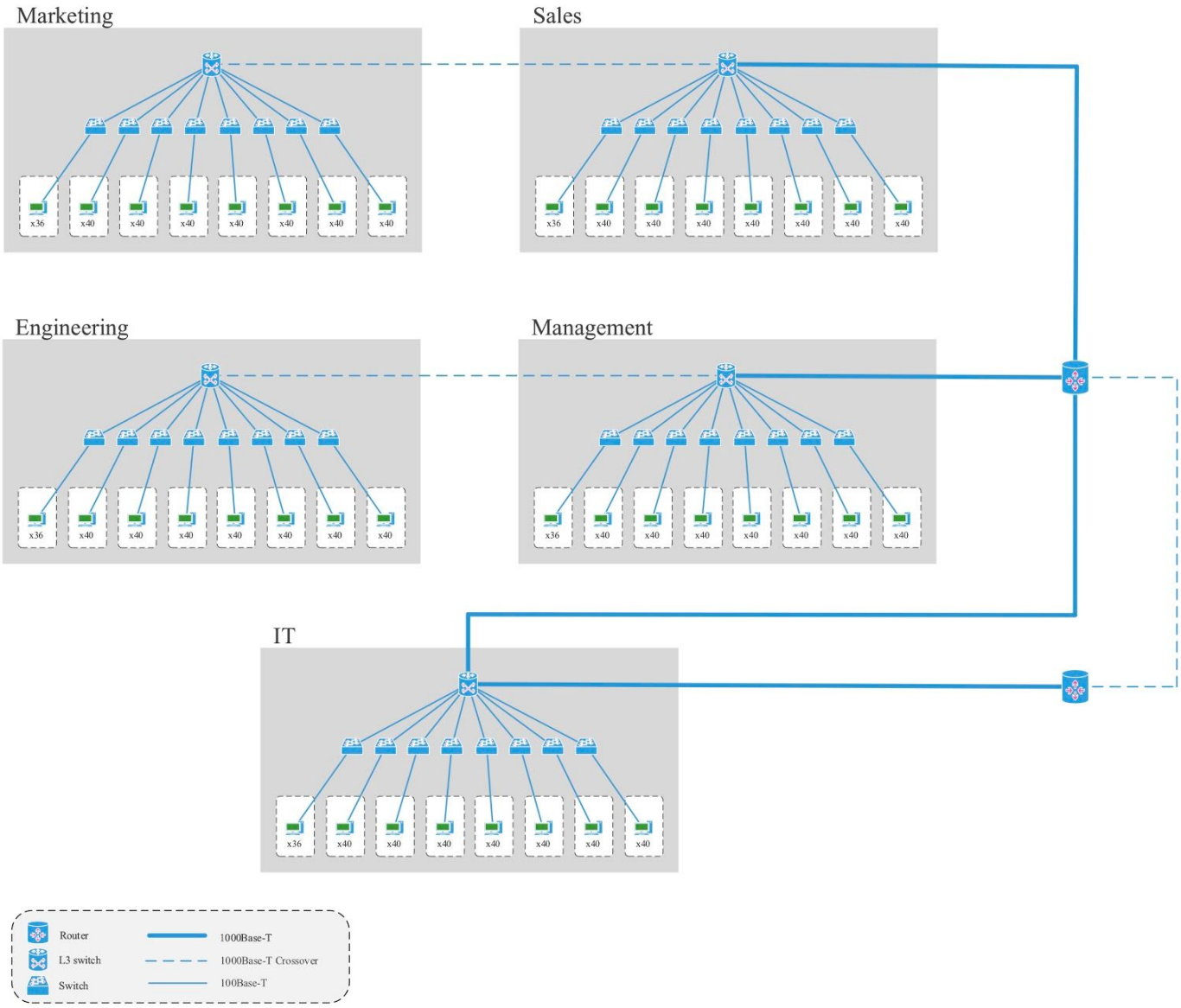


Figure 3: Enterprise layer network

In the Enterprise layer, all access layers are designed using the star topology

1.4 Device Layer (DL)

Requirements:

Devices	Size per department
Robots	40
PCs	50
MCDs	50
Sensors	306
Total	**446**

In the device layer, a spanning tree protocol topology was implemented in the network design of the plant. This layer consists of 6 LANs with each having 40 robots, 50 PCs, 50 MCDs (Manufacturing Control Devices) and 306 sensors. Each LAN has a total of 446 devices.

Switches with 48-ports are used in each LANs. Each LANs has a total of 446 devices, therefore, 10 switches are needed to handle all devices with 45 devices connected to 9 switches and 41 devices connected to the tenth switch as shown below.

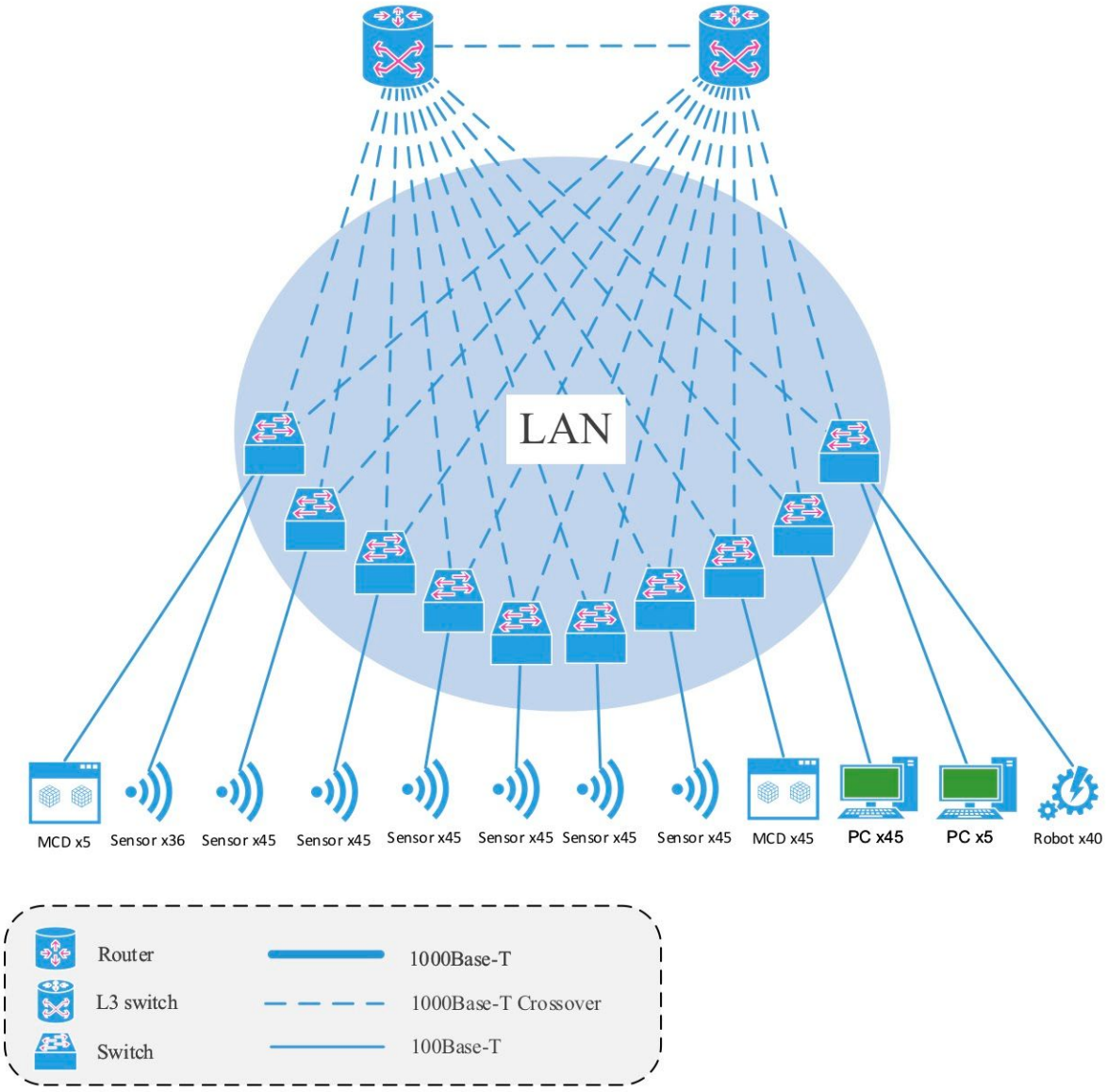


Figure 4: LAN network

The figure below shows the entire device layer network and its hierarchical network design, it shows the connections between devices and switches and also, the connections between the switches and layer 3 switches.

