# Network Layer



## COMP90007 Internet Technologies



Lecturer: Ling Luo

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# Outline

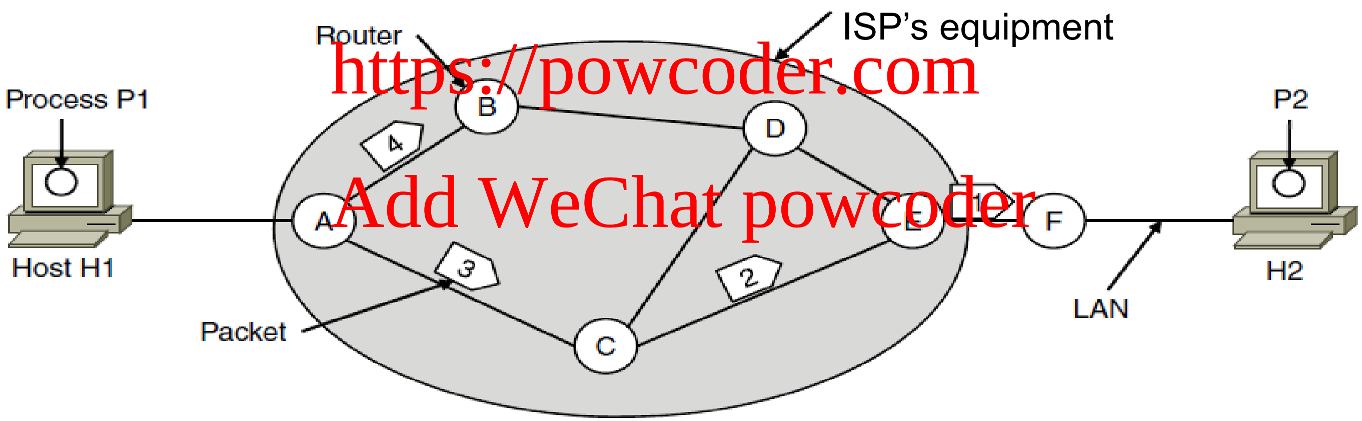
- Network layer in the Internet
- Types of services
- Internetworking
  - Tunneling
  - Fragmentation
  - Path MTU discovery
- Internet Protocol
  - Addressing
  - Subnetting
- Routing algorithms

# Routing

Consider the network as a **graph of nodes and links**:

- Routing is the process of discovering network paths
- Decide what to optimise: hops, delay, etc.
- Update routes for changes in topology (e.g. router failures)






A's table (initially)

| Dest. | Line |
|---|---|
| A | – |
| B | B |
| C | C |
| D | B |
| E | C |
| F | C |

A's table (later)

| | |
|---|---|
| A | – |
| B | B |
| C | C |
| D | B |
| E | B |
| F | B |

C's Table

| | |
|---|---|
| A | A |
| B | A |
| C | – |
| D | E |
| E | E |
| F | E |

E's Table

| | |
|---|---|
| A | C |
| B | D |
| C | C |
| D | D |
| E | – |
| F | F |

# Routing Algorithms (1)

- The routing algorithm is responsible for deciding on **which output line an incoming packet should be transmitted**



- **Non-Adaptive Algorithms**



  - Static routing, static decision-making process



- **Adaptive Algorithms**
  - Dynamic routing, dynamic decision-making process
  - Changes in network topology, traffic, etc.

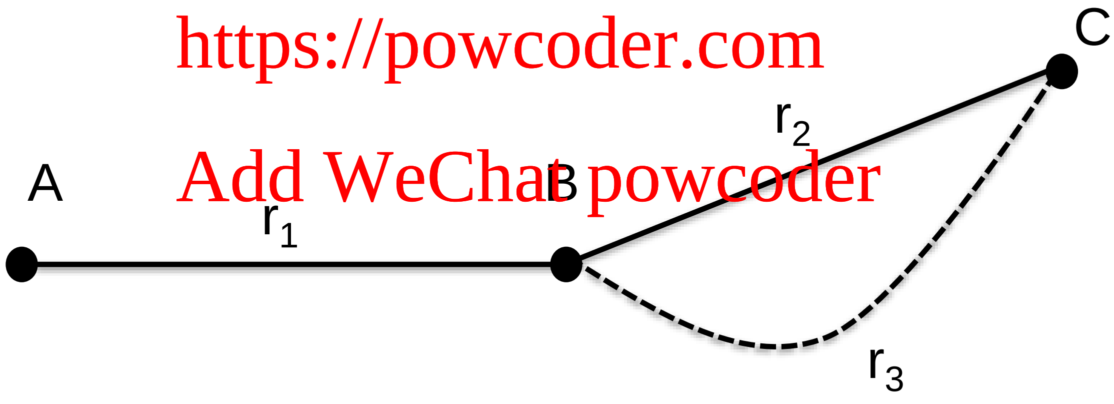
# Routing Algorithms (2)

