Inter-networking

COS 460 & 540

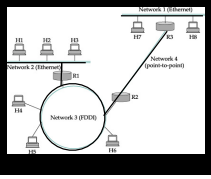
1

2

Problem

LAN's are great… but…

We want to **connect** them together



...across the world

3

Inter-networking

4

- Internet Protocol (IP)
- Routing
- The Internet
- Multicast*
- Multi-protocol Label Switching*

Internet Protocol (IP)

5

- What is an Internetwork
- Service Model
  - Datagrams, Packet Format, …
- Addressing
- Datagram Forwarding
- ARP, DHCP, ICMP, ...

What?

6

- “internet” vs “Internet”
- “network” vs “subnetwork”
- physical vs logical networks

Bridge, Router, Switch

7

- repeater & hub - physical
- bridge - link
- switch - network
- router - internet
- gateway - application

Alternatives?

8

- Novell's IPX

Internet Protocol (IP)

9

- ✓ What is an Internetwork
- Service Model
  - Datagrams, Packet Format, …
- Addressing
- Datagram Forwarding
- ARP, DHCP, ICMP, ...

10

Service Model

- Datagram Delivery
- Packet Format
- Fragmentation and Reassembly

11

Datagram Delivery

Underlying network is..

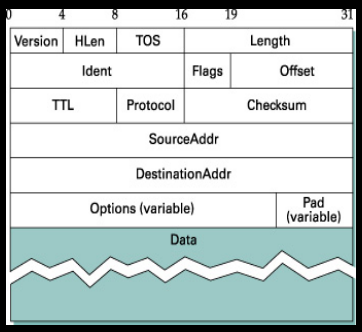
- reliable or unreliable
- connection-oriented or connectionless
- small or large packet/frame sized
- physical, logical, wireless, ...

12

Datagram Delivery

- IP **Datagram** is basis of protocol
- Provides a "**best-effort**" or unreliable service
- May be **out of order**
- **Connectionless**

Packet Format



13

HLen – length in 32-bit words (normal 5 words, 20 bytes)
Length – bytes, max 64k, includes header
TTL – hops

Fragmentation

- IP datagram can be 64kB
- Underlying network may have 512b MTU

14

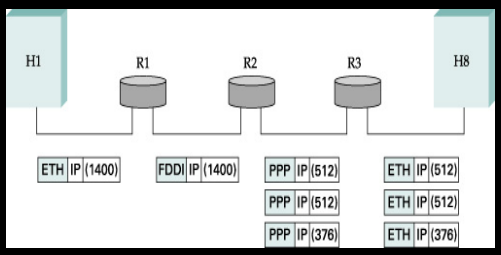
Fragmentation

- Each fragment is an IP datagram
- Each IP datagram is rebuilt for each network

15

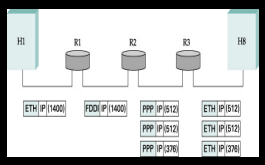
16

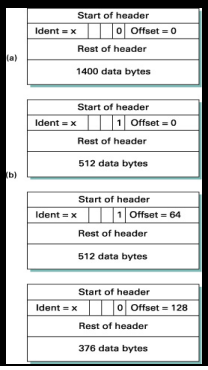
Fragmentation



17

Fragmentation





18

Internet Protocol (IP)

- ✓ What is an Internetwork
- ✓ Service Model
  - ✓ Datagrams, Packet Format, …
- Addressing
- Datagram Forwarding
- ARP, DHCP, ICMP, ...

19

IP Addressing

- Need to identify any host on the network
- Globally **unique**
- **Hierarchal** (not flat like Ethernet)
  - for easier routing
  - represents a network of networks

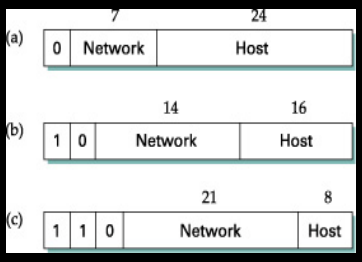
20

IP Addressing

- 32 bit addresses
- "Dotted Decimal" format
  - 130.111.135.26
- Contains two parts
  - **Network**
  - **Host**

21

IP Addressing



22

IP Addressing

- Network portion
  - specifies a unique physical* network
  - used for routing
- Host portion
  - specifies a unique host on the network
  - local delivery

23

Internet Protocol (IP)

- ✓ What is an Internetwork
- ✓ Service Model
  - ✓ Datagrams, Packet Format, …
- ✓ Addressing
- Datagram Forwarding
- ARP, DHCP, ICMP, ...