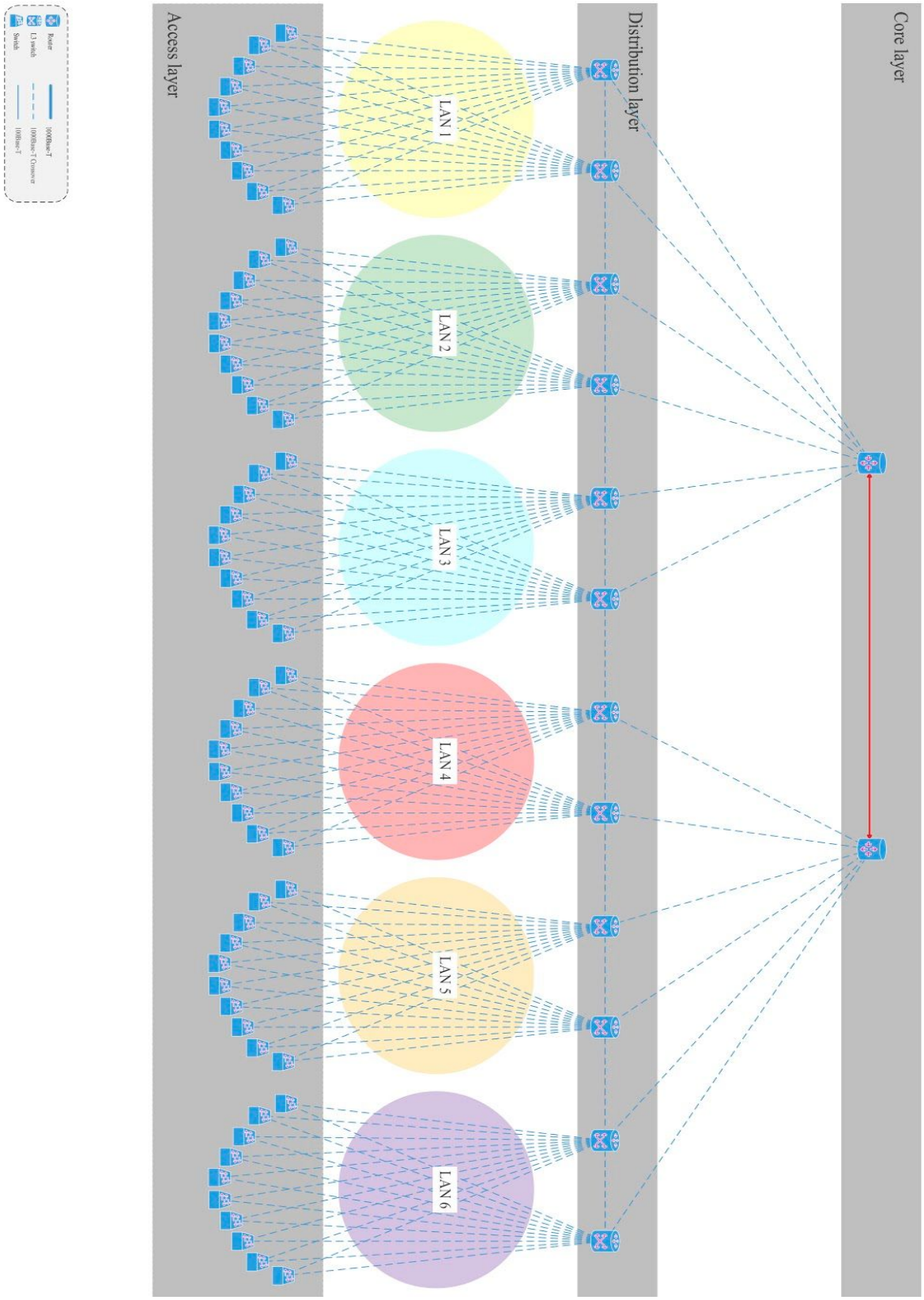


Figure 5: Device layer network

1.5 Control Layer (CL)

Requirements:

Devices	Size per department
Database servers	6
Manufacturing controllers	10
Human machine interface	15
Total	**31**

The control layer consists of 6 database servers, 10 manufacturing controllers and 15 HMIs (human machine interfaces). The mesh topology was implemented in the distribution layer between layer 3 switches and the star topology was implemented in the access layer between switches and devices.

The database servers are connected to a 12-ports switch while manufacturing controllers and HMIs are connected to a 48-ports switch. For engineers in the enterprise building to monitor these devices using a VPN connection, each device will have an IP address.

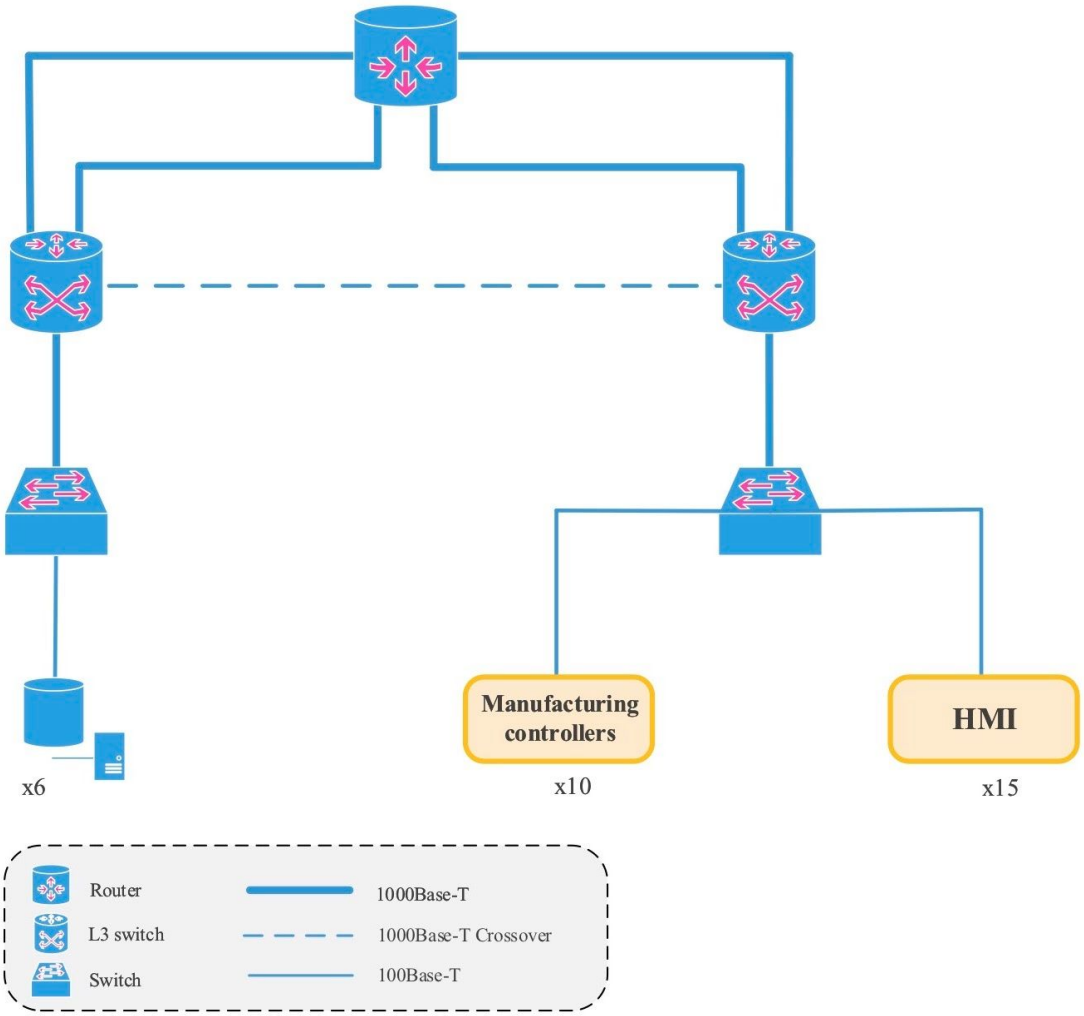


Figure 6: Control layer network

1.6 Plant Information Layer (PIL)

Requirements:

Devices	Size per department
Database servers	4
Application servers	8
Access terminals	80
Total	**92**

The plant information layer consists of 4 database servers, 8 application servers and 80 access terminals for IP phones and other plug-in terminals. Two 12-ports switches and two 48-ports switches are used, the empty ports are reserved for future expansions.

