Session 4B & 4C

IP Routing

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Session 4B & 4C: Focus

- Basic Routing Concepts
  - Static Vs Dynamic Routing
  - DHCP Revisited
  - Default Router or Gateway
  - Internet Gateway
  - Route Table
  - Route Table Maintenance
  - Datagram Forwarding - Recap
- Autonomous Systems and Routing Domains

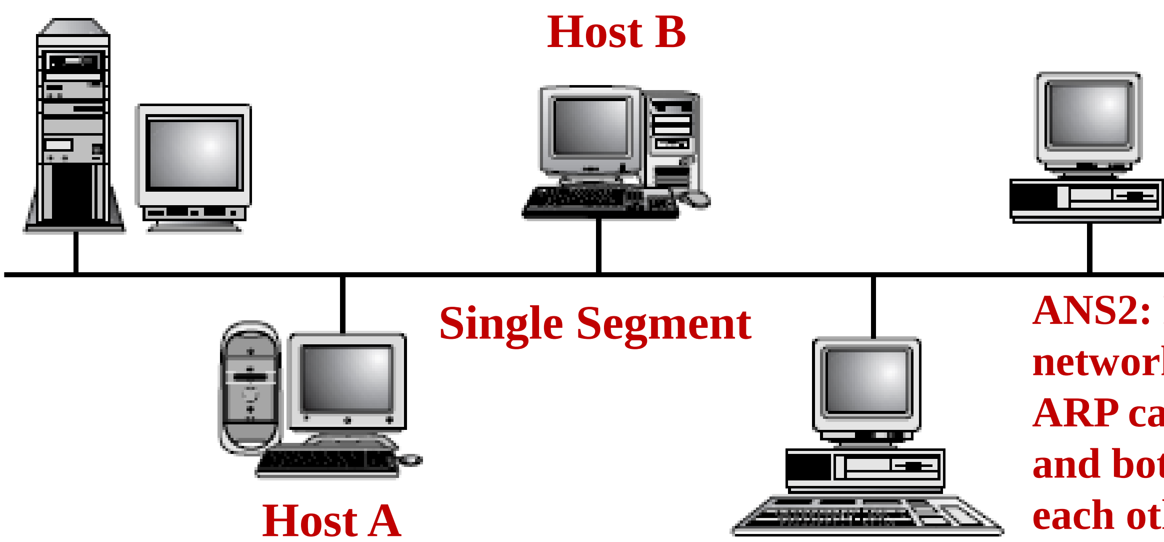
Course page where the course materials will be posted as the course progresses:

IP Routing

New Reference: **Ref5**: IP Routing Primer Plus By Heather Osterloh

Chapters 3 & 4: IP Routing and RIP

Basic Routing Concepts



Q1. For Host A and Host B to communicate with each other, is there a need for a Router? **ANS1: No**

Q2. Why is it not needed?

ANS2: Because both the hosts are on the same network. If the IP addresses of them are known ARP can be used to get their MAC addresses and both the hosts can communicate with each other without any routers involved.

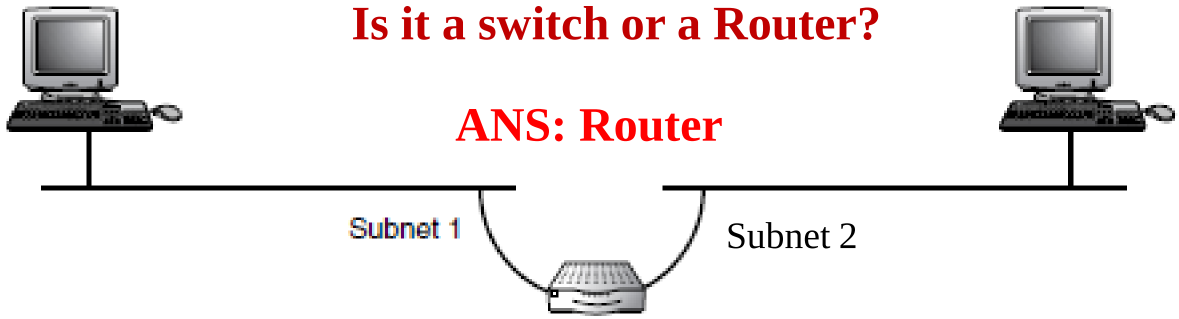
There is no routing involved here, only forwarding.

- **Routing** involves the **delivery of datagrams** between **end systems** located on **different networks**.
- **Without routers** and **routing protocols**, end **host communication** would be **limited** to **only** those **systems** on the **same physical segment**.

Communication over Multiple Segments

Is it a switch or a Router?

