CN-Advanced
L31

Link State Routing

Dr. Ram P Rustagi
rprustagi@ksit.edu.in
http://www.rprustagi.com
https://www.youtube.com/rprustagi

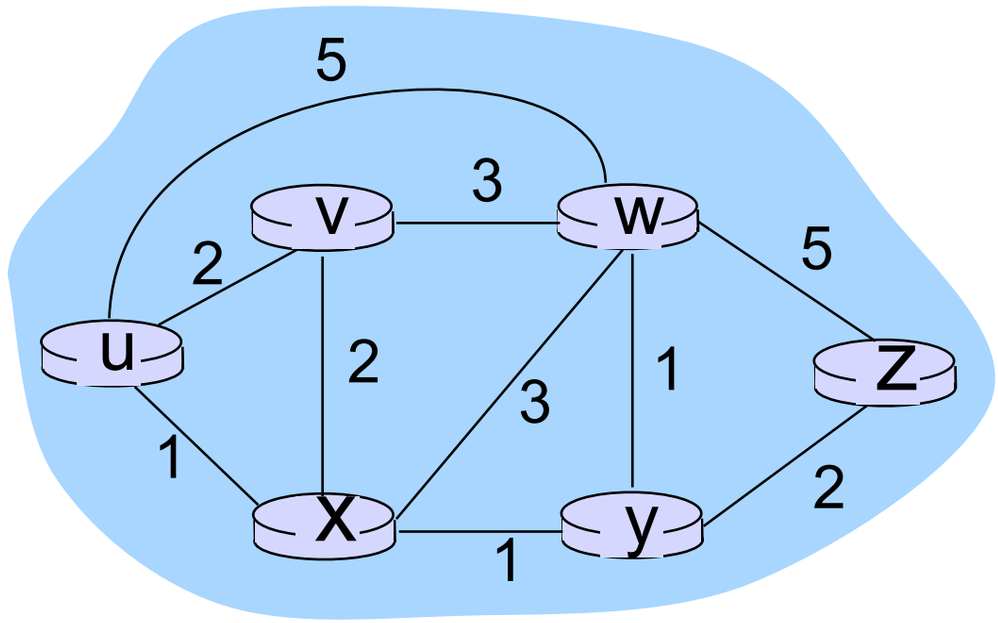
Routing Algorithm

- Purpose:
  - Given set of routers connected via links
    - find a good path from source to destination
- What is good path
  - Least cost
    - How to define the cost
      - Link length, links speed, monetary cost, others
  - Policy compliance
    - Organisation Y may not forward packet which originated from organisation X

Network as a graph

- Routing is essentially graph theory problem
- A graph represents the network
- Routers are nodes and links are edges
  - Each edge has an associated cost
- Basic problem: find least cost path between two nodes
  - Sum of costs of edges that make up the path
- Is it one time computation?
  - Nodes/links goes up/down
  - Link cost changes
  - New nodes get added (old gets deleted)
- Essentially, network topology keeps on changing
- Hence need **routing protocols**
- **Convergence:** getting consistent routing information

Graph abstraction



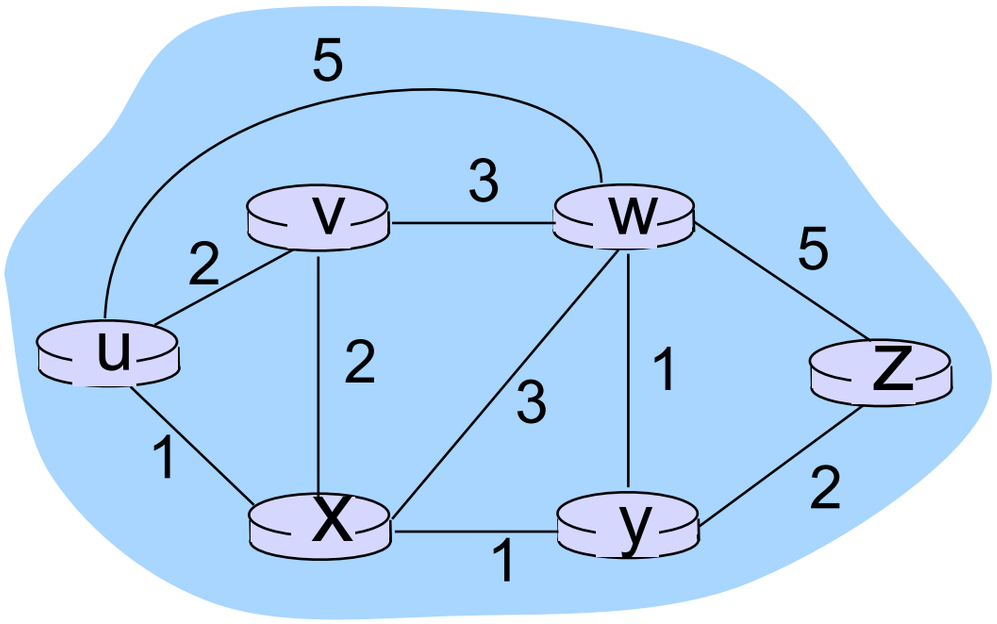
graph: G = (N,E)

