Module Four

CSG1105 Applied Communications

The Internetwork Layer and Routing

- The Internetwork Layer (AKA the network layer)

Functions of the Internetwork Layer

- Defines IP addresses
- Routes packets from source to destination through an internetwork
- Provides association between IP addresses and local delivery medium access control (MAC) addresses – Address Resolution Protocol (ARP)
- Fragmentation of packets if necessary (link with small MTU)

Internetwork Layer Protocols

- The Internetwork Layer uses four major protocols

1. IPv4 - the current dominant packet protocol
2. IPv6 - Covered later
3. ARP - Address Resolution Protocol (covered last module)
4. ICMP - Internet Control Message Protocol
   - Diagnostic and error reporting protocol
   - Encapsulated in an IP packet
   - Ping is an example, ICMP Echo

IP Network Addressing

- In a previous module, we looked at the structure of IP addresses
- An IP address consists of a **network** and a **host** portion
- In the examples given e.g. 192.168.0.1, there were 24 bits for the network address and 8 bits for the host addresses
- This used a mask of 255.255.255.0
- The question is, how is it decided how many bits are in the network address?

Classfull Subneting (obsolete)

- When the Internet protocols were first designed, a simple system of dividing address space was used.
- This created fixed-size subnetworks based on the first few bits of the 32-bit network address.
- Large companies were allocated a Class A, universities and smaller organisations Class B and small organisations Class C.
- This was a very inefficient allocation of address space. An example would be an organisation requiring 260 addresses having to acquire two Class C addresses wasting nearly 250 addresses
- Having a basic understanding is useful for comprehending Private IP ranges and reserved addresses e.g. 127.0.0.1

Class	Prefix	Net Size	Host Size	Networks	Addresses	Mask
A	0	8 bits	24 bits	128	16777216	255.0.0.0
B	10	16 bits	16 bits	16384	65536	255.255.0.0
C	110	24 bits	8 bits	2097152	256	255.255.255.0

Variable Length Subnet Masks (VLSM)

- Why do we need to subnet?
- The classful method of subnetting is very wasteful of address space and inflexible in the size of subnetworks.
- Variable Length Subnet Masks were introduced to allow the allocation of an appropriate number of addresses to a network.
- Subnetting also allows a network administrator to further subdivide the address space allocated for restricting the size of **broadcast domains.**
- A broadcast domain consists of an Ethernet LAN and all devices connected to it. A large LAN connected using multiple switches can experience congestion as a result of Ethernet broadcasts.
- Ethernet broadcasts are not propagated by **routers** which may be used to divide LANs into smaller subnets.

Routers 1

- Routers and layer three switches move packets between sub-networks (networks with a different network number).
- This is done by consulting a routing table which has been either configured by the network administrator or as a result of receiving route updates from other routers via routing protocol messages.
- The routing table associates network numbers with one of the router's interfaces.
- The Internet backbone consists of multiple routers connecting multiple networks, usually belonging to ISPs and backbone IP network providers
- To see how many routers are between you and a server try **tracert google.com (Windows) or traceroute google.com (OS X)**

- The Classful masks were fixed at 8,16 and 24 bits. VLSM masks may vary in size and if no ranges overlap, subnets within an organisation may be of different size.

Classful Network	Equivalent VLSM	Example
Class A	/8	10.0.0.1/8
Class B	/16	172.16.0.1/16
Class C	/24	192.168.0.1/24

Network Address and Broadcast Address

- Within each subnet, there is a network address and a broadcast address
- The network address is where the host portion of the address is all zeros
- The broadcast address is where the host portion is all ones
- Looking at a classical Class C network, a /24 in VLSM. The number of hosts possible with 8 bits for the host portion of the address is 2^8 or 256. The network mask for this network is 255.255.255.0 or 11111111.11111111.11111111.00000000 in binary.

		Host Portion in Binary
Network Address	192.168.0.0	00000000
First Host	192.168.0.1	00000001
Last Host	192.168.0.254	11111110
Broadcast	192.168.0.255	11111111

Subnetting a Range

- Any valid IP address range may be sub-netted. Let's subnet the above /24 into two subnets.
- To create two subnets, we need one more bit (2^1) in the network portion of the address resulting in a mask of /25 or 255.255.255.128 (11111111.11111111.11111111.10000000). The resulting subnets are:

Network:	192.168.0.0/25	11000000.10101000.00000000.0 0000000
Broadcast:	192.168.0.127	11000000.10101000.00000000.0 1111111
First:	192.168.0.1	11000000.10101000.00000000.0 0000001
Last:	192.168.0.126	11000000.10101000.00000000.0 1111110
Network:	192.168.0.128/25	11000000.10101000.00000000.1 0000000
Broadcast:	192.168.0.255	11000000.10101000.00000000.1 1111111
First:	192.168.0.129	11000000.10101000.00000000.1 0000001
Last:	192.168.0.254	11000000.10101000.00000000.1 1111110

Subnetting

-Look at the following (next slide) network diagram .
- It shows a LAN consisting of a single subnet (172.16.100.0/24).
- The infrastructure of the LAN consists of three peripheral switches, a core switch, three servers and multiple workstations. - This constitutes a single broadcast domain where all devices in the LAN will receive broadcast transmissions from any other device on the LAN.
- As the number of devices on a LAN grows, this broadcast traffic may increase to a point that it interferes with the expedient delivery of messages.
- A solution to this issue is to divide the network into subnets with a layer three device such as a router or layer three switch.
- This is usually done by segregating the devices along functional lines, grouping devices that are commonly communicating with one another.
- This is usually achieved by using organisational structures such as departments.

