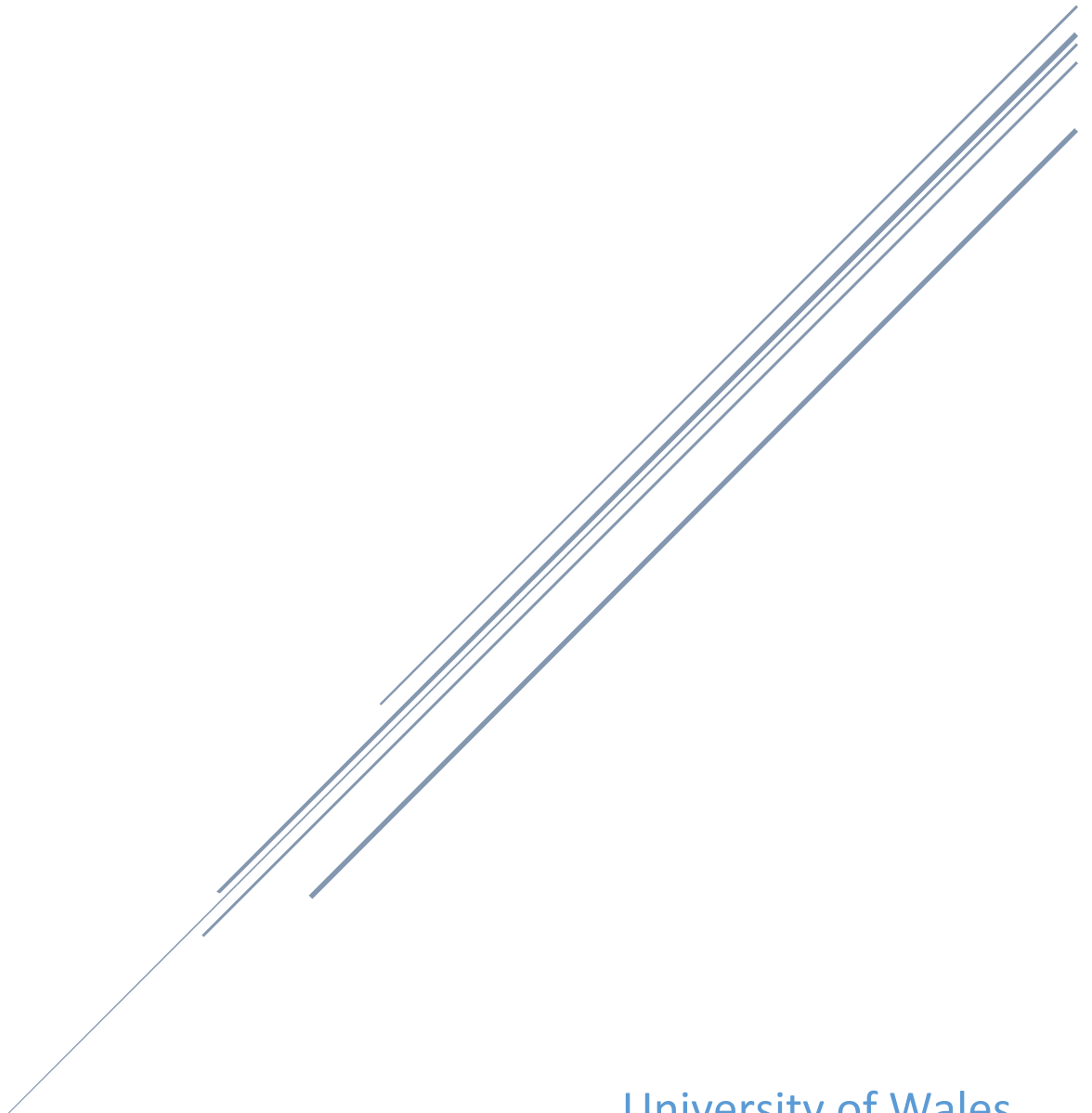


INTERNET PROTOCOLS

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Introduction

Nowadays, the Internet represents the most successful way to transmit the information between individuals globally, without regard for geographic location.

In August 1962, J.C.R. Licklider of MIT wrote a series of memos about “Galactic Network” concept, which was recorded as the first description of the social interactions that could be established using networking.