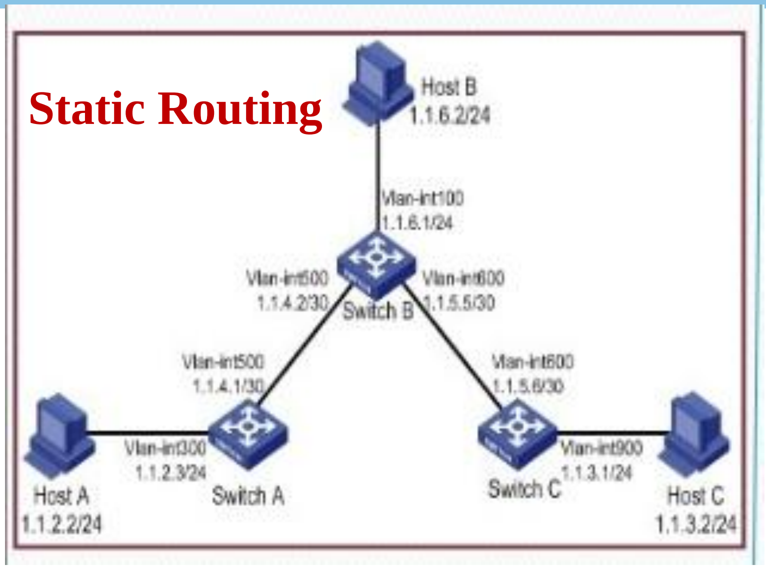
ANS: Router

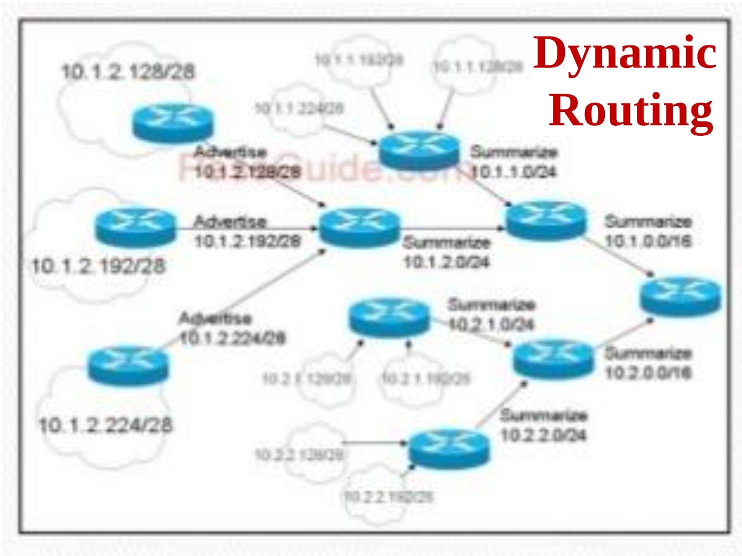


Note: **Different subnets** are **different networks**.

- **Routers** provide the **physical connection between networks**.
- **Routers** must be **configured** with some type of routing mechanism to **enable communication** between hosts **beyond their local segments**.
- Routers **connect multiple subnets** together allowing **remote hosts** to **communicate**.
- Above, the router forwards traffic between hosts on subnets 1 and 2.

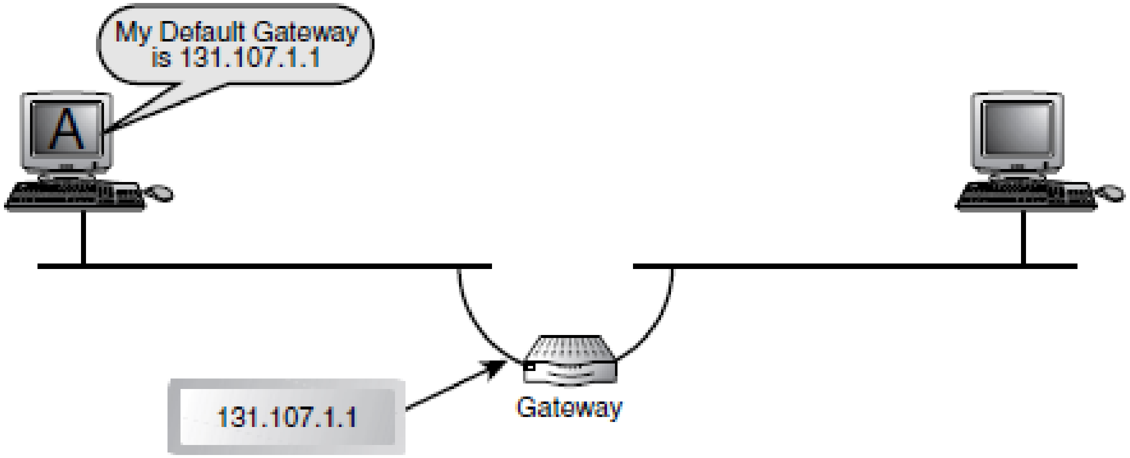
Static Vs Dynamic Routing





- **Routing mechanisms** are either **static** or **dynamic** in nature.
- Static means manual configuration of routing table entries.
  - Possible on small networks
- Dynamic mechanisms involve routing protocols that facilitate the exchange of information, allowing routers to learn and adapt to changes in a network's topology and update their routing tables
  - Using routing protocols (RIP, OSPF, BGP etc.)

Routing: Static and Dynamic



How does it dynamically find default router's IP address?

ANS: DHCP

- Whether a router is configured statically or dynamically or a combination of both the objective is the same, to facilitate communication between remote hosts.
- For hosts to communicate with other hosts located on different networks, end systems must be configured with the IP address of at least one local router (also referred to as the **default router**).
- **Hosts** may be **statically configured** or **dynamically discover** their **local router's IP address**.

Dynamic Host Configuration Protocol (DHCP)

Quiz 1: DHCP is in which layer?

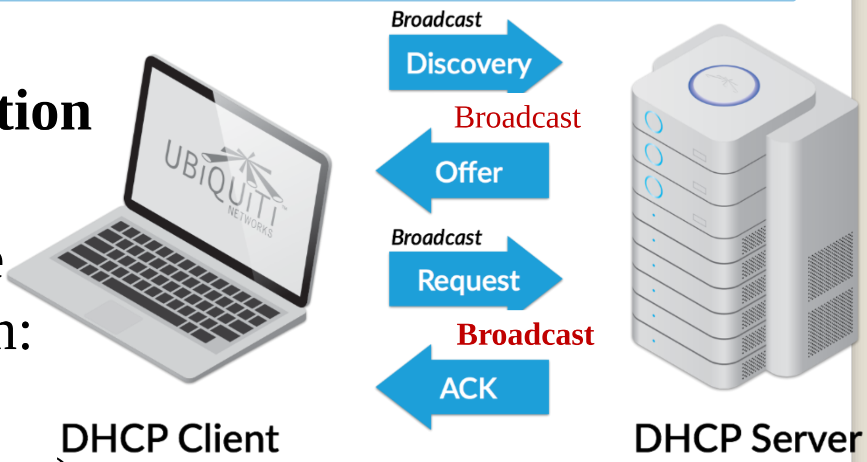
- DHCP is considered to be running on which layer?
  A. L2
  B. L3
  C. L4
  D. L7

ANS: **D**

OSI Layer	Role in DHCP
Layer 7 (Application)	**DHCP Protocol logic** – IP address assignment, options.
Layer 4 (Transport)	**UDP (Port 67, 68)** – Used for message delivery.
Layer 3 (Network)	**IP** – Broadcast IP (255.255.255.255) for discovery.
Layer 2 (Data Link)	**MAC address** – Identifies devices when IP is not available.

