IP Addressing

Campus Network Design & Operations Workshop

UNIVERSITY OF OREGON

Last updated 28th January 2021

NSRC Network Startup Resource Center

IP Addresses

- Internet connected networks use two types of IP Addressing
  - IPv4 – legacy Internet protocol
  - IPv6 – new Internet protocol
- Presentation describes IPv4 addresses and IPv6 addresses & addressing
- The Campus Network Design Workshop labs use both IPv4 and IPv6 for all exercises
  - Dual stack network (both protocols running in parallel)

IPv4 Addresses

- 32-bit binary number
  - How many unique addresses in total?

IPv4 Addresses

- 32-bit binary number
  - How many unique addresses in total?
  - 2^{32} which is 4,294,967,296 addresses
- Conventionally represented as four dotted decimal octets
- If you turn on all bits this is:

11111111111111111111111111111111

255 . 255 . 255 . 255

Can you explain why 11111111 = 255 in decimal?

IPv4 Addresses

- Remember binary mathematics!
- Each bit is basically to the power of 2. First bit is 2^0, second bit is 2^1 and so on to the eighth bit which is 2^7.

$$2^7 2^6 2^5 2^4 2^3 2^2 2^1 2^0$$

$$11111111$$

- This means that :
- $11111111 = 2^0*1+2^1*1+2^2*1+2^3*1+2^4*1+2^5*1+2^6*1+2^7*1$
- $11111111 = 1+2+4+8+16+32+64+128 = 255$

IPv4 Addresses

- 32-bit binary number
- Conventionally represented as four dotted decimal octets

10000000110111111001110100010011

128 . 223 . 157 . 19

Can you explain why 00010011 = 19 in decimal?

IPv4 Addresses

- 32-bit binary number
- Conventionally represented as four dotted decimal octets

10000000110111111001110100010011

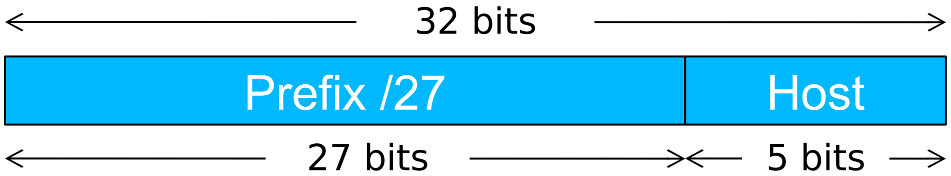
128 . 223 . 157 . 19

$2^7 2^6 2^5 2^4 2^3 2^2 2^1 2^0$

00010011

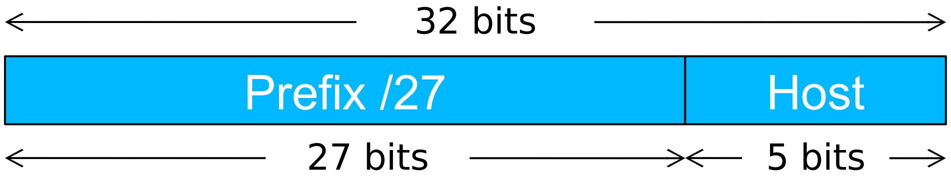
- $00010011 = 2^0*1+2^1*1+2^2*0+2^3*0+2^4*1+2^5*0+2^6*0+2^7*0$
- 00010011 = 1+2+0+0+16+0+0+0 = 19

Prefixes



- A range of IP addresses is given as a prefix, e.g. 192.0.2.128/27
- In this example:
  - How many addresses are available?
  - What are the lowest and highest addresses?