“He envisioned a globally interconnected set of computers through which everyone could quickly access data and programs from any site.” (Brief History of the Internet, 1997)

“In late 1966 researcher Lawrence G. Roberts went to DARPA (Defense Advanced Research Projects Agency) to develop the computer network concept and in 1967, he published his plan for the ARPANET” (Brief History of the Internet, 1997)

The growth of the original project continued, and new concepts were necessary to satisfy the requirements of this open-architecture networking in which “the individual networks may be separately designed and developed and each may have its own unique interface which it may offer to users and/or other providers”. (Brief History of the Internet, 1997)

One of the key elements of the internet is represented by the concept of Internet Protocol Address.

This thesis is intended to offer an overview of different types of addressing available in IPv6 and it contains an example of practical design of School of Management and Engineering network design network as following:

Chapter 1 “Types of IPv6 addresses”

Chapter 1 explains the basics of IPv6 addressing and the following types of IPv6 addresses: unicast addresses, multicast addresses, and anycast addresses.

Chapter 2 “School of Management and Engineering network design”

Chapter 2 exemplifies an IP addressing scheme design for the faculty’s network.

Chapter 1

Types of IPv6 addresses

“An IPv6 address has a length of 128 bits and it is written using hexadecimal number system. A single hexadecimal digit can represent every 4 bits and it will result in 32 hexadecimal values. The alphanumeric characters are not case-sensitive, there is no difference between lowercase and uppercase characters but the RFC 5952 standard recommends the use of lowercase instead of uppercase characters”. (IPv6 Fundamentals: A Straightforward Approach to Understanding IPv6, 2017)

General representation of an IPv6 address:



Figure 1: General Representation of an IPv6 Address (IPv6 Fundamentals: A Straightforward Approach to Understanding IPv6, 2017)

“Example of IPv6 address: *2001:0db8:3c4d:0015:0000:0000:1a2f:1a2b*”

The format recommended by RFC 4291 is x:x:x:x:x:x:x. Each x is a 16-bit section that can be represented using up to four hexadecimal digits, with the sections separated by colons. The result is eight 16-bit sections or hexets (0000 to ffff) for a total of 128 bits in the address, as previous shown.

IPv6 address types are defined in RFC 4291, IP Version 6 Addressing Architecture.” (IPv6 Fundamentals: A Straightforward Approach to Understanding IPv6, 2017)

IPv6 addresses types:

- Unicast
- Multicast
- Anycast

Unicast addresses

“A unicast address identifies a single interface within the scope of the type of address. The scope of an address is the region of the IPv6 network over which the address is unique. With the appropriate unicast routing topology, packets addressed to a unicast address are delivered to a single interface. To accommodate load-balancing systems, RFC 4291 allows for multiple interfaces to use the same address as long as they appear as a single interface to the IPv6 implementation on the host”. (Understanding IPv6, 2012)

IPv6 unicast addresses categories:

- Global
- Link-local
- Unique local

Global Unicast Addresses

“Global unicast addresses (GUAs), also known as aggregately global unicast addresses, are globally routable and reachable in the IPv6 Internet. They are equivalent to public IPv4 addresses.” (IPv6 Fundamentals: A Straightforward Approach to Understanding IPv6, 2017)

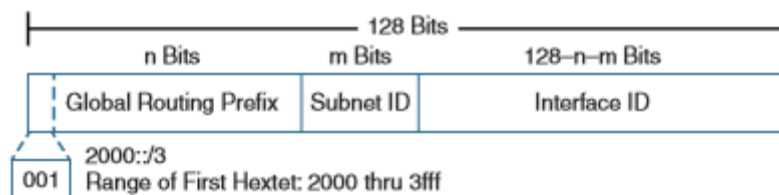


Figure 2: Structure of an IPv6 GUA Address (IPv6 Introduction and Configuration, 2012)

As Figure 2 shown, a global unicast address has three fields:

1. Global Routing Prefix

“A value assigned to a site for a cluster of subnets/links. The global routing prefix is structured hierarchically by the RIRs and ISPs”. (IPv6 Introduction and Configuration, 2012)

2. Subnet ID

“An identifier of a subnet within the site. The subnet field is structured hierarchically by site administrators”. (IPv6 Introduction and Configuration, 2012)

3. Interface ID

“Interface identifiers are used to identify interface on a link. They are required to be unique within a subnet prefix. They can also be unique over a broader scope”. (IPv6 Introduction and Configuration, 2012)

