Homework

- Being returned today
- Solutions are on the Web page
- If you have questions about grading contact David Yu (davidyu@ucsd.edu)
Projects

- Grades are in grade source

- Check your **UCSD** email account for your grade source id

- Walter will be posting more information about how he graded on the Web board
Midterm info

- It's on Thursday
- Covers everything from day 1 through Lecture #7 (Internetworking and IP) and associated reading in book
- Closed book, closed note, closed laptop, closed cell phone, etc
- You can bring one 8.5x11 piece of paper with notes on it (must be readable with the naked eye)

- Brian Lum will be going over questions in section
- I won’t be in tomorrow, so instead I have two alternate office hours
  - Today 5-6pm
  - Thursday 10-11am
Last class

- 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 take packets to the right place

- Intra-domain routing protocols
  - **Distance Vector**
    - Local exchange of global routing 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, sequence number]
- 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 at most once over each link
**Flooding example**

- LSP generated by X at T=0
- Nodes become orange as they receive it

![Diagram](image_url)

- T=0
- T=1
- T=2
- T=3
Dijkstra’s Shortest Path Tree (SPT) algorithm

- Graph algorithm for single-source shortest path tree

```
S ← {}
Q ← <remaining nodes keyed by distance>
While Q != {}
    u ← extract-min(Q)
    S ← S plus {u}
    for each node v adjacent to u
        "relax" the cost of v
← u is done
```
Dijkstra Example – Step 1

Diagram of a network with labeled edges.
Example – Step 2
Example – Step 3
Example – Step 4
Example – Step 5
Example – Done
Reliable flooding challenges

- When link/router fails and 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
Flooding challenges (2)

- 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 network with an 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
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
    - “Border” router pretends to be directly connected to all routers in an area (answers for them)
  - Load balancing: Multiple equal cost routes