The figure below shows the design implemented to satisfy the requirements of the network.

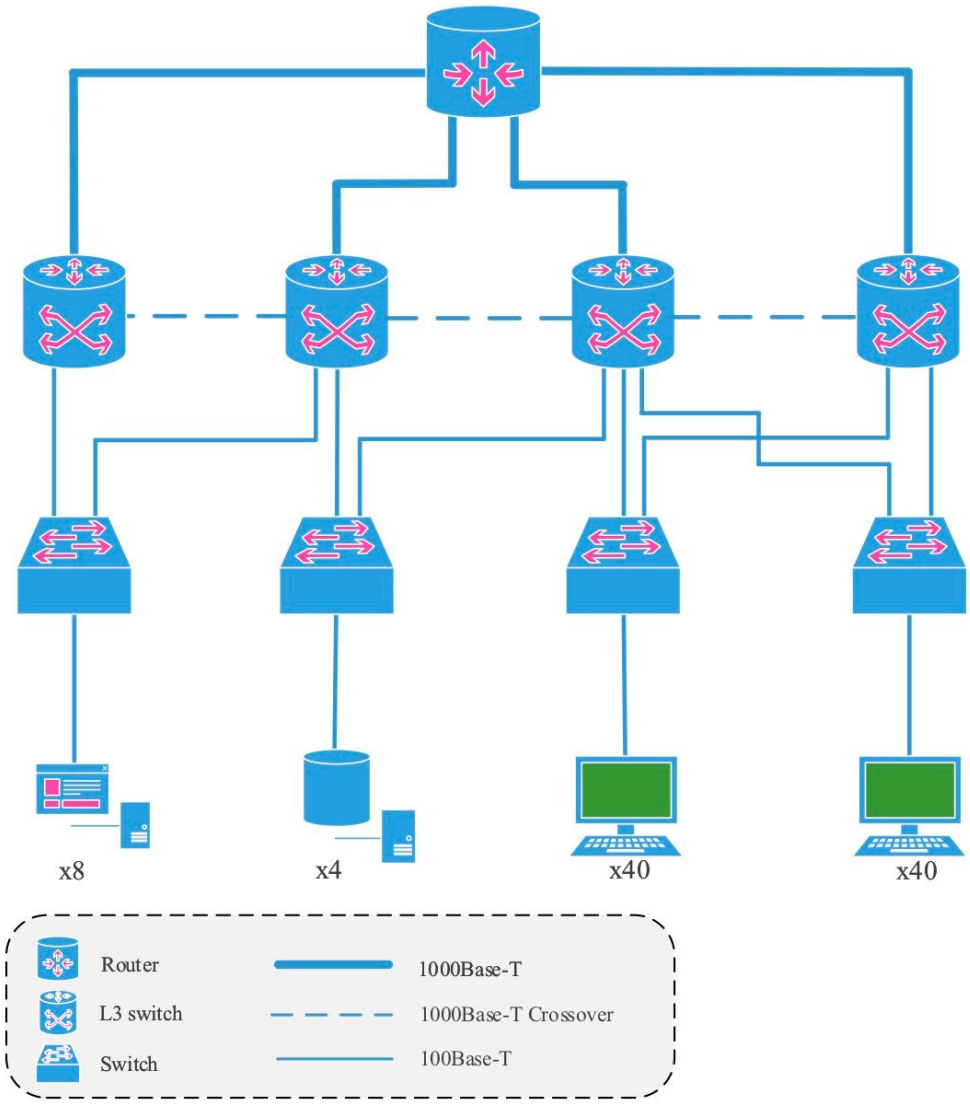


Figure 7: Control layer network

1.7 Site-to-Site VPN Connection

Due to the different geographical locations between the enterprise building and the plant there are many approaches in which communication links can be created between both buildings. One approach is the use of private links that run from one building to the other building. The further each building is apart from each other, the more expensive it becomes but in practice, this is not ideal. An alternative is the use of VPN (virtual private network), in this design, the site-to-site VPN is the preferred choice to create a communication link between both buildings.

One of the main advantages of the use VPNs is the ability to create a communication link between two different locations using the internet. Compared to other alternatives, this is a less expensive approach that also provides network security through its high encryption. With the use of VPN, the enterprise LAN and plant can communicate with each other. For engineers in the enterprise layer to monitor devices in the plant layer, devices in the plant layer are assigned with IP addresses.

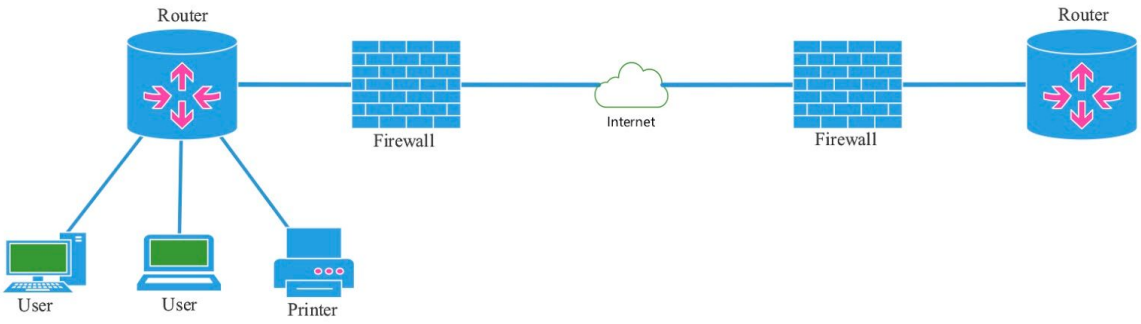


Figure 8

2.1 Protocols

Networking design and networking processes involves several protocols. The important ones are listed below:

- **Application layer:**

- **HTTP** (HyperText Transfer Protocol) - this is responsible for transferring website data across the internet.
- **FTP** (File Transfer Protocol) - this is responsible for transferring files between computers on a network.
- **POP3** (Post Office Protocol 3) - this is responsible for receiving emails from a remote server to a local client.
- **SMTP** (Simple Mail Transfer Protocol) - this is responsible for sending emails between servers.
- **BGP** (Border Gateway Protocol) - this is responsible for the exchange of routing information autonomous systems.
- **RIP** (Routing Information Protocol) - this is responsible for finding the best path between source and destination network through the use of hop counts as a routing metric.
- **Telnet** - this is responsible for accessing remote computers over TCP/IP networks like the Internet.

- **Transport layer:**
  - **TCP/IP** (Transmission Control Protocol / Internet Protocol) - this is responsible for interconnecting network devices on the internet and defines how computers send packets of data to each other.
- **Internet layer:**
  - **IPv6** (Internet Protocol version 6) - this is responsible for the providing system location and identification of computers on networks.
- **Link layer:**
  - **Ethernet** - this is responsible for connecting computers together in a local area network or LAN.
  - **MAC** (Media Access Control)

2.2 RIP Routing Protocol

The distance vector routing protocol is the routing information protocol implemented in this design. Information is being shared by the layer 3 switches to close neighbors, this approach makes it easy for routers to know the closest possible path for sent data to arrive at its specified destination. The destination information is provided in the routing table for each layer 3 switch.