N = set of routers = { u, v, w, x, y, z }

E = set of links ={ (u,v), (u,x), (v,x), (v,w), (x,w), (x,y), (w,y), (w,z), (y,z) }

aside: graph abstraction is useful in other network contexts, e.g., P2P, where *N* is set of peers and *E* is set of TCP connections

Graph abstraction: costs



c(x,x') = cost of link (x,x')
e.g., c(w,z) = 5

cost could always be 1, or inversely related to bandwidth, or inversely related to congestion

cost of path $(x_1, x_2, x_3, \ldots, x_p) = c(x_1,x_2) + c(x_2,x_3) + \ldots + c(x_{p-1},x_p)$

key question: what is the least-cost path between u and z ?
How many paths you considered?
if all edges have same cost, then it is shortest path

routing algorithm: algorithm that finds that least cost path

Routing algorithm classification

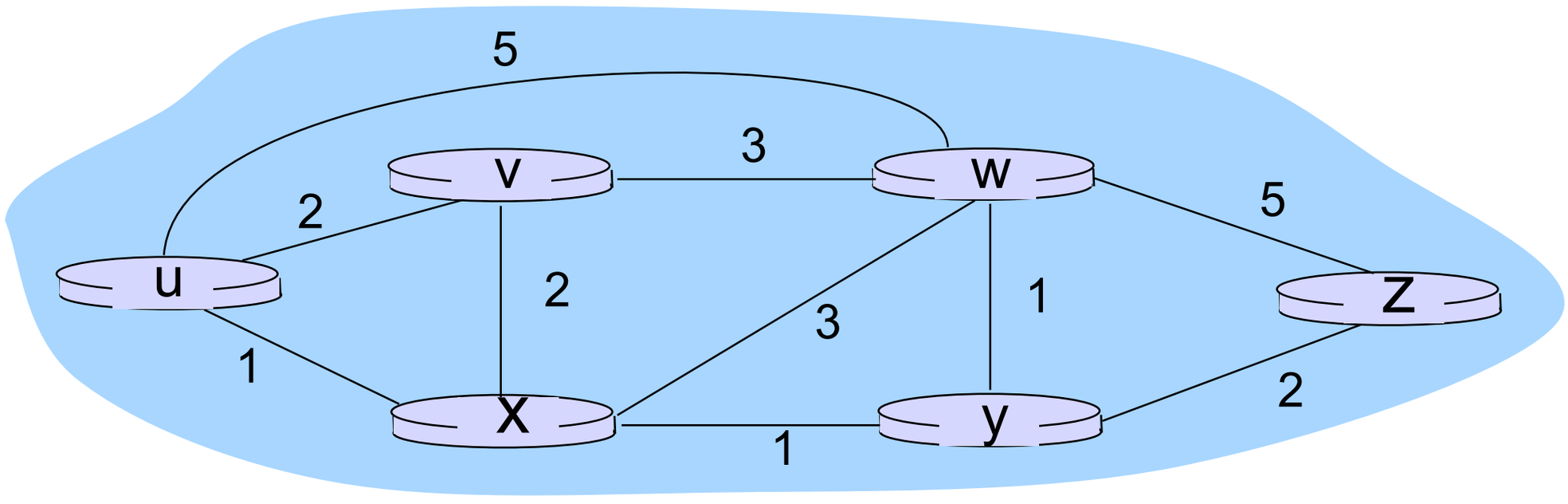
- *Q: Global or decentralized information?*
- *Global:*
- All routers have complete topology, link cost info
- "link state" algorithms
- *Decentralized:*
- Router knows physically-connected neighbors, link costs to neighbors
- Iterative process of computation, exchange of info with neighbors
- "distance vector" algorithms