Link-Local Addresses

“IPv6 link-local addresses, identified by the initial 64 bits being set to 1111 1110 1000 0000...0000, are used by nodes when communicating with neighboring nodes on the same link. For example, on a single-link IPv6 network with no router, link-local addresses are used to communicate between hosts on the link. IPv6 link-local addresses are similar to IPv4 link-local addresses defined in RFC 3927 that use the 169.254.0.0/16 prefix. The use of IPv4 link-local addresses is known as Automatic Private IP Addressing (APIPA) in Windows. The scope of a link-local address is the local link.” (Understanding IPv6, 2012)



Figure 3: Structure of an IPv6 link-local address (Understanding IPv6, 2012)

Unique Local Addresses

“To provide a type of address that is private to an organization and not routable on the IPv6 Internet, yet unique across all the sites of the organization, RFC 4193 defines unique local IPv6 unicast addresses”. (Understanding IPv6, 2012)

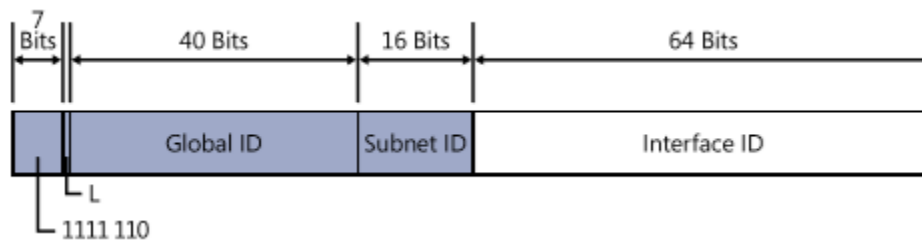


Figure 4: Structure of an IPv6 unique local address (Understanding IPv6, 2012)

“The first 7 bits have the fixed binary value of 1111110. All local addresses have the address prefix FC00::/7. The Local (L) flag is set to 1 to indicate that the prefix is locally assigned. The L flag value set to 0 is not defined in RFC 4193. Therefore, unique local addresses within an organization with the L flag set to 1 have the address prefix of FD00::/8. The Global ID identifies a specific site within an organization and is set to a randomly derived 40-bit value. By deriving a random value for the Global ID, an organization can have statistically unique 48-bit prefixes assigned to their sites. Additionally, two organizations that use unique local addresses that merge have a low probability of duplicating a 48-bit unique local address prefix, minimizing site renumbering. Unlike the Global Routing Prefix in global addresses, the Global IDs in unique local address prefixes are

not designed to be summarized. Unique local addresses have a global scope, but their reachability is defined by routing topology and filtering policies at Internet boundaries. Organizations will not advertise their unique local address prefixes outside of their organizations or create DNS entries with unique local addresses in the Internet DNS. Organizations can easily create filtering policies at their Internet boundaries to prevent all unique local-addressed traffic from being forward. Because they have a global scope, unique local addresses do not need a zone ID. The global address and unique local address share the same structure beyond the first 48 bits of the address. In both addresses, the 16-bit Subnet ID field identifies a subnet within an organization. Because of this, you can create a subnetted routing infrastructure that is used for both local and global addresses. For example, a specific subnet of your organization can be assigned both the global prefix 2001:db8:4d1c:221a::/64 and the unique local prefix fd0e:2d:ba9:221a::/64, where the subnet is identified for both types of prefixes by the Subnet ID value of 221a. Although the subnet identifier is the same for both prefixes, routes for both prefixes must still be propagated throughout the routing infrastructure so that addresses based on both prefixes are reachable.” (Understanding IPv6, 2012)

“Unique local addresses have the following characteristics:

1. They can be used just like global unicast addresses.
2. They can be used for devices that never need access to or from the global Internet.
3. They allow sites to be combined or privately interconnected without address conflicts and without requiring addressing renumbering.
4. They are independent of any ISP and can be used within a site even without having Internet connectivity.” (Understanding IPv6, 2012)

“Configure IPv6 Addressing on a Router

Optional: Set hostname of the router:

```
Router>enable
Router#configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
Router(config)#hostname R1-Sandra
R1-Sandra(config)#
```

For configuring an IPv6 addressing on a router, the following steps are necessary:

- *Enable the router to forward IPv6 packets*

Use the command `ipv6 unicast-routing` from global configuration exec mode:

```
R1-Sandra(config)#ipv6 unicast-routing
```

