Network : Internetworking

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Reference

William Stalling, Data and Computer Communications 10/E, Prentice Hall

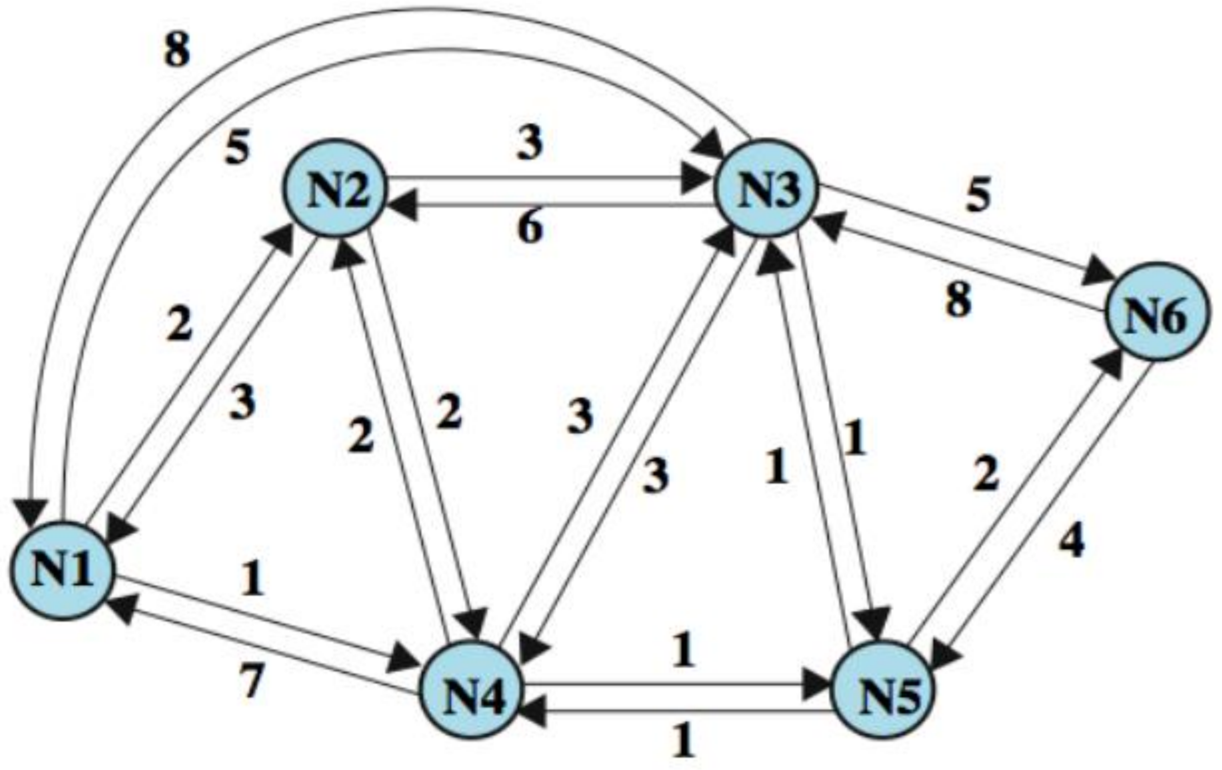
Routing

- Key design issue for (packet) switched networks
  - Many connections will need paths more than one switch
  - Select route across network between end nodes
- Characteristics required
  - Correctness
  - Simplicity
  - Robustness
  - Stability
  - Fairness
  - Optimality
  - Efficiency

Performance Criteria

- Used for selection of route
- Approach for the optimum route
  - Simplest is choose minimum hop (least number of nodes)
  - Can be generalized as “least one” routing because it is more flexible, therefore it is more common than “minimum hop”
  - Least-cost algorithms

– Example Packet Switched Network



Decision Time and Place

- Time
  - Packet or virtual circuit basis
  - Fixed or dynamically changing
- Place
  - Distributed routing : made by each node
    - More complex, but more robust
  - Centralized routing : made by some designated node
    - Network control center
  - Source routing : made by source station
    - Allows the user to dictate a route

