Network Layer

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Lecture 15

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Network Layer Functions

Recall: two network-layer functions:

- *forwarding:* move packets from router's input to appropriate router output

data plane

- *routing:* determine route taken by packets from source to destination

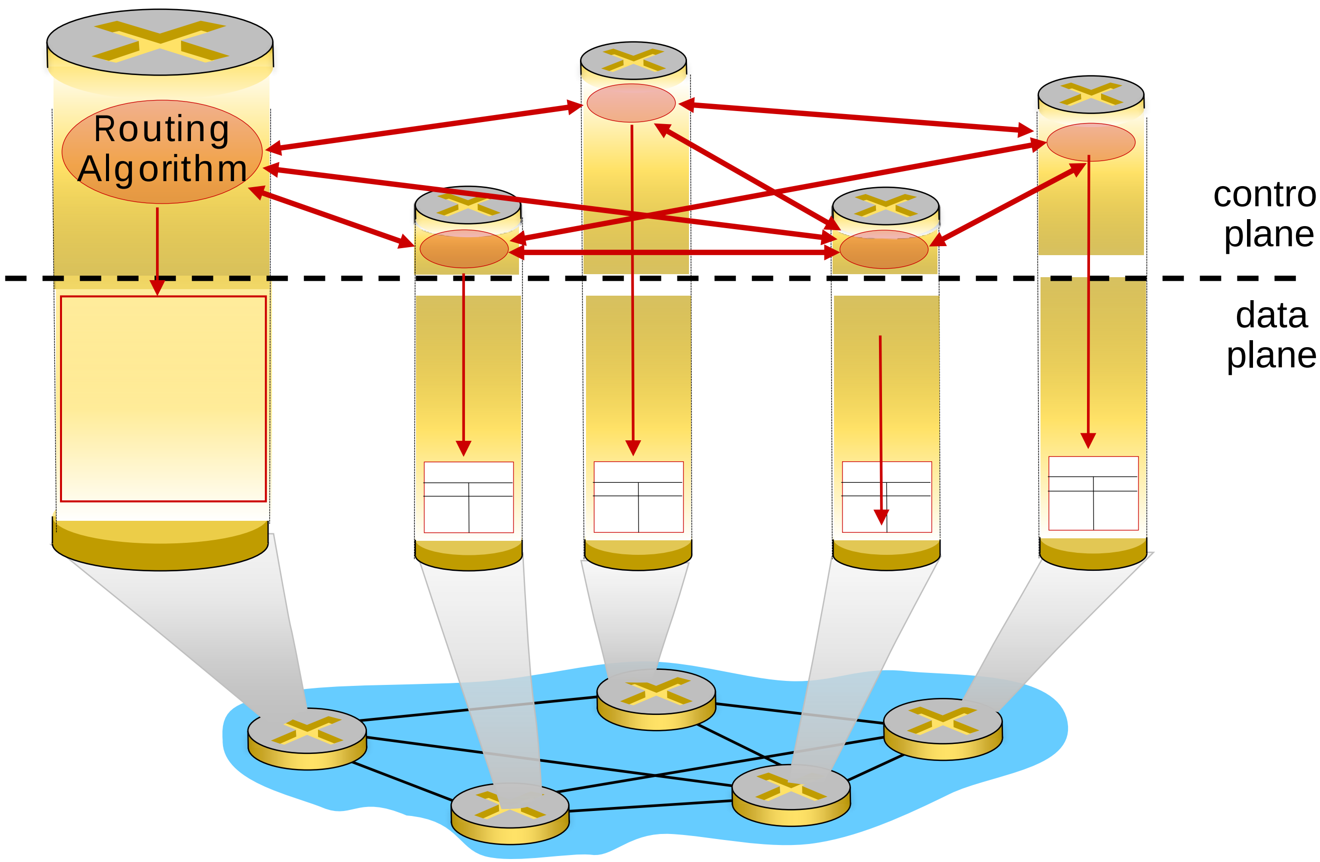
control plane

Two approaches to structuring network control plane:

- per-router control (traditional)
- logically centralized control (software defined networking)