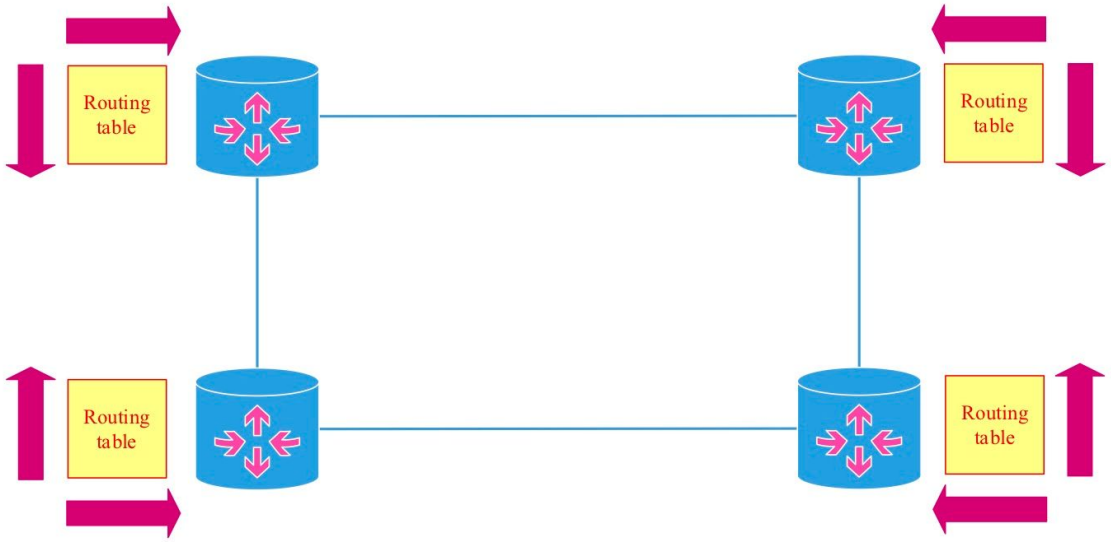


Figure 9: Distance vector routing protocol

2.3 Boundaries

Hard boundaries:

This network design consists of public and private networks, the internet is considered a public network while the enterprise or plant network are considered private networks. A DMZ is placed between the public and private networks, with this approach, the firewall protects the data in the private network and if the networks experiences any form attack, the attacker can only access data on the DMZ.

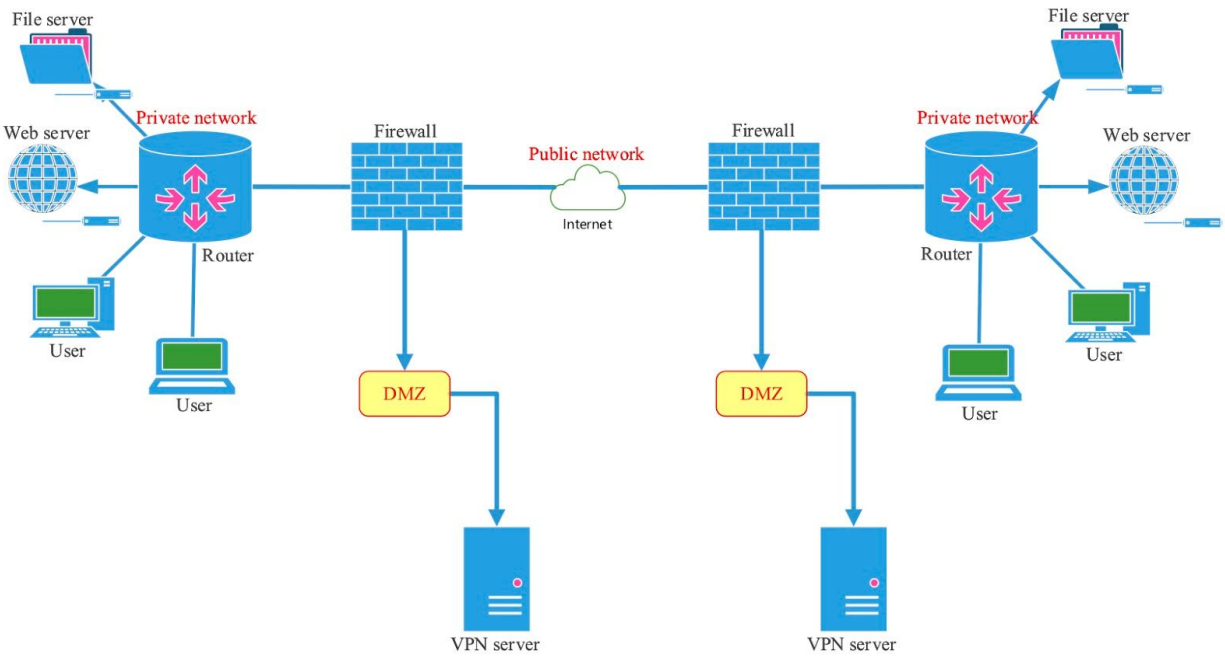


Figure 10: Hard boundaries

Soft boundaries:

The sales and marketing department are grouped together as a single functioning area due to their similar roles, although, both of these departments require individual work groups. The figure below shows the soft boundaries.