Prefixes



- A range of IP addresses is given as a prefix, e.g. 192.0.2.128/27
- In this example:
  - How many addresses are available?
    - Number of bits for the host = 32 – 27 = 5 bits
    - Number of available addresses = 2^5 = 32

Prefix Calculation

192 . 0 . 2 . 128

11000000000000000000000101000000

Prefix length /27 → First 27 bits are fixed

Prefix Calculation

192 . 0 . 2 . 128

11000000000000000000001010000000

Prefix length /27 → First 27 bits are fixed

Lowest address:

11000000000000000000001010000000

192 . 0 . 2 . 128

Prefix Calculation

192 . 0 . 2 . 128

110000000000000000000010100|00000

Prefix length /27 → First 27 bits are fixed

Lowest address:

11000000000000000000001010000000

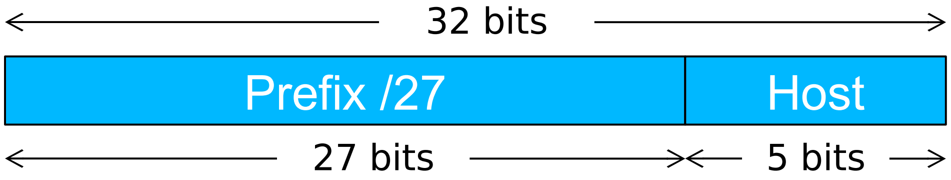
192 . 0 . 2 . 128

Highest address:

11000000000000000000001010011111

192 . 0 . 2 . 159

IPv4 “Golden Rules”



1. All hosts on the same L2 network must share the same prefix
2. All hosts with the same prefix have different host part
3. Host part of all-zeros and all-ones are reserved

Golden Rules for 192.0.2.128/27

- Lowest 192.0.2.128 = network address
- Highest 192.0.2.159 = broadcast address
- Usable: 192.0.2.129 to 192.0.2.158
- Number of usable addresses: 32 - 2 = 30

Exercises

- Network 10.10.10.0/25
  - How many addresses in total?
  - How many usable addresses?
  - What are the lowest and highest usable addresses?

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Hint...

10 . 10 . 10 . 0

0000101000001010000010100|0000000
0000101000001010000010100|1111111

Prefix length /25 → First 25 bits are fixed

Exercises

- Network 10.10.10.0/25
  - How many addresses in total?
    - Number of host bits is 32 – 25 = 7
    - Number of addresses is 2^7 = 128
  - How many usable addresses?
    - Network and broadcast addresses are unusable (2 ip addresses)
    - Number of usable address is 128 – 2 = 126
  - What are the lowest and highest usable addresses?
    - First IP address (network address) is 10.10.10.0 and last IP address (broadcast address) is 10.10.10.127. Both of them are unusable.
    - First usable IP address is 10.10.10.1 and last usable address is 10.10.10.126

An Edge Case

- How many usable addresses in a /30 prefix?
- What is this used for?
  - (Note: modern routers support /31 for this purpose to reduce IPv4 address wastage)

An Edge Case

- How many usable addresses in a /30 prefix?
  - Number of host bits is 32 – 30 = 2
  - Number of addresses is $2^2 = 4$
  - Number of usable address is 4 – 2 = 2
- What is this used for?
  - Used for Point-to-Point links

Netmask

- Netmask is just an alternative (old) way of writing the prefix length
- A ‘1’ for a prefix bit and ‘0’ for a host bit
- Hence N x 1’s followed by (32-N) x 0’s

/27 =

11111111111111111111111111100000

255 . 255 . 255 . 224

How did we get to 224?

Netmask

/27 =

11111111111111111111111111100000

255 . 255 . 255 . 224

How did we get 224?

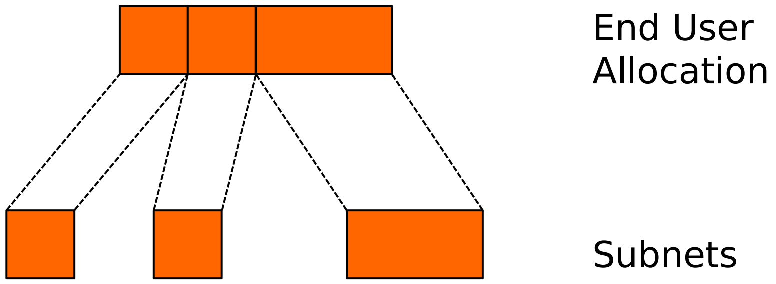
1. $256 - 2^{(32-27)}$
2. $256 - 2^5$
3. $256 - 32 = 224$