1. DHCP: Revisited

- DHCP allows a **server** to dynamically distribute **IP addressing** and **configuration information** to clients.
- Normally the DHCP server provides the client with at least this basic information:
  - **IP Address** (for the client)
  - **Subnet mask** (of the network the host is on)
  - **Default Gateway** (or IP address of the default router)



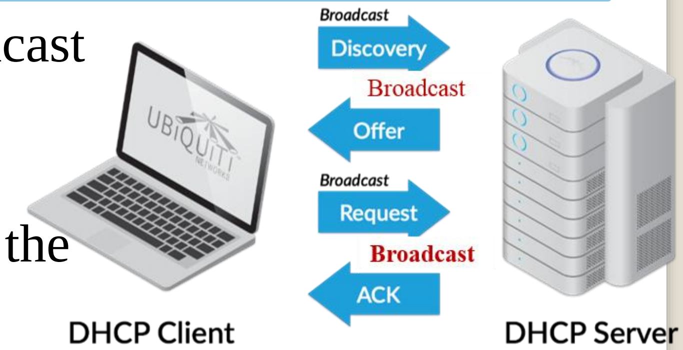
DHCP ACK from the **DHCP Server** contains all the **information** needed by the **DHCP Client. Client is configured fully after the successful reception of ACK**

Source MAC addr	Dest MAC addr	Source IP addr	Dest IP addr	Packet Description
Client	Broadcast	0.0.0.0	255.255.255.255	DHCP Discover
DHCPsrvr	Broadcast	DHCPsrvr	255.255.255.255	DHCP Offer
Client	Broadcast	0.0.0.0	255.255.255.255	DHCP Request
DHCPsrvr	Broadcast	DHCPsrvr	255.255.255.255	DHCP ACK

DHCP: Dynamic Host Configuration Protocol

Ref: DHCP Explained

2. DHCP: Revisited



- The Destination IP address of DHCP_ACK is a broadcast address, because client's IP address is not yet set.
- But, why should the destination MAC address of DHCP_ACK needs to be a broadcast address, though the DHCP server knows the Client's MAC address?
- The reason is that when the IP address of a client is not yet set, some IP protocol stacks running on the clients on the client may not be able to receive **unicast DHCP packets**, till the IP address is set. So, only broadcast messages are exchanged also on L2 (datalink layer) till the DHCP_ACK message.
- The reason for the OFFER and REQUEST phases is that there can be many DHCP servers in a network and the client needs to choose one of them who responds with an offer, to send the DHCP Request.
- Remember IP addresses allotted also has some lease period the IP address is valid.

Source MAC addr	Dest MAC addr	Source IP addr	Dest IP addr	Packet Description
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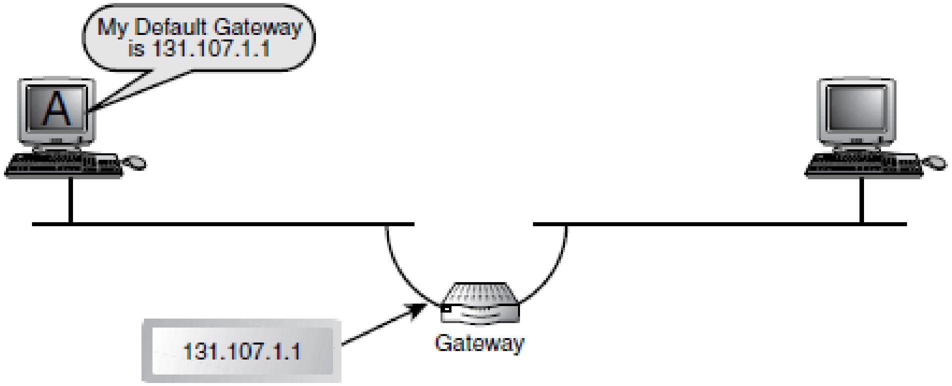
DHCPsrvr	Broadcast	DHCPsrvr	255.255.255.255	DHCP Offer
Client	Broadcast	0.0.0.0	255.255.255.255	DHCP Request
DHCPsrvr	Broadcast	DHCPsrvr	255.255.255.255	DHCP ACK

Ref: DHCP Standard

Default Router or Gateway

Default Router or Gateway

- The terms **gateway** and **router** are used interchangeably within the industry to describe a router.