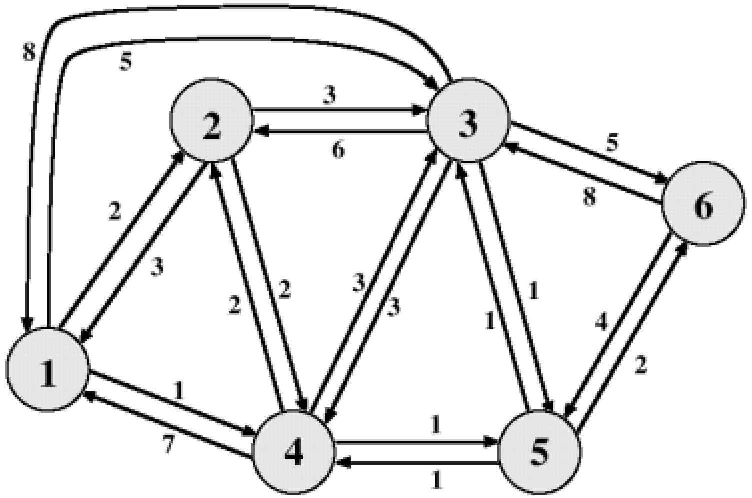
Network Information Source and Update Timing

- Routing decisions usually based on knowledge of network traffic load and link cost
  - Distribute routing : using local knowledge, information from adjacent nodes, information from all nodes on a potential route
  - Central routing : collect information from all nodes
- Issue of update timing
  - Fixed routing : never updated, simple, not sensible
  - Adaptive routing : regular updates, more overload

Routing Strategies (1)

- *Fixed routing*
- Use a single permanent route for each source to destination pair of nodes
- The route was determined using a least cost algorithm
- Route is fixed until a change in network topology : based on expected traffic or capacity
- Advantage is simplicity
- Disadvantage is lack of flexibility : does not react to network congestion

Fixed Routing Tables



Central Routing Directory

From node

To node	1	2	3	4	5	6
1	-	1	5	**2**	4	5
2	2	-	**5**	2	4	5
3	4	3	-	5	3	5
4	4	4	5	-	4	5
5	4	4	5	5	-	5
6	4	4	5	5	6	-