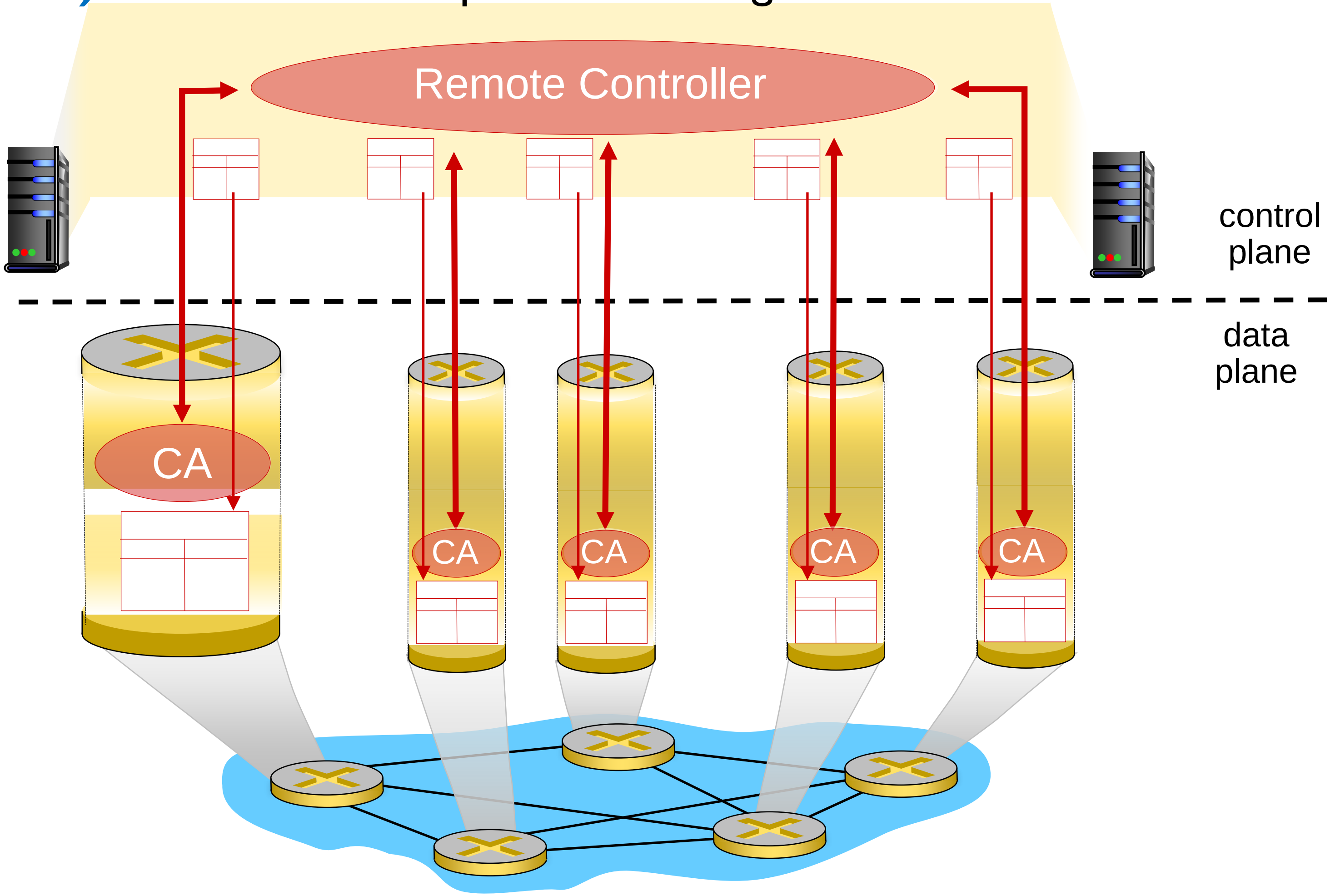
Per-router Control Plane

Individual routing algorithm components *in each and every router* interact with each other in control plane to compute forwarding tables



Logically Centralized Control Plane

A distinct (typically remote) controller interacts with **local control agents (CAs)** in routers to compute forwarding tables



Routing Protocols

- ***Routing protocol goal:***
  - determine "**good**" paths (equivalently, routes), from sending hosts to receiving host, through network of routers
- **path**:
  - sequence of routers packets will traverse in going from given initial source host to given final destination host
- "good": least "cost", "fastest", "least congested"
- routing: a "top-10" networking challenge!

Routing Protocols

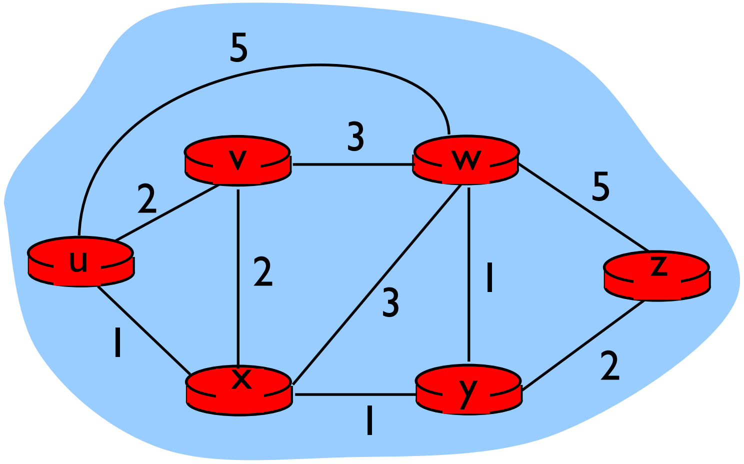
- A host is attached directly to one router, the ***default router*** for the host.
- Whenever a host sends a packet, the packet is transferred to its default router.
- We refer to the default router of the source host as the ***source router*** and the default router of the destination host as the ***destination router***.