24

Datagram Forwarding

How do datagrams traverse the internetwork

25

Forwarding vs Routing

- ***forwarding*** is taking an input packet and sending it out the appropriate port
- ***routing*** is the process of building forwarding tables.

26

Datagram Forwarding

- Every datagram has **destination** IP
- Network part **uniquely identifies** a physical network
  - All **hosts/routers** on network can **communicate** with all others
- Every network has a **router** on the net

27

Datagram Forwarding

Each host and router maintains a forwarding table

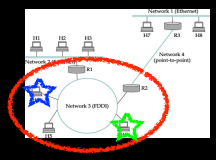
Network	Next-hop
1 130.111	R1 130.111.32.1
2 141.114	R2 141.114.1.1
default	R2 76.5.4.3

28

Datagram Forwarding

If destination network == source network

deliver locally

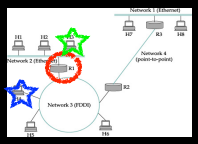


29

Datagram Forwarding

if destination network in forwarding table

deliver to next-hop

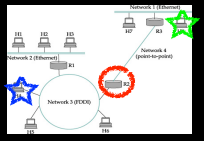


30

Datagram Forwarding

if destination network unknown

deliver to default



31

Datagram Forwarding

- Local delivery for local datagrams
- Routers forward datagrams towards the physical network

32

Internet Protocol (IP)

- ✓ What is an Internetwork
- ✓ Service Model
  - ✓ Datagrams, Packet Format, …
- ✓ Addressing
- ✓ Datagram Forwarding
- ARP, DHCP, ICMP, ...

33

Address Resolution Protocol (ARP)

Local delivery

it's not that simple

IP Address != Ethernet Address

34

Address Resolution

- Finds **local** or **link-level** address for an **IP** address
  - Both hosts on the same IP Network
  - Discover / Dynamic
- Uses *broadcast* feature of link-level

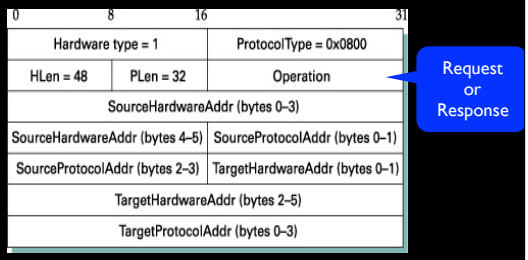
35

Address Resolution

1. Do we have the IP-MAC addresses cached?
2. Send out broadcast query
3. Look for response, and fill in cache

36

ARP Packet



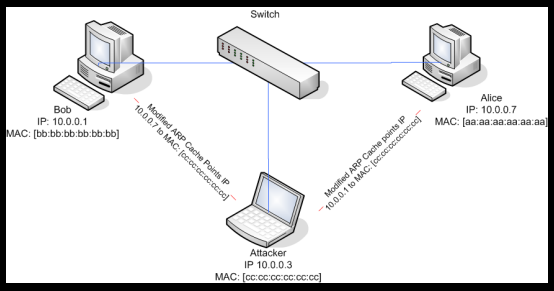
ARP

37

- Problems?
  - ARP Spoofing (http://en.wikipedia.org/wiki/ARP_spoofing)

ARP Spoofing

38



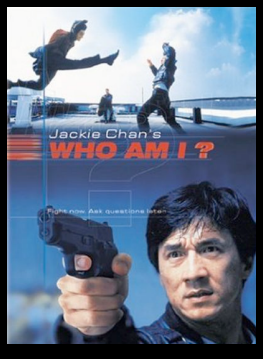
Defense: DHCP Snooping & ARP Security

DHCP

39

Dynamic Host Configuration Protocol

Who Am I?



40

DHCP

- Static configuration of hosts
  - not flexible or adaptable to changes
  - cumbersome
- Dynamic configuration
  - provide host with an IP address
  - additional information: router, boot info...

