ROUTING ON THE INTERNET

5-Dec-11

CSE 3213

Performance Criteria

- used for selection of route
- simplest is "minimum hop"
- can be generalized as "least cost"

Example Packet Switched Network

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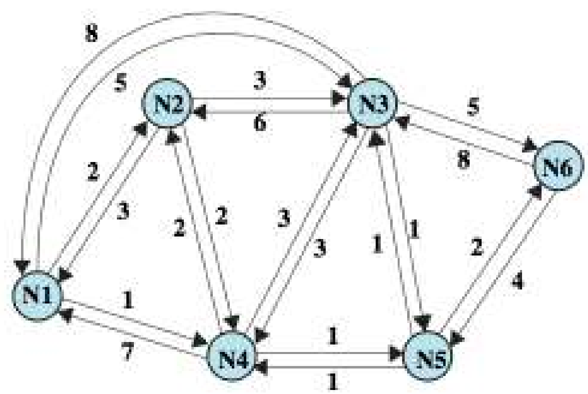

Autonomous Systems (AS)

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- is a group of routers and networks managed by single organization
- which exchange information via a common routing protocol
- form a connected network
  - at least one path between any pair of nodes
  - except in times of failure

Interior and Exterior Router Protocols

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- interior router protocol (IRP)
  - passes routing information between routers within AS
  - can be tailored to specific applications
  - needs detailed model of network to function
- may have more than one AS in internet
  - routing algorithms & tables may differ between them
- routers need info on networks outside own AS
- use an exterior router protocol (ERP) for this
  - supports summary information on AS reachability

Application of IRP and ERP

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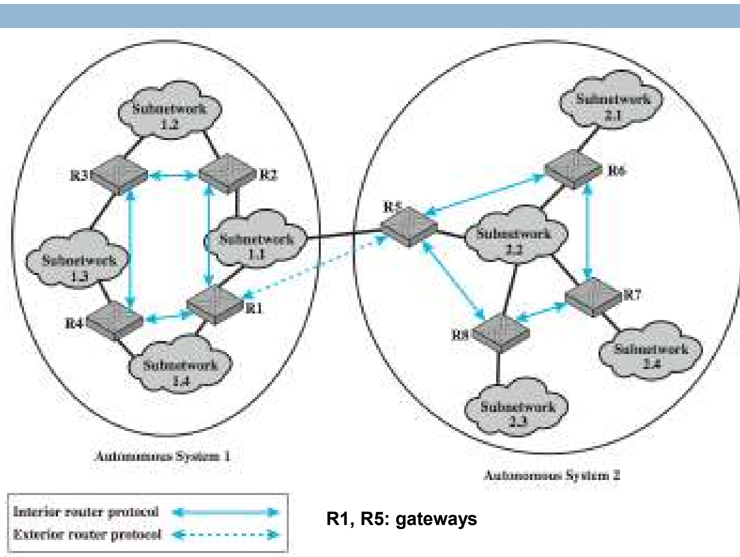

R1, R5: gateways

Interior Routing Approaches

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- Distance vector
  - Bellman-Ford
  - Routing Information Protocol (RIP)
  - Interior Gateway Routing Protocol (IGRP, Cisco proprietary)
- Link state
  - OSPF (Open Shortest Path First)
  - OLSR protocol for MANETs

Distance Vector Routing

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- each node (router or host) exchange information with neighboring nodes
- first generation routing algorithm for ARPANET
  - eg. used by Routing Information Protocol (RIP)
- Bellman-Ford algorihtm
- requires transmission of lots of info by routers
  - distance vector and estimated path costs
- changes take long time to propagate

Link State Routing

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- designed to overcome drawbacks of distance-vector
- each router determines link cost on each interface
- advertises set of link costs to all other routers in topology
- if link costs change, router advertises new values
- each router constructs topology of entire configuration
  - can calculate shortest path to each dest
  - use to construct routing table with first hop to each dest
- do not use distributed routing algorithm, but any suitable alg to determine shortest paths, eg. Dijkstra's algorithm
- Open Shortest Path First (OSPF) is a link-state protocol

Open Shortest Path First (RFC 2328)

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- interior routing protocol of the Internet
- replaced Routing Information Protocol (RIP)
- uses link state routing algorithm
  - each router keeps list of state of local links to network
  - transmits update state info
  - little traffic as messages are small and not sent often
- uses least cost based on user cost metric
- topology stored as directed graph
  - vertices or nodes (router, transit or stub network)
  - edges (between routers or router to network)