- Non-adaptive
  - Shortest path routing
  - Flooding
- Adaptive
  - Distance vector routing
  - Link state routing
- Hierarchical routing
- Broadcasting routing
- Multicasting routing

# Optimality Principle

- If router B is on the optimal path from router A to router C, then the optimal path from B to C also falls along the same route

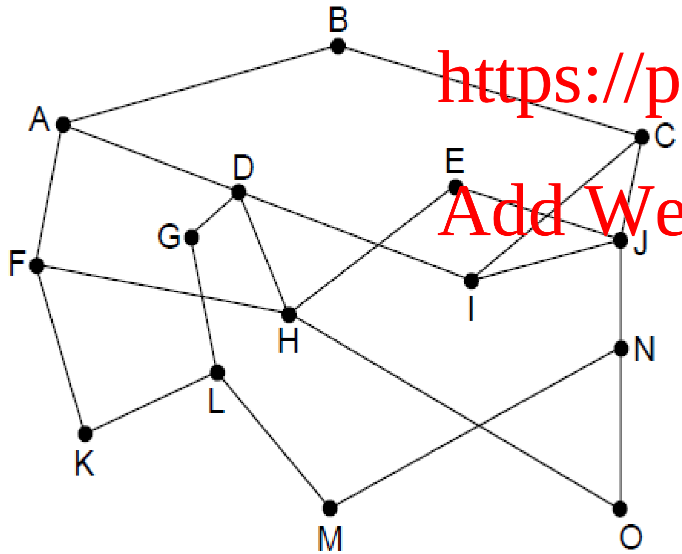




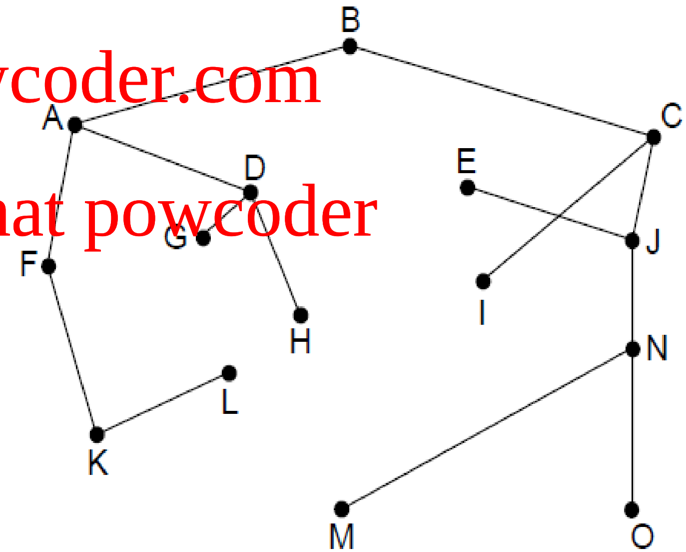
# Sink Tree

- **Sink Tree**: the set of optimal routes from all sources to a given destination forms a tree rooted at the destination
- **Goal** of a routing algorithm: discover and utilise the sink trees for all routers