- *Q: Static or dynamic?*
- *Static:*
- Routes change slowly over time
- *Dynamic:*
- Routes change more quickly
- Periodic update
- When link cost changes

- *Q: Load sensitive or insensitive?*
- *Insensitive:*
- Routing independent of load
- *Dynamic:*
- Routes change as load changes

Building Network Topology

- How does a router gets a complete topology
  - e.g. how node `u` knows about the link `w—z`
- Each node broadcasts its connectivity
  - Adds unique id (seq number) to this msg
- Receiving nodes forwards to all other links
  - only if it has not forwarded this particular message
- Thus, after D (network diameter), each node knows the topology



A link-state routing algorithm

Dijkstra's algorithm

- Network topology, link costs known to all nodes
  - Accomplished via "link state broadcast"
  - All nodes have same info
- Computes least cost paths from one node ("source") to all other nodes
  - Derives *forwarding table* for that node
- Iterative: after k iterations, know least cost path to k destinations.

notation:

- c(x,y): link cost from node x to y;
  - =∞ if not direct neighbors
- D(v): current value of cost of path from source to dest. v
- p(v): predecessor of node v along path from source to v
- N': set of nodes whose least cost path definitively known

Dijsktra's algorithm

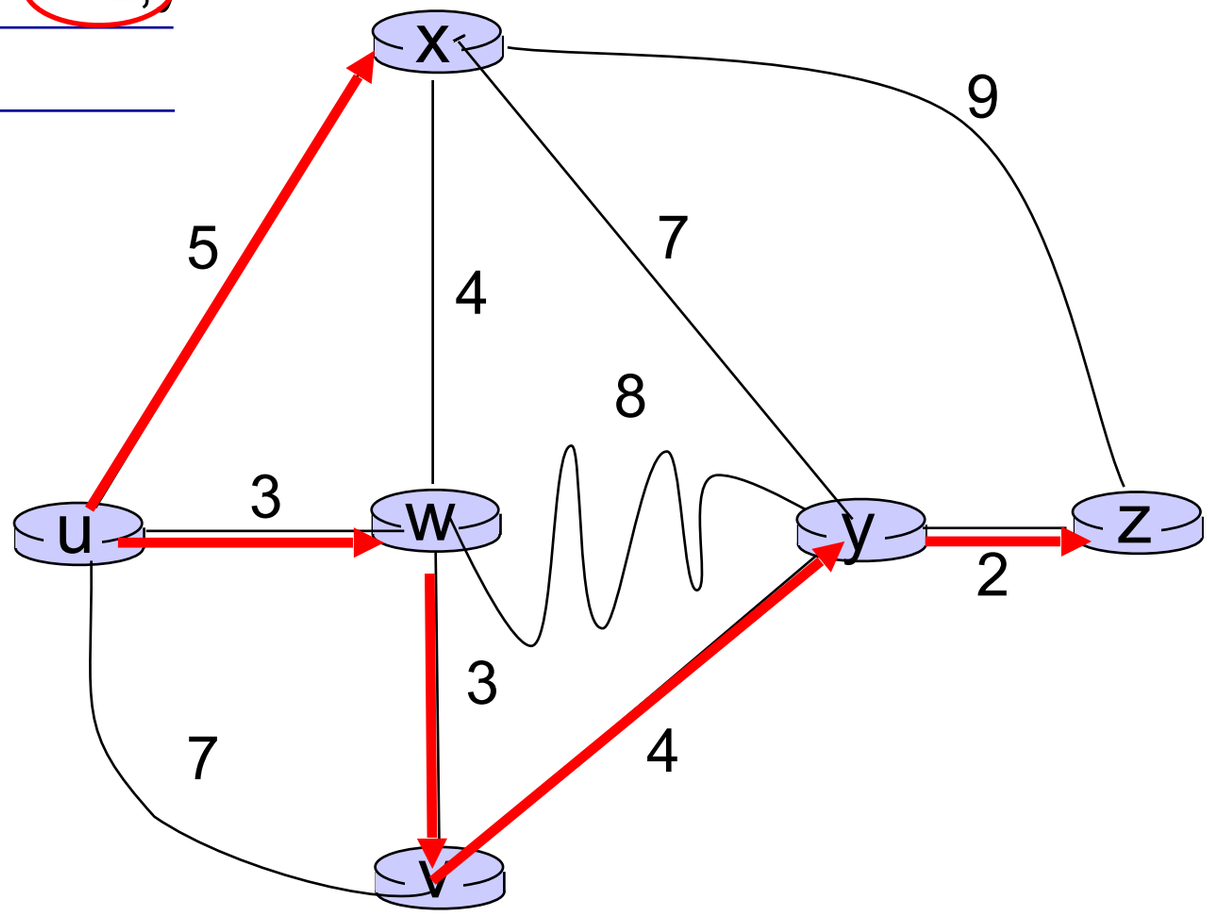
```
1  Initialization:
2    N' = {u}
3    for all nodes v
4      if v adjacent to u
5          then D(v) = c(u,v)
6      else D(v) = ∞
7
8  Loop
9      find w not in N' such that D(w) is a minimum
10     add w to N'
11     update D(v) for all v adjacent to w and not in N' :
12       D(v) = min( D(v), D(w) + c(w,v) )
13     /* new cost to v is either old cost to v or known
14      shortest path cost to w plus cost from w to v */
15 until all nodes in N'
```