41

DHCP

1. Broadcast request: DHCPDISCOVER
2. Look for responses: DHCPOFFERs
3. Pick one and DHCPREQUEST
4. Wait for DHCPACK

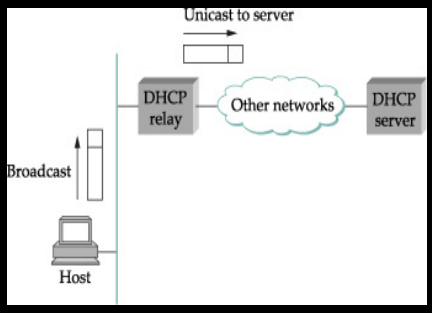
42

DHCP

Problem:
Broadcast means you need a DHCP server on every network.

Solution:
DHCP forwarding

DHCP Forwarding



43

DHCP

- IP Address is ***leased*** for a given amount of time.
- Host must ***renew*** the lease with the server.
- Server can deny renewal
  - Can request a new lease

44

ICMP

When things don't go as planned.

45

46

ICMP

Remember: Best-effort service

- Diagnostic purposes (ping)
- TTL (hops) reaches 0 at a router
- Host not reachable (network error)
- Network redirection

47

ARP, DHCP, ICMP

These protocols are at the **edge** between the **Network** and **IP** layers

- Address Resolution Protocol (ARP)
- Dynamic Host Configuration Protocol (DHCP)
- Internet Control Message Protocol (ICMP)

48

Internet Protocol (IP)

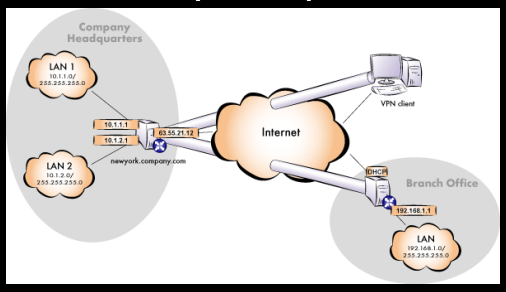
- ✓ What is an Internetwork
- ✓ Service Model
  - ✓ Datagrams, Packet Format, …
- ✓ Addressing
- ✓ Datagram Forwarding
- ✓ ARP, DHCP, ICMP, ...

Internet Protocol (IP)

- ✓ What is an Internetwork
- ✓ Service Model
  - ✓ Datagrams, Packet Format, …
- ✓ Addressing
- ✓ Datagram Forwarding
- ✓ ARP, DHCP, ICMP, ...

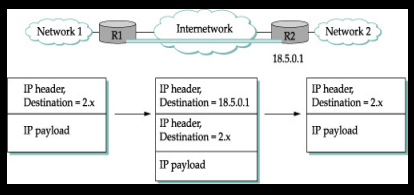
49

Virtual Networks (VPN)



50

VPN



Wrap an IP datagram in an IP datagram

51

52

Inter-networking

- ✓ Internet Protocol (IP)
- ★ Routing
- The Internet
- Multicast*
- Multi-protocol Label Switching*

53

Routing

- Network as a graph
- Distance Vector (RIP)
- Link State
  - Open Shortest Path First (OSPF)
- Mobile Routing

54

Forwarding vs Routing

- ***forwarding*** is taking an input packet and sending it out the appropriate port
- ***routing*** is the process of building forwarding tables.

55

Tables

Routing Table

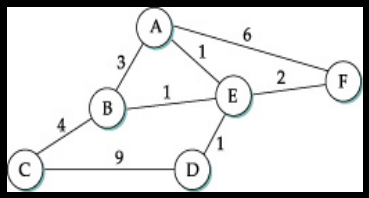
Network	Next Hop
42	192.168.1.1

Forwarding Table

Network	Port	MAC
42	1	00:BC:D4:34:32:0B

56

Network Graph

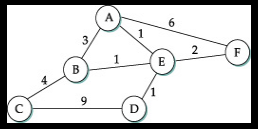


GOAL:
Find the lowest cost path between nodes

57

Distance Vector (RIP)

- Table of distance/cost to all nodes
- Distribute to immediate neighbors
- Link Down = ∞
- periodic & triggered