**Network**

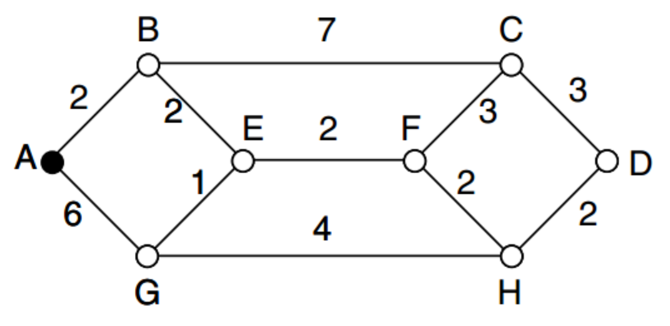



**Sink tree of best paths to router B**

# Shortest Path Routing

- A non-adaptive algorithm
- Shortest path can be determined by building a graph with each node representing a router, and each arc representing a communication link
- To choose a path between 2 routers, the algorithm finds the shortest path between them on the graph
- Metrics: number of hops, distance, delay etc.





# Shortest Path: Dijkstra's Algorithm (1)

- Computes a sink tree on the graph:
  - Each link is assigned a non-negative weight/distance
  - Shortest path is the one with lowest total weight



  - Using weights of 1 gives paths with fewest hops
- Algorithm:

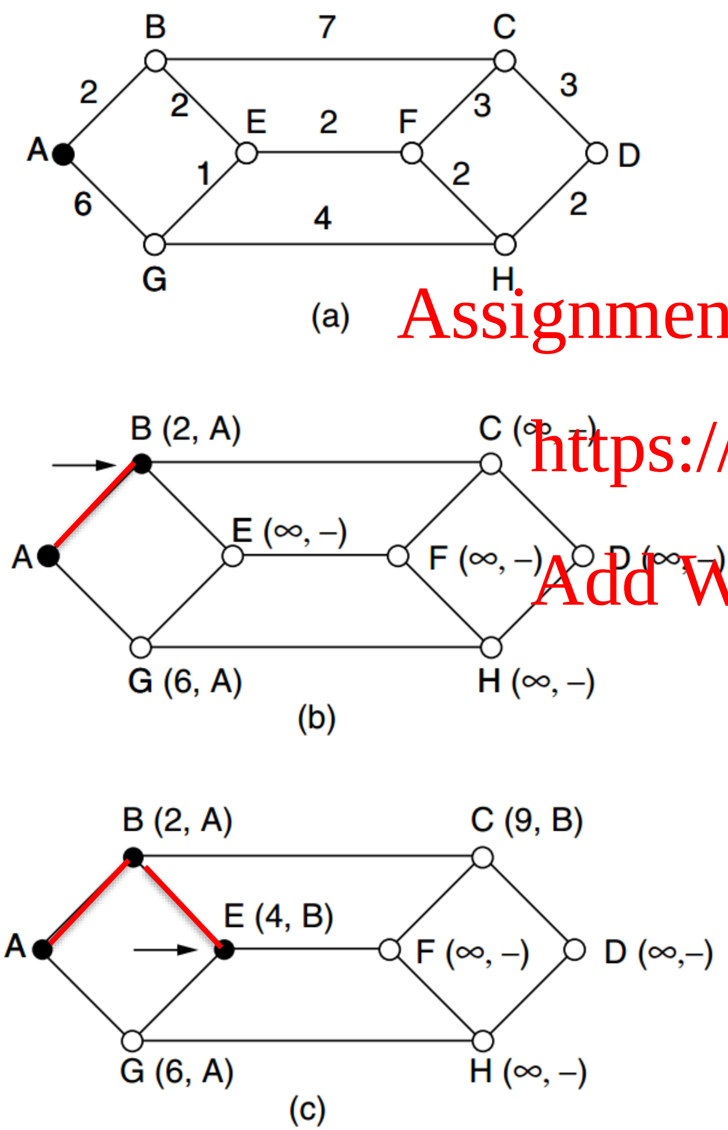


1) Create **a set *P, tracking* the nodes added in the tree**. Initialise it as empty.
2) For each node, assign a **distance value *d* from the node to sink**. Initialise the distance for all nodes as infinity.



