Network Layer

COMP nologies

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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)

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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**
  - Static routing, static decision-ma

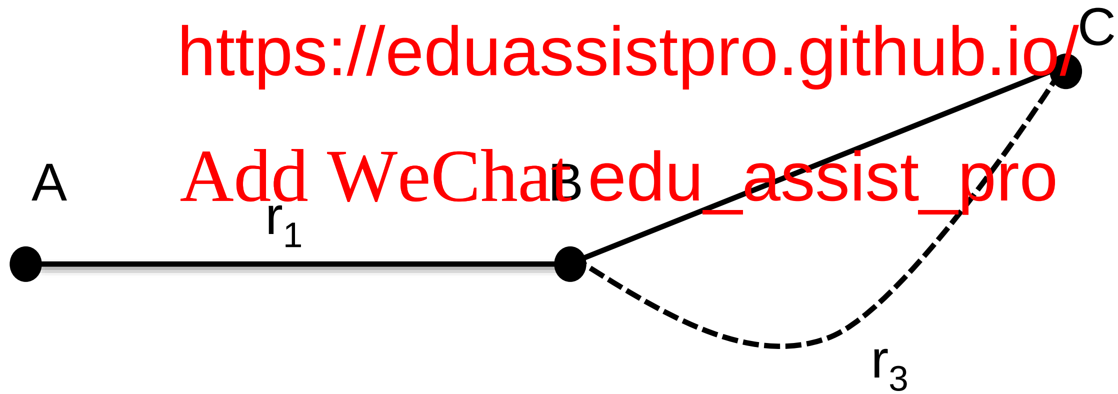
- **Adaptive Algorithms**
  - Dynamic routing, dynamic decision-making process
  - Changes in network topology, traffic, etc.

Routing Algorithms (2)

- Non-adaptive
  - Shortest path routing
  - Flooding
- Adaptive
  - Distance vecto
  - 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.



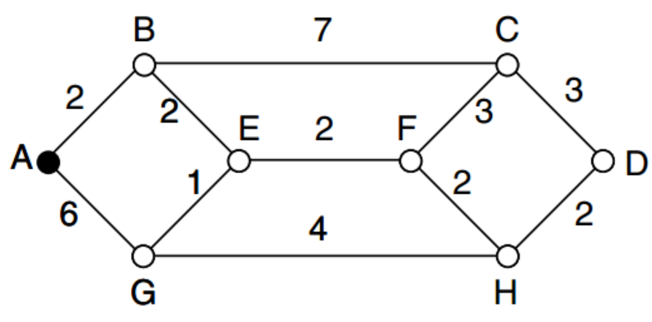
Sink Tree

- **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
- To choose a p he algorithm finds the shortest path between th raph
- Metrics: number of hops, dist etc.

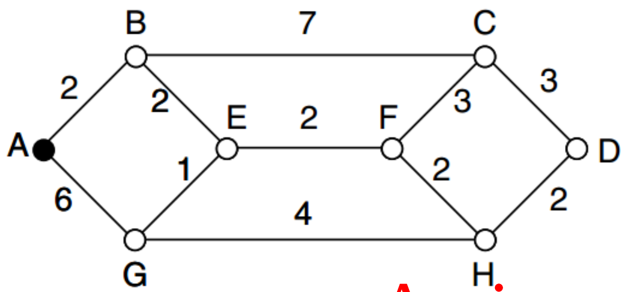


Shortest Path: Dijkstra's Algorithm (1)

- 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*, t** [illegible] **he tree**. Initialise it as empty.
2) For each node, assign a **distance v** [illegible] **e 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)