Dijkstra's algorithm: example

Step	N'	D(**v**) p(v)	D(**w**) p(w)	D(**x**) p(x)	D(**y**) p(y)	D(**z**) p(z)
0	u	7,u	3,u	5,u	∞	∞
1	uw	6,w		5,u	11,w	∞
2	uwx	6,w			11,w	14,x
3	uwxv				10,v	14,x
4	uwxvy					12,y
5	uwxvyz					

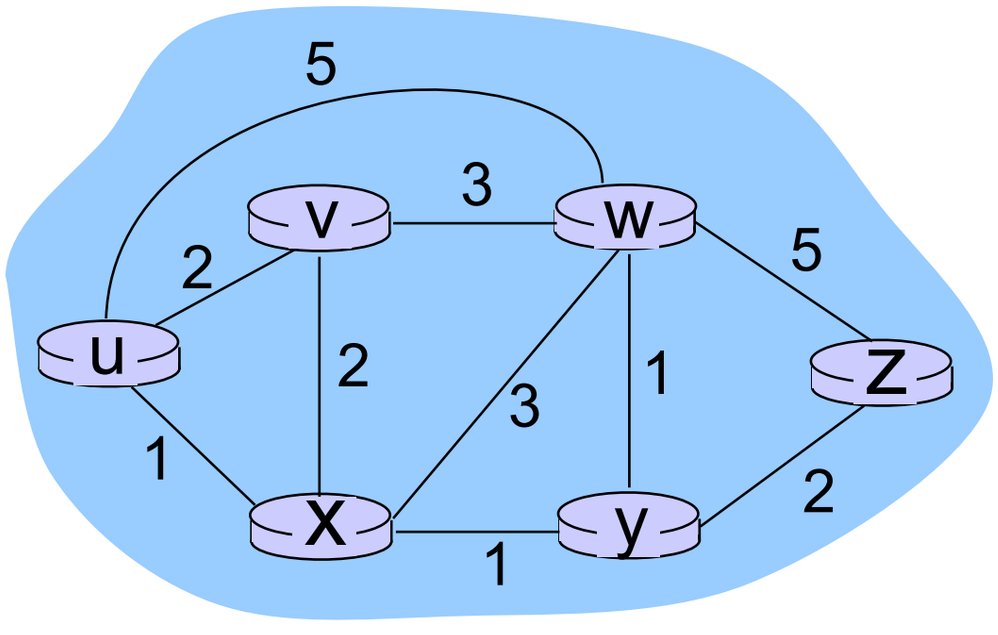
notes:

- construct shortest path tree by tracing predecessor nodes
- ties can exist (can be broken arbitrarily)