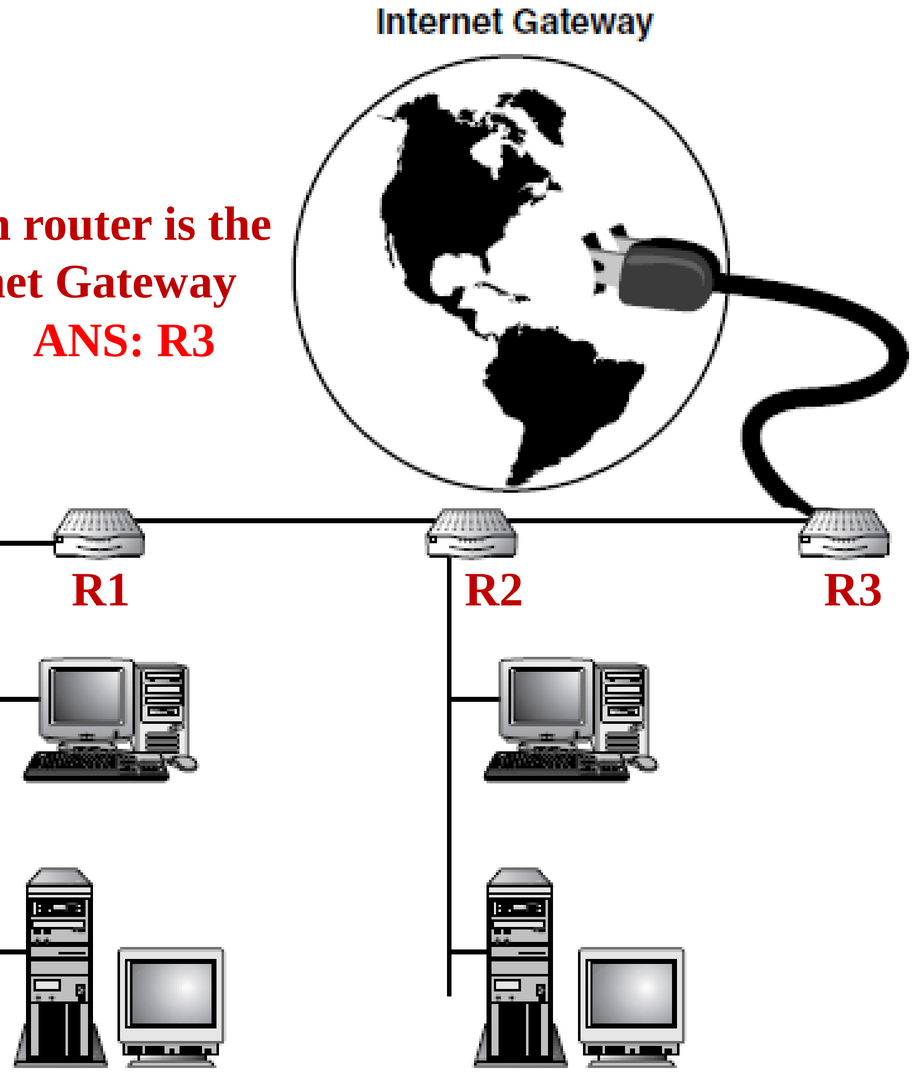


- The local router (131.107.1.1) is the **exit** and/or **entry point connecting** the **network** and its **local hosts** to the **outside world**.
- The reference to the "***outside world***" does not necessarily mean the Internet.
- Remember that hosts are limited to communicating with hosts connected to the same network unless a router is present.
- The ***outside world*** could simply be a **single network** on the **other side of this router** or it could be a series of networks connected through multiple routers leading out to the **Internet**

Internet Gateway

- A typical network with multiple internal subnets may contain a router providing a connection to the Internet.
- The **router** providing access to the Internet has one interface connected to the inside network and one connected to the **outside world**, is called the **Internet Gateway**.

Which router is the Internet Gateway here? ANS: R3



Route Table

Route Table

- All routers must have a local route table.
- Routers use different routing mechanisms to build and maintain a table known as a route table (also referred to as a forwarding database). - We will study them shortly.
- Several routing mechanisms exist (directly connected, static, default and dynamic).
- These **mechanisms** serve as route table **input sources** providing a router with network and subnet information necessary **to build** and **maintain** the **route table**.
- No matter what the source, the end result is the same. The router builds a table that identifies known **networks** (**cities**) and **subnets** (**streets**).
  - If we **compare** computer **network system** with **postal system**, **networks** correspond to **cities** and **streets** in **those cities** correspond to **subnets**.
  - Remember, the **network ID** part of the **IP address** will be in the **same range** for **all the subnets** of a **network**.
  - A router which understands subnet masks, can identify the subnets too.

Route Table: Multiple Entries for the same Destination

- If **multiple paths exist** to a **destination**, **more than one route** may be **included** in the **route table**.
- Typically, when more than one path to a destination exists, one path needs to be selected (as the best path) by the routing protocol and placed in the route table.
- This would be the primary (active) path the router would use to forward the traffic to that destination.
- However, some routing protocols support **load balancing** across multiple paths.
- In those cases, more than one path could become active for the destination and entries of both the paths are placed in the route table.
- Then, all the active paths could then be used by the router while forwarding the IP datagrams, thus balancing the traffic load across those paths.

Route Table: Maintenance

- Once a router has built its route table, it must accurately maintain the information contained in it, based on any changes happening to the network. E.g: Link is down or link is not reliable due to more errors, etc.
- Maintenance is done either through
  - **Manual configuration** of routes by an **administrator** or
  - Learned route information through the use of **dynamic routing protocols**.
- Whatever be the method, **accuracy** is key to a router's capability to successfully forward traffic.
- The contents of the route table are only as good as the information entered into the route table.
- Successful communication between remote systems depends on the maintenance of this information on routers.
- Bad information leads to bad forwarding decisions.
- Good information leads to good path selection.

Q: What **happens** when a **bad decision** is taken **by a router**?

ANS: The IP packet may go on a wrong path and can potentially get dropped because of TTL reaching a zero value.