- *Configure IPv6 addressing on GigabitEthernet0/0*

From privileged exec mode enter the command to access interface configuration mode and configure address 2001:db8:1:1::1/64 and link-local address to fe80::1 on GigabitEthernet0/0.

```
R1-Sandra>enable
R1-Sandra#configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R1-Sandra(config)#interface GigabitEthernet 0/0/0
R1-Sandra(config-if)#ipv6 address 2001:db8:1:1::1/64
R1-Sandra(config-if)#ipv6 address fe80::1 link-local
R1-Sandra(config-if)#no shutdown

R1-Sandra(config-if)#
%LINK-S-CHANGED: Interface GigabitEthernet0/0/0, changed state to up
```

➤ *Configure IPv6 addressing on GigabitEthernet0/1*

From privileged exec mode enter the command to access interface configuration mode and configure address 2001:db8:1:1::2/64 and link-local address to fe80::1 on GigabitEthernet0/0.” (CCNA Course)

```
R1-Sandra>enable
R1-Sandra#configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R1-Sandra(config)#interface GigabitEthernet 0/0/1
R1-Sandra(config-if)#ipv6 address 2001:db8:1:2::1/64
R1-Sandra(config-if)#ipv6 address fe80::1 link-local
R1-Sandra(config-if)#no shutdown

R1-Sandra(config-if)#
%LINK-S-CHANGED: Interface GigabitEthernet0/0/1, changed state to up
```

Multicast addresses

“A multicast address identifies zero or more interfaces on the same or different hosts. With the appropriate multicast routing topology, packets addressed to a multicast address are delivered to all interfaces identified by the address”. (Understanding IPv6, 2012)

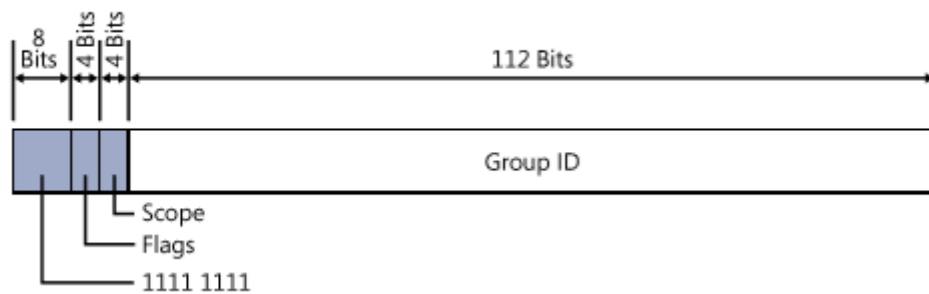


Figure 5: Structure of an IPv6 multicast address (Understanding IPv6, 2012)

“IPv6 multicast addresses have the first 8 bits set to 1111 1111. Therefore, an IPv6 multicast address always begins with FF. Multicast addresses cannot be used as source addresses or as intermediate destinations in a Routing extension header. Beyond the first 8 bits, multicast addresses include additional structure to identify flags, their scope, and the multicast group”. (Understanding IPv6, 2012)

Representation	IPv6 Multicast Address
Preferred	ff00:0000:0000:0000:0000:0000:0000:0000/8
Leading 0s omitted	ff00:0:0:0:0:0:0:0/8
Compressed	ff00::/8

Figure 6: Representations of IPv6 multicast addresses (Understanding IPv6, 2012)

Based on the flag value, there are two types of multicast addresses:

1. Permanent -> flag = 0

“These addresses, known as predefined multicast addresses, are assigned by IANA and include both well-known and solicited multicast”. (Understanding IPv6, 2012)

2. Nonpermanent -> flag = 1

“These are *transient* or *dynamically* assigned multicast addresses. They are assigned by multicast applications”. (Understanding IPv6, 2012)

Anycast addresses

“An anycast address is assigned to multiple interfaces. Packets addressed to an anycast address are forward by the routing infrastructure to the nearest interface to which the anycast address is assign. To facilitate delivery, the routing infrastructure must be aware of the interfaces that have anycast addresses assigned to them and their distance in terms of routing metrics. This awareness is accomplished by the propagation of host routes throughout the routing infrastructure of the portion of the network that cannot summarize the anycast address by using a route prefix.” (Understanding IPv6, 2012)