Node 1 Directory

Destination	Next Node
2	2
3	4
4	4
5	4
6	4

Node 2 Directory

Destination	Next Node
1	1
3	3
4	4
5	4
6	4

Node 3 Directory

Destination	Next Node
1	5
2	5
4	5
5	5
6	5

Node 4 Directory

Destination	Next Node
1	2
2	2
3	5
5	5
6	5

Node 5 Directory

Destination	Next Node
1	4
2	4
3	3
4	4
6	6

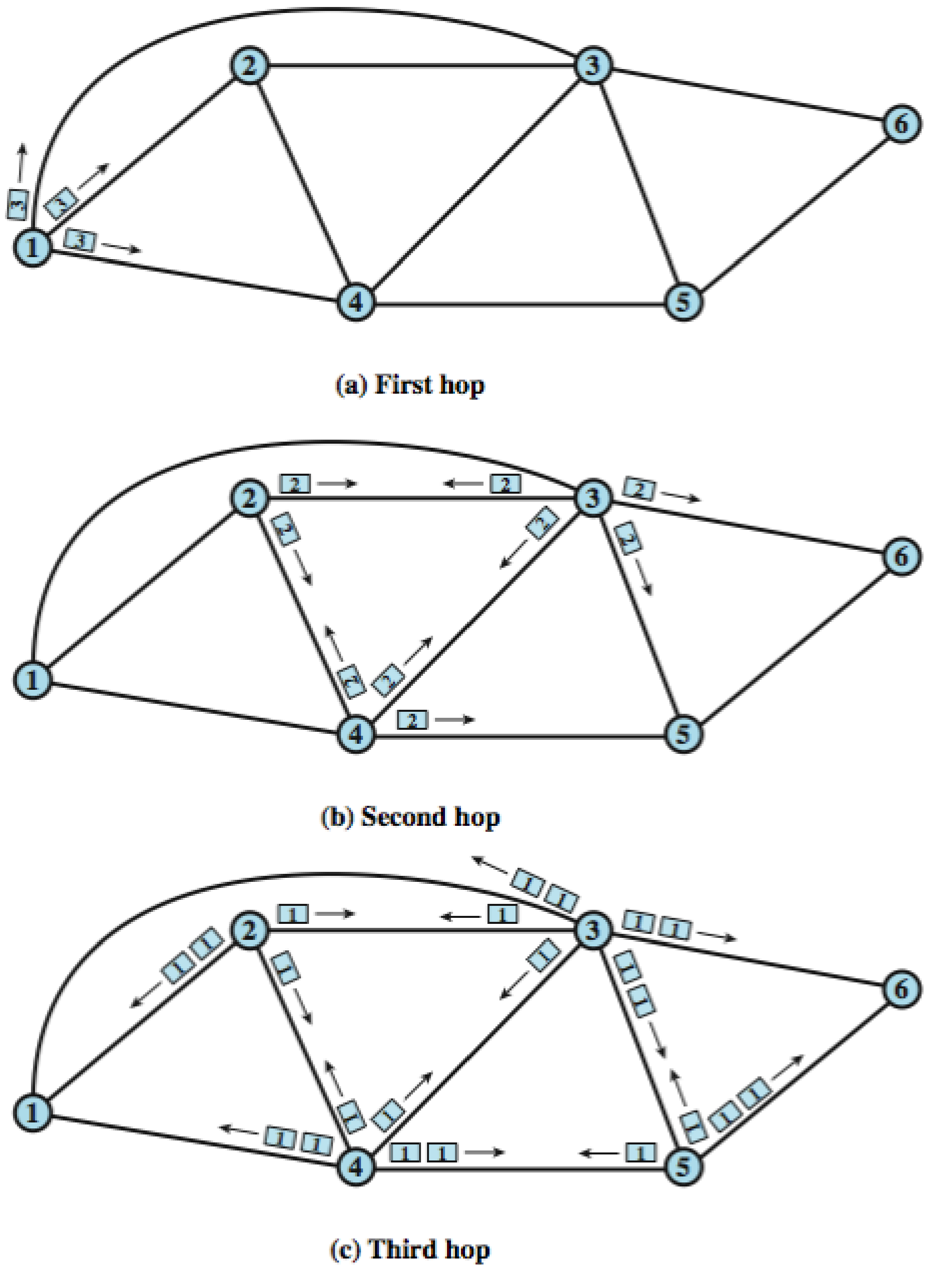
Node 6 Directory

Destination	Next Node
1	5
2	5
3	5
4	5
5	5

Routing Strategies (2)

- *Flooding*
- Packet sent by node to every neighbor
- No network information required
- Eventually multiple copies arrive at destination
- Each packet is uniquely numbered so duplicates can be discarded
- Need to limit incessant retransmission of packets
    - Node can remember identity of packet retransmitted

– Flooding Example



Properties and Disadvantage

- All possible routes are tried
  - Very robust, military network
- At least one packet will have taken minimum hop route
  - Can be used to set up virtual circuit
- Nodes directly or indirectly connected to source are visited
  - Useful to distribute information
- Disadvantage
  - High traffic load
  - Security concerns

Routing Strategies (3)

- *Random routing*
- Simplicity of flooding with much less traffic load
- A route node selects one outgoing path for retransmission of incoming packet
- Selection can be random or round robin
- A refinement is to select outgoing path based on probability calculation
- No network information needed
- Random route is typically neither least cost nor minimum hop

Routing Strategies (4)