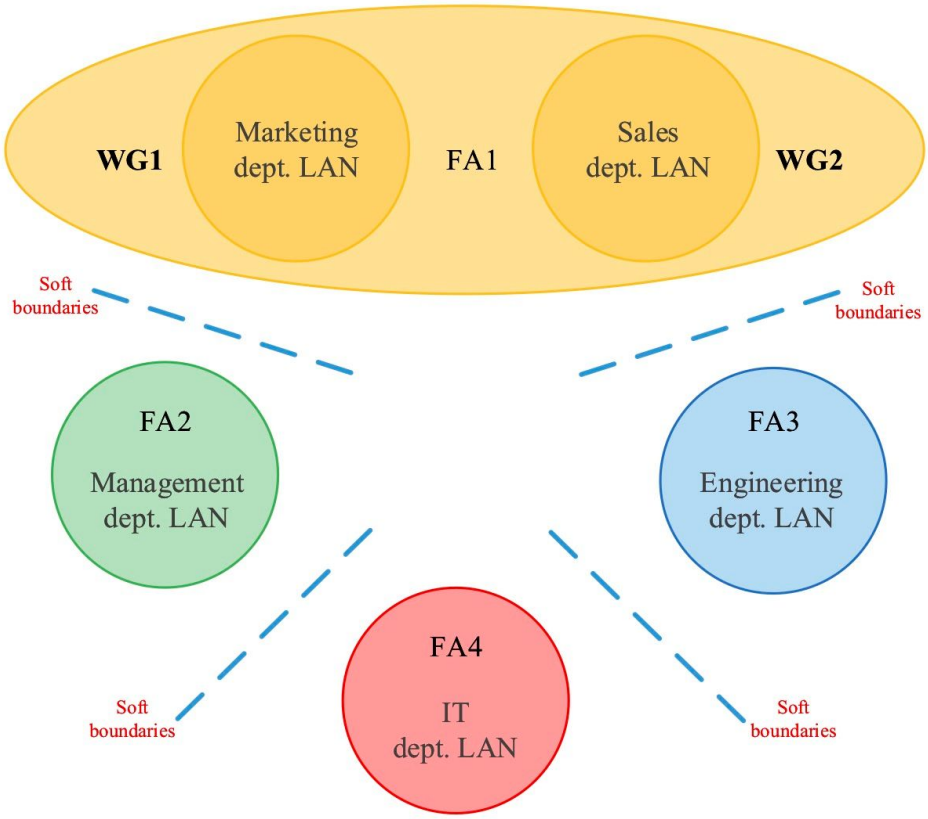
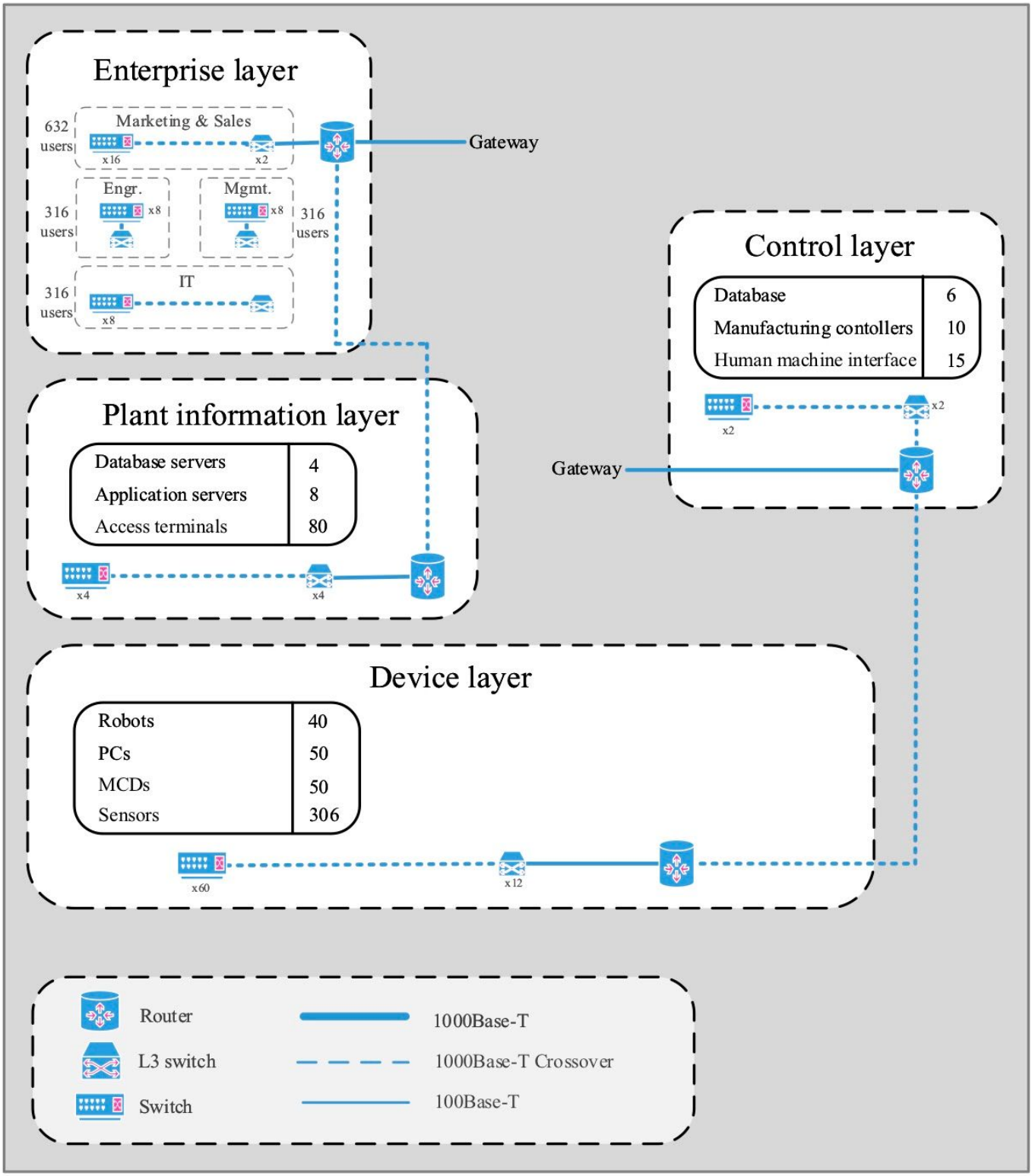


Figure 10: Soft boundaries

3.1 Blueprints



3.2 IP Addressing

The preferred for IP addressing is a classless addressing. The VLSM (Variable Length Subnet Mask) is implemented, the method is chosen because of the following advantages:

- It provides flexibility in network design.
- It breaks up an address block into smaller custom blocks.
- It permits efficient use of address space.
- It permits the use of several subnet mask lengths.

To dynamically assign IP addresses, the following protocols are required:

- RIPv2 (Routing Information Protocol version 2)
- OSPF (Open Shortest Path First)
- DHCP (Dynamic Host Configuration Protocol)

EL LAN	Groups	Size	Size allocated
Marketing & sales (MS)	2	316	510
Management (MGMT)	1	316	510
Engineering (ENGR)	1	316	510
IT	1	316	510
Router-to-router	7	2	2
Total	**12**	**1594**	**2564**

DL LAN	Groups	Size	Size allocated
LAN 1	20	45	62
LAN 2	20	45	62
LAN 3	20	45	62
LAN 4	20	45	62

LAN 5	20	45	62
LAN 6	20	45	62
Router-to-router	24	2	2
Total	**144**	**5448**	**7488**

CL LAN	Groups	Size	Size allocated
LAN	1	31	62
Router-to-router	5	2	2
Total	**6**	**41**	**72**

PIL LAN	Groups	Size	Size allocated
LAN	1	92	126
Router-to-router	7	2	2
Total	**8**	**106**	**140**

Number of subnets needed	Number of hosts allocated
170	**10264**

From the information provided above, to target a high redundancy, the needed subnets and hosts for the entire network design is 170 and 10264, respectively.

The IP address of **192.168.0.0/18** is assumed to be purchased, with 32 - 18 = 14 bit mask, this allows a number of $2^{14} - 2 = 16382$ usable hosts.

Therefore:

Number of available hosts (before addressing) is 16382 hosts

Number of used hosts is 10264 hosts

Number of hosts available (after addressing) is 6118 hosts

Enterprise layer

Subnet	Allocated Size	Network ID	Bit Mask	Subnet Mask	User Range	Broadcast
MS1	510	192.168.0.0	/23	255.255.254.0	192.168.0.1 - 192.168.1.254	192.168.1.255
MS2	510	192.168.2.0	/23	255.255.254.0	192.168.2.1 - 192.168.3.254	192.168.3.255
MGMT	510	192.168.4.0	/23	255.255.254.0	192.168.4.1 - 192.168.5.254	192.168.5.255
ENGR	510	192.168.6.0	/23	255.255.254.0	192.168.6.1 - 192.168.7.254	192.168.7.255
IT	510	192.168.8.0	/23	255.255.254.0	192.168.8.1 - 192.168.9.254	192.168.9.255

Plant information layer

Subnet	Allocated Size	Network ID	Bit Mask	Subnet Mask	User Range	Broadcast
PIL	126	192.168.10.0	/25	255.255.255.128	192.168.10.1 - 192.168.10.126	192.168.10.127

Device layer

LAN 1

Subnet	Allocated Size	Network ID	Bit Mask	Subnet Mask	User Range	Broadcast
DL1	62	192.168.10.128	/26	255.255.255.192	192.168.10.129 - 192.168.10.190	192.168.10.191
DL1	62	192.168.10.192	/26	255.255.255.192	192.168.10.193 - 192.168.10.254	192.168.10.255
DL1	62	192.168.11.0	/26	255.255.255.192	192.168.11.1 - 192.168.11.62	192.168.11.63
DL1	62	192.168.11.64	/26	255.255.255.192	192.168.11.65- 192.168.11.126	192.168.11.127
DL1	62	192.168.11.128	/26	255.255.255.192	192.168.11.129 - 192.168.11.190	192.168.11.191
DL1	62	192.168.11.192	/26	255.255.255.192	192.168.11.193 - 192.168.11.254	192.168.11.255

