CSE 461: Link State Routing
Link State Routing

- Same assumptions/goals, but different idea than DV:
  - Make sure all routers have a view of the global topology
  - Have them all independently compute the best routes
    - Note our good old “same input + same algorithm → consistent output” trick
- Two phases:
  1. Topology dissemination (flooding)
    - New News travels fast.
    - Old News should eventually be forgotten
  2. Shortest-path calculation (Dijkstra’s algorithm)
    - $N \log(n)$
Flooding

- Each router monitors state of its directly connected links
- Periodically, send this information to your neighbors
  - Generate a link state packet
  - Contains router ID, link list, sequence number, time-to-live
- Store and forward LSPs received – if (ID, seqno) is more recent
  - Remember this packet for routing calculations
  - Forward LSP to all ports other than incoming ports
  - This produces a flood; each LSP will travel over the same link at most once in each direction
- Flooding is fast, and can be made reliable with acknowledgments
Example

LSP generated by X at T=0

Will B transmit this LSP to C or A? Why or why not?
Flooding Sequence Numbers

How do we keep the sequence number space from being exhausted?

- Use nonces instead of sequence numbers? (i.e., accept any LSP with a nonce not equal to the one stored)
  - Why is this a bad idea?
- Just make the space really big (e.g., 128-bit)?
  - What happens if we accidentally emit an $n-1$ seqno?
- Allow the sequence number space to wrap around?
Sequence Number Wraparound

Does this solve sequence number exhaustion?
ARPANet failed in 1981, because…

A dying router emitted 3 LSPs with 3 very unlucky sequence numbers. Soon, the entire network was doing nothing but propagating these same three LSPs everywhere.
Other Complications

- When link/router fails need to remove old data. How?
  - LSPs carry sequence numbers to determine new data
  - Send a new LSP with cost infinity to signal a link down

- What happens if the network is partitioned and heals?
  - Different LS databases must be synchronized
  - Inconsistent data across routers → loops
Shortest Paths: Dijkstra’s Algorithm

- $N$: Set of all nodes
- $M$: Set of nodes for which we think we have a shortest path
- $s$: The node executing the algorithm
- $L(i,j)$: cost of edge $(i,j)$ (inf if no edge connects)
- $C(i)$: Cost of the path from $s$ to $i$.

Two phases:
- Initialize $C(n)$ according to received link states
- Compute shortest path to all nodes from $s$
  - Link costs are symmetric
The Algorithm

// Initialization
M = \{s\}  // M is the set of all nodes considered so far.
For each n in N - \{s\}
    C(n) = L(s,n)

// Find Shortest paths
Forever {
    Unconsidered = N-M
    If Unconsidered == {} break
    M = M + \{w\} such that C(w) is the smallest in Unconsidered
    For each n in Unconsidered
        C(n) = \text{MIN}(C(n), C(w) + L(w,n))
}
Open Shortest Path First (OSPF)

- Most widely-used Link State implementation today
- Basic link state algorithms plus many features:
  - Authentication of routing messages
  - Extra hierarchy: partition into routing areas
    - Only bordering routers send link state information to another area
    - Reduces chatter.
    - Border router “summarizes” network costs within an area by making it appear as though it is directly connected to all interior routers
- Load balancing
Distance Vector Message Complexity

N: number of nodes in the system
M: number of links
D: diameter of network (longest shortest path)
Da: Average degree of a node (# of outgoing links)

- Size of each update:
- Number of updates sent in one iteration:
- Number of iterations for convergence:
- Total message cost:
- Number of messages:
- Incremental cost per iteration:
Link State Message Complexity

N: number of nodes in the system
M: number of links
D: diameter of network (longest shortest path)
Da: Average degree of a node (# of outgoing links)

- Size of each update:
- Number of updates sent in one iteration:
- Number of iterations for convergence:
- Total message cost:
- Number of messages:
- Incremental cost per iteration:
Distance Vector vs. Link State

- When would you choose one over the other?
  - Be warned when reading about this on the Internet: people rate implementations, not fundamentals

- Bandwidth consumed
- Memory used
- Computation required
- Robustness
- Functionality
  - Global view of network vs. local?
  - Troubleshooting?
- Speed of convergence
Why have two protocols?