Datagram Forwarding

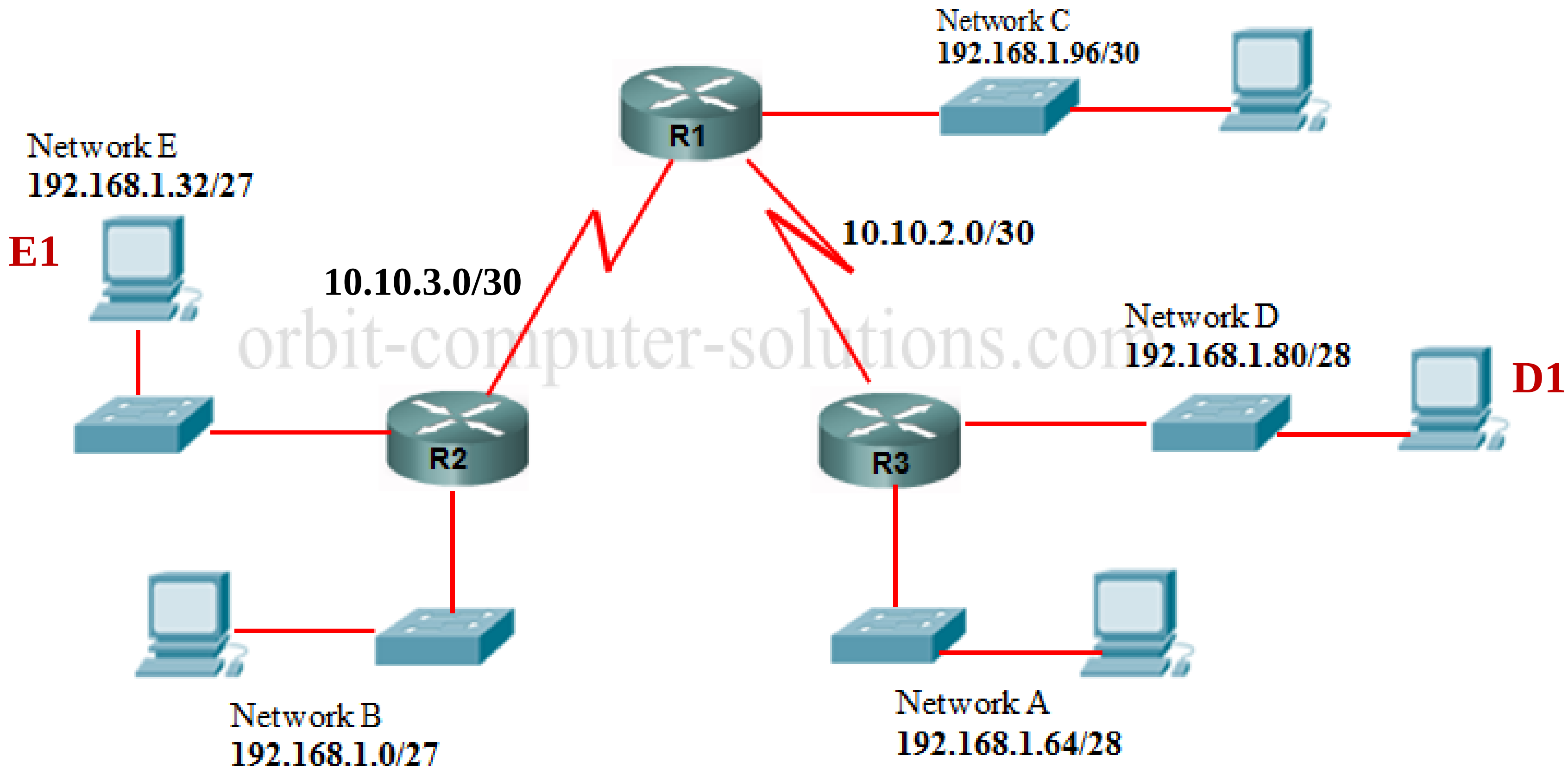
1. Datagram Forwarding: Recap

What happens when a router receives a frame in one of its interfaces?

1. It strips off the Data Link header and trailer and passes the datagram to the upper layer routing process.
2. The router examines the **logical destination address** (**destination IP**), conducting a BITwise ANDing comparison against its local mask to determine the destination network address (city and/or street).

2. Datagram Forwarding: Recap

3. The **router checks** its local cached **route table** to see if it has a **specific route** to the destination network, subnet, or end host and which local interface should be used to reach the destination.



3. Datagram Forwarding: Recap

3. If the destination network address matches a directly attached network or subnet, the router uses a local interface in an **attempt** to **locate the recipient** (end system) on that subnet using the end host's IP address.
   - If the router determines that the destination network is not local, the router identifies the **local interface** and **IP address of the next hop router** it will use to reach this destination.
   - If a route to the specific destination network does not exist in the route table, the router looks to see if a **default route** is present.
   - A default route is a route used as a last resort when no other route to a destination exists within the route table.
   - If there is **no default route** specified, it sends a **routing error** in the form of an **ICMP Destination Unreachable** message to the **originating host**. ICMP was discussed earlier.

ICMP: Internet Control Message Protocol

Is **ICMP** a L2 or L3 or L4 or L7 protocol?
ANS: L3

4. Datagram Forwarding: Recap

4. Once the IP address of either the destination end system or the next hop router has been identified, the router must resolve this address to a MAC address for delivery.
   - The router accomplishes IP-to-MAC resolution by examining its local ARP (the Address Resolution Protocol is a broadcast-based protocol used to resolve IP addresses to MAC addresses) cache first to see if it has resolved the address recently for the destination host or next hop router.
   - If an IP address to MAC address mapping resides in cache, the resolution is complete.
   - If the IP address does not exist in the local ARP cache, the router broadcasts a local ARP request to resolve the network address to a physical address (MAC).

5. Datagram Forwarding: Recap

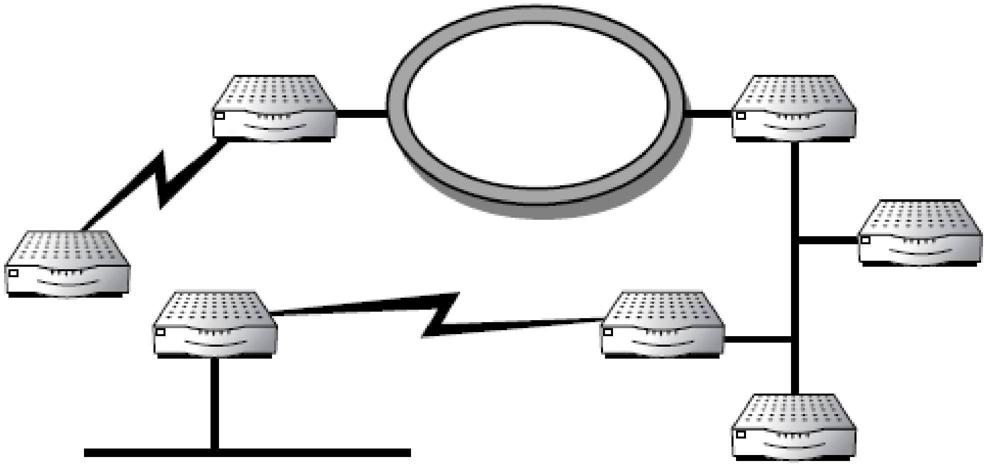
5. Once the IP address has been resolved, the router then uses this information to re-encapsulate the Data Link portion of the datagram.
   - Re-encapsulation does not change the logical IP addresses of the source and destination hosts.
   - The router does however add its own MAC address (of the outbound interface) and the destination host or next hop router's MAC address to the Data Link header.
   - The router also calculates a **new CRC**, adding this to the end of the datagram as a trailer.
- Although routers **do not modify** the **source** and **destination IP address** information they do **modify some parameters** within the **IP header**.
- For instance, the **TTL timer** is decremented by at least 1 hop by each forwarding router.
  - If the TTL becomes zero, router drops the packet and generates an ICMP message back to the sender (source IP) with the reasoning.
- Because changing the TTL value is a modification to the datagram, the IP header checksum value must be recalculated.

6. Datagram Forwarding: Recap

6. After re-encapsulation, it sends the frame out the local interface either directly to the destination host or to the next hop router for forwarding.
7. The next hop router then performs the same process until the datagram reaches the final destination network.

