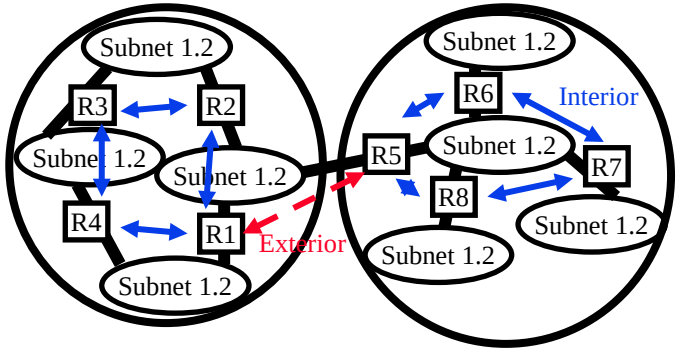
The Network Layer: Control Plane



Raj Jain
Washington University in Saint Louis
Saint Louis, MO 63130
Jain@wustl.edu

Audio/Video recordings of this lecture are available online at:

http://www.cse.wustl.edu/~jain/cse473-25/

Student Questions

©2025 Raj Jain
Next Q 10b



Overview

1. Routing Algorithms: Link-State, Distance Vector
   Dijkstra's algorithm, Bellman-Ford Algorithm
2. Routing Protocols: OSPF, BGP
3. SDN Control Plane
4. ICMP
5. SNMP

Note: This class lecture is based on Chapter 5 of the textbook (Kurose and Ross) and the figures provided by the authors.

Student Questions

- Are there standard routing algorithms other than the ones discussed here?

Yes, there are many more, but they are rare.

©2025 Raj Jain

Network Layer Functions

- Forwarding: Deciding what to do with a packet using a routing table ⇒ Data plane
- Routing: Making the routing table ⇒ Control Plane

Student Questions

- Is there one way that is best to make a routing table?

Every network uses one method for all nodes in the network. OSPF is generally used inside the enterprise, and BGP is between enterprises.

©2025 Raj Jain



Routing Algorithms

1. Graph abstraction
2. Distance Vector vs. Link State
3. Dijkstra's Algorithm
4. Bellman-Ford Algorithm

Student Questions

©2025 Raj Jain

Rooting or Routing

- *Rooting* is what fans do at football games, what pigs do for truffles under oak trees in the Vaucluse, and what nursery workers intent on propagation do to cuttings from plants.
- *Routing* is how one creates a beveled edge on a tabletop or sends a corps of infantrymen into a full-scale, disorganized retreat.

Student Questions

Ref: Piscitello and Chapin, "Open Systems Networking: TCP/IP and OSI," Adison-Wesley, 1993, p413

©2025 Raj Jain

Routeing or Routing

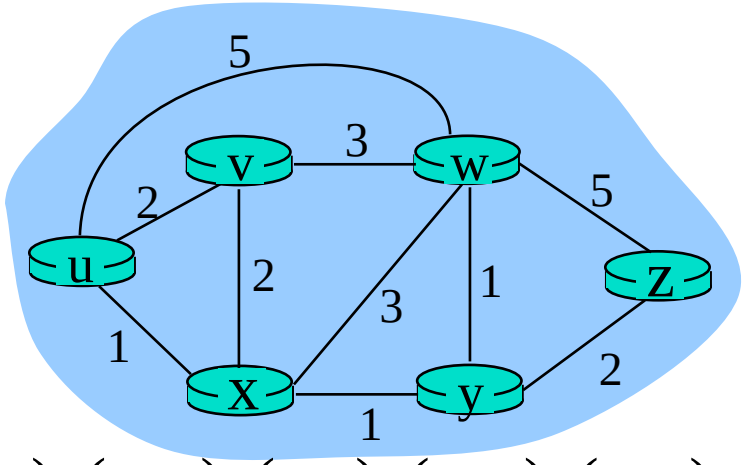
- Routeing: British
- Routing: American
- Since Oxford English Dictionary is much heavier than any other dictionary of American English, British English generally prevails in the documents produced by ISO and CCITT; wherefore, most of the international routing standards use the routeing spelling.