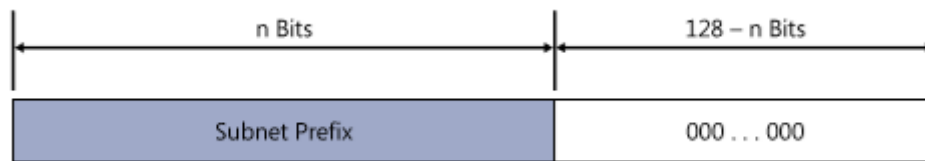


Figure 7: Structure of an IPv6 Subnet-Router anycast address (Understanding IPv6, 2012)

“For example, for the anycast address 3ffe:2900:d005:6187:2aa:ff:fe89:6b9a, host routes for this address are propagated within the routing infrastructure of the organization assigned the 48-bit prefix 3ffe:2900:d005::/48. Because a node assigned this anycast address can be placed anywhere on the organization’s intranet, host routes for all nodes assigned this anycast address are needed in the routing tables of all routers within the organization. Outside the organization, this anycast address is summarized by the 3ffe:2900:d005::/48 prefix that is assigned to the organization. Therefore, the host routes needed to deliver IPv6 packets to the nearest anycast group member within an organization’s intranet are not needed in the routing infrastructure of the IPv6 Internet”. (Understanding IPv6, 2012)

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Chapter 2

School of Management and Engineering network design

Requirement

The main propose of this chapter is to exemplify a hierarchical IP addressing scheme design for the faculty's network. The network address should support more than 2000 users and future growth and has the following specifications:

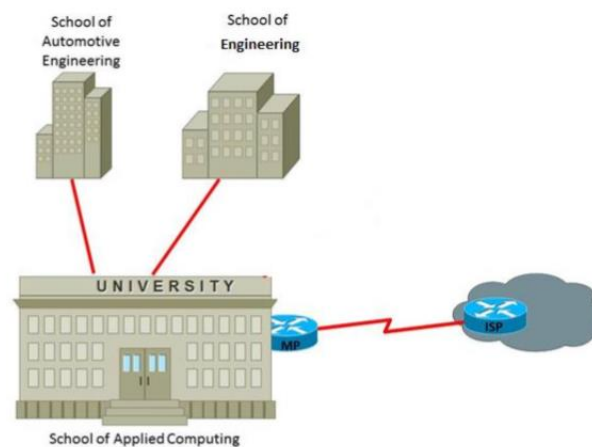


Figure 8: Network requirement

School of Automotive Engineering

STAFF	255
Room Name PCs number	
Lab101	40
Lab102	25
Lab103	35

<i>Lab205</i>	40
<i>Lab206</i>	48
<i>CAD lab</i>	20
<i>Lab301</i>	50

School of Engineering

STAFF	18
--------------	-----------

<i>Room Name</i>	<i>PCs number</i>
<i>Lab201</i>	20
<i>Lab202</i>	80
<i>Lab203</i>	65
<i>Lab205</i>	25
<i>Lab404</i>	45
<i>Lab408</i>	28
<i>Lab409</i>	80
<i>Lab410</i>	45

School of Applied Computing

STAFF	20
--------------	-----------

<i>Room Name</i>	<i>PCs number</i>
<i>Lab301</i>	60
<i>Lab302</i>	30
<i>Lab303</i>	36
<i>Lab304</i>	45
<i>Lab306</i>	40
<i>Lab308</i>	140
<i>Lab309</i>	50

Test center	20 PCs	1 IP phone	1 Printer
Open Access Lab	245 PCs	5 Printers	
Servers (IPv6)		DNS, Email, Registry, File, Printer	

Analyzing the requirements, the network should be able to support 2000 users and additional number added in the future and currently contains a total number of:

School of Automotive Engineering = 258 hosts (devices)

School of Engineering = 388 hosts (devices)

School of Applied Computing = 419 hosts (devices) + 22 (hosts (devices) - Test center) + 250 (hosts (devices) – Open Access Lab) = 691 hosts (devices)

Total = 1337 hosts (devices)

We can notice that there are differences in terms of hosts needed per each building, which can be translated into hosts needed per subnet and we also need to take in consideration the 2000 users supported by the network which result in the ability of double the existing hosts.

Because of this reason, designing this network using FLSM (Fixed Length Subnet Mask) approach can determine a huge amount of IP addresses to be lost because all the subnets will have the same size.