- Adaptive routing
- Used by almost all packet switching networks
- Routing decisions change as conditions on the network change
- Requires information about network
- Disadvantages
  - Decisions more complex
  - Tradeoff between quality of network info. And overhead
  - Reacting too quickly can cause oscillation
  - Reacting too slowly means info may be irrelevant
- Advantages
  - Improved performance
  - Aid congestion control

ARPANET Routing Evolution (1)

- 1st generation : distance vector routing (1969)
  - Distributed adaptive estimated delay, such as queue length
  - Version of Bellman-Ford algorithm(doesn’t consider line speed)
- 2nd generation : link state routing (1979)
  - Distributed adaptive using measured delay, such as RTT
  - Version of Dijkstra’s algorithm
    - ✓ Re-computed average delays every 10 seconds, and any changes are flooded to all other nodes
    - ✓ Good under light, medium loads, but under heavy loads, little correlation between reported delays and those experienced

ARPANET Routing Evolution (2)

- 3^{rd} generation : link state routing (1987)
  - Link cost calculation changed
    - ✓ To damp routing oscillations
    - ✓ To reduce routing overhead
  - Measure average delay over last 10 seconds and transform into link utilization estimate
  - Normalize this based on current value and previous results
  - Set link cost as function of average utilization

Internet Routing Protocols

- Routers are responsible for receiving and forwarding packets through the interconnected set of networks Link cost
  - makes routing decisions based on knowledge of the topology and traffic/delay conditions of the Internet
  - routers exchange routing information using a special routing protocol
- Two concepts in considering the routing function:
  - routing information
    - ✓ Information about the topology and delays of the Internet
  - routing algorithm
    - ✓ The algorithm used to make a routing decision for a particular datagram, based on current routing information

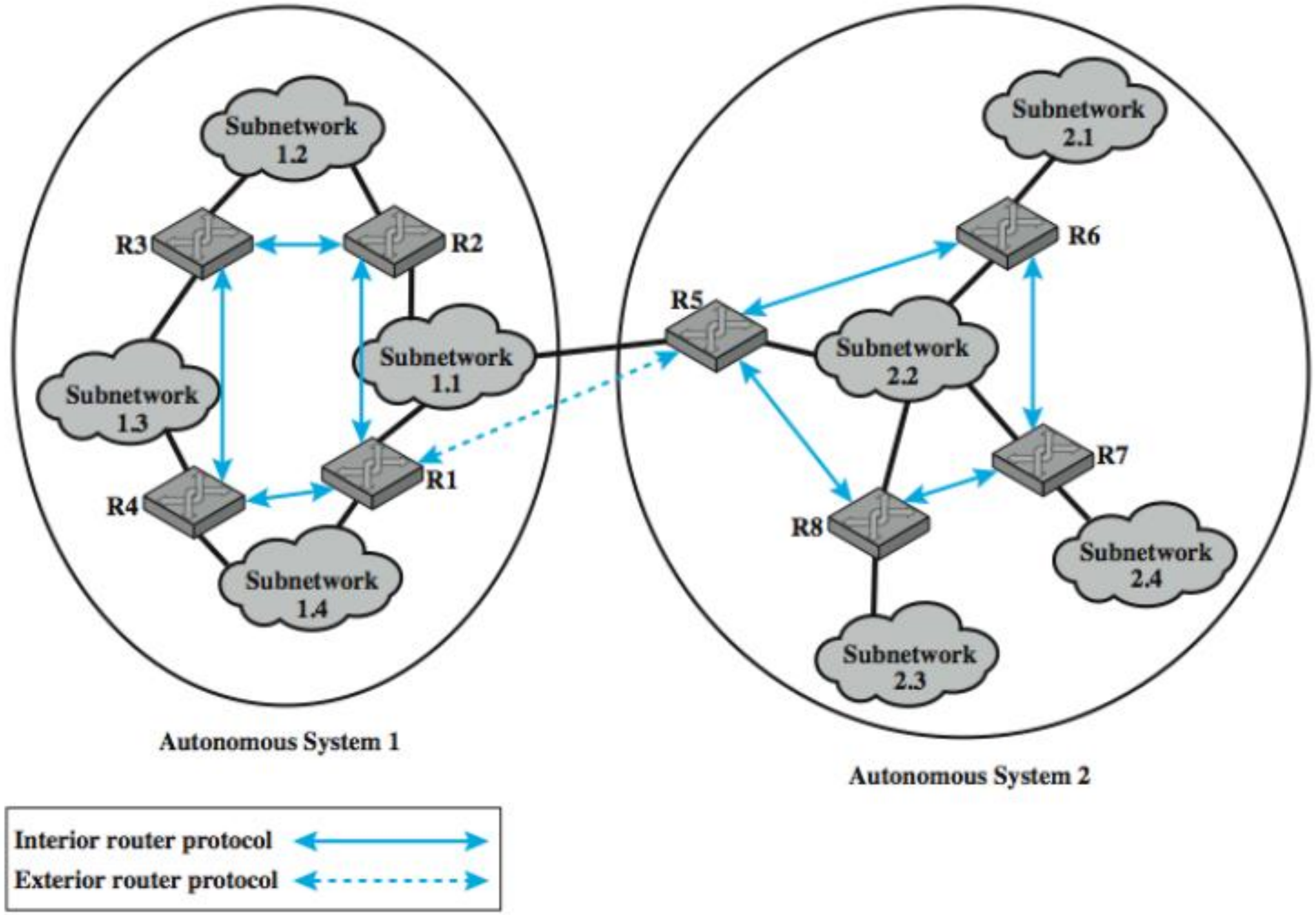
Autonomous System (AS)