3) Start from the sink node, assign distance as 0*.*
4) **Repeat** when *P* doesn't include all nodes:
   i. For all the nodes not in *P,* compare distance *d*
   ii. Pick a node *v* with min distance and add it to *P*
   iii. Update *d* for all the adjacent nodes of *v* (newly added node)

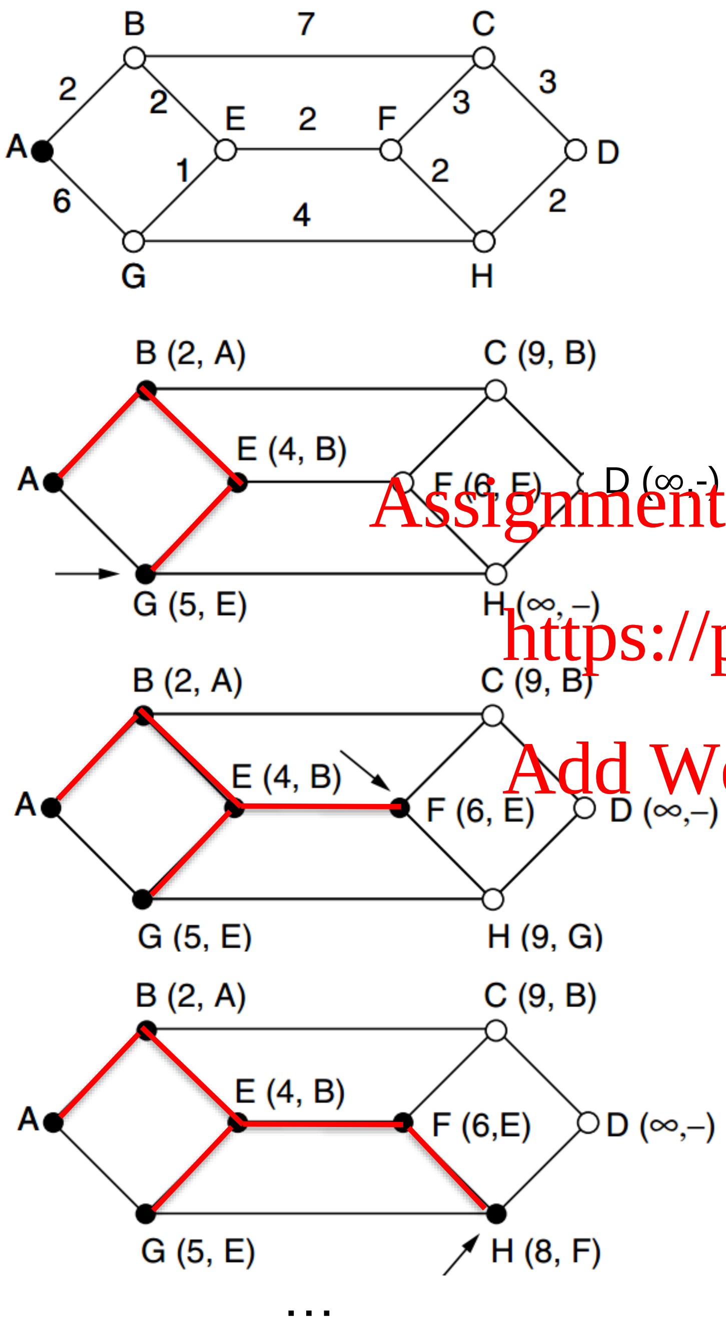
# Shortest Path: Dijkstra's Algorithm (2)






**Distance to A** | **Set P**

| n | A | B | C | D | E | F | G | H | Set P |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 0 | ∞ | ∞ | ∞ | ∞ | ∞ | ∞ | ∞ | {A} |
| **2** | -- | **2** | ∞ | ∞ | ∞ | ∞ | 6 | ∞ | {A, B} |
| **3** | -- | -- | 9 | ∞ | **4** | ∞ | 6 | ∞ | {A, B, E} |




## Distance to A

## Set P

| n | A | B | C | D | E | F | G | H | Set P |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | ∞ | ∞ | ∞ | ∞ | ∞ | ∞ | ∞ | {A} |
| 2 | -- | 2 | ∞ | ∞ | ∞ | ∞ | 6 | ∞ | {A, B} |
| 3 | -- | -- | 9 | ∞ | 4 | ∞ | 6 | ∞ | {A, B, E} |
| **4** | -- | -- | 9 | ∞ | -- | 6 | **5** | ∞ | {A, B, E, G} |
| **5** | -- | -- | 9 | ∞ | -- | **6** | -- | 9 | {A, B, E, G, F} |
| **6** | -- | -- | 9 | ∞ | -- | -- | -- | **8** | {A, B, E, G, F, H} |
| **7** | -- | -- | **9** | 10 | -- | -- | -- | -- | {A, B, E, G, F, H, C} |
| **8** | -- | -- | **--** | **10** | -- | -- | -- | -- | {A, B, E, G, F, H, C, D} |