For optimization, I choose VSLM (Variable Length Subnet Mask) technique, which is more efficient as we can assign different subnets, different numbers of host bits in order to support different number of hosts, following the steps:

- Identify the area that has the largest number of hosts required
- Apply subnetting on it for meeting the requirements
- For this segment assign the subnet mask
- Identify the second segment (same criteria – number of required hosts)
- Starting from a new created subnet – apply subnetting on it (different subnet mask) to meet the new required number of hosts for this segment.
- Repeat the steps until all segments (hosts) are covered

The network used for this IP addressing scheme is:

- Network: **172.16.0.0/21**
- Class: B
- Default network mask: 255.255.0.0

For meeting the requirements, we will have the IP addressing table:

*School name abbreviations:

SAE = School of Automotive Engineering

SE = School of Engineering

SAC = School of Applied Computing

School Name	Hosts	Network Address	Subnet Mask	First Host	Last Host	Broadcast Address
SAC	691	172.16.0.0/22	255.255.255.192	172.16.0.1	172.16.3.254	172.16.3.255
	<u>Lab name</u>		<u>Hosts</u>	<u>IP Range</u>		
	Lab301		60	172.16.0.1 – 172.16.0.61		
	Lab302		30	172.16.0.62 – 172.16.0.92		
	Lab303		36	172.16.0.93 - 172.16.0.129		
SE	388	172.16.4.0/23	255.255.255.128	172.16.4.1	172.16.5.254	172.16.5.255
	<u>Lab name</u>		<u>Hosts</u>	<u>IP Range</u>		
	Lab201		20	172.16.4.1 – 172.16.4.21		
	Lab202		80	172.16.4.22 – 172.16.4.102		
	Lab203		65	172.16.4.103 – 172.16.4.168		
SAE	258	172.16.6.0/24	255.255.255.0	172.16.6.1	172.16.6.254	172.16.6.255
		172.16.7.0/29	255.255.255.248	172.16.7.1	172.16.7.6	172.16.7.7
	<u>Lab name</u>		<u>Hosts</u>	<u>IP Range</u>		
	Lab101		40	172.16.6.1 – 172.16.6.41		
	Lab102		25	172.16.6.42 – 172.16.6.67		
	Lab103		35	172.16.6.68 – 172.16.6.103		
Device		Interface		IPv6 Address/Prefix		Default Gateway
MP		G0/0		2001:dc9:1:1::1/64		N/A
		G0/1		2001:dc9:1:2::1/64		N/A
		G0/2		2001:dc9:1:3::1/64		N/A
		G0/3		2001:dc9:1:4::1/64		N/A

	S0/0/0	2001:dc9:1:a001::1/64	N/A
	Link-local	fe80::1	N/A
DNS Server	NIC	2001:dc9:1:1::2/64	fe80::1
Email Server	NIC	2001:dc9:1:1::3/64	fe80::1
Finance Server	NIC	2001:dc9:1:1::4/64	fe80::1
Registry Server	NIC	2001:dc9:1:1::5/64	fe80::1
File Server	NIC	2001:dc9:1:1::6/64	fe80::1
Print Server	NIC	2001:dc9:1:1::7/64	fe80::1