- **DV**: “Tell your neighbors about the world.”
  - Easy to get confused
  - Simple but limited, costly and slow
    - Number of hops might be limited
    - Periodic broadcasts of large tables
    - Slow convergence due to ripples and hold down

- **LS**: “Tell the world about your neighbors.”
  - Harder to get confused
  - More expensive sometimes
    - As many hops as you want
    - Faster convergence (instantaneous update of link state changes)
    - Able to impose global policies in a globally consistent way
      - load balancing
Cost Metrics

- How should we choose cost?
  - To get high bandwidth, low delay or low loss?
  - Do they depend on the load?

- Static Metrics
  - Hopcount is easy but treats OC3 (155 Mbps) and T1 (1.5 Mbps)
  - Can tweak result with manually assigned costs

- Dynamic Metrics
  - Depend on load; try to avoid hotspots (congestion)
  - But can lead to oscillations (damping needed)
Revised ARPANET Cost Metric

- Based on load and link
- Variation limited (3:1) and change damped
- Capacity dominates at low load; we only try to move traffic if high load
Key Concepts

- Routing uses global knowledge; forwarding is local
- Many different algorithms address the routing problem
  - We have looked at two classes: DV (RIP) and LS (OSPF)
- Challenges:
  - Handling failures/changes
  - Defining “best” paths
  - Scaling to millions of users
Dijkstra Example – After the flood

// Initialization
M = \{s\} // M is the set of all nodes considered so far.
For each n in N - \{s\}
    C(n) = L(s,n)

* The Considered
* The Unconsidered.
Dijkstra Example – Post Initialization

// Initialization
M = {s} // M is the set of all nodes considered so far.
For each n in N - {s}
C(n) = L(s,n)

The Considered
The Unconsidered
Considering a Node

```
// Find Shortest paths
Forever {
    Unconsidered = N-M
    If Unconsidered == {} break
    M = M + {w} such that C(w) is the smallest in Unconsidered
    For each n in Unconsidered
        C(n) = MIN(C(n), C(w) + L(w,n))
}
```

Cost updates of 8, 14, and 7

The Considered
The Unconsidered
The Under Consideration (w).
Pushing out the horizon

// Find Shortest paths
Forever {
    Unconsidered = N-M
    If Unconsidered == {} break
    M = M + (w) such that C(w) is the smallest in Unconsidered
    For each n in Unconsidered
        C(n) = MIN(C(n), C(w) + L(w,n))
}

The Considered
The Unconsidered
The Under Consideration (w)

Cost updates of 13
Next Phase

The Unconsidered.

The Considered

The Under Consideration \( w \).

Cost updates of 9
Considering the last node

```plaintext
// Find Shortest paths
Forever {
    Unconsidered = N-M
    If Unconsidered == {} break
    M = M + (w) such that C(w) is the smallest in Unconsidered
    For each n in Unconsidered
        C(n) = MIN(C(n), C(w) + L(w,n))
}
```

Diagram:

- **0** (The Considered)
- **5** (The Under Consideration \( w \))
- **7** (The Unconsidered)
- **8**
- **9**

- Connections and distances:
  - 0 → 5: 2
  - 5 → 8: 3
  - 8 → 9: 1
  - 5 → 7: 2
  - 7 → 9: 6
  - 8 → 5: 5
  - 9 → 7: 4
  - 9 → 5: 9
  - 7 → 5: 7
Dijkstra Example – Done

Graph with vertices 0, 5, 7, 8, and 9, and edges with weights 2, 3, 4, 5, 6, 7, 9.