What about a "/26" ?
What about a "/28" ?

https://nsrc.org/workshops/2009/summer/ref/netmask-table.html

Subnetting

- Since each L2 network needs its own prefix, then if you route more than one network you need to divide your allocation
- Ensure each prefix has enough IPs for the number of hosts on that network



Subnetting Example

- You have been given 192.0.2.128/27
- However, you want to build two Layer 2 networks and route between them
- The Golden Rules demand a different prefix for each network
- Let's split this address space into two equal-sized pieces

Subnetting /27

192 . 0 . 2 . 128

110000000000000000000010100 | 00000

Move one bit from host part to prefix

Subnetting /27

192 . 0 . 2 . 128

110000000000000000000010100 | 00000

Move one bit from host part to prefix

We now have two /28 prefixes

1100000000000000000000101000 | 0000

192 . 0 . 2 . 128

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Subnetting /27

192 . 0 . 2 . 128

110000000000000000000010100 | 00000

Move one bit from host part to prefix

We now have two /28 prefixes

1100000000000000000000101000 | 0000

192 . 0 . 2 . 128

Second prefix:

1100000000000000000000101001 | 0000

192 . 0 . 2 . 144

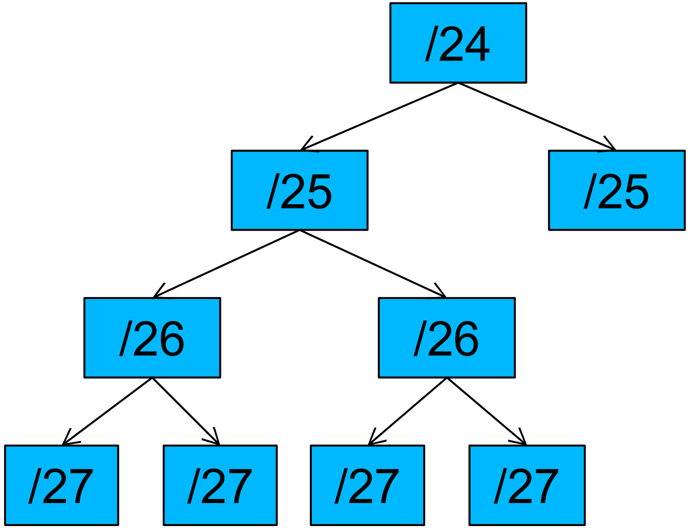
How did we get “144” for the second prefix?

Check correctness

- Expand each new prefix into lowest and highest
- Ranges should not overlap
  - 192.0.2.128/28
    - Lowest (network) = 192.0.2.128
    - Highest (broadcast) = 192.0.2.143
  - 192.0.2.144/28
    - Lowest (network) = 192.0.2.144
    - Highest (broadcast) = 192.0.2.159
  - How many usable addresses now?

Aggregation tree

- Continue to divide prefixes as required
- Can visualise this as a tree



Questions about IPv4?

IPv6 addresses

- 128-bit binary number
  - How many unique addresses in total?

IPv6 addresses

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  - How many unique addresses in total?
  - 3.402823669209 $x10^{38}$
- Conventionally represented in hexadecimal – 8 words of 16 bits, separated by colons

2607:8400:2880:0004:0000:0000:80DF:9D13

IPv6 addresses

- 128-bit binary number
  - How many unique addresses in total?
  - 3.402823669209 x10^{38}
- Conventionally represented in hexadecimal – 8 words of 16 bits, separated by colons

  2607:8400:2880:0004:0000:0000:80DF:9D13

- Leading zeros can be dropped
- The largest contiguous run of all-zero words can be replaced by "::" (see RFC5952)

  2607:8400:2880:~~000~~4:~~0000:0000~~:80DF:9D13

  2607:8400:2880:4::80DF:9D13

Hexadecimal

0000	**0**	1000	**8**
0001	**1**	1001	**9**
0010	**2**	1010	**A**
0011	**3**	1011	**B**
0100	**4**	1100	**C**
0101	**5**	1101	**D**
0110	**6**	1110	**E**
0111	**7**	1111	**F**