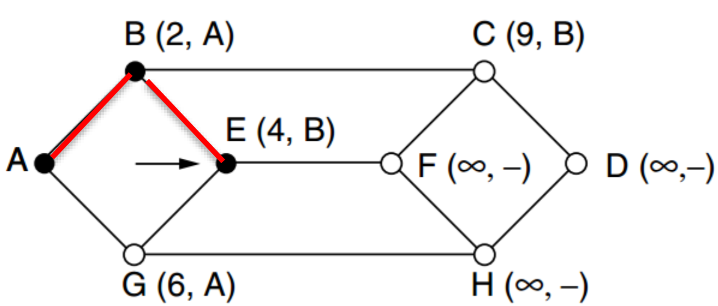
Shortest Path: Dijkstra's Algorithm (2)



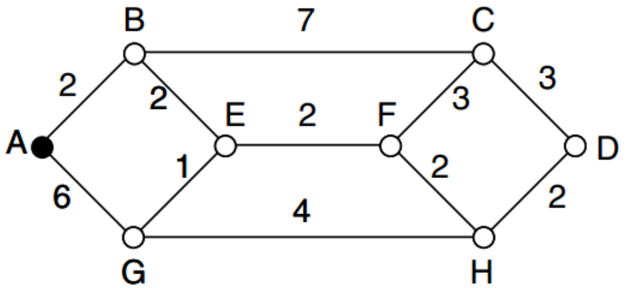
(a)

Distance to A **Set P**

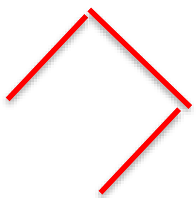
					E	F	G	H	
					∞	∞	∞	∞	{A}
2	--					∞	6	∞	{A, B}
3	--	--	9	∞	4	∞	6	∞	{A, B, E}

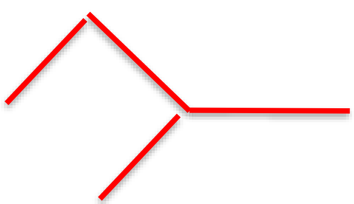


(c)



(a)

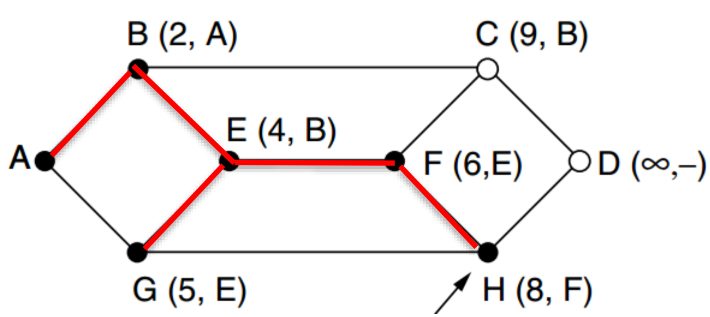




D (∞,-)

Distance to A

n	A	B	C	D	E	F	G	H	Set P
1	0	∞	∞	∞	∞	∞	∞	∞	{A}
2	--	2	∞	∞	∞	∞	6	∞	{A, B}
					4	∞	6	∞	{A, B, E}
4	--					6	**5**	∞	{A, B, E, G}
5	--			∞		**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}



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Flooding

- A non-adaptive algorithm
- Every incoming packet is sent out on **every outgoing line except the one on which it arrived**

- Inefficient: gen f duplicate packets

- Selective flooding is an impro n

  - Routers send packets only on lin 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 informa

- 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

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 informati oding
- Algorithm: eac

1) Discover neighbours and learn n sses
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 **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 other routers in its region but nothing about ro er regions