Autonomous Systems and Routing Domains

Autonomous Systems or Routing Domain

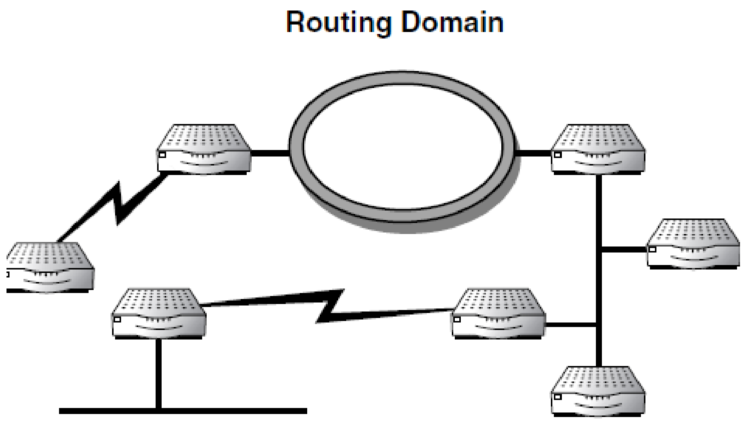


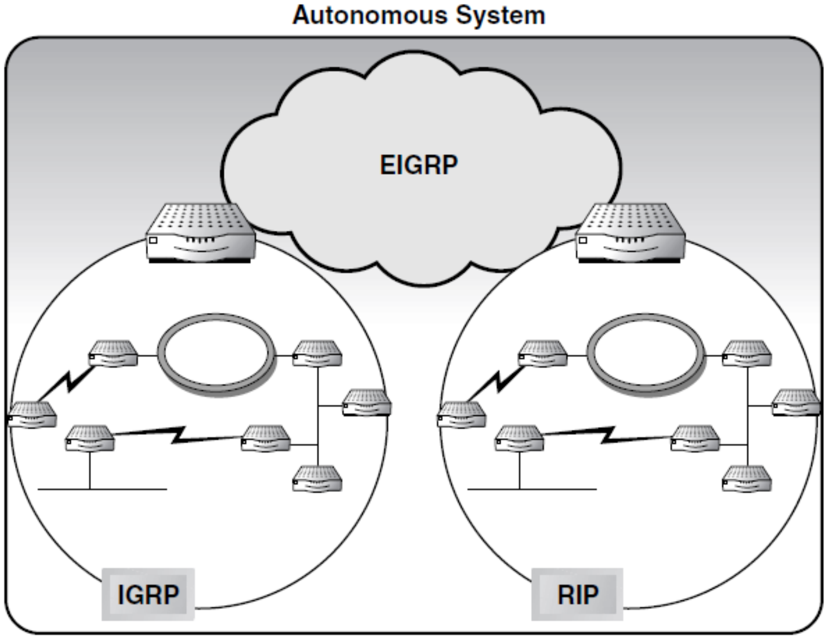
- Most routing occurs within logical boundaries referred to as Autonomous Systems (AS), or routing domains.
- Up until recently these terms were used interchangeably within the industry to describe a collection of related networks, subnets, and routers that use the same routing protocol and share information within the common area controlled by a single administrative entity.
- However, that is not necessarily the case these days, and most companies do not operate in this manner

Autonomous Systems and Routing Domain

- Take an organization’s network that spans a large geographic area.
- It might deploy several different routing protocols (for example, RIP and OSPF) within each geographic location.
- Each location might have a separate IT (Information Technology) department (administrative body) controlling it.
- In this example, RIP and OSPF would be considered separate routing domains.
- Each routing domain consists of the routing protocol (RIP or OSPF) and the networks, subnets, and routers within this domain.
- The organization’s network as a whole, regardless of the number of routing protocols operating within it, is considered a single Autonomous System

Autonomous Systems and Routing Domain





- Presently it is more common to use the term routing domain when referring to routers and networks sharing a common routing protocol.
- The term AS is now used to describe a group of routing domains.
- For example, an organization running three routing protocols, such as **RIP**, **IGRP** and **EGRP** would be considered to have **three** separate **routing domains** within a **single Autonomous System**.