0000 = 0000000000000000
FFFF = 1111111111111111

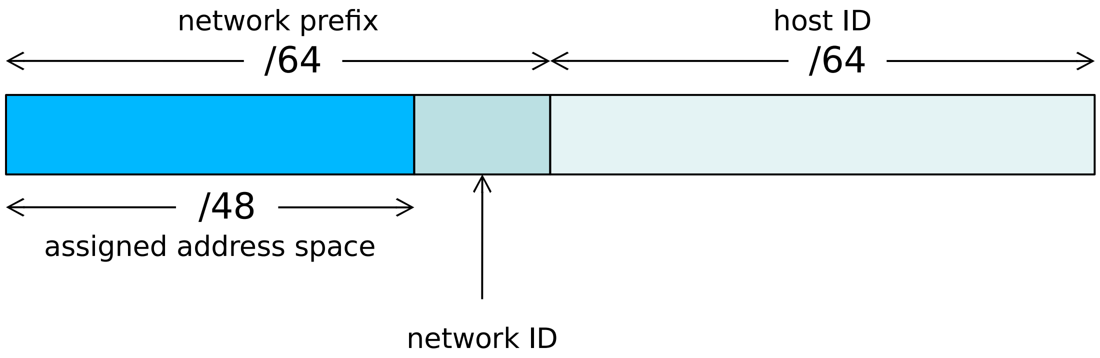
IPv6 rules

- With IPv6, every subnet is /64 (*1)
- The remaining 64 bits can be assigned by hand, or picked automatically
  - all-zeros address is reserved (*1) - *Subnet-Router Anycast address*
- There are special prefixes
  - e.g. link-local addresses start with FE80::
- Total available IPv6 space is ≈ 2^{61} subnets

(*1) Except /127 recommended for point-to-point links (RFC 6164), in which case the all-zeros address is allowed

IPv6 addressing

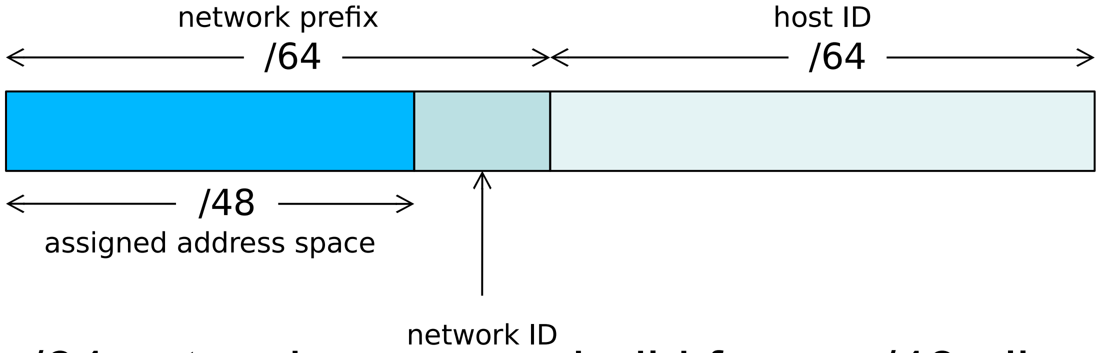
- Typical end-user allocation is /48



- How many /64 networks can you build from a /48 allocation?

IPv6 addressing

- Typical end-user allocation is /48



- How many /64 networks can you build from a /48 allocation?
  - IPv6 address is 128 bits which means you have 128 – 64 – 48 = 16 bits
  - Number of networks = 2^{16} = 65,536

IPv6 addressing

- You are assigned 2001:DB8:123::/48
  - 2001:0DB8:0123:0000:0000:0000:0000:0000
- Lowest /64 network?