DL1	62	192.168.12.0	/26	255.255.255.192	192.168.12.1 - 192.168.12.62	192.168.12.63
DL1	62	192.168.12.64	/26	255.255.255.192	192.168.12.65- 192.168.12.126	192.168.12.127
DL1	62	192.168.12.128	/26	255.255.255.192	192.168.12.129 - 192.168.12.190	192.168.12.191
DL1	62	192.168.12.192	/26	255.255.255.192	192.168.12.193 - 192.168.12.254	192.168.12.255
DL1	62	192.168.13.0	/26	255.255.255.192	192.168.13.1 - 192.168.13.62	192.168.13.63
DL1	62	192.168.13.64	/26	255.255.255.192	192.168.13.65- 192.168.13.126	192.168.13.127
DL1	62	192.168.13.128	/26	255.255.255.192	192.168.13.129 - 192.168.13.190	192.168.13.191
DL1	62	192.168.13.192	/26	255.255.255.192	192.168.13.193 - 192.168.13.254	192.168.13.255
DL1	62	192.168.14.0	/26	255.255.255.192	192.168.14.1 - 192.168.14.62	192.168.14.63
DL1	62	192.168.14.64	/26	255.255.255.192	192.168.14.65- 192.168.14.126	192.168.14.127
DL1	62	192.168.14.128	/26	255.255.255.192	192.168.14.129 - 192.168.14.190	192.168.14.191
DL1	62	192.168.14.192	/26	255.255.255.192	192.168.14.193 - 192.168.14.254	192.168.14.255
DL1	62	192.168.15.0	/26	255.255.255.192	192.168.15.1 - 192.168.15.62	192.168.15.63
DL1	62	192.168.15.64	/26	255.255.255.192	192.168.15.65- 192.168.15.126	192.168.15.127

LAN 2

Subnet	Allocated Size	Network ID	Bit Mask	Subnet Mask	User Range	Broadcast
DL2	62	192.168.15.128	/26	255.255.255.192	192.168.15.129 - 192.168.145190	192.168.15.191
DL2	62	192.168.15.192	/26	255.255.255.192	192.168.15.193 - 192.168.15.254	192.168.15.255
DL2	62	192.168.16.0	/26	255.255.255.192	192.168.16.1 - 192.168.16.62	192.168.16.63
DL2	62	192.168.16.64	/26	255.255.255.192	192.168.16.65- 192.168.16.126	192.168.16.127
DL2	62	192.168.16.128	/26	255.255.255.192	192.168.16.129 - 192.168.16.190	192.168.16.191
DL2	62	192.168.16.192	/26	255.255.255.192	192.168.16.193 - 192.168.16.254	192.168.16.255
DL2	62	192.168.17.0	/26	255.255.255.192	192.168.17.1 - 192.168.17.62	192.168.17.63
DL2	62	192.168.17.64	/26	255.255.255.192	192.168.17.65- 192.168.17.126	192.168.17.127

DL2	62	192.168.17.128	/26	255.255.255.192	192.168.17.129 - 192.168.17.190	192.168.17.191
DL2	62	192.168.17.192	/26	255.255.255.192	192.168.17.193 - 192.168.17.254	192.168.17.255
DL2	62	192.168.18.0	/26	255.255.255.192	192.168.18.1 - 192.168.18.62	192.168.18.63
DL2	62	192.168.18.64	/26	255.255.255.192	192.168.18.65- 192.168.18.126	192.168.18.127
DL2	62	192.168.18.128	/26	255.255.255.192	192.168.18.129 - 192.168.18.190	192.168.18.191
DL2	62	192.168.18.192	/26	255.255.255.192	192.168.18.193 - 192.168.18.254	192.168.18.255
DL2	62	192.168.19.0	/26	255.255.255.192	192.168.19.1 - 192.168.19.62	192.168.19.63
DL2	62	192.168.19.64	/26	255.255.255.192	192.168.19.65- 192.168.19.126	192.168.19.127
DL2	62	192.168.19.128	/26	255.255.255.192	192.168.19.129 - 192.168.19.190	192.168.19.191
DL2	62	192.168.19.192	/26	255.255.255.192	192.168.19.193 - 192.168.19.254	192.168.19.255
DL2	62	192.168.20.0	/26	255.255.255.192	192.168.20.1 - 192.168.20.62	192.168.20.63
DL2	62	192.168.20.64	/26	255.255.255.192	192.168.20.65- 192.168.20.126	192.168.20.127

LAN 3

Subnet	Allocated Size	Network ID	Bit Mask	Subnet Mask	User Range	Broadcast
DL3	62	192.168.20.128	/26	255.255.255.192	192.168.20.129 - 192.168.20.190	192.168.20.191
DL3	62	192.168.20.192	/26	255.255.255.192	192.168.20.193 - 192.168.20.254	192.168.20.255
DL3	62	192.168.21.0	/26	255.255.255.192	192.168.21.1 - 192.168.21.62	192.168.21.63
DL3	62	192.168.21.64	/26	255.255.255.192	192.168.21.65- 192.168.21.126	192.168.21.127
DL3	62	192.168.21.128	/26	255.255.255.192	192.168.21.129 - 192.168.21.190	192.168.21.191
DL3	62	192.168.21.192	/26	255.255.255.192	192.168.21.193 - 192.168.21.254	192.168.21.255
DL3	62	192.168.22.0	/26	255.255.255.192	192.168.22.1 - 192.168.22.62	192.168.22.63
DL3	62	192.168.22.64	/26	255.255.255.192	192.168.22.65- 192.168.22.126	192.168.22.127
DL3	62	192.168.22.128	/26	255.255.255.192	192.168.22.129 - 192.168.22.190	192.168.22.191
DL3	62	192.168.22.192	/26	255.255.255.192	192.168.22.193 - 192.168.22.254	192.168.22.255

DL3	62	192.168.23.0	/26	255.255.255.192	192.168.23.1 - 192.168.23.62	192.168.23.63
DL3	62	192.168.23.64	/26	255.255.255.192	192.168.23.65- 192.168.23.126	192.168.23.127
DL3	62	192.168.23.128	/26	255.255.255.192	192.168.23.129 - 192.168.23.190	192.168.23.191
DL3	62	192.168.23.192	/26	255.255.255.192	192.168.23.193 - 192.168.23.254	192.168.23.255
DL3	62	192.168.24.0	/26	255.255.255.192	192.168.24.1 - 192.168.24.62	192.168.24.63
DL3	62	192.168.24.64	/26	255.255.255.192	192.168.24.65- 192.168.24.126	192.168.24.127
DL3	62	192.168.24.128	/26	255.255.255.192	192.168.24.129 - 192.168.24.190	192.168.24.191
DL3	62	192.168.24.192	/26	255.255.255.192	192.168.24.193 - 192.168.24.254	192.168.24.255
DL3	62	192.168.25.0	/26	255.255.255.192	192.168.25.1 - 192.168.25.62	192.168.25.63
DL3	62	192.168.25.64	/26	255.255.255.192	192.168.25.65- 192.168.25.126	192.168.25.127

LAN 4

Subnet	Allocated Size	Network ID	Bit Mask	Subnet Mask	User Range	Broadcast
DL4	62	192.168.25.128	/26	255.255.255.192	192.168.25.129 - 192.168.25.190	192.168.25.191
DL4	62	192.168.25.192	/26	255.255.255.192	192.168.25.193 - 192.168.25.254	192.168.25.255
DL4	62	192.168.26.0	/26	255.255.255.192	192.168.26.1 - 192.168.26.62	192.168.26.63
DL4	62	192.168.26.64	/26	255.255.255.192	192.168.26.65- 192.168.26.126	192.168.26.127
DL4	62	192.168.26.128	/26	255.255.255.192	192.168.26.129 - 192.168.26.190	192.168.26.191
DL4	62	192.168.26.192	/26	255.255.255.192	192.168.26.193 - 192.168.26.254	192.168.26.255
DL4	62	192.168.27.0	/26	255.255.255.192	192.168.27.1 - 192.168.27.62	192.168.27.63
DL4	62	192.168.27.64	/26	255.255.255.192	192.168.27.65- 192.168.27.126	192.168.27.127
DL4	62	192.168.27.128	/26	255.255.255.192	192.168.27.129 - 192.168.27.190	192.168.27.191
DL4	62	192.168.27.192	/26	255.255.255.192	192.168.27.193 - 192.168.27.254	192.168.27.255
DL4	62	192.168.28.0	/26	255.255.255.192	192.168.28.1 - 192.168.28.62	192.168.28.63
DL4	62	192.168.28.64	/26	255.255.255.192	192.168.28.65- 192.168.28.126	192.168.28.127

