Lecture 20

Routing in Data Networks

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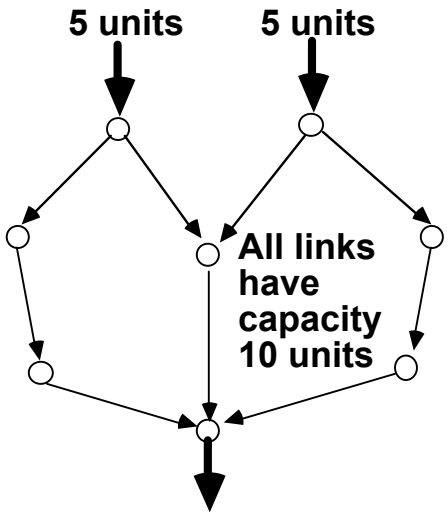
Routing

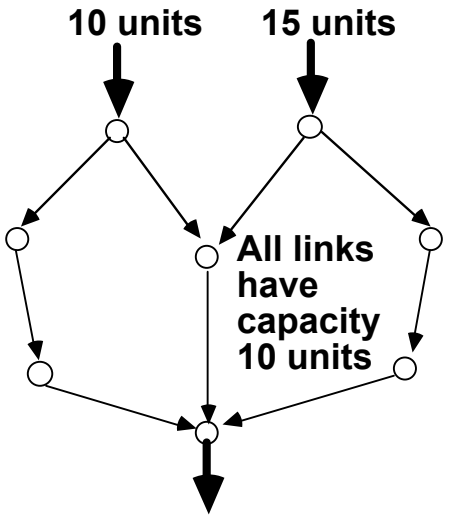
- **Must choose routes for various origin destination pairs (O/D pairs) or for various sessions**
  - **Datagram routing: route chosen on a packet by packet basis**

    Using datagram routing is an easy way to split paths
  - **Virtual circuit routing: route chosen a session by session basis**
  - **Static routing: route chosen in a prearranged way based on O/D pairs**

Routing is a global problem



Either session alone is best routed through center path, but both cannot go through center.



Both sessions must split their traffic between two paths.

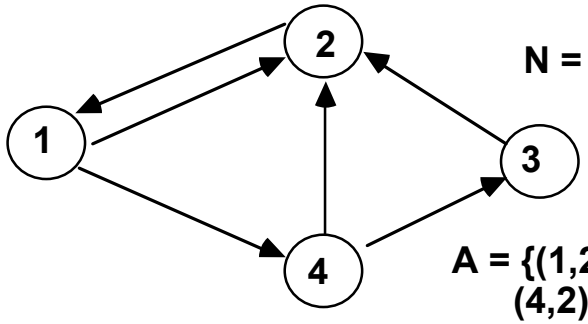
- Static routing is not desirable
- Datagam routing is a natural way to split the traffic
  - How?

Shortest Path routing

- Each link has a cost that reflects
  - The length of the link
  - Delay on the link
  - Congestion
  - $$ cost
- Cost may change with time
- The length of the route is the sum of the costs along the route
- The shortest path is the path with minimum length
- Shortest Path algorithms
  - Bellman-Ford: centralized and distributed versions
  - Dijkstra's algorithm
  - Many others

Directed graphs (digraphs)

- A directed graph (digraph) G = (N,A) is a finite nonempty set of nodes N and a set of ordered node pairs A called directed arcs.



- Directed walk: (4,2,1,4,3,2)
- Directed path: (4,2,1)
- Directed cycle: (4,2,1,4)
- Data networks are best represented with digraphs, although typically links tend to be bi-directional (cost may differ in each direction)
  - For simplicity we will use bi-directional links of equal costs in our examples

Bellman Ford algorithm

- **Finds the shortest paths, from a given source node, say node 1, to all other nodes.**
- **General idea:**
  - **First find the shortest single arc path,**
  - **Then the shortest path of at most two arcs, etc.**
  - **Let dij=∞ if (i,j) is not an arc.**
- **Let Di(h) be the shortest distance from 1 to i using at most h arcs.**
  - **Di(1) = d1i ; i≠1 D1(1) = 0**
  - **Di(h+1) = min {j} [Dj(h) + dji] ;i≠1 D1(h+1) = 0**
- **If all weights are positive, algorithm terminates in N-1 steps.**

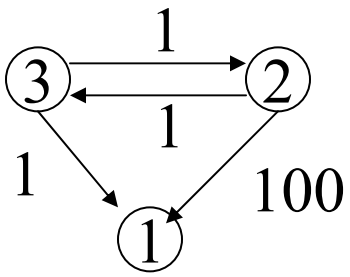
Bellman Ford - example

Distributed Bellman Ford

- Link costs may change over time
  - Changes in traffic conditions
  - Link failures
  - Mobility
- Each node maintains its own routing table
  - Need to update table regularly to reflect changes in network
- Let Di be the shortest distance from node i to the destination
  - Di = min {j} [Dj + dij] : update equation
- Each node (i) regularly updates the values of Di using the update equation
  - Each node maintains the values of dij to its neighbors, as well as values of Dj received from its neighbors
  - Uses those to compute Di and send new value of Di to its neighbors
  - If no changes occur in the network, algorithm will converge to shortest paths in no more than N steps

