NETWORK LAYER

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References :

- Computer Networks - A Tanenbaum - 5th edition (2011)
- Data Communications and Networking - Behrouz A.Forouzan - 4th edition (2007)
- Cisco System Inc - 2011 - Cisco Configuration Profesional User Guide.

Chapter 4: Objectives

In this chapter, you will be able to:

- Explain how network layer protocols and services support communications across data networks.
- Explain how routers enable end-to-end connectivity in a small-to-medium-sized business network.
- Determine the appropriate device to route traffic in a small-to-medium-sized business network.
- Configure a router with basic configurations.

Chapter 4:

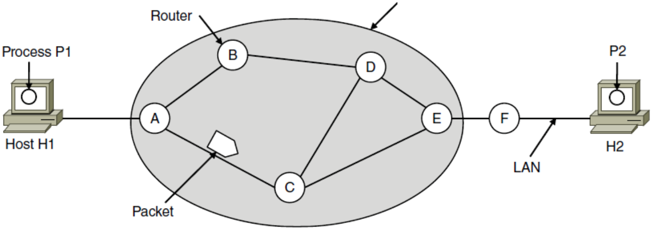
- 4.1 Network Layer Protocols
- 4.2 Routing
- 4.3 Routing Protocols
- 4.4 Routers
- 4.5 Configuring a Cisco Router

4.1 Network Layer Protocols

Network Layer Design Issues

- Store-and-forward packet switching.
- Services provided to transport layer.
- Implementation of connectionless service.
- Implementation of connection-oriented service.

Store-and-Forward Packet Switching



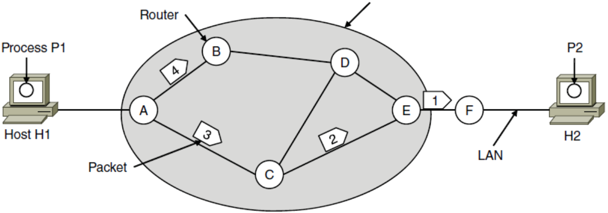
Services Provided to the Transport Layer

- Services independent of router technology.
- Transport layer shielded from number, type, topology of routers.
- Network addresses available to transport layer use uniform numbering plan.

Data Transmission Method

- Connectionless
  Connectionless communication, often referred to as CL-mode communication, is a data transmission method used in packet switching networks by which each data unit is individually addressed and routed based on information carried in each unit, rather than in the setup information of a prearranged, fixed data channel as in connection-oriented communication.

Implementation of Connectionless Service



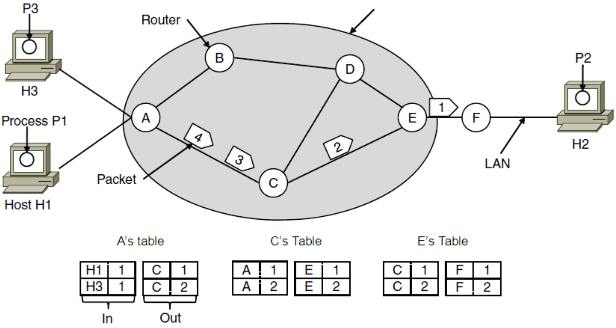
A's table (initially)		A's table (later)		C's Table		E's Table	
A	⊠	A	⊠	A	A	A	C
B	B	B	B	B	A	B	D
C	C	C	C	C	⊠	C	C
D	B	D	B	D	E	D	D
E	C	E	D	E	E	E	⊠
F	C	F	D	F	E	F	F
Dest.	Line						

Routing within a datagram network

Data Transmission Method

- Connection oriented
  Connection-oriented communication is a network communication mode in telecommunications and computer networking, where a communication session or a semi-permanent connection is established before any useful data can be transferred, and where a stream of data is delivered in the same order as it was sent.

Implementation of Connection Oriented Service



Routing within a virtual-circuit network

Comparison of Virtual Circuit and Datagram Networks

Issue	Datagram network	Virtual-circuit network
Circuit setup	Not needed	Required
Addressing	Each packet contains the full source and destination address	Each packet contains a short VC number
State information	Routers do not hold state information about connections	Each VC requires router table space per connection
Routing	Each packet is routed independently	Route chosen when VC is set up; all packets follow it
Effect of router failures	None, except for packets lost during the crash	All VCs that passed through the failed router are terminated
Quality of service	Difficult	Easy if enough resources can be allocated in advance for each VC
Congestion control	Difficult	Easy if enough resources can be allocated in advance for each VC

The Network Layer

The network layer, or OSI Layer 3, provides services to allow end devices to exchange data across the network. To accomplish this end-to-end transport, the network layer uses four basic processes:

- Addressing end devices.
- Encapsulation.
- Routing.
- De-encapsulating.

