Routing

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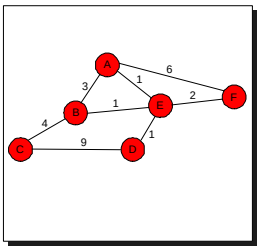
Routing

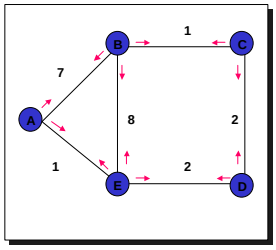
- Routing algorithms view the network as a graph
- Problem: find lowest cost path between two nodes
- Factors:
  - Static topology
  - Dynamic load
  - Policy
- Two main approaches:
  - Distance-vector protocol
  - Link state protocol



Distributed Bellman-Ford

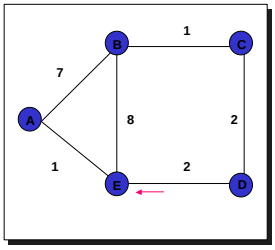
- Start Conditions:
  - Each router starts with a vector of distances to all directly attached networks
- Send step:
  - Each router advertises its current vector to all neighboring routers
- Receive step:
  - For every network X, router finds shortest distance to X
    - Considers current distance to X
    - Then takes into account distance to X from its neighbors
  - Router updates its cost to X
  - After doing this for all X, router goes to send step

Example - Initial Distances



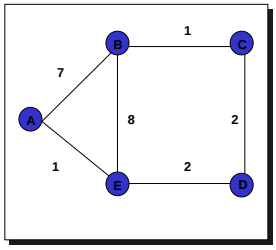
Info at Node	Distance to Node A	B	C	D	E
A	0	7	~	~	1
B	7	0	1	~	8
C	~	1	0	2	~
D	~	~	2	0	2
E	1	8	~	2	0

E receives D's routes; Updates Costs



Info at Node	Distance to Node A	B	C	D	E
A	0	7	~	~	1
B	7	0	1	~	8
C	~	1	0	2	~
D	~	~	2	0	2
E	1	8	**4**	2	0

Final Distances



Info at Node	Distance to Node A	B	C	D	E
A	**0**	**6**	**5**	**3**	**1**
B	**6**	**0**	**1**	**3**	**5**
C	**5**	**1**	**0**	**2**	**4**
D	**3**	**3**	**2**	**0**	**2**
E	**1**	**5**	**4**	**2**	**0**

Complexity

- Each message size: O(n)
- Number of messages in each step: O(m)
  - Each node sends distance vector to all of its neighbors
- Convergence time?

Link State Protocol: Basic Steps

- Start condition
  - Each node assumed to know state of links to its neighbors
- Periodically, each node creates a link state packet containing:
  - Node ID
  - List of neighbors and link cost
  - Sequence number
    - Needed to avoid stale information from flood
  - Time to live (TTL)
  - Node outputs LSP on all its links
- Step 1
  - Each node broadcasts its state to all other nodes
  - Reliable flooding mechanism
- Step 2
  - Each node locally computes shortest paths to all other nodes from global state
  - Dijkstra's shortest path tree (SPT) algorithm

Complexity

- Message size of message from node k:
  - O(number of edges attached to node k)
- Number of messages for each broadcast: O(m)
- Total number of messages: O(nm)

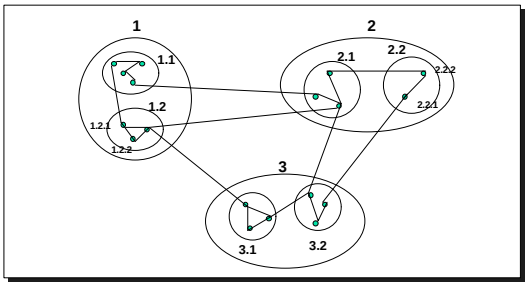
Summary: LS vs. DV

- In DV send everything you know to your neighbors
- In LS send info about your neighbors to everyone
- Msg size: small with LS, potentially large with DV
- Space requirements:
  - LS maintains entire topology
  - DV maintains only neighbor state
- Robustness: DV can have cycles

Routing Hierarchies

- Flat routing doesn't scale
  - Each node cannot be expected to have routes to every destination (or destination network)
- Key observation
  - Need less information with increasing distance to destination
- Two radically different approaches for routing
  - The area hierarchy
  - The landmark hierarchy
- Area hierarchy:
  - Divide network into areas
    - Areas can have nested sub-areas
    - Constraint: no path between two sub-areas of an area can exit that area
  - Hierarchically address nodes in a network
    - Sequentially number top-level areas
    - Sub-areas of area are labeled relative to that area

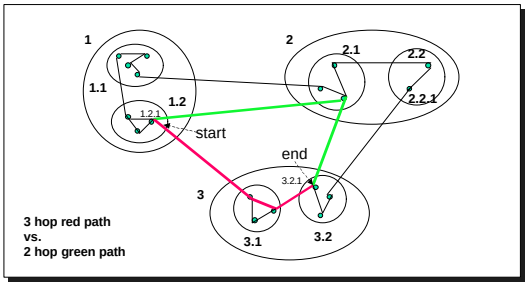
The Area Hierarchy



Routing

- Within area
  - Each node has routes to every other node
- Outside area
  - Each node has routes for other top-level areas only
  - Inter-area packets are routed to nearest appropriate border router
- Can result in sub-optimal paths

Path Sub-optimality



Internet's Area Hierarchy

- What is an Autonomous System (AS)?
  - A set of routers under a single technical administration
  - using an *interior gateway protocol (IGP)* and common metrics to route packets within the AS, and
  - using an *exterior gateway protocol (EGP)* to route packets to other AS's
- Each AS assigned unique ID
- AS's peer at network exchanges