Dijkstra's algorithm: another example

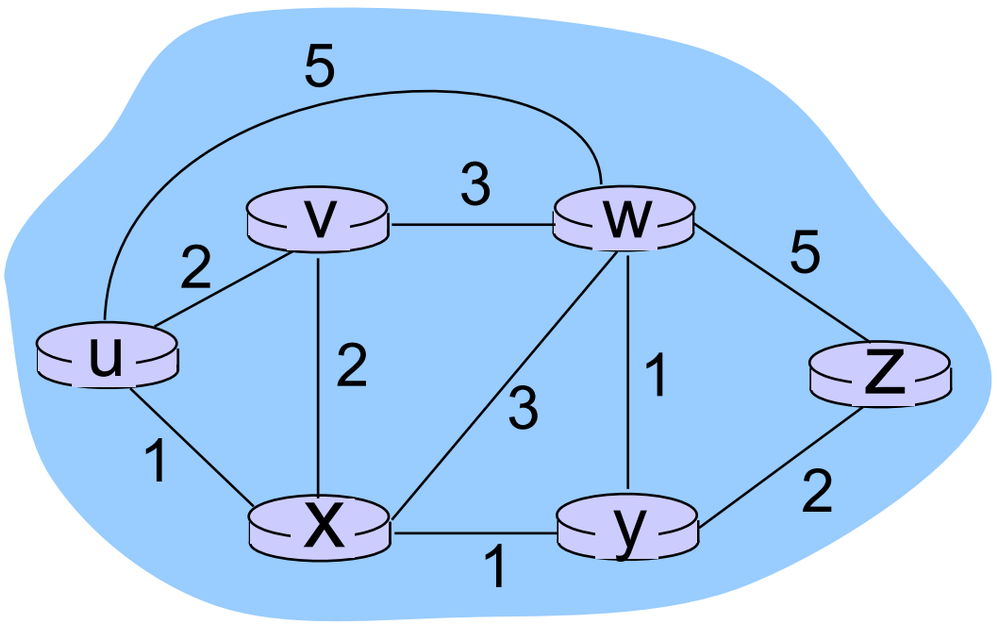
Step	N'	D(v),p(v)	D(w),p(w)	D(x),p(x)	D(y),p(y)	D(z),p(z)
0	u	2,u	5,u	1,u	∞	∞
1	ux	2,u	4,x		2,x	∞
2	uxy	2,u	3,y			4,y
3	uxyv		3,y			4,y
4	uxyvw					4,y
5	uxyvwz					

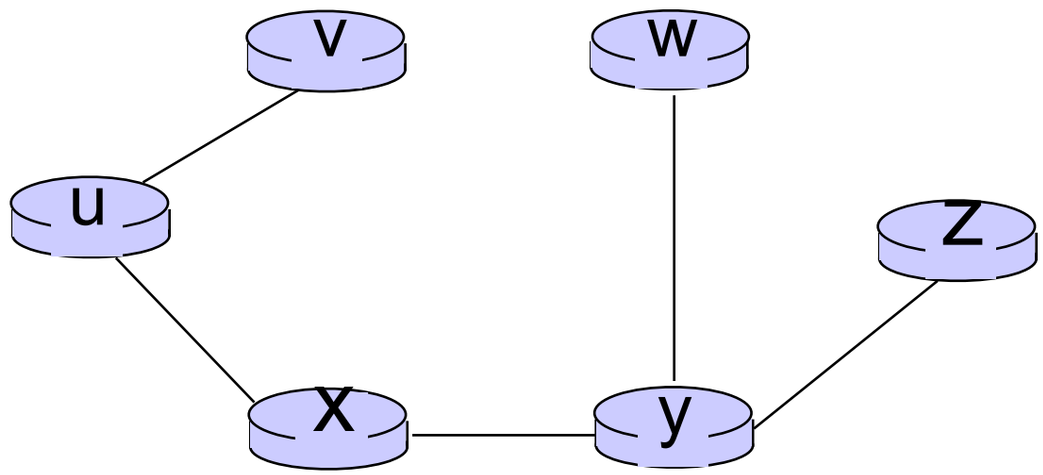


- Check out the online interactive exercises for more examples:
  - http://gaia.cs.umass.edu/kurose_ross/interactive/

Dijkstra's algorithm: example (2)

resulting shortest-path tree from u:





resulting forwarding table in u:

destination	link
v	(u,v)
x	(u,x)
y	(u,x)
w	(u,x)
z	(u,x)