Network Layer Protocols

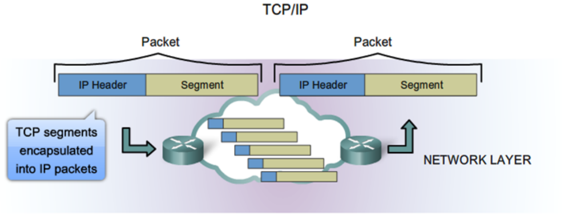
Common network layer protocols include:

- IP version 4 (IPv4)
- IP version 6 (IPv6)

Legacy network layer protocols include:

- Novell Internetwork Packet Exchange (IPX)
- AppleTalk
- Connectionless Network Service (CLNS/DECNet)

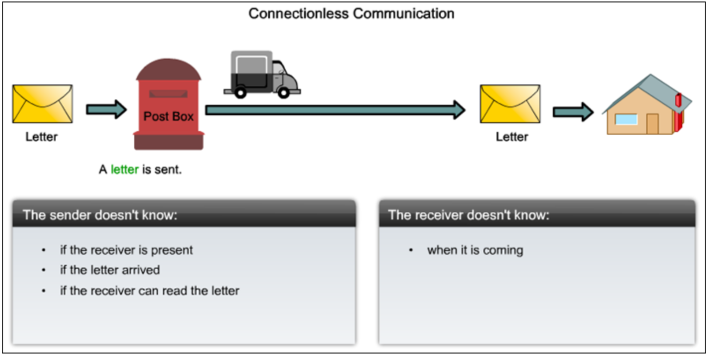
IP Components



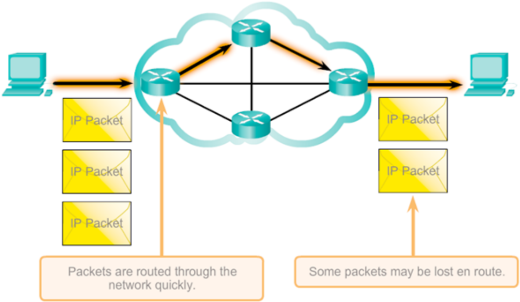
IP Packets flow through the internetwork.

- Connectionless - No connection is established before sending data packets.
- Best Effort (unreliable) - No overhead is used to guarantee packet delivery.
- Media Independent - Operates independently of the medium carrying the data.

Characteristics of the IP protocol - Connectionless

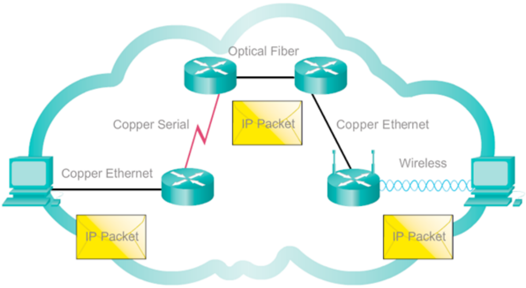


Characteristics of the IP protocol - Best Effort Delivery



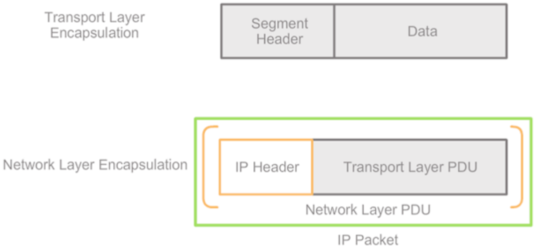
As an unreliable network layer protocol, IP does not guarantee that all sent packets will be received. Other protocols manage the process of tracking packets and ensuring their delivery.

Characteristics of the IP protocol - Media Independent



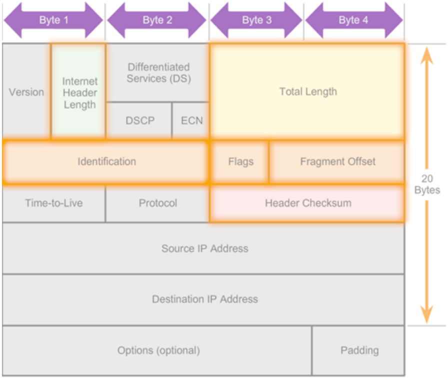
IP packets can travel over different media.

Encapsulating IP



The network layer adds a header so packets can be routed through complex networks and reach their destination. In TCP/IP based networks, the network layer PDU is the IP packet.

IPv4 Header Fields



Limitations of IPv4

- IP Address depletion
- Internet routing table expansion
- Lack of end-to-end connectivity

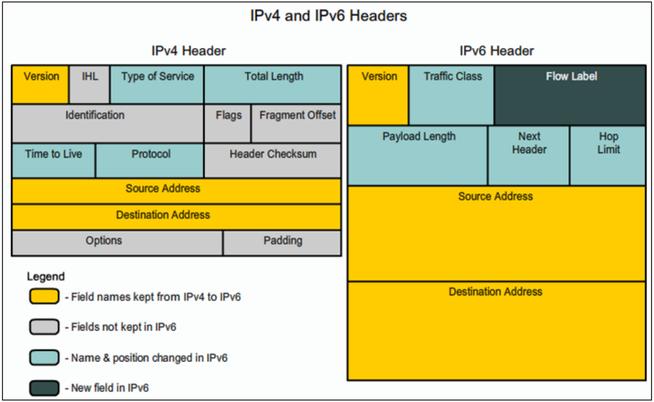
Introducing IPv6

- Increased address space
- Improved packet handling
- Eliminates the need for NAT
- Integrated security
- 4 billion IPv4 addresses (4,000,000,000)
- 340 undecillion IPv6 addresses (340,000,000,000,000,000,000,000,000,000,000,000,000)