  - Routers which connect to t act as exchange points for routing decisions

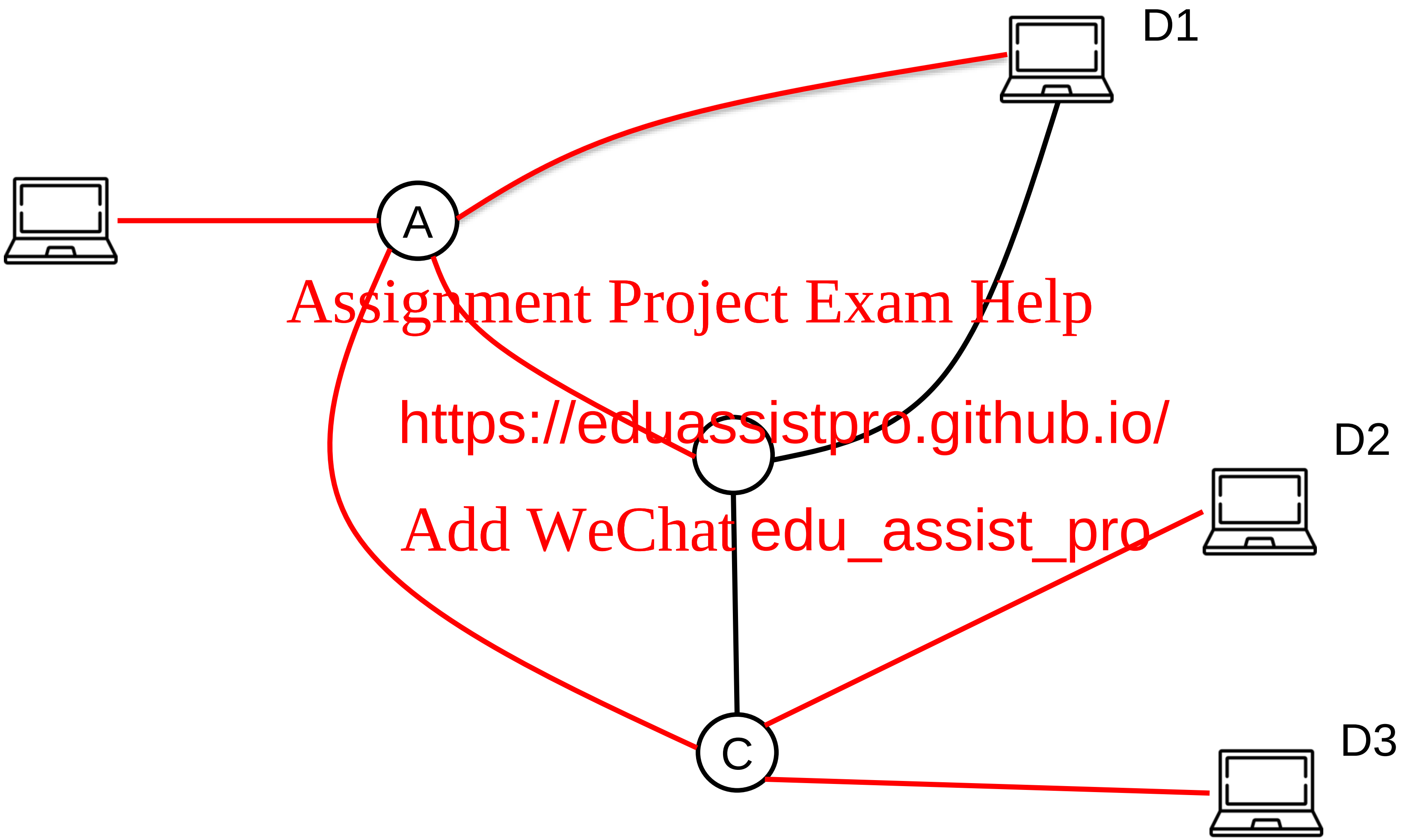
Hierarchical Routing (2)

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

Broadcast Routing (1)

- Broadcast routing allows hosts to send messages to all other hosts.
  - **Single distinct packet** to each destination: inefficient, and source dresses
  - **Multi-destin** copies th for each outgoing line. Use more efficiently, but source needs to know nation 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 t the route used to transmit this packet is the is packet is the **first copy**. The router then 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 g tree covering all other rout
  - Spanning tree: subset of th t 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)

A

net tree for router A

A

multicast tree for Group 1

multicast tree for Group 2

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- Routing algorithms