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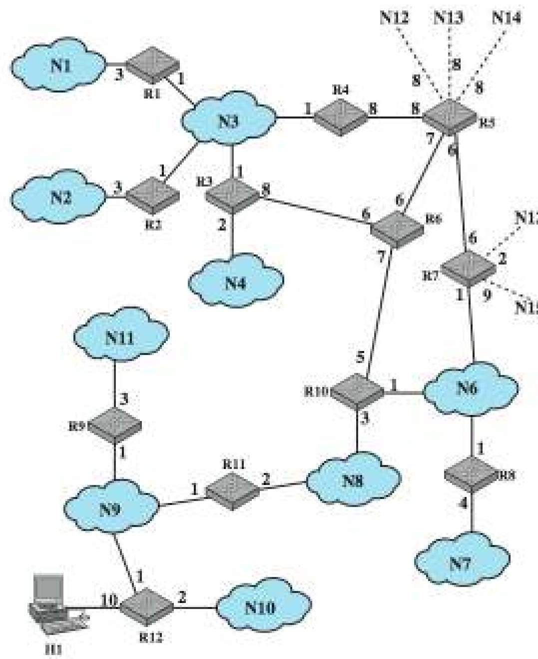
Example OSPF AS



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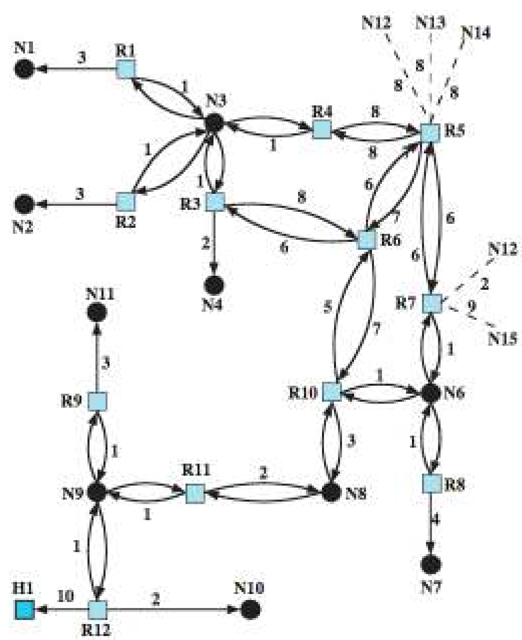
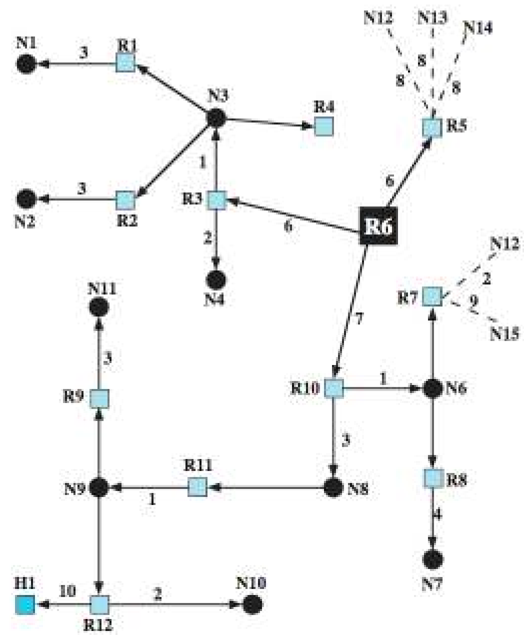
Directed Graph of AS



SPF Tree for Router 6



Destination	Next Hop	Distance
N1	R3	10
N2	R3	10
N3	R3	7
N4	R3	8
N6	R10	8
N7	R10	12
N8	R10	10
N9	R10	11
N10	R10	13
N11	R10	14
H1	R10	21
R5	R5	6
R7	R10	8
N12	R10	10
N13	R5	14
N14	R5	14
N15	R10	17

Exterior Routing

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- link-state and distance-vector not effective for exterior routing protocols
- distance-vector
  - assumes routers share common distance metric
  - but different ASs may have different priorities & needs
  - but have no info on AS's visited along route
- link-state
  - different ASs may use different metrics and have different restrictions
  - flooding of link state information to all routers unmanageable

Path Vector for Exterior Routing

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- alternative **path-vector** routing protocol
  - provides info about which networks can be reached by a given router and ASs crossed to get there
  - does not include distance or cost estimate
  - hence dispenses with concept of routing metrics
- have list of all ASs visited on a route
- enables router to perform policy routing
  - eg. avoid path to avoid transiting particular AS
  - eg. link speed, capacity, tendency to become congested, and overall quality of operation, security
  - eg. minimizing number of transit ASs

Border Gateway Protocol (BGP)

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- developed for use with TCP/IP model
- is preferred exterior routing protocol of the Internet
- uses messages sent over TCP connections
- current version is BGP-4 (RFC 1771, RFC 4271)

BGP Functional Procedures

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- neighbor acquisition: agree to exchange routing info regularly
  - send OPEN messages to each otehr over a TCP connection. Reply with a KEEP-ALIVE message.
- neighbor reachability: to maintain relationship
  - periodically issue KEEP-ALIVE messages to each other
- network reachability: to update database of routes
  - each router maintains a database of the networks that it can reach and the preferred route for reaching each network. When a change is made to this database, the router issues an UPDATE message that is broadcast to all other routers implementing BGP.