Main advantages of the new protocol

- Extended addressing capabilies
  - Extended address space (128bit against 32bit in IPv4)
  - New type of addresses - anycast
  - Multicast addresses have ,,scope” field
- Header format simplification - faster processing in most common cases
  - No checksums in IPv6 header
  - Optional fields are moved to the extension headers
- Privacy and authentication
  - Authentication Header is not any longer optional
  - Support for ESP

Encapsulating IPv6



4.2 Routing

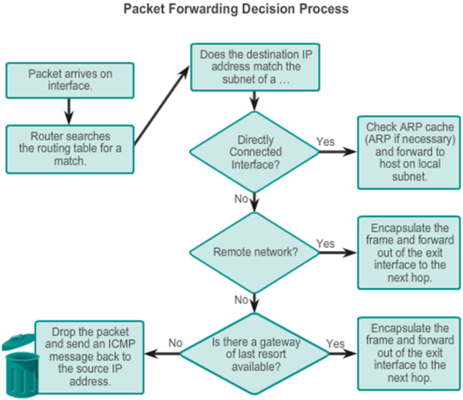
Routing

- Determining the best path to send packets
- Forwarding packets toward their destination

Routing used Router

- The router uses its routing table to determine the best path to forward the packet. When the router receives a packet, it examines its destination IP address and searches for the best match with a network address in the router's routing table.
- The routing table also includes the interface to be used to forward the packet. Once a match is found, the router encapsulates the IP packet into the data link frame of the outgoing or exit interface, and the packet is then forwarded toward its destination.

Routing Decisions

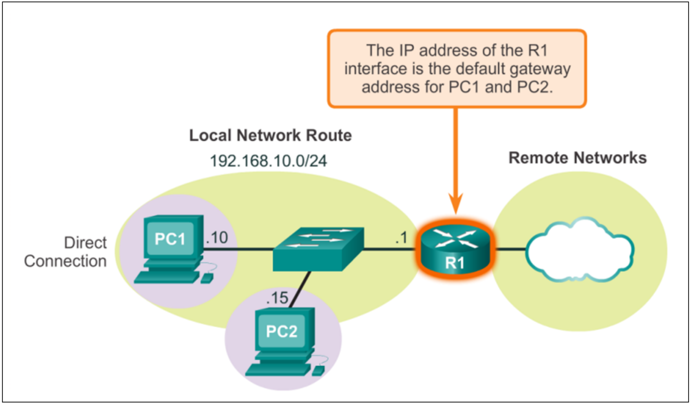


Administrative Distance

Route Source	Administrative Distance
Connected	0
Static	1
EIGRP summary route	5
External BGP	20
Internal EIGRP	90
IGRP	100
OSPF	110
IS-IS	115
External EIGRP	170
Internal BGP	200

If multiple paths to a destination are configured on a router, the path installed in the routing table is the one with the lowest Administrative Distance (AD)

Host Packet Forwarding Decision



Default Gateway

Hosts must maintain their own, local, routing table to ensure that network layer packets are directed to the correct destination network. The local table of the host typically contains:

- Direct connection
- Local network route
- Local default route

The Routing Table

A routing table is a file stored in RAM that contains information about:

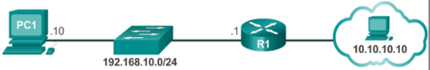
- Directly connected routes
- Remote routes
- Network or next hop associations

Routing Table Sources

The show ip route command is used to display the contents of the routing table:

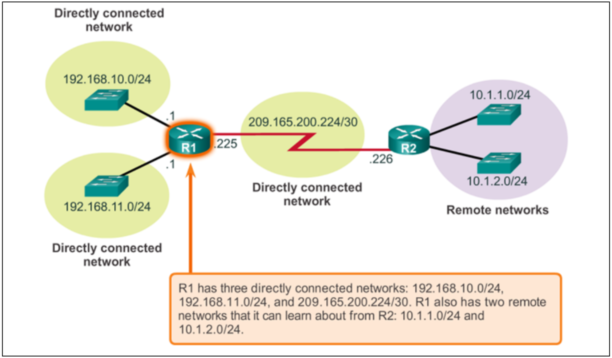
- **Local route interfaces** - Added to the routing table when an interface is configured. (displayed in IOS 15 or newer)
- **Directly connected interfaces** - Added to the routing table when an interface is configured and active.
- **Static routes** - Added when a route is manually configured and the exit interface is active.
- **Dynamic routing protocol** - Added when EIGRP or OSPF are implemented and networks are identified.