IPv6 addressing

- You are assigned 2001:DB8:123::/48
  - 2001:0DB8:0123:0000:0000:0000:0000:0000
- Lowest /64 network?
  - 2001:DB8:123:0000::/64
  - written simply 2001:DB8:123::/64

IPv6 addressing

- You are assigned 2001:DB8:123::/48
  - 2001:0DB8:0123:0000:0000:0000:0000:0000
- Lowest /64 network?
  - 2001:DB8:123:0000::/64
  - written simply 2001:DB8:123::/64
- Highest /64 network?
  - 2001:DB8:123:FFFF::/64

Ways to allocate the host part

- Do it automatically from MAC address – “stateless autoconfiguration”
  - Not recommended for servers: if you change the NIC then the IPv6 address changes!

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- Can number sequentially from 1, or use the last octet of the IPv4 address

Ways to allocate the host part

- Do it automatically from MAC address – “stateless autoconfiguration”
  - Not recommended for servers: if you change the NIC then the IPv6 address changes!
- Can number sequentially from 1, or use the last octet of the IPv4 address
- Or embed the whole IPv4 address
  - e.g. 2607:8400:2880:4::80DF:9D13
  - 80DF9D13 hex = 128.223.157.19 in decimal
  - Can write 2607:8400:2880:4::128.223.157.19

Notes on IPv6

- Broadly similar to IPv4
- “ARP” is replaced by “NDP”
- IPv6 client configuration options
  - Stateless autoconf (router advertisements)
  - Stateless autoconf + stateless DHCPv6
  - Stateful DHCPv6
- Interfaces typically get both a link-local address and one or more routable prefixes
- “Dual stack” = v4 and v6 side-by-side

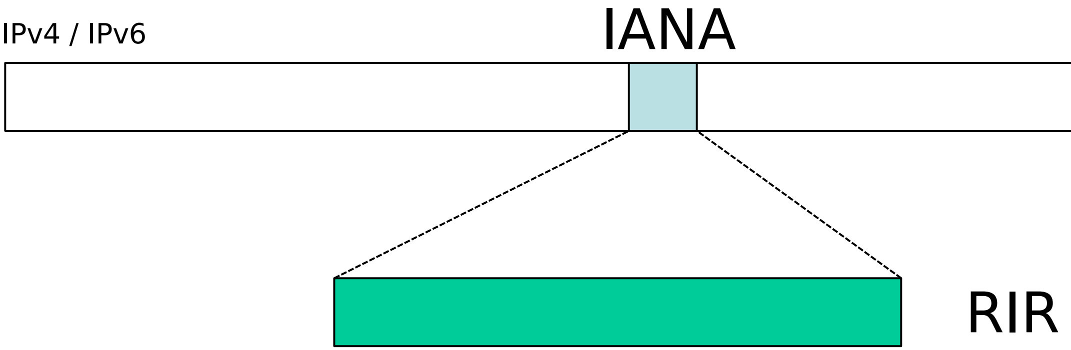
Questions about IPv6?