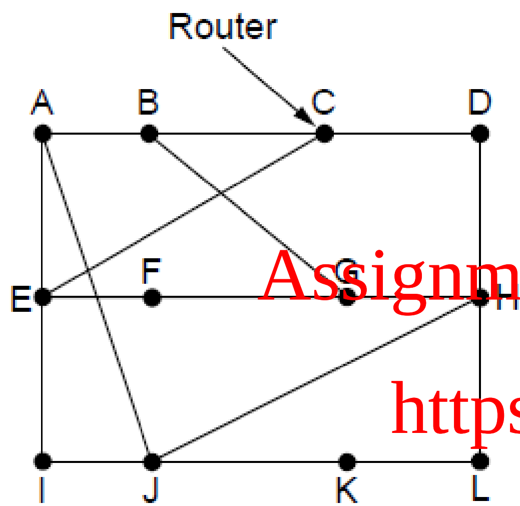
# Flooding

- A non-adaptive algorithm
- Every incoming packet is sent out on **every outgoing line except the one on which it arrived**
- Inefficient: generates a large number of duplicate packets
- Selective flooding is an improved variation
  - Routers send packets only on links which are approximately in the right direction

# Distance Vector Routing (1)

- A dynamic algorithm
  - Each router maintains a table which includes the best-known distance to each destination and which line to use to get there
  - Tables are updated by exchanging information with neighbouring routers
  - Global information shared locally
- Algorithm:
  1) Each node knows distance of links to its neighbors
  2) Each node **advertises** vector of lowest known distances to **all neighbors**
  3) Each node uses received vectors to **update** its own
  4) Repeat periodically

# Distance Vector Routing (2)




**Network**

**JA = 8, JI = 10, JH = 12, JK = 6**

| To | A | I | H | K | New estimated delay from J | Line |
|---|---|---|---|---|---|---|
| A | 0 | 24 | 20 | 21 | 8 | A |
| B | 12 | 36 | 31 | 28 | 20 | A |
| C | 25 | 18 | 19 | 36 | 28 | I |
| D | 40 | 27 | 8 | 24 | 20 | H |
| E | 14 | 7 | 30 | 22 | 17 | I |
| F | 23 | 20 | 19 | 40 | 30 | I |
| G | 18 | 31 | 6 | 31 | 18 | H |
| H | 17 | 20 | 0 | 19 | 12 | H |
| I | 21 | 0 | 14 | 22 | 10 | I |
| J | 9 | [illegible] | 7 | 10 | 0 | – |
| K | 24 | 22 | 22 | 0 | 6 | K |
| L | 29 | 33 | 9 | 9 | 15 | K |

**Vectors received from neighbors A, I, H and K**

**New vector for J**

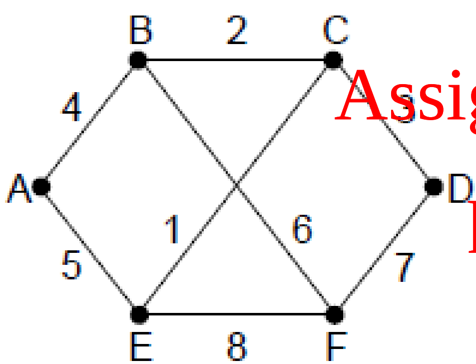
# Link State Routing

- A dynamic algorithm
  - An alternative to distance vector: **too long to converge** after the network topology changed
  - Widely used in the Internet, e.g. Open Shortest Path First (OSPF)
  - More computation than distance vector
  - Local information shared globally, using flooding
- Algorithm: each router has to

1) Discover neighbours and learn network addresses
2) Measure delay or cost to each neighbour
3) **Build link state packet**
4) Send this packet to **all other routers**
5) **Compute the shortest path** to every other router, e.g. using Dijkstra's algorithm