Sample IPv4 Host Routing Table

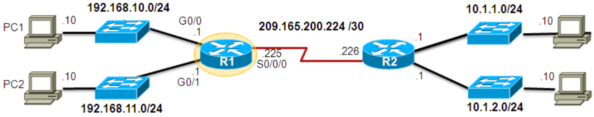



```
C:\Users\PC1> netstat -r
<Output omitted>
IPv4 Route Table
===========================================================================
Active Routes:
Network Destination        Netmask          Gateway       Interface  Metric
          0.0.0.0          0.0.0.0     192.168.10.1    192.168.10.10     25
        127.0.0.0        255.0.0.0         On-link         127.0.0.1    306
        127.0.0.1  255.255.255.255         On-link         127.0.0.1    306
  127.255.255.255  255.255.255.255         On-link         127.0.0.1    306
     192.168.10.0    255.255.255.0         On-link     192.168.10.10    281
    192.168.10.10  255.255.255.255         On-link     192.168.10.10    281
   192.168.10.255  255.255.255.255         On-link     192.168.10.10    281
        224.0.0.0        240.0.0.0         On-link         127.0.0.1    306
        224.0.0.0        240.0.0.0         On-link     192.168.10.10    281
  255.255.255.255  255.255.255.255         On-link         127.0.0.1    306
  255.255.255.255  255.255.255.255         On-link     192.168.10.10    281
===========================================================================
<Output omitted>
```

Router Packet Forwarding Decision



IPv4 Router Routing Table

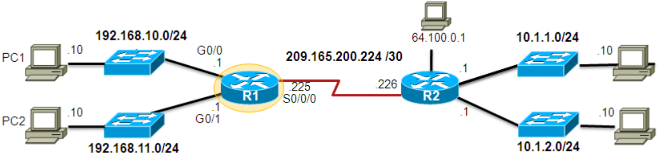



```
R1#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

     10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
D       10.1.1.0/24 [90/2170112] via 209.165.200.226, 00:00:05, Serial0/0/0
D       10.1.2.0/24 [90/2170112] via 209.165.200.226, 00:00:05, Serial0/0/0
     192.168.10.0/24 is variably subnetted, 2 subnets, 3 masks
C       192.168.10.0/24 is directly connected, GigabitEthernet0/0
L       192.168.10.1/32 is directly connected, GigabitEthernet0/0
     192.168.11.0/24 is variably subnetted, 2 subnets, 3 masks
C       192.168.11.0/24 is directly connected, GigabitEthernet0/1
L       192.168.11.1/32 is directly connected, GigabitEthernet0/1
     209.165.200.0/24 is variably subnetted, 2 subnets, 3 masks
C       209.165.200.224/30 is directly connected, Serial0/0/0
L       209.165.200.225/32 is directly connected, Serial0/0/0
R1#
```

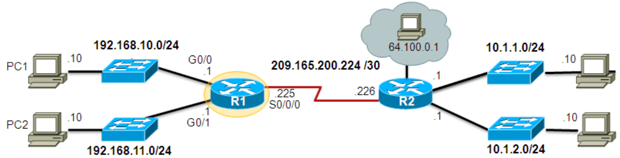
Directly Connected Routing Table Entries



A	B	C
C	192.168.10.0/24 is directly connected,	GigabitEthernet0/0
L	192.168.10.1/32 is directly connected,	GigabitEthernet0/0

A	Identifies how the network was learned by the router.
B	Identifies the destination network and how it is connected.
C	Identifies the interface on the router connected to the destination network.

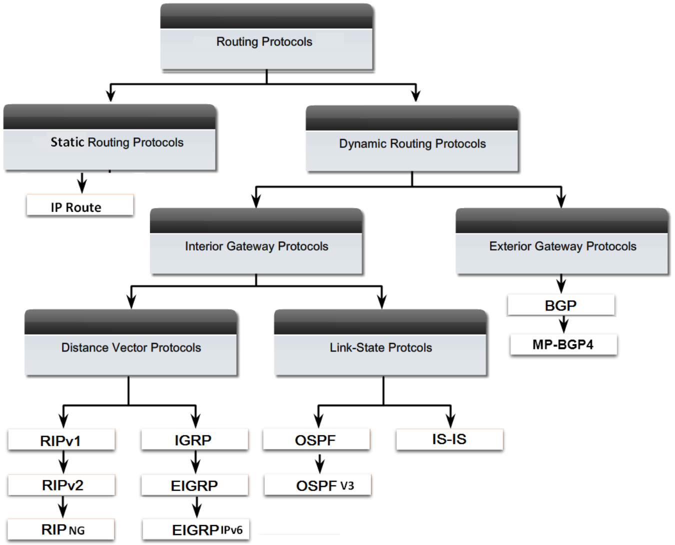
Remote Network Routing Table Entries




```
D    10.1.1.0/24 [90/2170112] via 209.165.200.226, 00:00:05, Serial0/0/0
```

A	Identifies how the network was learned by the router.
B	Identifies the destination network.
C	Identifies the administrative distance (trustworthiness) of the route source.
D	Identifies the metric to reach the remote network.
E	Identifies the next hop IP address to reach the remote network.
F	Identifies the amount of elapsed time since the network was discovered.
G	Identifies the outgoing interface on the router to reach the destination network.