58

Exercise

1. Make "Routing Table" of network

Destination	Cost	Next Hop

2. Send messages to neighbors with

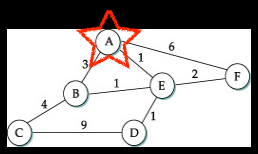
From: _____	
Destination	Cost

3. Use messages from neighbors and destroy
4. Repeat from step 2

59

Distance Vector (RIP)

Dest	Cost	Hop
B	3	B
C	∞	-
D	∞	-
E	1	E
F	6	F

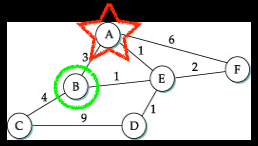


60

Distance Vector (RIP)

Dest	Cost	Hop
B	3	B
C	7	B
D	∞	-
E	1	E
F	6	F

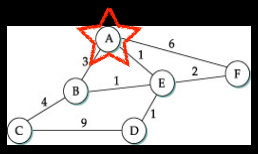
Dest	Cost	Hop
A	3	A
C	4	C
D	∞	-
E	1	E
F	∞	-



Distance Vector (RIP)

61

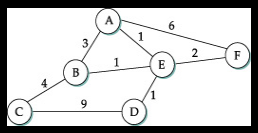
Dest	Cost	Hop
B	2	E
C	6	E
D	2	E
E	1	E
F	3	E



Distance Vector (RIP)

62

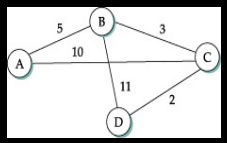
- Complete Map
- Exchange with immediate neighbors



Link State

63

- Link State Packet (LSP)
  - Distance/Cost of neighbors
  - Flood to all routers



64

Exercise

1. Make "Routing Table" of network

Confirmed	Tentative

2. Flood messages to everyone with neighbor information only, keep your own

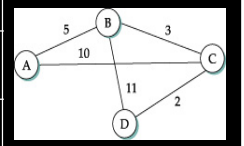
From: _____		
Neighbor	Cost	NextHop

3. Use messages from others (Dijkstra's Alg.)
4. Repeat from step 2, until tentative is empty

65

Link State

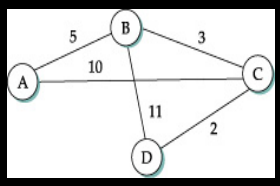
Step	Confirmed	Tentative	Replaced
1	(A,0,-)		
2	(A,0,-)	(B,5,B) (C,10,C)	
3	(A,0,-) (B,5,B)	(C,8,B) (D,14,B)	(C,10,C)
4	(A,0,-) (B,5,B) (C,8,B)	(D,10,B)	(D,14,B)
5	+(D,10,B)		



66

Link State

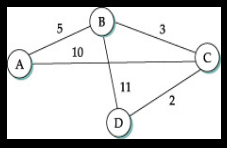
Dest	Cost	Hop
B	5	B
C	8	B
D	10	B



Link State

67

- Link State Packet (LSP)
  - Distance/Cost of neighbors
  - Flood to all routers



Metrics

68

- Bandwidth
- Latency
- "hops"
- Cost (dollars)
- Utilization
- Geo-Political boundaries

Inter-networking

69

- ✓ Internet Protocol (IP)
- ✓ Routing
- ★ The Internet
- Multicast*
- Multi-protocol Label Switching*

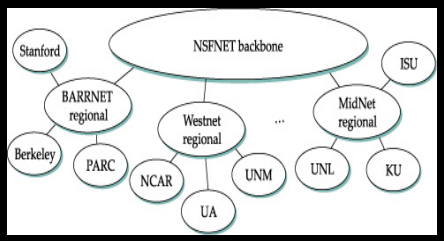
The Internet

70

- Construction
  - Autonomous Systems
- Subnetting
- Classless Routing (CIDR)
- Border Gateway Routing (BGP)
- IPv6

What does it look like

71



Simplified view - Autonomous Systems (AS)

Subnetting

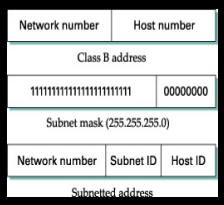
72

- Network part of address uniquely identifies a physical network
  - Class B network (16 & 16 bits) - unused
  - Class C network (24& 8 bits) - too small