Hierarchical address allocation

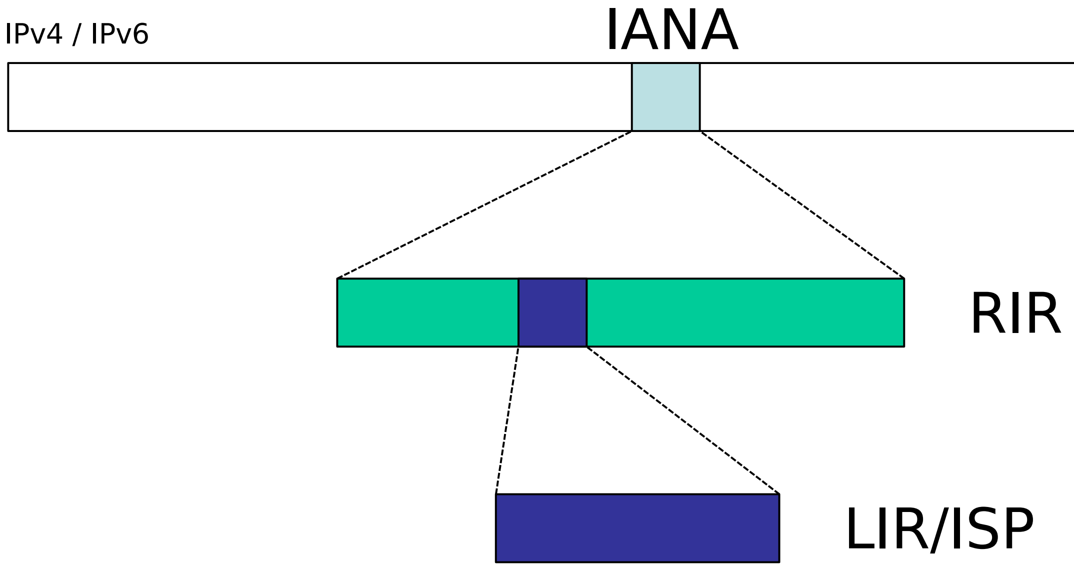
IPv4 / IPv6

IANA

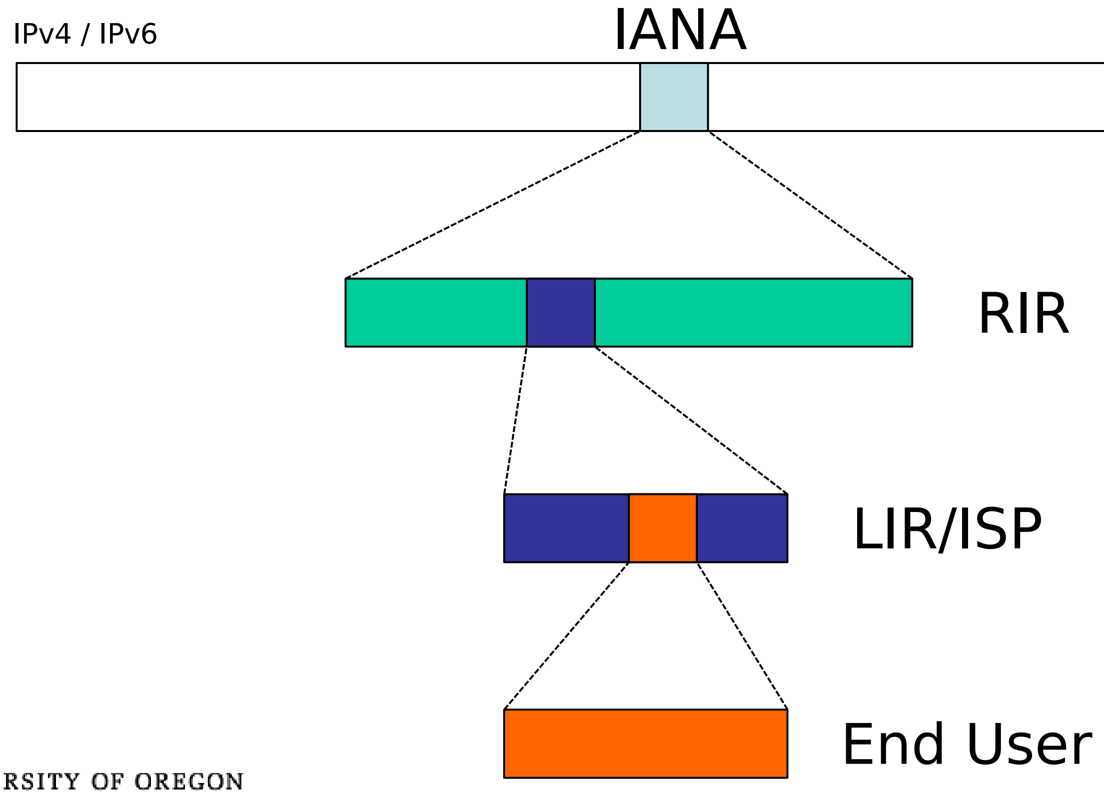
Hierarchical address allocation



Hierarchical address allocation



Hierarchical address allocation



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IPv4 Address Distribution

- IPv4 addresses
  - Distributed by RIRs according to demonstrated need
  - Have almost all run out
  - RIRs have IPv4 run out policies
    - E.g. one off assignment from a limited pool
- Typical Campus:
  - Small public address block
    - For public servers, NAT pools
    - Anything from /28 to /21 depending on RIR region/upstream
  - Private address block
    - For internal end users, network management, etc