4.3 Routing Protocols


Routing Protocols
Static Routing Protocols
Dynamic Routing Protocols
IP Route
Interior Gateway Protocols
Exterior Gateway Protocols
BGP
MP-BGP4
Distance Vector Protocols
Link-State Protcols
RIPv1
RIPv2
RIP NG
IGRP
EIGRP
EIGRP IPv6
OSPF
OSPF V3
IS-IS

Best Path

Best path is selected by a routing protocol based on the value or metric it uses to determine the distance to reach a network:

- A metric is the value used to measure the distance to a given network.
- Best path to a network is the path with the lowest metric.

Dynamic routing protocols use their own rules and metrics to build and update routing tables:

- Routing Information Protocol (RIP) - Hop count.
- Open Shortest Path First (OSPF) - Cost based on cumulative bandwidth from source to destination.
- Enhanced Interior Gateway Routing Protocol (EIGRP) - Bandwidth, delay, load, reliability

Dynamic Route vs Static Route

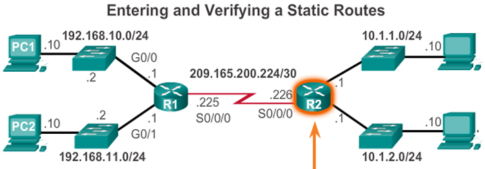
	Dynamic routing	Static routing
Configuration Complexity	Generally independent of the network size	Increases with network size
Required administrator knowledge	Advanced knowledge required	No extra knowledge required
Topology changes	Automatically adapts to topology changes	Administrator intervention required
Scaling	Suitable for simple and complex topologies	Suitable for simple topologies
Security	Less secure	More secure
Resource usage	Uses CPU, memory, link bandwith	No extra resources needed
Predictability	Route depends on the current topology	Route to destination is always the same

Static Routes

Static routes and default static routes can be implemented after directly connected interfaces are added to the routing table:

- Static routes are manually configured.
- They define an explicit path between two networking devices.
- Static routes must be manually updated if the topology changes.
- Their benefits include improved security and control of resources.
- Configure a static route to a specific network using the **ip route network mask** *next-hop-ip* — *exit-intf* command.
- A default static route is used when the routing table does not contain a path for a destination network.
- Configure a default static route using the **ip route 0.0.0.0 0.0.0.0** *exit-intf* — *next-hop-ip* command.

Static Routes Example

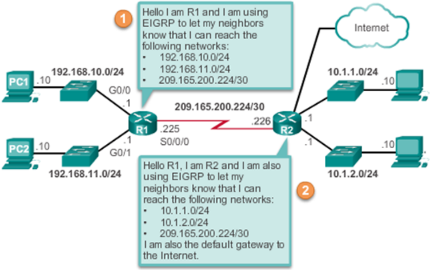



```
R2(config)# ip route 192.168.10.0 255.255.255.0 s0/0/0
R2(config)# ip route 192.168.11.0 255.255.255.0 209.165.200.225
R2(config)# exit
R2#
R2# show ip route | begin Gateway
Gateway of last resort is not set

      10.0.0.0/8 is variably subnetted, 4 subnets, 2 masks
C       10.1.1.0/24 is directly connected, GigabitEthernet0/0
L       10.1.1.1/32 is directly connected, GigabitEthernet0/0
C       10.1.2.0/24 is directly connected, GigabitEthernet0/1
L       10.1.2.1/32 is directly connected, GigabitEthernet0/1
S     192.168.10.0/24 is directly connected, Serial0/0/0
S     192.168.11.0/24 [1/0] via 209.165.200.225
      209.165.200.0/24 is variably subnetted, 2 subnets, 2 masks
C       209.165.200.224/30 is directly connected, Serial0/0/0
```

Dynamic Routing

Dynamic routing is used by routers to share information about the reachability and status of remote networks. It performs network discovery and maintains routing tables.



IPv4 Routing Protocols

- **EIGRP** Enhanced Interior Gateway Routing Protocol.
- **OSPF** Open Shortest Path First.
- **IS-IS** Intermediate System-to-Intermediate System.
- **RIP** Routing Information Protocol.

IPv6 Routing Protocols

- **RIPng** - RIP next generation.
- **OSPFv3**.
- **EIGRP** for IPv6.
- **MP-BGP4** - Multicast Protocol-Border Gateway Protocol.