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  - DHCP Revisited
  - Default Router or Gateway
  - Internet Gateway
  - Route Table
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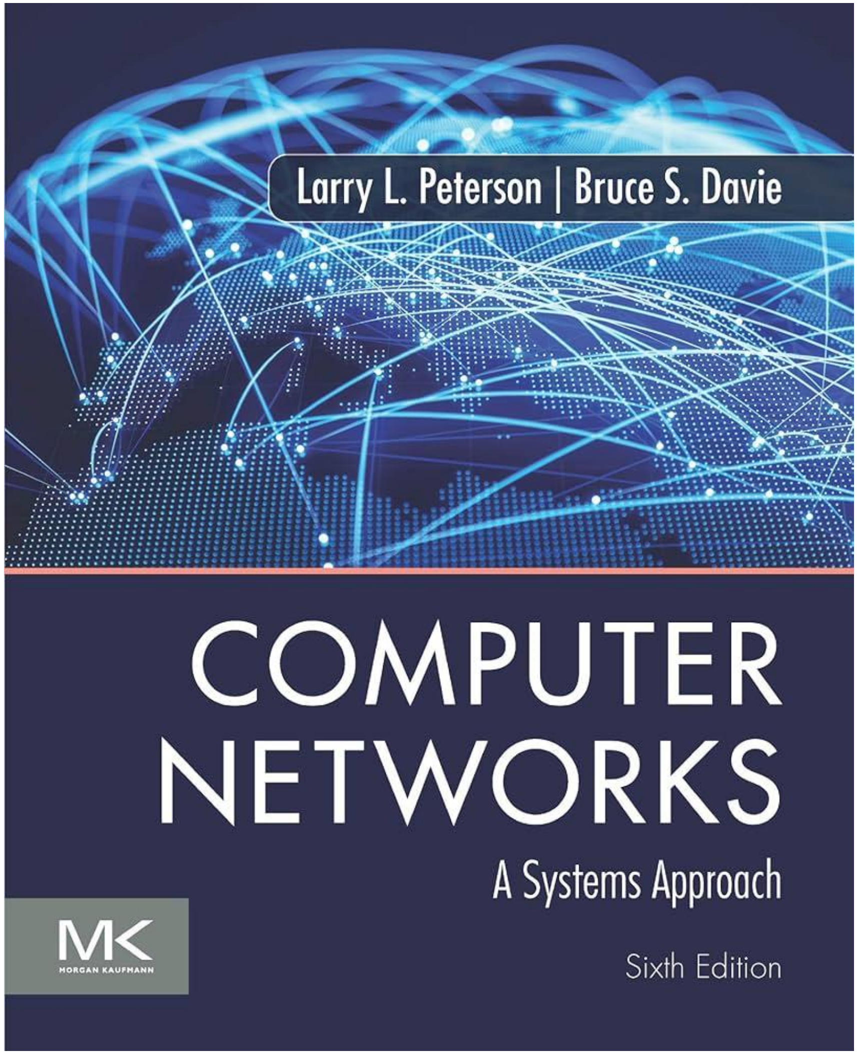
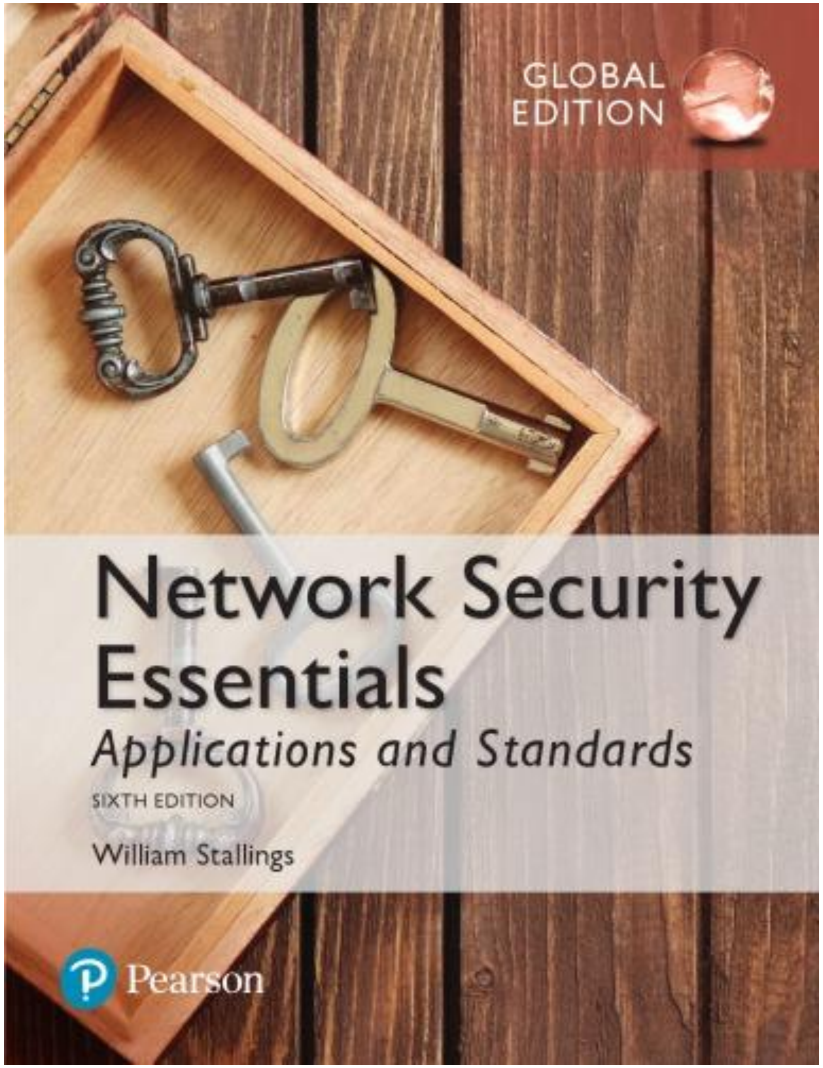
  - Datagram Forwarding - Recap
- Autonomous Systems and Routing Domains

Textbooks

Textbook 1

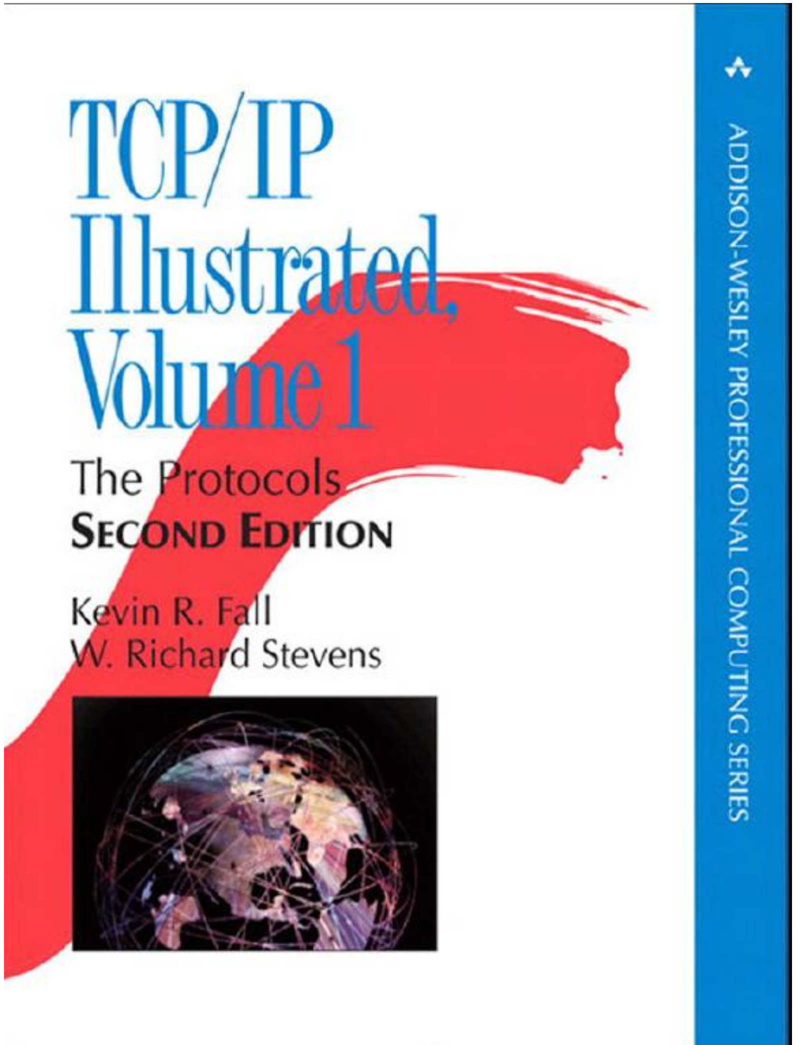


Textbook 2



References

Ref 1



Ref 2

[TCP Congestion Control: A Systems Approach]