DL4	62	192.168.28.128	/26	255.255.255.192	192.168.28.129 - 192.168.28.190	192.168.28.191
DL4	62	192.168.28.192	/26	255.255.255.192	192.168.28.193 - 192.168.28.254	192.168.28.255
DL4	62	192.168.29.0	/26	255.255.255.192	192.168.29.1 - 192.168.29.62	192.168.29.63
DL4	62	192.168.29.64	/26	255.255.255.192	192.168.29.65- 192.168.29.126	192.168.29.127
DL4	62	192.168.29.128	/26	255.255.255.192	192.168.29.129 - 192.168.29.190	192.168.29.191
DL4	62	192.168.29.192	/26	255.255.255.192	192.168.29.193 - 192.168.29.254	192.168.29.255
DL4	62	192.168.30.0	/26	255.255.255.192	192.168.30.1 - 192.168.30.62	192.168.30.63
DL4	62	192.168.30.64	/26	255.255.255.192	192.168.30.65- 192.168.30.126	192.168.30.127

LAN 5

Subnet	Allocated Size	Network ID	Bit Mask	Subnet Mask	User Range	Broadcast
DL5	62	192.168.30.128	/26	255.255.255.192	192.168.30.129 - 192.168.30.190	192.168.30.191
DL5	62	192.168.30.192	/26	255.255.255.192	192.168.30.193 - 192.168.30.254	192.168.30.255
DL5	62	192.168.31.0	/26	255.255.255.192	192.168.31.1 - 192.168.31.62	192.168.31.63
DL5	62	192.168.31.64	/26	255.255.255.192	192.168.31.65- 192.168.31.126	192.168.31.127
DL5	62	192.168.31.128	/26	255.255.255.192	192.168.31.129 - 192.168.31.190	192.168.31.191
DL5	62	192.168.31.192	/26	255.255.255.192	192.168.31.193 - 192.168.31.254	192.168.31.255
DL5	62	192.168.32.0	/26	255.255.255.192	192.168.32.1 - 192.168.32.62	192.168.32.63
DL5	62	192.168.32.64	/26	255.255.255.192	192.168.32.65- 192.168.32.126	192.168.32.127
DL5	62	192.168.32.128	/26	255.255.255.192	192.168.32.129 - 192.168.32.190	192.168.32.191
DL5	62	192.168.32.192	/26	255.255.255.192	192.168.32.193 - 192.168.32.254	192.168.32.255
DL5	62	192.168.33.0	/26	255.255.255.192	192.168.33.1 - 192.168.33.62	192.168.33.63
DL5	62	192.168.33.64	/26	255.255.255.192	192.168.33.65- 192.168.33.126	192.168.33.127
DL5	62	192.168.33.128	/26	255.255.255.192	192.168.33.129 - 192.168.33.190	192.168.33.191
DL5	62	192.168.33.192	/26	255.255.255.192	192.168.33.193 - 192.168.33.254	192.168.33.255

DL5	62	192.168.34.0	/26	255.255.255.192	192.168.34.1 - 192.168.34.62	192.168.34.63
DL5	62	192.168.34.64	/26	255.255.255.192	192.168.34.65- 192.168.34.126	192.168.34.127
DL5	62	192.168.34.128	/26	255.255.255.192	192.168.34.129 - 192.168.34.190	192.168.34.191
DL5	62	192.168.34.192	/26	255.255.255.192	192.168.34.193 - 192.168.34.254	192.168.34.255
DL5	62	192.168.35.0	/26	255.255.255.192	192.168.35.1 - 192.168.35.62	192.168.35.63
DL5	62	192.168.35.64	/26	255.255.255.192	192.168.35.65- 192.168.35.126	192.168.35.127

LAN 6

Subnet	Allocated Size	Network ID	Bit Mask	Subnet Mask	User Range	Broadcast
DL6	62	192.168.35.128	/26	255.255.255.192	192.168.35.129 - 192.168.35.190	192.168.35.191
DL6	62	192.168.35.192	/26	255.255.255.192	192.168.35.193 - 192.168.35.254	192.168.35.255
DL6	62	192.168.36.0	/26	255.255.255.192	192.168.36.1 - 192.168.36.62	192.168.36.63
DL6	62	192.168.36.64	/26	255.255.255.192	192.168.36.65- 192.168.36.126	192.168.36.127
DL6	62	192.168.36.128	/26	255.255.255.192	192.168.36.129 - 192.168.36.190	192.168.36.191
DL6	62	192.168.36.192	/26	255.255.255.192	192.168.36.193 - 192.168.36.254	192.168.36.255
DL6	62	192.168.37.0	/26	255.255.255.192	192.168.37.1 - 192.168.37.62	192.168.37.63
DL6	62	192.168.37.64	/26	255.255.255.192	192.168.37.65- 192.168.37.126	192.168.37.127
DL6	62	192.168.37.128	/26	255.255.255.192	192.168.37.129 - 192.168.37.190	192.168.37.191
DL6	62	192.168.37.192	/26	255.255.255.192	192.168.37.193 - 192.168.37.254	192.168.37.255
DL6	62	192.168.38.0	/26	255.255.255.192	192.168.38.1 - 192.168.38.62	192.168.38.63
DL6	62	192.168.38.64	/26	255.255.255.192	192.168.38.65- 192.168.38.126	192.168.38.127
DL6	62	192.168.38.128	/26	255.255.255.192	192.168.38.129 - 192.168.38.190	192.168.38.191
DL6	62	192.168.38.192	/26	255.255.255.192	192.168.38.193 - 192.168.38.254	192.168.38.255
DL6	62	192.168.39.0	/26	255.255.255.192	192.168.39.1 - 192.168.39.62	192.168.39.63
DL6	62	192.168.39.64	/26	255.255.255.192	192.168.39.65- 192.168.39.126	192.168.39.127

DL6	62	192.168.39.128	/26	255.255.255.192	192.168.39.129 - 192.168.39.190	192.168.39.191
DL6	62	192.168.39.192	/26	255.255.255.192	192.168.39.193 - 192.168.39.254	192.168.39.255
DL6	62	192.168.40.0	/26	255.255.255.192	192.168.40.1 - 192.168.40.62	192.168.40.63
DL6	62	192.168.40.64	/26	255.255.255.192	192.168.40.65- 192.168.40.126	192.168.40.127

Control layer

Subnet	Allocated Size	Network ID	Bit Mask	Subnet Mask	User Range	Broadcast
CL	62	192.168.40.128	/26	255.255.255.192	192.168.40.129 - 192.168.40.190	192.168.40.191

Router-to-router

Enterprise layer

Subnet	Allocated Size	Network ID	Bit Mask	Subnet Mask	User Range	Broadcast
R-to-R	2	192.168.40.192	/30	255.255.255.252	192.168.40.193 - 192.168.40.194	192.168.40.195
R-to-R	2	192.168.40.196	/30	255.255.255.252	192.168.40.197 - 192.168.40.198	192.168.40.199
R-to-R	2	192.168.40.200	/30	255.255.255.252	192.168.40.201 - 192.168.40.202	192.168.40.203
R-to-R	2	192.168.40.204	/30	255.255.255.252	192.168.40.205 - 192.168.40.206	192.168.40.207
R-to-R	2	192.168.40.208	/30	255.255.255.252	192.168.40.209 - 192.168.40.210	192.168.40.211
R-to-R	2	192.168.40.212	/30	255.255.255.252	192.168.40.213 - 192.168.40.214	192.168.40.215
R-to-R	2	192.168.40.216	/30	255.255.255.252	192.168.40.217 - 192.168.40.218	192.168.40.219

Device layer

Subnet	Allocated Size	Network ID	Bit Mask	Subnet Mask	User Range	Broadcast
R-to-R	2	192.168.40.220	/30	255.255.255.252	192.168.40.221 - 192.168.40.222	192.168.40.223
R-to-R	2	192.168.40.224	/30	255.255.255.252	192.168.40.225 - 192.168.40.226	192.168.40.227