# Building Link State Packets

- Link State Packet (LSP) for a node lists neighbours and the distance to reach them




**Network**

Link State Packets

| A | | B | | C | | D | | E | | F | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Seq. | | Seq. | | Seq. | | Seq. | | Seq. | | Seq. | |
| Age | | Age | | Age | | Age | | Age | | Age | |
| B | 4 | A | 4 | B | 2 | C | 3 | A | 5 | B | 6 |
| E | 5 | C | 2 | D | 3 | F | 7 | C | 1 | D | 7 |
| | | F | 6 | E | 1 | | | F | 8 | E | 8 |

**LSP for all nodes**



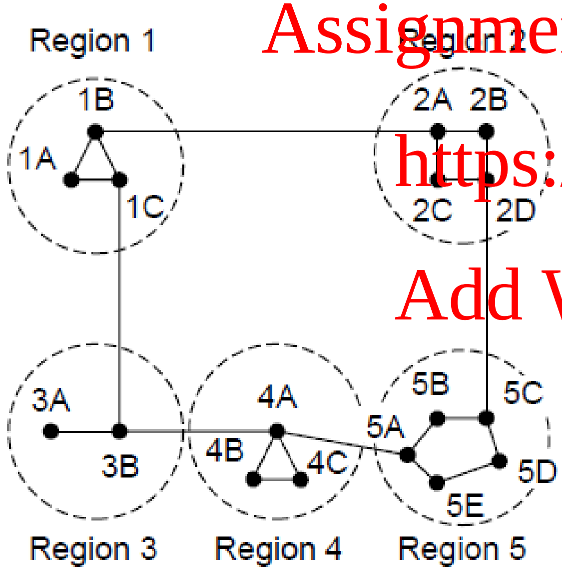
- When to build new LSP?
  - Periodically at regular intervals
  - Build them when some significant event occurs

# Hierarchical Routing (1)

- As networks grow in size, routing tables expand and this impacts CPU and memory requirements
- Dividing all routers into regions increases efficiencies
  - Each router knows everything about other routers in its region but nothing about routers in other regions
  - Routers which connect to two regions act as exchange points for routing decisions

# Hierarchical Routing (2)

- Hierarchical routing reduces the work of computation but may result in slightly longer paths than flat routing




Full table for 1A

| Dest. | Line | Hops |
|---|---|---|
| 1A | – | – |
| 1B | 1B | 1 |
| 1C | 1C | 1 |
| 2A | 1B | 2 |
| 2B | 1B | 3 |
| 2C | 1B | 3 |
| 2D | 1B | 4 |
| 3A | 1C | 3 |
| 3B | 1C | 2 |
| 4A | 1C | 3 |
| 4B | 1C | 4 |
| 4C | 1C | 4 |
| 5A | 1C | 4 |
| 5B | 1C | 5 |
| 5C | 1B | 5 |
| 5D | 1C | 6 |
| 5E | 1C | 5 |