Switched Network

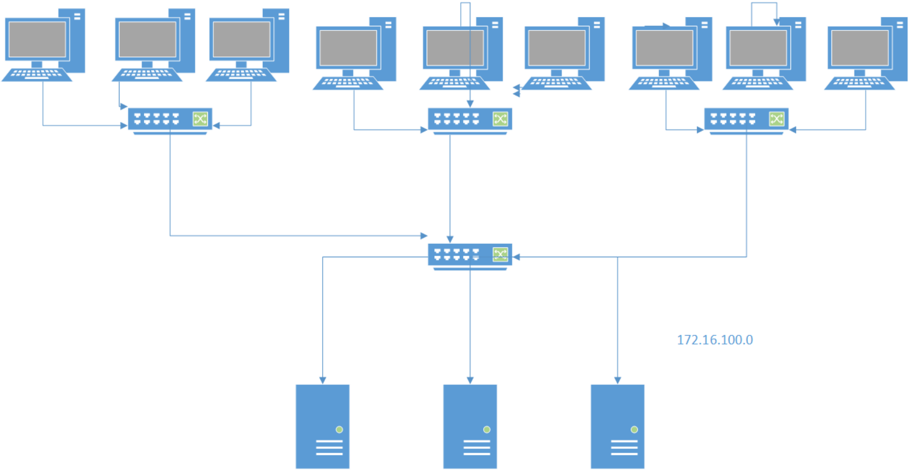

Figure 1: Switched Network - Single Broadcast domain

Subnetting Example 1

- In this example, there are three groups: Human Resources, Accounting and Procurement.
- Dividing the original network address space into three requires some thought as the subnetting process results in an **even power of two for the number of networks**.
- One key fact in this process is that the subnets don't need to be the same size.
- Again, analysis of the size requirements of each group may reveal that one is larger than the others.
- The first division results in two subnets of 128.
- One of these subnets is assigned to the largest group, the second is further sub-netted to result in two networks of 64 addresses.

subnetting Example 2

	Network	Subnet Mask	Addresses
Original Network	172.16.100.0/24	255.255.255.0	256
First	172.16.100.0/25	255.255.255.128	128
Subnet network into two	172.16.100.128/25	255.255.255.128	128
Remains unchanged	172.16.100.0/25	255.255.255.128	128
Second	172.16.100.128/26	255.255.255.192	64
Subnet network into two	172.16.100.192/26	255.255.255.192	64

Switched/Routed Network

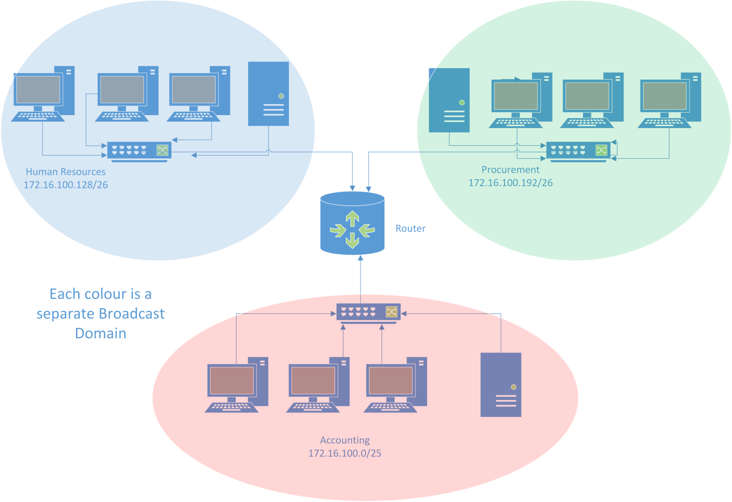

Figure 2: Switched/Routed Network

Switching vs Routing

- Switching frames is much faster than routing packets
- Frames are switched using ASIC that operate purely in silicon
- Packets are routed by software decisions and are slower than switching
- CISCO, a major networking company has a mantra "Switch where you can, route where you must"
- For LAN use there is a "Layer 3 Switch", that combines switching and routing and had better performance than most routers.
- A common architecture is to use a L3 Switch for dividing internal broadcast domains and a connected router for Internet and WAN links

Routers 2

- Routers are special purpose computers that have multiple network interfaces
- They run a purpose built operating system that requires to be configured to function correctly
- **Note:** Your ISP "router" has minimal routing functions. It is actually a multi-purpose device that encompasses a Modem, Router, Switch, WiFi Access Point, Firewall, DHCP server, Web Server, DLNA Server, SMB Server and possibly several other functions. They generally run an embedded Linux kernel with a proprietary interface layered over it.
- Commercial routers are more sophisticated devices, often with the ability to add and remove interfaces, have the OS upgraded and are more robust
- Like managed switches, commercial routers have a CLI and may be accessed remotely for management purposes.