Slow reaction to link failures

- **Start with D3=1 and D2=100**
  - **After one iteration node 2 receives D3=1 and D2 = min [1+1, 100] = 2**

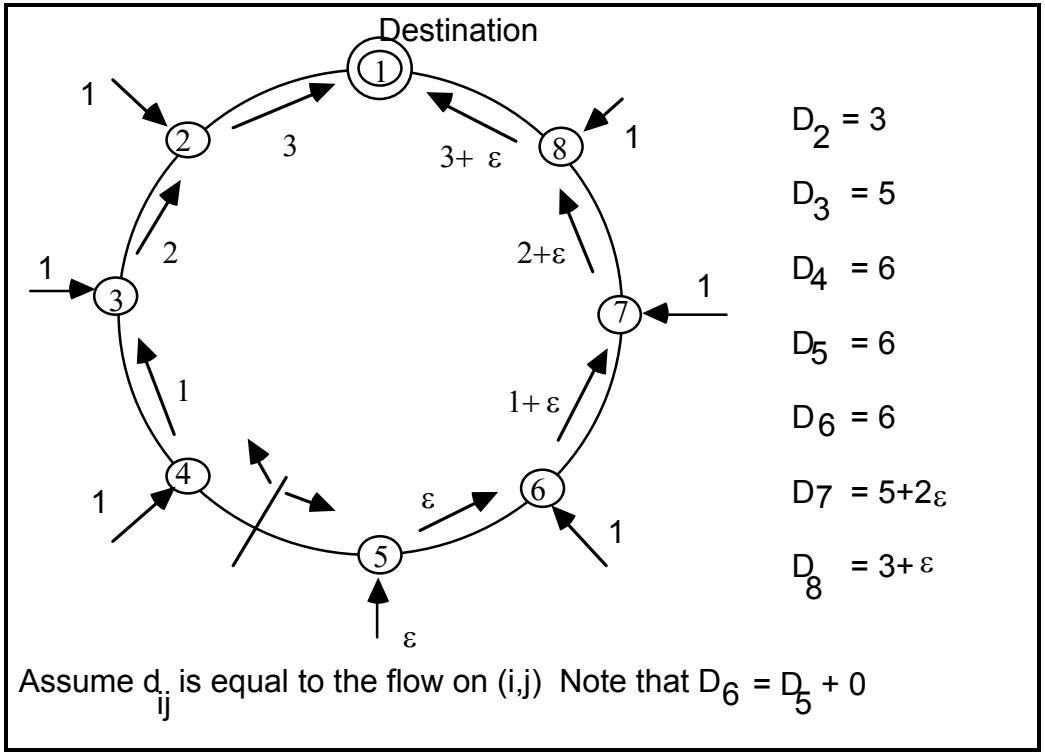


- **In practice, link lengths occasionally change**
  - **Suppose link between 3 and 1fails (I.e., d31=infinity)**
  - **Node 3 will update D3 = d32 + D2 = 3**
  - **In the next step node 2 will update: D2 = d23+D3 = 4**
  - **It will take nearly 100 iterations before node 2 converges on the correct route to node 1**

- **Possible solutions:**
  - **Propagate route information as well**
  - **Wait before rerouting along a path with increasing cost**

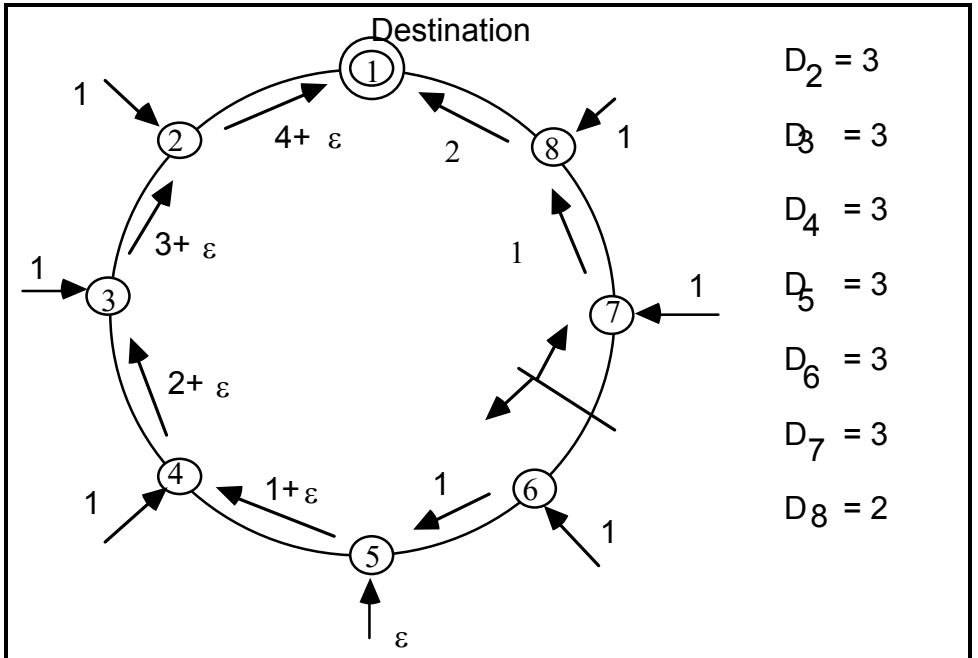
    Node next to failed link should announce D=infinity for some time to prevent loops