Subnetting

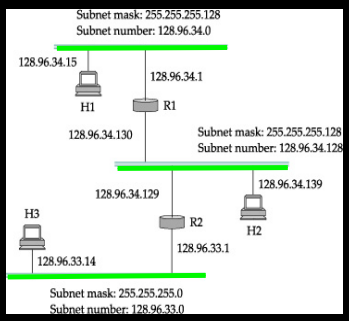
73

- Allocate one "network" to several physical networks
- internal to network
- outside routes same



Subnetting

74



Subnetting

75

- Solves scalability problem
  - improve address assignment efficiency
  - aggregates information, from a distance

Classless Routing (CIDR)

76

- Scalability problems in the backbone
  - Single location with multiple C nets
  - Lots of entries to maintain outside
  - Assignment of Class B wastes

CIDR

77

- Solution: aggregate routes
  - 192.4.16/20 = 192.4.16 to 192.4.31
  - 192.4.16/24 = 192.4.16

CIDR

78

- Solution: Assign **blocks** of Class C addresses
  - creates aggregate routes to AS

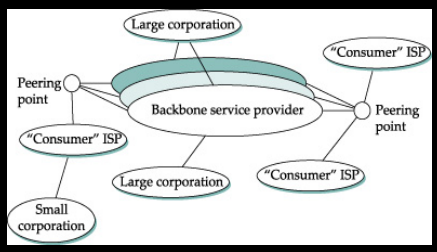
79

Interdomain Routing

- Each Autonomous System (AS)
  - Has a "border"
  - Handles its own internal routing
  - Has its own policies for in & out

80

Interdomain Routing



Stub AS, Multi-homed AS, & Transit AS

81

Interdomain Routing

- Find *some* path to destination
- Avoid *loops*
- Compliant with *policies* of ASs

82

Interdomain Routing

- Border Gateway Protocol (BGP)
  - AS numbers are *unique*
  - One node is the *speaker* for the network
  - Advertises *complete paths* to networks
  - Prevent *loops*
  - Path *withdrawn* messages

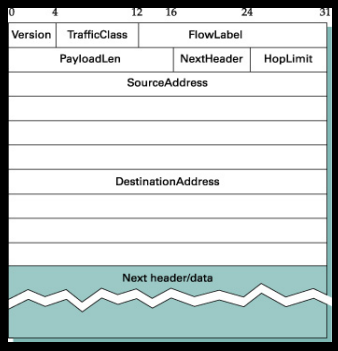
83

Interdomain Routing

- Scalable (by hierarchy)
  - AS has own internal policies and routing
  - Only AS borders run BGP on backbone
  - Aggregate networks
  - Only need to find path to border

84

IPv6



IPv6 - Why?

85

- Address exhaustion (really Class B)
- Real-time services
- Security
- Configuration
- Routing - mobile hosts

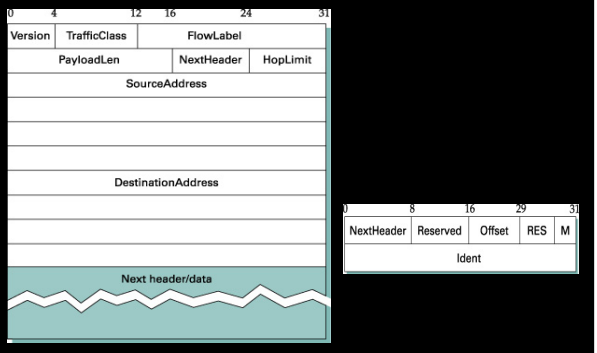
Addresses

86

- 128 bits = 3.4 x 10^{38} nodes
- Notation = x:x:x:x:x:x:x:x
  - :: = zeros; 45de:1230:FG::11:12
  - IPv4 (zero extended) ::FFFF:128.96.33.81

Packet Format

87



88

Configuration

- No more DHCP servers...
- Prefixes are assigned to networks (at AS)
  - Obtain interface ID
  - Obtain address prefix for subnet
    - local link only (1111 1110 10)
    - routers periodically advertise prefix

89

Inter-networking

- ✓ Internet Protocol (IP)
- ✓ Routing
- ✓ The Internet
- Multicast*
- Multi-protocol Label Switching*

90

Inter-networking

fin