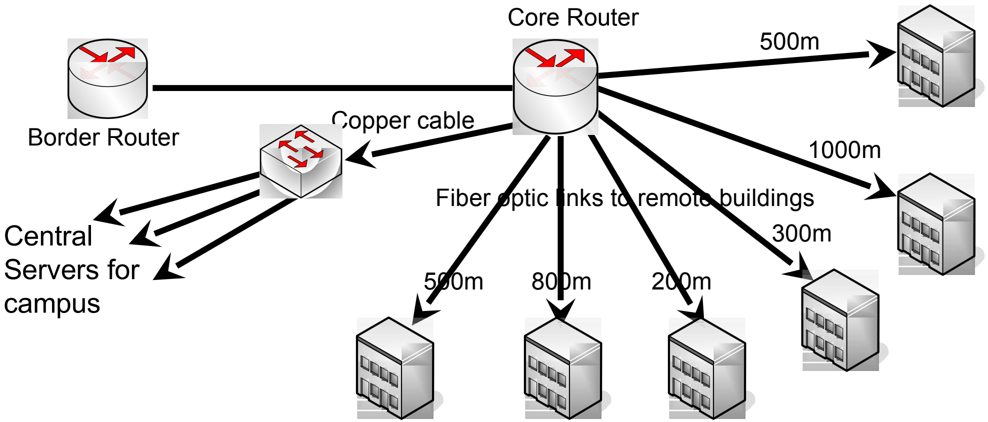
IPv6 Address Distribution

- IPv6 addresses
  - Network operators receive minimum of /32
    - Includes RENs, University Campuses, etc
  - End-sites receive /48
  - Smallest subnet size is /64
- Typical Single Campus:
  - /48 divided out amongst buildings
- Typical Multi-Campus or Multi-Faculty:
  - /32 divided out amongst Campuses
    - /48 per campus

Questions about IP Address Distribution?

Designing an Address Plan

- Now we will look at how to design an address plan for a simple campus
  - Let's use our campus from the fibre pricing exercise



Designing an Address Plan

- The following table shows the host allocation for each part of that campus

Network	Number of Devices
Border Router to Core Router	2
Server Network	23
Science Building	120
Arts Building	52
Engineering Building	200
Library	80
Administration Building	40
Languages Building	30
Staff & Student Hostel	60
Wireless Network	350

Designing an Address Plan

- The University has the following address space:
  - 172.16.0.0/16 IPv4 Address block
  - 2001:DB8:8::/48 IPv6 Address block
- We will now use these address blocks to design an IPv4 and IPv6 address plan for the campus

IPv4 Plan

- Using the previous table, let's add a column to show the subnet sizes for each function

Network	Number of Devices	IPv4 Subnet Size
Border Router to Core Router	2	/30
Server Network	23	/27
Science Building	120	/25
Arts Building	52	/26
Engineering Building	200	/24
Library	80	/25
Administration Building	40	/26
Languages Building	30	/26
Staff & Student Hostel	60	/25
Wireless Network	350	/23

IPv4 Plan

- And now let's assign address blocks accordingly

Network	Number of Devices	IPv4 Subnet Size	Allocation
Border Router to Core Router	2	/30	172.16.0.0/30
Server Network	23	/27	172.16.0.32/27
Science Building	120	/25	172.16.5.0/25
Arts Building	52	/26	172.16.5.128/26
Engineering Building	200	/24	172.16.1.0/24
Library	80	/25	172.16.4.0/25
Administration Building	40	/26	172.16.0.192/26
Languages Building	30	/26	172.16.5.192/26
Staff & Student Hostel	60	/25	172.16.4.128/25
Wireless Network	350	/23	172.16.2.0/23