Table 1: Addressing table

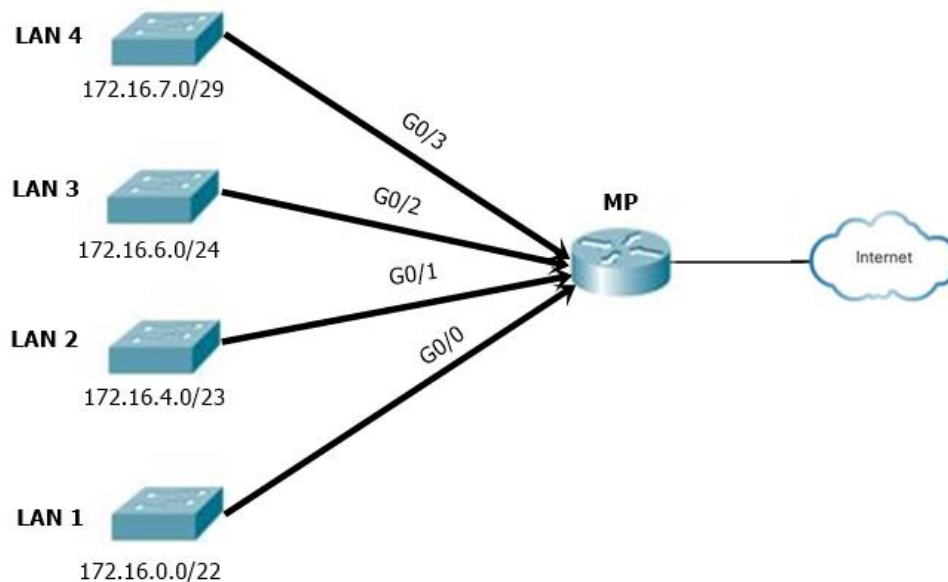


Figure 9: Network subnetting

In our case, School of Applied Computing is the subnet with the largest number of hosts – 691 hosts. Because the size of a subnet including the network and broadcast addresses is always a power of 2, we can determine the max power of 2 that is greater or equal with 691. It is represented by 10 ($2^{10} = 1024$). We will need at least a /22 network (Number of prefix-bit (/22) is calculated as $32 - 10 = 22$, netmask = 255.255.252.0).

First subnet (subnet for School of Applied Computing) will have assign network: 172.16.0.0/22, broadcast address 172.16.3.255 and IP range 172.16.0.1 – 172.16.3.254 that will cover the current 691 devices and can support an additional number of devices in the future. For example, Open Access Lab can be extended with 300 devices.

The next free IP address in the range will be 172.16.4.0 and it will be the start point for the second network. For School of Engineering, we have currently 388 hosts. The smallest network that can hold 388 host-addresses is /23 ($2^9 = 512$).

The second subnet (subnet for School of Engineering) will have assign network: 172.16.4.0/23, broadcast address 172.16.5.255 and IP range 172.16.4.1 – 172.16.5.254.

Finally, we need to create the subnet for School of Automotive Engineering. The currently required number of hosts is 258. The maximum available subnetting remained is /24 and it will result in 254 hosts ($2^8 - 2 = 256 - 2 = 254$ usable hosts addresses). In this case, there could be created two subnets: one for 254 hosts and another for remaining 4 hosts.

For School of Automotive Engineering can be assign the network: 172.16.6.0/24, broadcast address 172.16.6.255 and IP range 172.16.6.1 – 172.16.6.254 that will cover 254 hosts and network: 172.16.7.0/29, broadcast address 172.16.7.7 and IP range 172.16.7.1 – 172.16.7.6 for holding the remaining 4 hosts.

For the scope of this proof of concept and simplicity of the exemplification, I tried to keep the broadcast domain created as simple as possible. The main target when we have to deal with large broadcast domain that can negatively affect the network is to reduce the size of the network by creating smaller broadcast domains through the process of subnetting. As we can notice SAC broadcast domain is quite large, and it can, for example be reduce by creating additional subnets of max 200 hosts/subnet. The same approach can be applied to SE network, which currently supports 388 hosts. (For example: starting from 172.16.0.0/16 and following the above mechanism, we can easily obtain two subnets of 200 users each with network addresses 172.16.0.0/24 and 172.16.1.0/24.) By subnetting we have the advantage to reduce overall network traffic and improve the network performance. The devices and services can be grouped into subnets by different categories: location (ex: floors in a building), device types, organizational unit etc.

In our network design, an organizational unit approach was applied. Based on faculties that need to communicate with the main university building and number of hosts the network was designed. Another alternative could be grouping for example all servers into a subnet, all printers into another subnet and finally all hosts would create a third network.

The university has also 6 servers (DNS Server, Email Server, Finance Server, Registry Server, File Server and Print Server). For these and for the main router an ipv6 address will be assigned. There are 4 subnet that are connected with the router. Starting from IP address 2001:DB8:1:1::1/64 (full

IP address: 2001:0dc9:0001:0001:0000:0000:0000:0001) which gives an IP range: 2001:0dc9:0001:0001:0000:0000:0000:0000-2001:0dc9:0001:0001:ffff:ffff:ffff:ffff, the router interfaces G0/0, G0/1, G0/2, G0/3 can be configured as shown above (Table 1: Addressing table). "IPv6 requires a link-local address on every network interface on which the protocol is enabled. The hosts will use the router's link-local address (fe80::1) as default gateway." (CCNA Course)

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