R-to-R	2	192.168.40.228	/30	255.255.255.252	192.168.40.229 - 192.168.40.230	192.168.40.231
R-to-R	2	192.168.40.232	/30	255.255.255.252	192.168.40.233 - 192.168.40.234	192.168.40.235
R-to-R	2	192.168.40.236	/30	255.255.255.252	192.168.40.237 - 192.168.40.38	192.168.40.239
R-to-R	2	192.168.40.240	/30	255.255.255.252	192.168.40.241 - 192.168.40.242	192.168.40.243
R-to-R	2	192.168.40.244	/30	255.255.255.252	192.168.40.245 - 192.168.40.246	192.168.40.247
R-to-R	2	192.168.40.248	/30	255.255.255.252	192.168.40.249 - 192.168.40.250	192.168.40.251
R-to-R	2	192.168.40.252	/30	255.255.255.252	192.168.40.253 - 192.168.40.254	192.168.40.255
R-to-R	2	192.168.41.0	/30	255.255.255.252	192.168.41.1 - 192.168.41.2	192.168.41.3
R-to-R	2	192.168.41.4	/30	255.255.255.252	192.168.41.5 - 192.168.41.6	192.168.41.7
R-to-R	2	192.168.41.8	/30	255.255.255.252	192.168.41.9 - 192.168.41.10	192.168.41.11
R-to-R	2	192.168.41.12	/30	255.255.255.252	192.168.41.13 - 192.168.41.14	192.168.41.15
R-to-R	2	192.168.41.16	/30	255.255.255.252	192.168.41.17 - 192.168.41.18	192.168.41.19
R-to-R	2	192.168.41.20	/30	255.255.255.252	192.168.41.21 - 192.168.41.22	192.168.41.23
R-to-R	2	192.168.41.24	/30	255.255.255.252	192.168.41.25 - 192.168.41.26	192.168.41.27
R-to-R	2	192.168.41.28	/30	255.255.255.252	192.168.41.29 - 192.168.41.30	192.168.41.31
R-to-R	2	192.168.41.32	/30	255.255.255.252	192.168.41.33 - 192.168.41.34	192.168.41.35
R-to-R	2	192.168.41.36	/30	255.255.255.252	192.168.41.37 - 192.168.41.38	192.168.41.39
R-to-R	2	192.168.41.40	/30	255.255.255.252	192.168.41.41 - 192.168.41.42	192.168.41.43
R-to-R	2	192.168.41.44	/30	255.255.255.252	192.168.41.45 - 192.168.41.46	192.168.41.47
R-to-R	2	192.168.41.48	/30	255.255.255.252	192.168.41.49 - 192.168.41.50	192.168.41.51
R-to-R	2	192.168.41.52	/30	255.255.255.252	192.168.41.53 - 192.168.41.54	192.168.41.55
R-to-R	2	192.168.41.56	/30	255.255.255.252	192.168.41.57 - 192.168.41.58	192.168.41.59

Control layer

Subnet	Allocated Size	Network ID	Bit Mask	Subnet Mask	User Range	Broadcast
R-to-R	2	192.168.41.60	/30	255.255.255.252	192.168.41.61 - 192.168.41.62	192.168.41.63
R-to-R	2	192.168.41.64	/30	255.255.255.252	192.168.41.65 - 192.168.41.66	192.168.41.67
R-to-R	2	192.168.41.68	/30	255.255.255.252	192.168.41.69 - 192.168.41.70	192.168.41.71
R-to-R	2	192.168.41.72	/30	255.255.255.252	192.168.41.73 - 192.168.41.74	192.168.41.75
R-to-R	2	192.168.41.76	/30	255.255.255.252	192.168.41.77 - 192.168.41.78	192.168.41.79

Plant information layer

Subnet	Allocated Size	Network ID	Bit Mask	Subnet Mask	User Range	Broadcast
R-to-R	2	192.168.41.80	/30	255.255.255.252	192.168.41.81 - 192.168.41.82	192.168.41.83
R-to-R	2	192.168.41.84	/30	255.255.255.252	192.168.41.85 - 192.168.41.86	192.168.41.87
R-to-R	2	192.168.41.88	/30	255.255.255.252	192.168.41.89 - 192.168.41.90	192.168.41.91
R-to-R	2	192.168.41.92	/30	255.255.255.252	192.168.41.93 - 192.168.41.94	192.168.41.95
R-to-R	2	192.168.41.96	/30	255.255.255.252	192.168.41.97 - 192.168.41.98	192.168.41.99
R-to-R	2	192.168.41.100	/30	255.255.255.252	192.168.41.101 - 192.168.41.102	192.168.41.103
R-to-R	2	192.168.41.104	/30	255.255.255.252	192.168.41.105 - 192.168.41.106	192.168.41.107

- Gateway IP addresses can be assigned with any usable IP addresses within the range.
- Subnets that connect two routers can be assigned with any R-to-R IP address.

3.3 Network Cables

FastEthernet and GigabitEthernet cables are used in the network to connect devices such as PCs, routers and switches within a local area network.

The 100Base-T FastEthernet cables are used to connect routers to switches and PCs to switches. This is an unshielded twisted pair cable that supports up to 100 Mbps baseband signals of data transfer rates for a maximum distance of 100 meters. Also, the 100Base-T crossover cables are used to connect switches to switches.

The 1000Base-T GigabitEthernet cables are used in the network for faster data delivery and the traffic management. This is also an unshielded twisted pair cable that supports up to 1000 Mbps or 1Gbps baseband signals of data transfer rates for a maximum distance of 100 meters.

3.4 Network Devices

I am familiar with Cisco devices hence why the brand's routers, layer 3 switches and switches are my preferred choice. Models listed below were selected based on analysis performed in terms of cost and compatibility with the required technologies.

Switches

Model	Number of ports	Quantity	Cost per device
Cisco WS-C2960C-12PC-L	12	3	CA$1,080.67
Cisco WS-C2960-48TT-L	48	103	CA$314.30
Total		106	CA$35,614.91

Layer 3 switches

Model	Number of ports	Quantity	Cost per device
Cisco WS-C3750G-12S-E	12	11	CA$452.07
Cisco WS-C3750G-24TS-S	24	12	CA$331.52
Total		23	CA$8,951.01

Routers

Model	Quantity	Cost per device
Cisco ASR1002-X	6	CA$12,906.33
Total		CA$77,437.98

It is very important to note that these devices must be situated in a secure location within the building.

3.5 Cost-Benefit Analysis

Designing a network with high reliability and redundancy is one of the objectives of this project while also taking into consideration the cost of the network. High network reliability and redundancy is achieved by ensuring that packets are forwarded / received from more than one source. By implementing this into the design, it causes the probability of the network failing to reduce and the productivity of the network to increase. In section 1.3, an analysis was performed in the decision-making process for the preferred topologies. From the information gathered, the bus, partial mesh and star topologies were the best fit in terms of low cost, reliability and simplicity, these topologies are implemented in the network design.

For IP addressing, the VLSM (Variable Length Subnet Mask) is implemented, this is a classless addressing. An alternative which is the classful addressing, will require more networks and fewer hosts or fewer networks and more hosts. Based on the cost-benefit analysis, this will cost more to meet the required number of networks/hosts and the design will have way too many unused networks.

3.6 Security

In network design, security and privacy of a network is very important, this helps reduce unauthorized access, unauthorized disclosure, theft, viruses, corruption, dismissal of serve and physical damage. To access the public network, the use of firewalls are implemented in the

design. These firewalls are situated after every router, this protects the network and gets rid of unwanted traffic.

Also, the use of DMZ (Demilitarized Zone) and VPN (Virtual Private Network) are implemented in the design. The DMZ ensures that all incoming network packets are screened while the VPN ensures secured communications through the use of data encryption and user authentication.

3.7 Regulations / Codes / Standards

The IEEE 802.1 is a working group concerned with the architecture, internetworking of local area networks, metropolitan area networks and wide area networks. Also, it is responsible for management of networks, security and protocol layers that are above MAC and LLC layers. As an engineer, I ensured that the IEEE 802.1 standards were taken into considerations in the development of the network design.

4.0 Conclusion

Design for the networks were implemented taking into consideration the cost, reliability, efficiency, and redundancy of the network. This design effectively reduces cost implications while improving the efficiency of the network. The VLSM IP addressing was implemented to support the required number of hosts on the network and there are 6118 hosts available for future development if growth occurs. This report also contains discussions on security, protocols, regulations, cost analysis, and network.

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