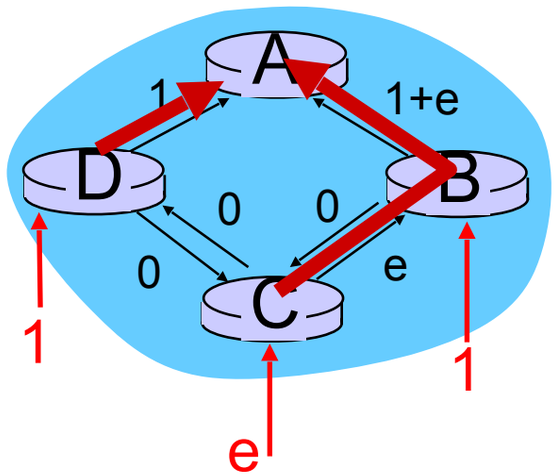
Dijkstra's algorithm, discussion

algorithm complexity: n nodes

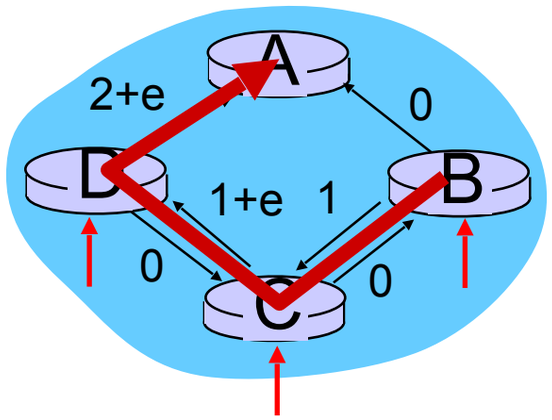
- each iteration: need to check all nodes, w, not in N
- $n(n+1)/2$ comparisons: $O(n^2)$
- more efficient implementations possible: O(mlogn)

oscillations possible:

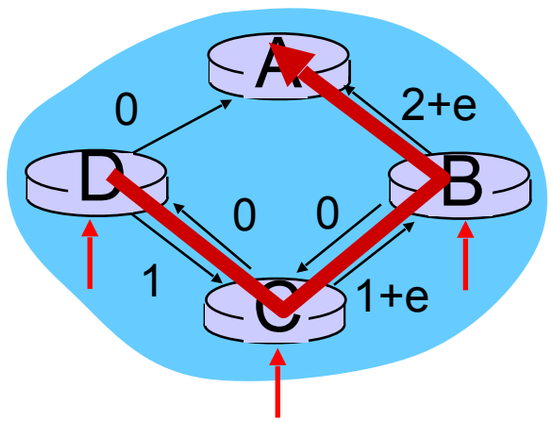
- e.g., support link cost equals amount of carried traffic:



initially



given these costs, find new routing…. resulting in new costs



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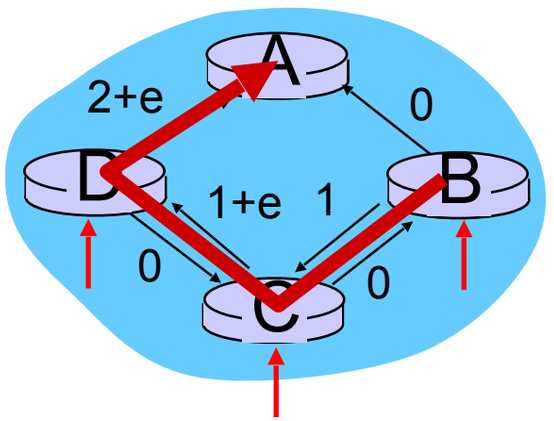