IPv4 Plan Explanation

- Keep 172.16.0.0/24 for infrastructure and administrative network
  - Border Router to Core Router gets 172.16.0.0/30
  - Server Network gets 172.16.0.32/27 which is the first available /27 prefix in that range after the Border Router to Core Router assignment but any free /27 prefix in 172.16.0.0/24 range can be used
  - Administration building gets 172.16.0.192/26
- Assign the biggest subnet first
  - Wireless gets 172.16.2.0/23 (172.16.2.0→172.16.3.255)
  - Remember that a /23 prefix is equivalent two /24 prefixes, so the first available /23 prefix is 172.16.2.0/23. You can use any free /23 prefixes in the 172.16.0.0/16 pool.
- Then we assign the /24 which is the next biggest subnet
  - 172.16.1.0/24 goes to Engineering

IPv4 Plan Explanation

- Then we assign the /25s
  - 172.16.4.0/25 goes to the Library
  - 172.16.4.128/25 goes to the Staff and Student Hostel
  - 172.16.5.0/25 goes to the Science building
- Finally we assign the /26s
  - Arts Building gets 172.16.5.128/26
  - Languages Building gets 172.16.5.192/26.
- It is easier to do the big pieces first, and then fill in the gaps with the smaller subnets
- Use of the aggregation tree concept covered in the previous section is very helpful in the creation of an IPv4 plan

IPv4 Plan Conclusion

- We have addressed our network using 172.16.0.0 through to 172.16.5.255
- This is contained within the 172.16.0.0/21 address block
- An example of an efficient use of IPv4 address space

IPv6 Plan

- Let's repeat now for IPv6
  - Only subnet size is /64 – so this is easy!

Network	Number of Devices	IPv6 Subnet Size
Border Router to Core Router	2	/127
Server Network	23	/64
Science Building	120	/64
Arts Building	52	/64
Engineering Building	200	/64
Library	80	/64
Administration Building	40	/64
Languages Building	30	/64
Staff & Student Hostel	60	/64
Wireless Network	350	/64

IPv6 Addressing Notes

- Campus gets a whole /48
  - So let's not think like IPv4 when we design our plan
  - We have 2001:DB8:8:XXYY::/48 available to us
    - XX can be used to count functions – this gives us a total of 256 /56s in campus
    - YY can be used to count subnets within the function – this gives us a total of 256 /64s in each function
    - Each function might be a Faculty, or a Building, or Core Infrastructure

IPv6 Addressing Notes

- Let’s do this:
  - One /56 for Campus Network Infrastructure
    - This gives us 256 possible /64s for Campus Network Infrastructure
    - We will use one /64 for the point to point link
    - We will use another /64 for the servers
  - One /56 for each Building
    - This gives us 256 possible /64s within each Building
    - But we only have one LAN per Building in this example
      - We have plenty of room to add more in the future

IPv6 Plan

- And now let's assign address blocks accordingly

Network	Number of Devices	IPv6 Subnet Size	Allocation
Border Router to Core Router	2	/127	2001:DB8:8:0000::/64
Server Network	23	/64	2001:DB8:8:0010::/64
Science Building	120	/64	2001:DB8:8:0100::/64
Arts Building	52	/64	2001:DB8:8:0200::/64
Engineering Building	200	/64	2001:DB8:8:0300::/64
Library	80	/64	2001:DB8:8:0400::/64
Administration Building	40	/64	2001:DB8:8:0500::/64
Languages Building	30	/64	2001:DB8:8:0600::/64
Staff & Student Hostel	60	/64	2001:DB8:8:0700::/64
Wireless Network	350	/64	2001:DB8:8:0800::/64

Further IPv6 Address Plan Advice

- Use the “nibbles” in the IPv6 address to indicate function
  - Nibble is 4 bits – each character in the IPv6 address represents 4 bits.
- You might do this for 2001:DB8:8:XYZZ::/48

X	The Faculty	15 Faculties
Y	The Department	16 Departments per Faculty
ZZ	The LANs	256 per Department

  - Use X=0 for the campus backbone infrastructure
- There are many variations on this theme
  - But use the “nibbles” to indicate function as it makes the address plan easy, memorable, and scalable

Questions?