Routing Algorithms (1)

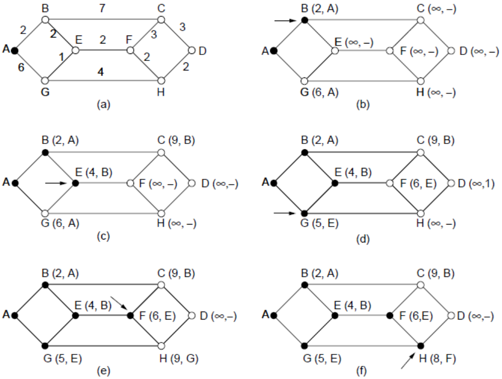
- Optimality principle
- Shortest path algorithm
- Flooding
- Distance vector routing
- Link state routing
- Routing in ad hoc networks

Routing Algorithms (2)

- Broadcast routing
- Multicast routing
- Anycast routing
- Routing for mobile hosts
- Routing in ad hoc networks

Shortest Path Algorithm (1)

The first five steps used in computing the shortest path from A to D. The arrows indicate the working node



Shortest Path Algorithm (2)

Dijkstras algorithm to compute the shortest path through a graph.

```
#define MAX_NODES 1024                    /* maximum number of nodes */
#define INFINITY 1000000000               /* a number larger than every maximum path */
int n, dist[MAX_NODES][MAX_NODES];        /* dist[i][j] is the distance from i to j */

void shortest_path(int s, int t, int path[])
{ struct state {                          /* the path being worked on */
      int predecessor;                    /* previous node */
      int length;                         /* length from source to this node */
      enum {permanent, tentative} label;  /* label state */
  } state[MAX_NODES];

  int i, k, min;
  struct state *p;
```

Shortest Path Algorithm (3)

Dijkstras algorithm to compute the shortest path through a graph.

```
for (p = &state[0]; p < &state[n]; p++) {        /* initialize state */
    p->predecessor = –1;
    p->length = INFINITY;
    p->label = tentative;
}
state[t].length = 0;  state[t].label = permanent;
k = t;                                           /* k is the initial working node */
do {                                             /* Is there a better path from k? */
    for (i = 0; i < n; i++)                      /* this graph has n nodes */
        if (dist[k][i] != 0 && state[i].label == tentative) {
            if (state[k].length + dist[k][i] < state[i].length) {
                state[i].predecessor = k;
                state[i].length = state[k].length + dist[k][i];
            }
        }
```

Shortest Path Algorithm (4)

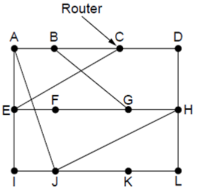
Dijkstras algorithm to compute the shortest path through a graph.

```
    /* Find the tentatively labeled node with the smallest label. */
    k = 0; min = INFINITY;
    for (i = 0; i < n; i++)
         if (state[i].label == tentative && state[i].length < min) {
              min = state[i].length;
              k = i;
         }
    state[k].label = permanent;
} while (k != s);

/* Copy the path into the output array. */
i = 0;  k = s;
do {path[i++] = k; k = state[k].predecessor; } while (k >= 0);
}
```

Distance Vector Routing

(a) A network. (b) Input from A, I, H, K, and the new routing table for J.



(a)

To	A	I	H	K	New estimated delay from J	Line
A	0	24	20	21	8	A
B	12	36	31	28	20	A
C	25	18	19	36	28	I
D	40	27	8	24	20	H
E	14	7	30	22	17	I
F	23	20	19	40	30	I
G	18	31	6	31	18	H
H	17	20	0	19	12	H
I	21	0	14	22	10	I
J	9	11	7	10	0	–
K	24	22	22	0	6	K
L	29	33	9	9	15	K
	JA delay is 8	JI delay is 10	JH delay is 12	JK delay is 6		

Vectors received from J's four neighbors

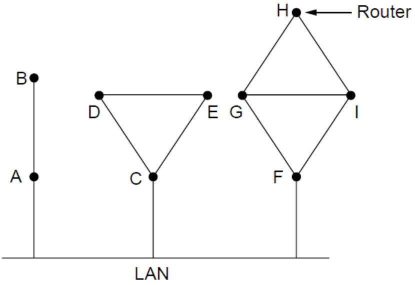
New routing table for J

(b)

Link State Routing

- Discover neighbors, learn network addresses.
- Set distance/cost metric to each neighbor.
- Construct packet telling all learned.
- Send packet to, receive packets from other routers.
- Compute shortest path to every other router.

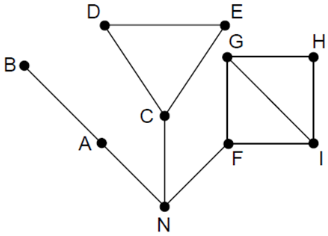
Learning about the Neighbors (1)



Nine routers and a broadcast LAN.

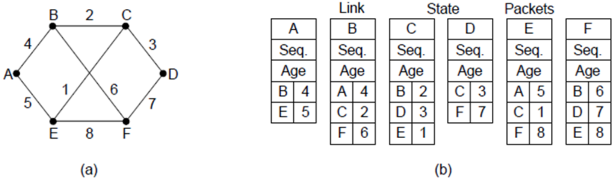
Road to 2025
IT Based International Standard

Learning about the Neighbors (2)



A graph model of previous slide.