Student Questions

Ref: Piscitello and Chapin, "Open Systems Networking: TCP/IP and OSI," Adison-Wesley, 1993, p413

©2025 Raj Jain

Graph abstraction



- Graph: G = (N, E)
- N = Set of routers
  = { u, v, w, x, y, z }
- E = Set of links
  ={ (u,v), (u,x), (u,w), (v,x), (v,w), (x,w), (x,y), (w,y), (w,z), (y,z) }
- Each link has a cost, e.g., c(w,z) = 5
- Cost of path $(x_1, x_2, \ldots, x_p) = c(x_1,x_2) + c(x_2,x_3) + \ldots + c(x_{p-1},x_p)$
- Routing Algorithms find the least cost path
- We limit to "Undirected" graphs, i.e., the cost is the same in both directions

Student Questions

- What would the cost of the link represent? Throughput?

Opposite of nominal bit rate, delay, or distance

- Do we have a cost for nodes?

Node cost is ignored. But it could be added to all links connected to that node.

- Is the link cost function based on the RTT between the links or the distance?

See above.

- Do real-world routing algorithms use directed graphs as abstractions as well?

Yes.

- Can we apply Dijkstra's algorithm in this graph?

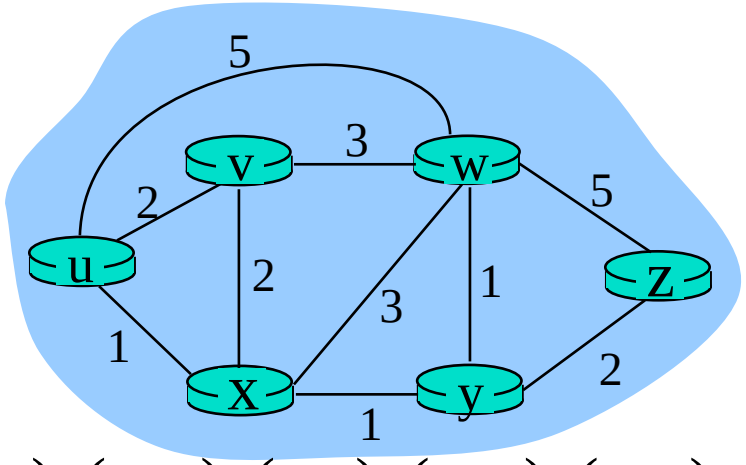
Yes.

- How does each router know which path will lead to the lowest cost while sending data?

The paths have been pre-calculated as per the discussion in this chapter.

©2025 Raj Jain

Graph abstraction



- Graph: G = (N, E)
- N = Set of routers
  = { u, v, w, x, y, z }
- E = Set of links
  ={ (u,v), (u,x), (u,w), (v,x), (v,w), (x,w), (x,y), (w,y), (w,z), (y,z) }
- Each link has a cost, e.g., c(w,z) = 5
- Cost of path $(x_1, x_2, \ldots, x_p) = c(x_1,x_2) + c(x_2,x_3) + \ldots + c(x_{p-1},x_p)$
- Routing Algorithms find the least cost path
- We limit to "Undirected" graphs, i.e., the cost is the same in both directions

Student Questions

- Considering the distinction between link-state and distance-vector routing algorithms, how do their operational characteristics influence a network's scalability and convergence time?

Discussed in Slide 5.17 (Part 2).

- Is cost dynamic or predetermined when the node gets added to the graph?

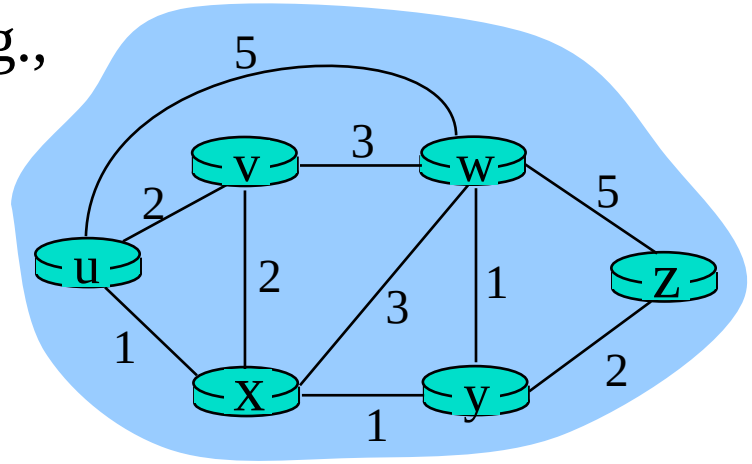
It is determined before the path calculation. If cost changes, the paths will have to be recalculated.