Routing

- Routing is the process of making a decision about how to forward incoming packets
- In a previous module, we have seen that an IP address contains a network portion and a host portion
- When a router receives a packet, it examines the destination network address and does one of three things:
    1. If the destination network is in the **routing table**, it forwards the packet via the interface associated with that network
    2. If the destination network is **not** in the routing table, but a **route of last resort** is set, it will forward the packet to the interface associated with that route. (This is usually what your ISP Router does). The route of last resort is usual an Internet Service Provider (ISP.
    3. If the destination is not in the routing table and no last resort route has be set, the pack is dropped (not forwarded and no error is passed back to sender - TCP will deal with this)
    4.
- Routers can deal with there being multiple possible paths for a packet to travel from source to destination.

Routing Tables 1

- Routing tables are required by routers to make forwarding decisions
- Unlike switches, routing tables are not built by examining the incoming packets
- Routers must be configured by an administrator who understands the required network structure
- Each interface of the router needs to be configured with an IP address for traffic to be directed to a network. These are assigned by the administrator
- The IP address of a specific interface becomes the default gateway for devices on a broadcast domain. By convention, this is usually the first or last address in an IP subnetwork range.

Routing Tables 2

- Routing tables may be built in three ways
  1. The router will recognise directly connected networks from the IP assigned to an interface
  2. The administrator may assign a **Static Route**, manually associating an IP subnetwork with an Interface. This is for specific purposes (e.g. route of last resort) and should be used sparingly as it may become difficult to mange
  3. Routing protocols: unlike switches, routers have the ability to share information about routes from one network to another.

Routing Protocols 1

- Routers only have direct knowledge of directly connected networks
- Routing protocols share this knowledge with immediate neighbours and eventually throughout the Internet
- The routers also share information about the "distance" to remote networks. This permits the choice of the "best" route for traffic to travel.
- There are several metrics for the "cost" of a route, a simple one is **hop count**, the number of routers between source and destination.
- Routing protocols exchange message regularly to dynamically update the routing tables. This can remove routes that are no longer available or downgrade routes that are congested

Routing Protocols 2

- Routing Protocols fall into two major groups

1. Exterior Gateway Protocols (EGP)
2. Interior Gateway Protocols (IGP)

- EGPs are for configuring routes between **Autonomous Systems** and are usually the domain of ISPS. An example of an EGP is **BGP** the Border Gateway Protocol. EGPs are beyond the scope of this unit.
- IGPs are for exchanging routes **within** an Autonomous system. i.e. between routing devices (routers, L3 switches) within a network controlled by a single entity.

Interior Gateway Protocols

- IGPs fall into two categories:

1. Distance Vector Protocols
2. Link State Protocols

Distance Vector Proto

- Distance vector protocols don't carry information about the network topology
- Each router advertises it's "Distance" value (e.g. hop count) from other routers
- Each router receives advertisements from other routers on the network
- These messages populate the routing table
- Periodically these messages are exchanged and changes in the network are updated
- The convergence of the routing tables to stable values my be slow
- Distance vector protocols send the entire routing table and are considered "noisy"
- Examples of Distance Vector Protocols are RIP,RIPv2,IGRP

Link State Protocols

- Each router using a Link State Protocol has information about the topology of the network
- Each router performs calculations to determine the best route from itself to each other router in the network
- These calculated routes become the routing table
- Only connectivity information is passed from router to router
- Link State Protocols generate less traffic, but require higher levels of local processing
- Examples of Link State Protocols are OSPF and IS-IS

Route Aggregation

- In an earlier slide, subnetting was shown as a means of dividing broadcast domains
- The network 172.16.100.0/24 was subnetted into three networks, 172.16.100.0/25,172.16.100.128/26 and 192.168.100.192/26
- does this mean we have to share three routes with a connected router?
- We can advertise that we have a route for 172.16.100.0/24 to a connected router, and it will send packets that to this router that will be eventually directed to the interfaces for each subnet
- This may be used as long as we have contiguous subnets that align on the correct binary boundary
- Example if we had networks 192.168.0.0/24,192.168.1.0/24,192.168.2.0/24 and 192.168.3.0/24, we could advertise the aggregated route 192.168.0.0/22

CIDR Classless Internet Domain Routing

- CIDR is based on VLSM
- It allows more efficient allocation of IP address
- Allocations are based on the number of addresses required by an organisation
- The suffix /24 we have seen in previous slides is CIDR notation, indicating the number of bits in the network portion of the address
- Blocks of allocated IPs are advertised as **Supernets**, reducing the size of global routing tables.