Routing: how to get packets to their destination

- **Forwarding**: local calculation to decide next hop for each packet
- **Routing**: global calculation to ensure that forwarding decisions ultimately take packets to the right place

**Intra-domain routing protocols**
- Also called Interior Gateway Protocols (IGP)
- Distance Vector
  - Local exchange of global topology information
  - In steady-state converges to correct solution
  - Problems during failures: count-to-infinity

This class

- Finish Intra-domain routing
  - Link-state protocols

Link State routing

- Same goal as DV, but a different approach
- Two phases
  - **Reliable flooding**
    - Tell all routers what you know about your local topology
  - **Path calculation** (Dijkstra’s algorithm)
    - Each router computes best path over complete network

Motivation

- Using DV, routers only have local information, making it difficult to decide what to do when there are changes
- With LS, faster convergence and better stability (hopefully)
- But… more complex

Reliable flooding

- Goal: tell everyone what you know about local topology
- Periodically send link state packets (LSPs) on all links
  - LSP contains [node, neighbors, costs]
- If node X receives an LSP from node Y over link Q
  - Save it in local link state database
  - Forward LSP on all links except Q
- Use explicit ACKs and retransmits to make flooding reliable
- Each LSP will travel exactly once over each link

Flooding example

- LSP generated by X at T=0
- Nodes become orange as they receive it
Dijkstra’s Shortest Path Tree (SPT) algorithm

- Graph algorithm for single-source shortest path tree

\[
\begin{align*}
S &\leftarrow \emptyset \\
Q &\leftarrow \{\text{all nodes keyed by distance}\} \\
\text{While } Q \neq \emptyset & \\
\quad u &\leftarrow \text{extract-min}(Q) \\
\quad S &\leftarrow S +\{u\} \\
\quad \text{for each node } v \text{ adjacent to } u & \\
\quad &\text{"relax" the cost of } v \\
\end{align*}
\]

Dijkstra Example – Step 1

Example – Step 2

Example – Step 3

Example – Step 4

Example – Step 5
Example – Done

Reliable flooding challenges

- When link/router fails need to remove old data...how?
  - LSPs carry sequence numbers to distinguish new from old
  - Only accept (and forward) the "newest" LSP seen from a node
  - Send a new LSP with cost infinity to signal a link down

- What happens when a router fails and restarts?
  - What sequence # should it use? Don't want data ignored
  - Aging
    - Put a TTL in the LSP, periodically decremented by each router
    - When TTL = 0, purge the LSP and flood the LSP with TTL 0 to tell everyone else to do the same
  - If router waits for LSP to age out can use any sequence number
  - Alternative: when receiving an "old" LSP from a node, tell the node what the current sequence # is rather than simply dropping the LSP

More challenges

- What happens if the network is partitioned and heals?
  - Different LS databases must be synchronized
  - Use version #s on each LSP (incremented for each update)
  - Compare version #s when a link comes back up and request out of date LSPs

Link State evaluation

- Strengths
  - Loop free as long as LSDB's are consistent
  - Can have transient routing loops
  - Messages are small (esp compared to DV)
  - Converges quickly (esp compared to DV)

- Weaknesses
  - Must flood data across entire network (scalability?)
  - Must maintain state for entire topology

Link State in practice

- OSPF (Open Shortest Path First) and IS-IS
  - Most widely used intra-domain routing protocol
  - Run by almost all ISPs and many large organizations

  - Basic link state algorithm plus many features:
    - Authentication of routing messages
    - Extra hierarchy: Partition into routing areas
    - Load balancing: Multiple equal cost routes

For next time...

- Inter-domain routing
- Read 4.3-4.3.3
Flooding

- Each router maintains link state database and periodically sends link state packets (LSPs) to neighbor
  - LSPs contain [router, neighbors, costs]
- Each router forwards LSPs not already in its database on all ports except where received
  - Each LSP will travel over the same link at most once in each direction
- Flooding is fast, and can be made reliable with acknowledgments