given these costs, find new routing…. resulting in new costs

Routing protocols and Metrics

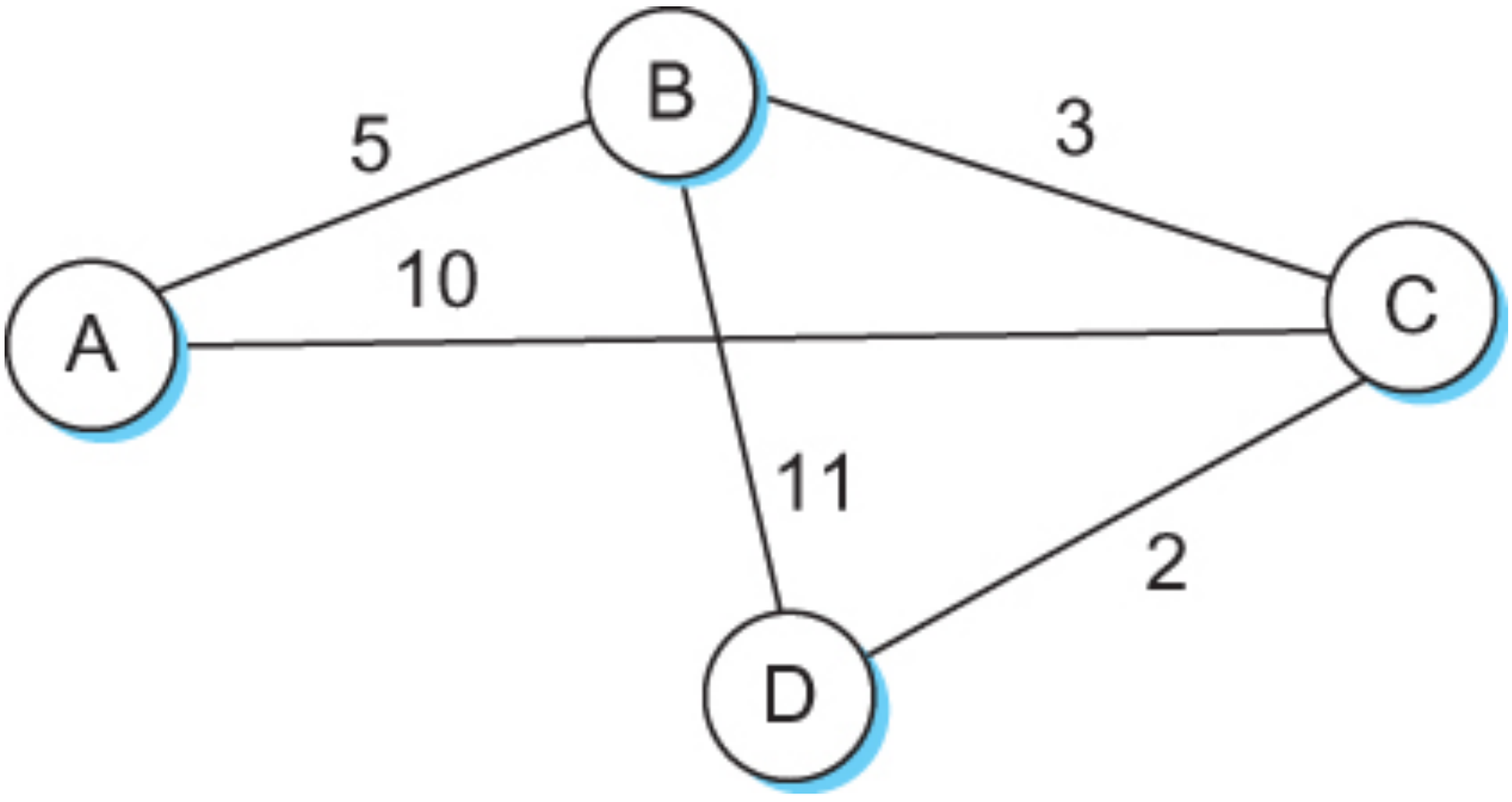
- Hop count
- Bandwidth
- Load - Traffic utilisation
- Delay
- Reliability
- Cost

Linux Routing Table (route -n)

```
Destination     Gateway         Genmask         Flags MSS Window irtt Iface
0.0.0.0         10.1.12.1       0.0.0.0           UG    0   0        0 eth0
0.0.0.0         0.0.0.0         0.0.0.0           U     0   0        0 eth1
10.1.12.0       0.0.0.0         255.255.255.0     U     0   0        0 eth0
10.200.0.0      10.1.13.2       255.255.0.0       UG    0   0        0 eth1
10.250.0.1      0.0.0.0         255.255.255.255   UH    0   0        0 eth1
```

Exercises:

- Find shortest path from D in following network
  - Src: Peterson and Davies, 5th edition



Static vs Dynamic Routing

- **Quiz**:
- Which of the following is applicable to static routing
  - configuration is less error prone
  - more secure because no routing advertisements
  - scaling the network does not pose any problems
  - no computing overhead
  - administrator has less work maintaining the configuration
- Answer
  - more secure
  - no computing overhead

Convergence

- **Q:** Which statement best describes convergence ?
  - Amount of time required for routers to share administrative configuration changes e.g. password
  - The time required for routers in the network to update their routing tables after a topology change has occurred
  - The time required for routers running disparate routing protocols to update their routing tables
- Answer
  - The time required for routers in the network to update their routing tables after a topology change has occurred

Summary

- Network : graph abstraction
- Routing: Shortest path
- Link State: Each node know network topology
- Cost Metric
- Convergence