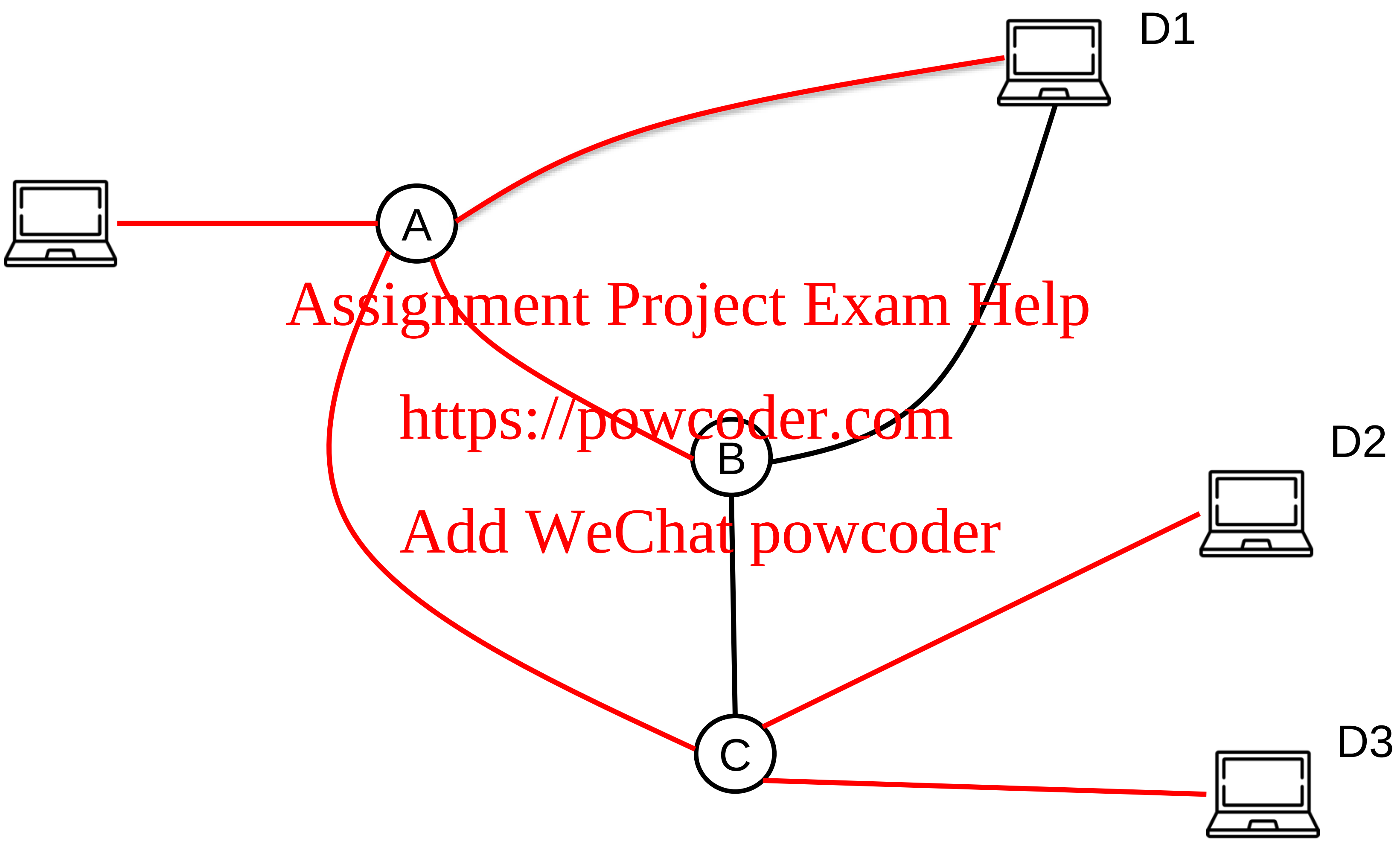
Hierarchical table for 1A

| Dest. | Line | Hops |
|---|---|---|
| 1A | – | – |
| 1B | 1B | 1 |
| 1C | 1C | 1 |
| 2 | 1B | 2 |
| 3 | 1C | 2 |
| 4 | 1C | 3 |
| 5 | 1C | 4 |

# Broadcast Routing (1)

- Broadcast routing allows hosts to send messages to all other hosts.
  - **Single distinct packet** to each destination: inefficient, and source needs all destination addresses
  - **Multi-destination routing**: a router copies the packet for each outgoing line. Use bandwidth more efficiently, but source needs to know all the destination addresses
  - **Flooding**
  - **Reverse path forwarding**

# Broadcast Routing (2)



# Broadcast Routing (3)

- Reverse path forwarding

  The router checks if the broadcast packet is arrived on the line normally used for sending packets to the source of the broadcast

  - **Yes**: there is a **high probability** that the route used to transmit this packet is the **best**, and this packet is the **first copy**. The router then copies the packet and forwards them onto all other lines.

  - **No:** the packet is **discarded as** a likely **duplicate**.