BGP Routing Information Exchange

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- within AS a router builds topology picture using an interior routing protocol
- router issues UPDATE messages to other routers outside AS using BGP
- these routers exchange info with other routers in other ASs
- routers must then decide best routes for exterior routing

BGP-4 Messages

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Open	Used to open a neighbor relationship with another router.
Update	Used to (1) transmit information about a single route and/or (2) list multiple routes to be withdrawn.
Keepalive	Used to (1) acknowledge an Open message and (2) periodically confirm the neighbor relationship.
Notification	Send when an error condition is detected.

Reference

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- Data and Computer Communications, William Stallings, 9th edition, section 19.2

Least Cost Algorithms

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- basis for routing decisions
  - can minimize hop with each link cost 1
  - or have link value inversely proportional to capacity
- defines cost of path between two nodes as sum of costs of links traversed
  - in network of nodes connected by bi-directional links
  - where each link has a cost in each direction
- for each pair of nodes, find path with least cost
  - link costs in different directions may be different
- alternatives: Dijkstra or Bellman-Ford algorithms

Dijkstra's Algorithm

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- finds shortest paths from given source node s to all other nodes
- by developing paths in order of increasing path length
- algorithm runs in stages (next slide)
  - each time adding node with next shortest path
- algorithm terminates when all nodes processed by algorithm (in set T)

Dijkstra's Algorithm Method

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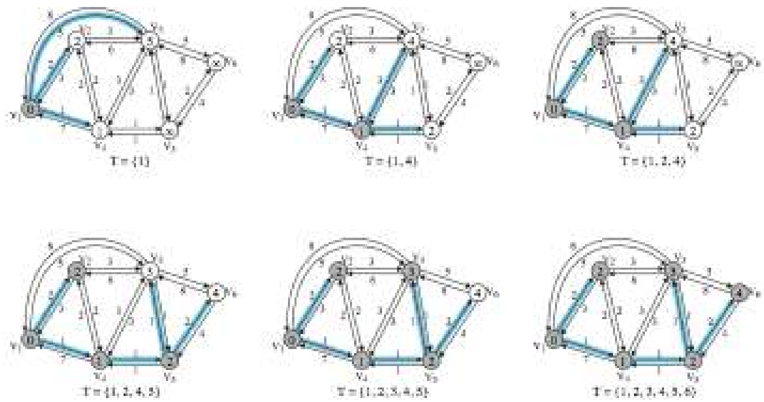
- Step 1 [Initialization]
  - T = {s} Set of nodes so far incorporated
  - $L(n) = w(s, n)$ for $n \neq s$
  - initial path costs to neighboring nodes are simply link costs
- Step 2 [Get Next Node]
  - find neighboring node not in T with least-cost path from s
  - incorporate node into T
  - also incorporate the edge that is incident on that node and a node in T that contributes to the path
- Step 3 [Update Least-Cost Paths]
  - $L(n) = \min[L(n), L(x) + w(x, n)]$ for all $n \notin T$
  - f latter term is minimum, path from s to n is path from s to x concatenated with edge from x to n

Dijkstra's Algorithm Example



Dijkstra's Algorithm Example

Iter	T	L(2)	Path	L(3)	Path	L(4)	Path	L(5)	Path	L(6)	Path
1	{1}	2	1–2	5	1-3	1	1–4	∞	-	∞	-
2	{1,4}	2	1–2	4	1-4-3	1	1–4	2	1-4–5	∞	-
3	{1, 2, 4}	2	1–2	4	1-4-3	1	1–4	2	1-4–5	∞	-
4	{1, 2, 4, 5}	2	1–2	3	1-4-5–3	1	1–4	2	1-4–5	4	1-4-5–6
5	{1, 2, 3, 4, 5}	2	1–2	3	1-4-5–3	1	1–4	2	1-4–5	4	1-4-5–6
6	{1, 2, 3, 4, 5, 6}	2	1-2	3	1-4-5-3	1	1-4	2	1-4–5	4	1-4-5-6