- It exhibits the following characteristics as
  - it is a set of routers and networks managed by a single organization
  - consists of a group of routers exchanging information via a common routing protocol
  - except in times of failure, it is connected (in a graph-theoretic sense); there is a path between any pair of nodes
- Interior Router Protocol (IRP)
  - a shared routing protocol which passes routing information between routers within an AS
  - custom tailored to specific applications and requirements

Exterior Routing Protocol (ERP)

- May be more than one AS in an internetwork
  - Routing algorithms and tables may differ between different AS
- Routers need information about networks outside their AS
  - Use an exterior router protocol (ERP) for this
  - Supports summary information on AS reachability
- Example
  - Border gateway protocol (BGP)

– Application of IRP and ERP



Approaches : Distance-vector Routing

- Requires that each node (router or host) exchange information with its neighboring nodes
  - Two nodes are said to be neighbors if they are both directly connected to the same network
- First generation routing algorithm for ARPANET
  - Used by Routing Information Protocol (RIP)
- A node maintains a vector of link costs for each directly attached network, distance and next-hop for each destination
  - Requires transmission of lots of information by each router
- Changes take long time to propagate

Approaches : Link-state Routing

- Designed to overcome drawbacks of distance-vector
- When a router is initialized, it determines the link cost on each of its network interfaces
  - It then advertises this set of link costs to all other routers in the internet topology, not just neighboring routers
- From then on, the router monitors its link costs
  - Whenever there is a significant change, the router again advertises its set of link costs to all other routers in the configuration
- The OSPF protocol is an example

Consideration for ERP

- Both are not effective for exterior router protocol
- Not distance-vector
  - Assumes routers share common distance metric
  - But different Ass may have different priorities & needs
  - But have no info. On AS that will be visited along a route
- Not link-state
  - Different Ass may use different metrics and have different restrictions
  - Flooding of link state information to all routers unmanageable

ERP : Path-vector Routing

- Alternative to dispense with concept of routing metrics
  - that is, does not include distance or cost estimate
  - simply provides information about which networks can be reached by a given router and ASs crossed to get there
  - so, each block of routing information lists all of the ASs visited in order to reach the destination network by this route
- BGP (Border Gateway Protocol)
  - it was developed for use in conjunction with the TCP/IP suite
  - it has become the preferred ERP for the Internet
  - designed to allow routers in different ASs to cooperate in the exchange of routing information
  - current version is known as BGP-4 (RFC 4271)