- The problem of routing a packet from source host to destination host

  ==

  the problem of routing the packet from source router to destination router

Graph Abstraction

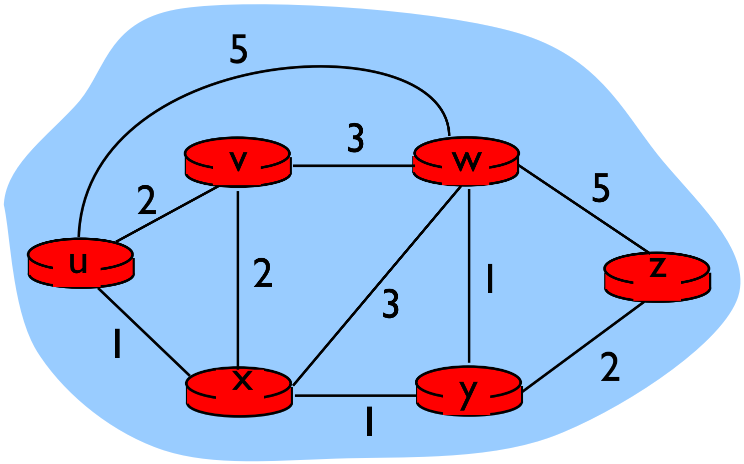


Graph: G = (N, E)

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) }

Graph Abstraction: Cost



- $c(x, x')$ = 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 $(x_1, x_2, x_3, \ldots, x_p) = c(x_1, x_2) + c(x_2, x_3) + \ldots + c(x_{p-1}, x_p)$

Question: What's the least-cost path between u and z ?

Routing algorithm: algorithm that finds least-cost path

Routing Algorithm Classification

Global or decentralized information?

Global routing algorithm:

- all routers have complete topology, link cost info
- "link state" algorithms

Decentralized routing algorithm:

- router knows physically-connected neighbors, link costs to neighbors
- iterative process of computation, exchange of info with neighbors
- "distance vector" algorithms

Static or dynamic?

Static routing algorithm:

- routes change slowly over time

Dynamic routing algorithm:

- routes change more quickly
  - periodic update
  - in response to link cost changes

A Link-State Routing Algorithm

Dijkstra's algorithm

- net. Topology and link costs known to all nodes
  - accomplished via "link state broadcast"
  - all nodes have same info.
- compute least cost paths from one node ("source") to all other nodes
  - gives forwarding table for that node
- iterative: after k iterations, know least cost path to k dest.'s

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 node along path from source to v
- N': set of nodes whose least cost path definitively known

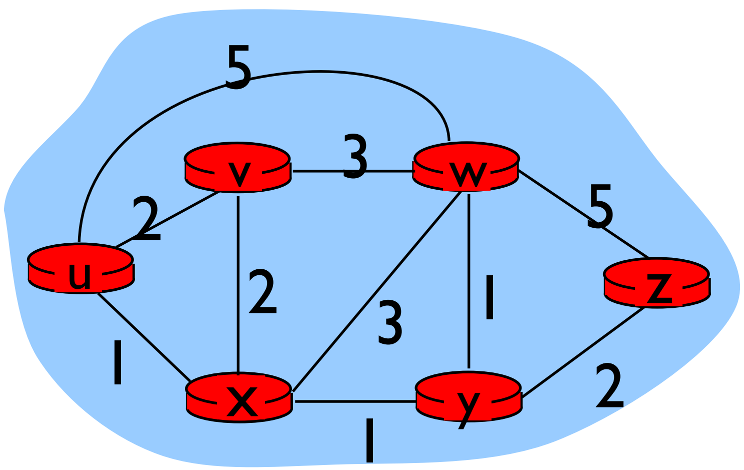
Dijsktra's Algorithm

Initialization:
N' = {u}
for all nodes v
if v adjacent to u
then D(v) = c(u,v)
else D(v) = ∞

Loop
find w not in N' such that D(w) is a minimum
add w to N'
update D(v) for all v adjacent to w and not in N' :
D(v) = min(D(v), D(w) + c(w,v))
/* new cost to v is either old cost to v or known
shortest path cost to w plus cost from w to v */
until all nodes in N'

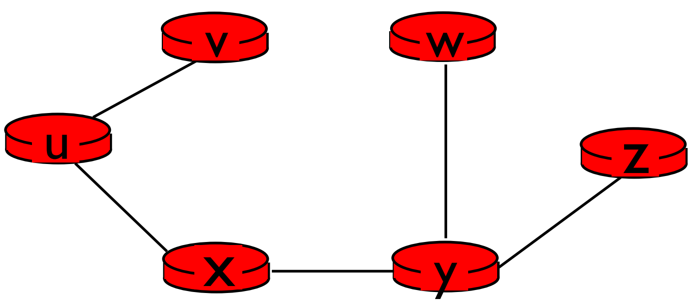
Dijsktra's Algorithm: Example

Step	N'	D(v),p(v)	D(w),p(w)	D(x),p(x)	D(y),p(y)	D(z),p(z)
0	u	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					



Dijsktra's Algorithm: Example (cont.)

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)