# Multicast Routing (1)

- Multicast routing allows hosts to send a message to a well-defined group within the whole network



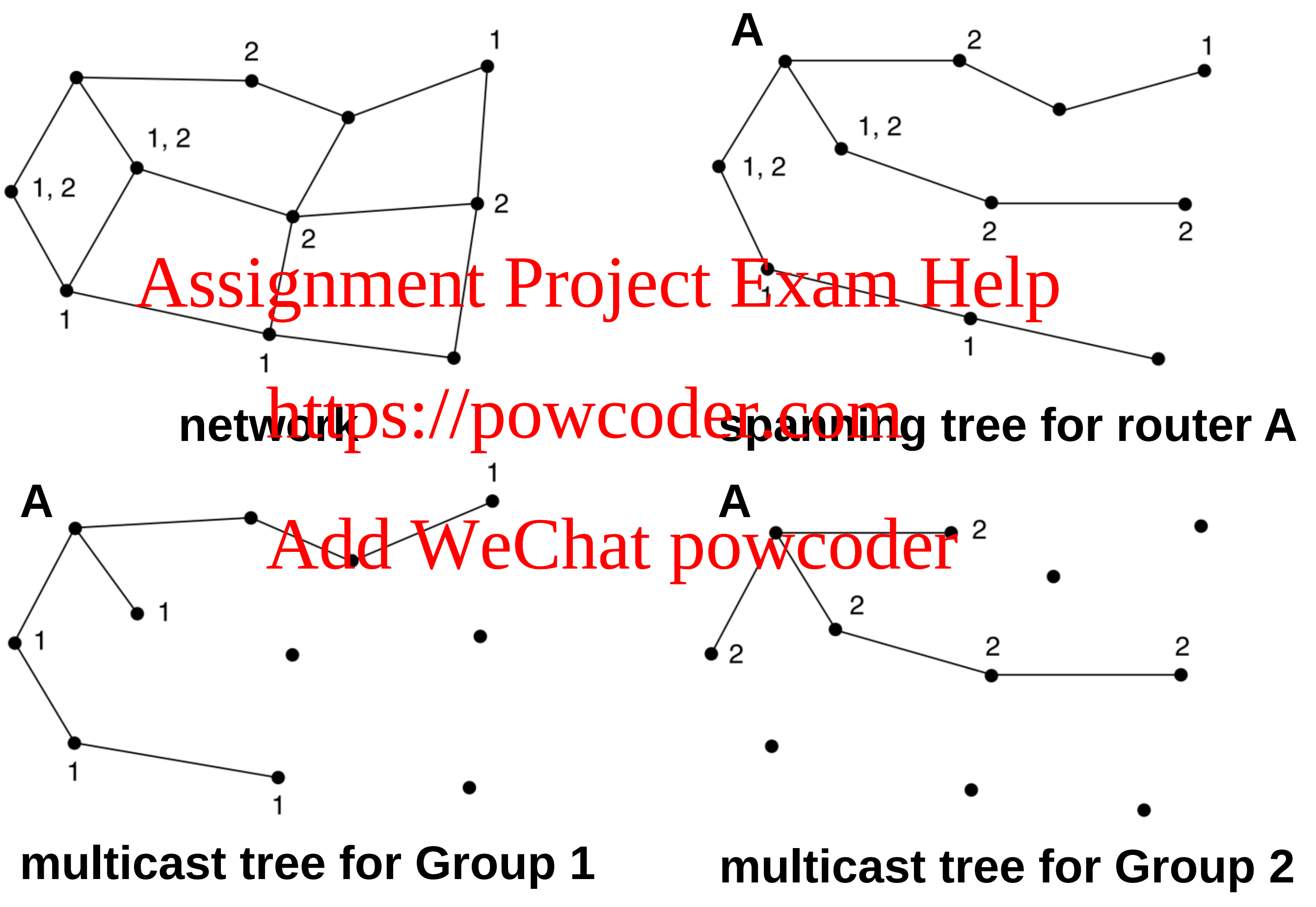
- Each router computes a spanning tree covering all other routers





  - Spanning tree: subset of the graph that includes all nodes, but no loops.
  - Prunes the spanning tree to eliminate all lines which do not lead to members of the group

# Multicast Routing (2)



# Summary

- Network layer in the Internet
- Types of services
- Internetworking
  - Tunneling
  - Fragmentation
  - Path MTU discovery
- Internet Protocol
  - Addressing
  - Subnetting
- Routing algorithms