Building Link State Packets



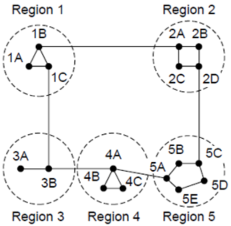
(a) A network. (b) The link state packets for this network.

Distributing the Link State Packets

Source	Seq.	Age	Send flags A	Send flags C	Send flags F	ACK flags A	ACK flags C	ACK flags F	Data
A	21	60	0	1	1	1	0	0	
F	21	60	1	1	0	0	0	1	
E	21	59	0	1	0	1	0	1	
C	20	60	1	0	1	0	1	0	
D	21	59	1	0	0	0	1	1	

The packet buffer for router B in previous slide.

Hierarchical Routing



(a)

Full table for 1A

Dest.	Line	Hops
1A	–	–
1B	1B	1
1C	1C	1
2A	1B	2
2B	1B	3
2C	1B	3
2D	1B	4
3A	1C	3
3B	1C	2
4A	1C	3
4B	1C	4
4C	1C	4
5A	1C	4
5B	1C	5
5C	1B	5
5D	1C	6
5E	1C	5

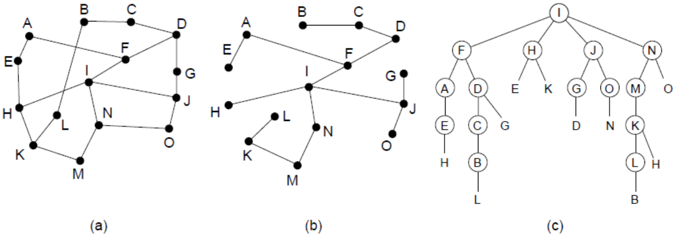
(b)

Hierarchical table for 1A

Dest.	Line	Hops
1A	–	–
1B	1B	1
1C	1C	1
2	1B	2
3	1C	2
4	1C	3
5	1C	4

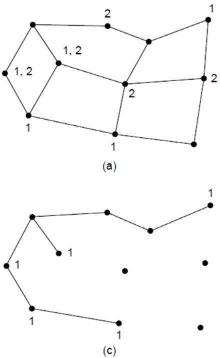
(c)

Broadcast Routing



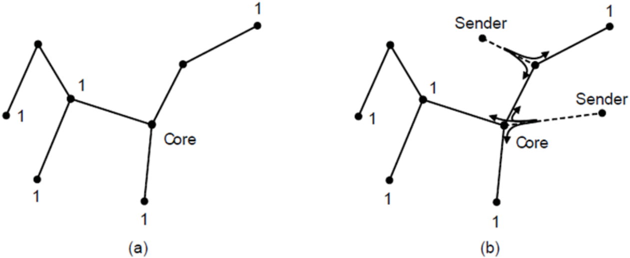
Reverse path forwarding. (a) A network. (b) A sink tree. (c) The tree built by reverse path forwarding.

Multicast Routing (1)



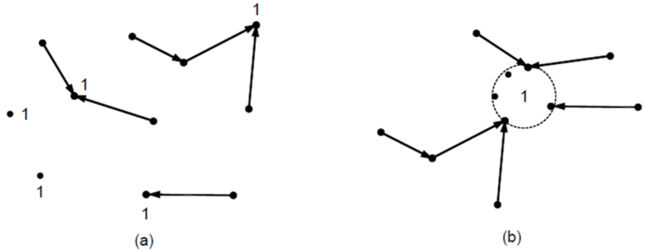
(a) A network. (b) A spanning tree for the leftmost router. (c) A multicast tree for group 1. (d) A multicast tree for group 2.

Multicast Routing (2)



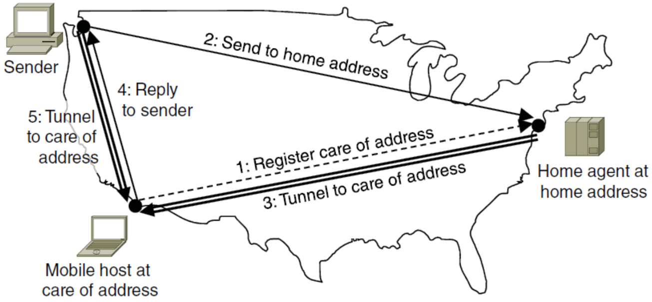
(a)Core-based tree for group 1. (b)Sending to group 1.

Anycast Routing

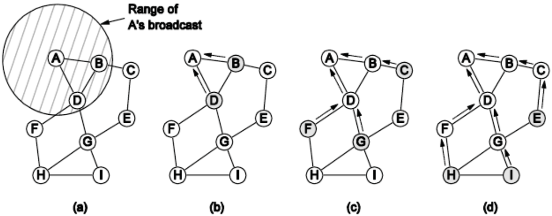


Anycast routes to group 1. Topology seen by the routing protocol.

Routing for Mobile Hosts



Routing in Ad Hoc Networks



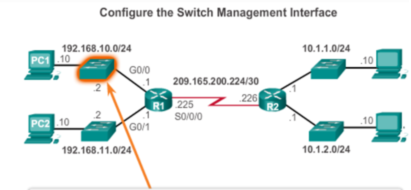
(a) Range of As broadcast. (b) After B and D receive it. (c) After C, F, and G receive it. (d) After E, H, and I receive it.