Instability



As routes change due to traffic conditions, they affect the Loadings on the links, hence routes may oscillate

Instability



- **Having a bias independent of flow in the arc distances helps to prevent this problem.**
- **Asynchronous updates also helps.**

Dijkstra's algorithm

- Find the shortest path from a given source node to all other nodes
  - Requires non-negative arc weights
- Algorithm works in stages:
  - Stage k: the k closest nodes to the source have been found
  - Stage k+1: Given k closest nodes to the source node, find k+1st.
- Key observation: the path to the k+1st closest nodes includes only nodes from among the k closest nodes
- Let M be the set of nodes already incorporated by the algorithm
  - Start with Dn = dsn for all n (Dn = shortest path distance from node n to the source node
  - Repeat until M=N

    Find node w$\notin$M which has the next least cost distance to the source node
    Add w to M
    Update distances: Dn = min [Dn, Dw + dwn] (for all nodes n $\notin$M)

  - Notice that the update of Dn need only be done for nodes not already in M and that the update only requires the computation of a new distance by going through the newly added node w.

Dijkstra example

Dijkstra's algorithm implementation

- **Centralized version: Single node gets topology information and computes the routes**
  - **Routes can then be broadcast to the rest of the network**
- **Distributed version: each node i broadcasts {dij all j} to all nodes of the network; all nodes can then calculate shortest paths to each other node**
  - **Open Shortest Path First (OSPF) protocol used in the internet**

Routing in the Internet

- **Autonomous systems (AS)**
  - **Internet is divided into AS's each under the control of a single authority**
- **Routing protocol can be classified in two categories**
  - **Interior protocols - operate within an AS**
  - **Exterior protocols - operate between AS's**

- **Interior protocols**
  - **Typically use shortest path algorithms**
    - **Distance vector - based on distributed Bellman-ford**
    - **link state protocols - Based on "distributed" Dijkstra's**

Distance vector protocols

- **Based on distributed Bellman-Ford**
  - **Nodes exchange routing table information with their neighbors**

- **Examples:**
  - **Routing information protocols (RIP)**
    - **Metric used is hop-count (dij=1)**
    - **Routing information exchanged every 30 seconds**

  - **Interior Gateway Routing Protocol (IGRP)**
    - **CISCO proprietary**
    - **Metric takes load into account**
    - **Dij ~ 1/(μ–λ) (estimate delay through link)**
    - **Update every 90 seconds**
    - **Multi-path routing capability**

Link State Protocols

- **Based on Dijkstra's Shortest path algorithm**
  - **Avoids loops**
  - **Routers monitor the state of their outgoing links**
  - **Routers broadcast the state of their links within the AS**
  - **Every node knows the status of all links and can calculate all routes using dijkstra's algorithm**

    Nonetheless, nodes only send packet to the next node along the route with the packets destination address. The next node will look-up the address in the routing table

- **Example: Open Shortest Path First (OSPF) commonly used in the internet**

- **Link State protocols typically generate less "control" traffic than Distance-vector**

Inter-Domain routing

- Used to route packets across different AS's
- Options:
  - Static routing - manually configured routes
  - Distance-vector routing
    Exterior Gateway Protocol (EGP)
    Border Gateway Protocol (BGP)
- Issues
  - What cost "metric" to use for Distance-Vector routing
    Policy issues: Network provider A may not want B's packets routed through its network or two network providers may have an agreement

    Cost issues: Network providers may charge each other for dlivery of packets

Bridges, Routers and Gateways

- A Bridge is used to connect multiple LAN segments
  - Layer 2 routing (Ethernet)
  - Does not know IP address
  - Varying levels of sophistication
    - Simple bridges just forward packets
    - smart bridges start looking like routers
- A Router is used to route connect between different networks using network layer address
  - Within or between Autonomous Systems
  - Using same protocol (e.g., IP, ATM)
- A Gateway connects between networks using different protocols
  - Protocol conversion
  - Address resolution
- These definitions are often mixed and seem to evolve!

Bridges, routers and gateways