ECE453 – Introduction to Computer Networks

Lecture 9 - The Network Layer (I) - Routing

Recap

- Framing
- Error detection and correction
- Reliable or unreliable data transfer
- Channel allocation protocol

Network Core and Network Edge
Network Core – Information Transmission

- Circuit switching
  - Telephone system
- Message switching
  - Mail delivery
    - The message travels as a complete unit. At any one time, it completely exists in one place.
- Packet switching
  - The Internet

Design Issues

- Store-and-forward packet switching
- Services to the transport layer
  - Connection-oriented vs. Connectionless
  - Quality of service (QoS)

Network Layer Services

- Connectionless
  - Best-effort
  - No guarantee
  - The Internet
  - No advance setup is needed
  - Datagram subnet
- Connection-oriented
  - Guaranteed delivery
  - ATM
  - A path from the source router to the destination router is established before any data packets can be sent
  - Virtual circuit
The Internet Network Layer

Routing protocols:
- path selection
- RIP, OSPF, BGP

IP protocol:
- addressing conventions
- datagram format
- packet handling conventions

ICMP protocol:
- error reporting
- router "signaling"

Transport layer: TCP, UDP

Link layer

Physical layer

Routing - In the Middle of Intersection ...

Different Strategies

- Nonadaptive algorithms (or static routing)
- Adaptive algorithms (or dynamic routing)
  - Global algorithm
    - (have a global knowledge - a map)
  - Decentralized algorithm
    - (get information only from neighbor)
Graph Abstraction for Routing Algorithms

- Graph nodes ↔ Routers
- Graph edge ↔ Physical links
- Edge weight ↔ Link cost
- Link cost
  - Delay, power consumption, congestion level, $cost$, etc.
- Good path or optimal path
  - Minimum link cost

Two Fundamental Routing Algorithms

- Link state routing
  - A global algorithm
- Distance vector routing (or Bellman-Ford routing, Ford-Fulkerson routing)
  - A decentralized algorithm
  - The original ARPANET routing algorithm, replaced by LS routing in 1979

A Link State Routing Algorithm

- **Dijkstra’s algorithm**
  - Net topology, link costs known to all nodes
    - accomplished via “link state broadcast”
    - all nodes have the same info
  - computes least cost paths from the source to all other nodes
  - iterative algorithm
Dijkstra's Algorithm: An Example

<table>
<thead>
<tr>
<th>Step</th>
<th>start N</th>
<th>D(B)p(B)</th>
<th>D(C)p(C)</th>
<th>D(D)p(D)</th>
<th>D(E)p(E)</th>
<th>D(F)p(F)</th>
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<td>2.A</td>
<td>4.D</td>
<td>2.D</td>
<td>infinity</td>
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<td>ADEB</td>
<td>3.E</td>
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</tbody>
</table>

Dijkstra's Algorithm: Discussion

**Algorithm complexity:** n nodes
- each iteration: need to check all nodes, not in N
- \(n^2(n+1)/2\) comparisons: \(O(n^2)\)
- more efficient implementations possible: \(O(n\log n)\)

Oscillations possible:
- e.g., link cost = amount of carried traffic

DV Routing
- Each router maintains a distance table
- Initialization
  - 0 for itself
  - Infinity for non-neighbor
  - Link cost for neighbor
- Message exchange between neighbors
  - When a neighbor first comes up
  - When information changes (e.g., change in link cost)
- Distance vector calculation
  - Minimize cost to each destination

**Formula:**
\[D(X,Y,Z) = c(X,Z) + \min_{w} \{D(Y,w)\}\]
DV: Example

DV: Link Cost Changes
“good news travels fast”

algorithm terminates

DV: Link Cost Changes
“bad news travels slow”

Count to infinity problem
### Distance Table: An Example

**Diagram:**

- **Nodes:** A, B, C, D, E
- **Edges and Costs:**
  - A-C: 1
  - A-D: 4
  - B-C: 8
  - B-D: 7
  - C-E: 2
  - D-E: 5
  - A-E loop: 11

**Distance Table: 

<table>
<thead>
<tr>
<th>Destination</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
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<tbody>
<tr>
<td>A</td>
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<td></td>
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<tr>
<td>B</td>
<td></td>
<td>7</td>
<td>8</td>
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<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td>6</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
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<td>11</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Cost Calculations:**

- **D(C,D) = c(E,D) + min_{w} \{ D^2(C,w) \} = 2 + 2 = 4**
- **D(A,D) = c(E,D) + min_{w} \{ D^2(A,w) \} = 2 + 3 = 5** (loop)
- **D(A,B) = c(E,B) + min_{w} \{ D^2(A,w) \} = 8 + 6 = 14** (loop)