4.4 Routers

(a) Router Cisco. (b) Router Juniper. (c) Router Mikrotik . (d) Router HP. (3) Router 3Com.

4.5 Configuring a Cisco Router

Enable IP on a Switch




```
S1(config)#interface vlan 1
S1(config-if)#ip address 192.168.10.2 255.255.255.0
S1(config-if)#no shutdown
%LINK-5-CHANGED: Interface Vlan1, changed state to up
S1(config-if)#exit
S1(config)#
S1(config)#ip default-gateway 192.168.10.1
S1(config)#
```

Network infrastructure devices require IP addresses to enable remote management.

Configure Basic Router Settings

```
R1(config)#enable secret class
R1(config)#
R1(config)#line console 0
R1(config-line)#password cisco
R1(config-line)#login
R1(config-line)#exit
R1(config)#
R1(config)#line vty 0 4
R1(config-line)#password cisco
R1(config-line)#login
R1(config-line)#exit
R1(config)#
R1(config)#service password-encryption
R1(config)#
```

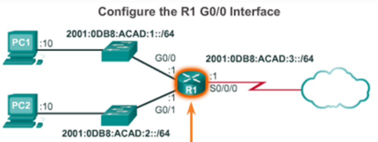
Network infrastructure devices require IP addresses to enable remote management.

Configure an IPv4 Router Interface


```
R1(config)#interface gigabitethernet 0/0
R1(config-if)#description Link to LAN 1
R1(config-if)#ip address 192.168.10.1 255.255.255.0
R1(config-if)#no shutdown
R1(config-if)#exit
R1(config)#
*Jan 30 22:04:47.551: %LINK-3-UPDOWN: Interface
GigabitEthernet0/0, changed state to down
R1(config)#
*Jan 30 22:04:50.899: %LINK-3-UPDOWN: Interface
GigabitEthernet0/0, changed state to up
*Jan 30 22:04:51.899: %LINEPROTO-5-UPDOWN: Line protocol on
Interface GigabitEthernet0/0, changed state to up
R1(config)#
```

Name the device, Secure management access , Configure a banner, Save the Configuration

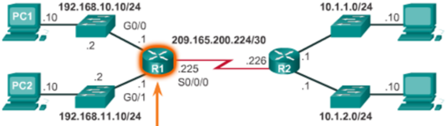
Configure an IPv6 Router Interface




```
R1(config)#interface gigabitethernet 0/0
R1(config-if)#description Link to LAN 1
R1(config-if)#ipv6 address 2001:db8:acad:1::1/64
R1(config-if)#no shutdown
R1(config-if)#exit
R1(config)#
*Feb  3 21:38:37.279: %LINK-3-UPDOWN: Interface
GigabitEthernet0/0, changed state to down
*Feb  3 21:38:40.967: %LINK-3-UPDOWN: Interface
GigabitEthernet0/0, changed state to up
*Feb  3 21:38:41.967: %LINEPROTO-5-UPDOWN: Line protocol on
Interface GigabitEthernet0/0, changed state to up
R1(config)#
```

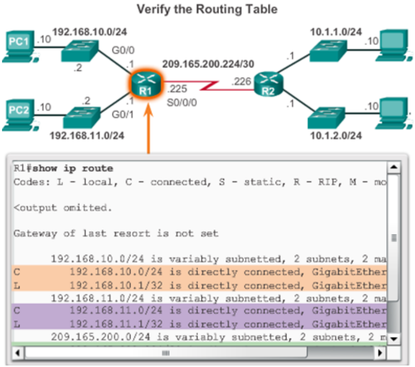
Configure a Loopback Interface

Configure the Loopback0 Interface



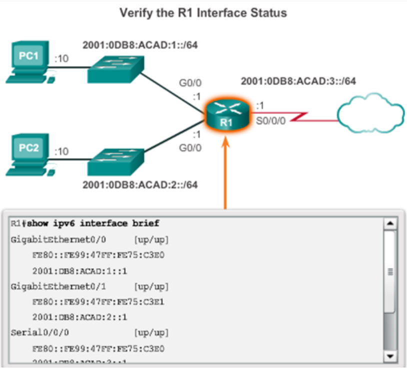

```
R2(config)#interface loopback 0
R2(config-if)#ip address 10.0.0.1 255.255.255.0
R2(config-if)#exit
R1(config)#
*Jan 30 22:04:50.899: %LINK-3-UPDOWN: Interface loopback0,
changed state to up
*Jan 30 22:04:51.899: %LINEPROTO-5-UPDOWN: Line protocol on
Interface loopback0, changed state to up
```

Verify Interface Settings



A loopback interface is a logical interface that is internal to the router:

Verify Interface Settings



show ip interfaces brief, show ip route, show running-config, show interfaces, show ip interfaces


Terima kasih!