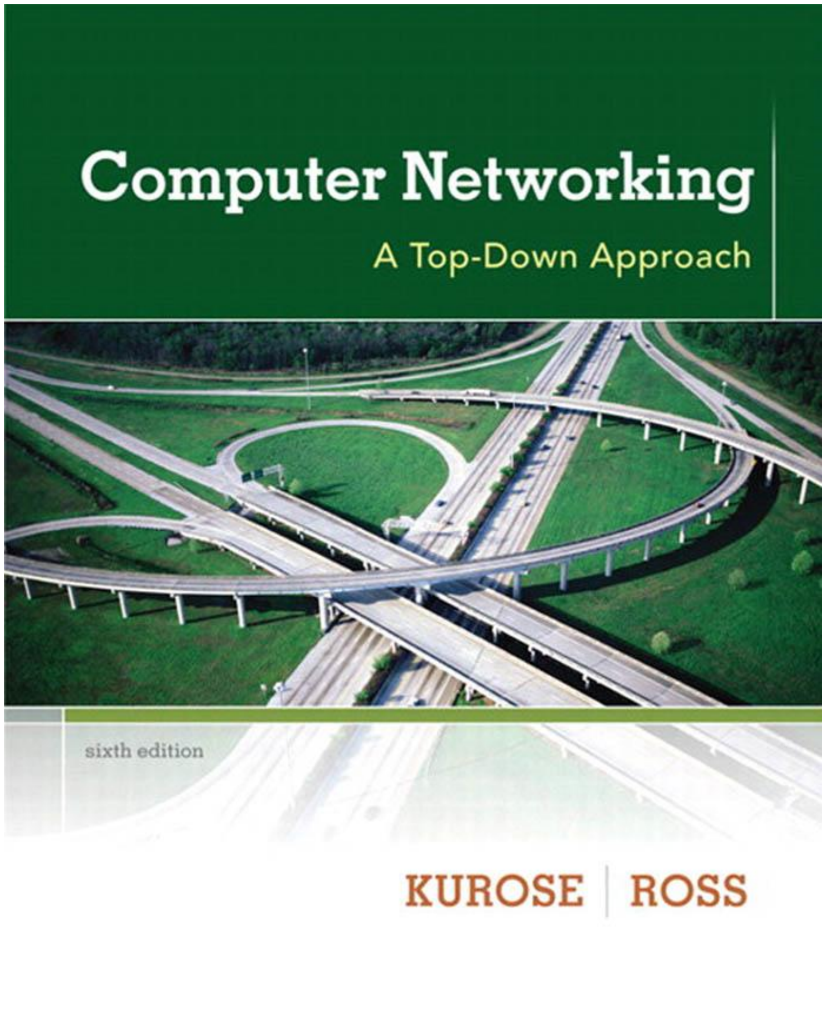
HTTPS://SYSTEMSAPPROACH.ORG

TCP Congestion Control: A Systems Approach

Peterson, Brakmo, and Davie

References

Ref 3



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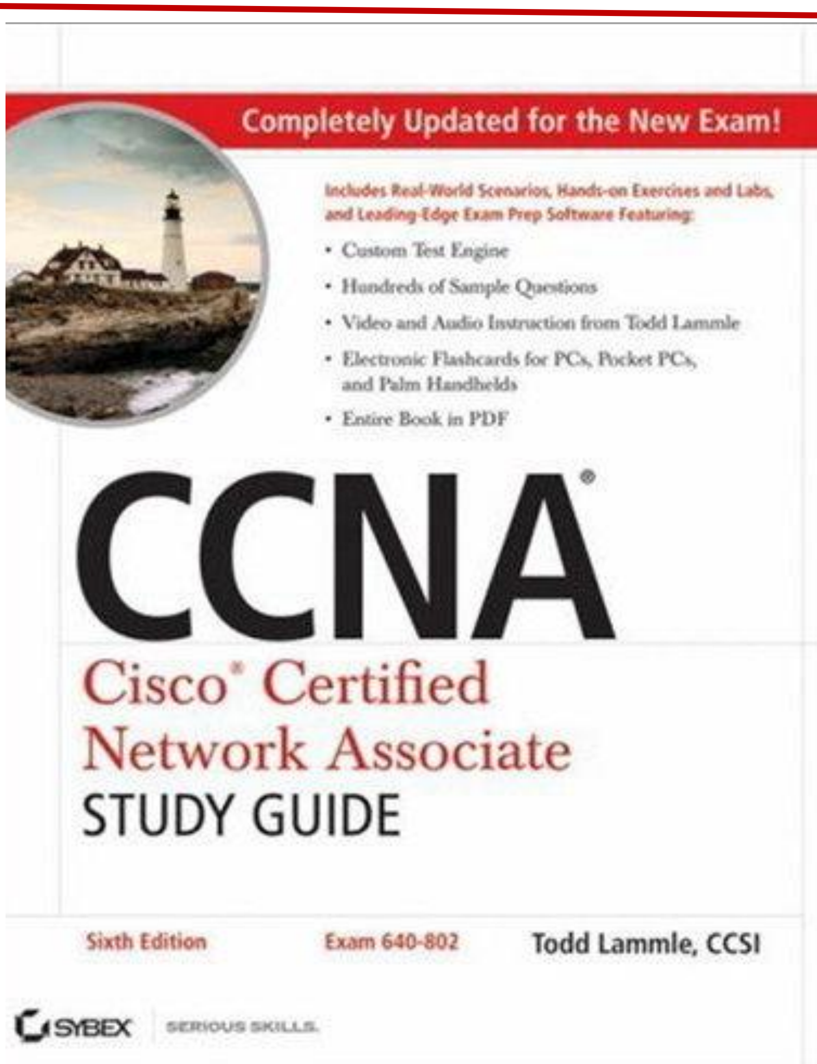

References

Ref 5