©2025 Raj Jain

Distance Vector vs. Link State

Distance Vector:

- Vector of distances to all nodes, e.g., u: {u:0, v:2, w:5, x:1, y:2, z:4}
- Sent to neighbors, e.g., u will send to v, w, x
- Large vectors to a small # of nodes Tell about the world to neighbors.
- Older method. Used in RIP.



Link State:

- Vector of link cost to neighbors, e.g., u: {v:2, w:5, x:1}
- Sent to all nodes, e.g., u will send to v, w, x, y, z
- Small vectors to a large # of nodes Tell about the neighbors to the world
- Newer method. Used in OSPF.

Student Questions

- Is there a reason, other than the fact that link-state algorithms do not encounter counting-to-infinity problems, that link-state is preferable to distance-vector?

No. But counting to infinity is a BIG problem.

- Will distance vector and link state result in different routing tables?

No. The final answer is the same. However, the number of iterations required to settle down after a change in the network is significantly different.

- Why is it called a vector? It seems more like a set.

A vector is a set with one column.

- What does RIP stand for? I couldn't find it in the list of acronyms.

Routing Information Protocol

- What is meant by large vectors to a small # of nodes?

The number of elements in the vector is large.

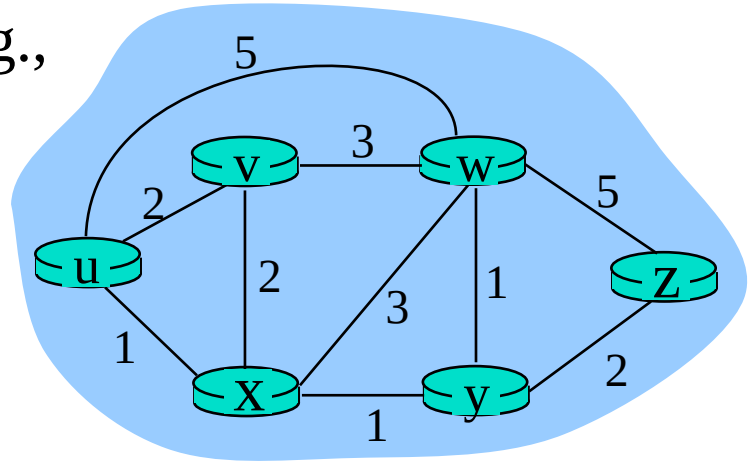
- How is the distance vector sent to fewer nodes than the link state?

The link state is sent to the world.

Distance Vector vs. Link State

Distance Vector:

- Vector of distances to all nodes, e.g.,
  u: {u:0, v:2, w:5, x:1, y:2, z:4}
- Sent to neighbors, e.g.,
  u will send to v, w, x
- Large vectors to a small # of nodes
  Tell about the world to neighbors.
- Older method. Used in RIP.



Link State:

- Vector of link cost to neighbors, e.g., u: {v:2, w:5, x:1}
- Sent to all nodes, e.g., you will send to v, w, x, y, z
- Small vectors to a large # of nodes
  Tell about the neighbors to the world
- Newer method. Used in OSPF.

Student Questions

- When would it be better to use link state instead of distance vector, and vice versa?

They are discussed later in this module.

- Why are we telling information about distance or cost to other nodes?

To find the best route.

- To which routing algorithm mentioned here does Dijkstra's algorithm belong? Link state?

Yes

- Which one is better in terms of frequency of updates?

Both need to be run after every configuration change. Distance vectors will send more messages, although small.

- Does this imply that a router needs to store information about all other routers in the network?

Yes.

- Are there still hardware being produced that uses distance vector over link state?

These are software protocols. The network manager decides which protocols to use. Most will use OSPF, which runs link state.

- Why is transmitting the Link State generally preferred to the Distance Vector?

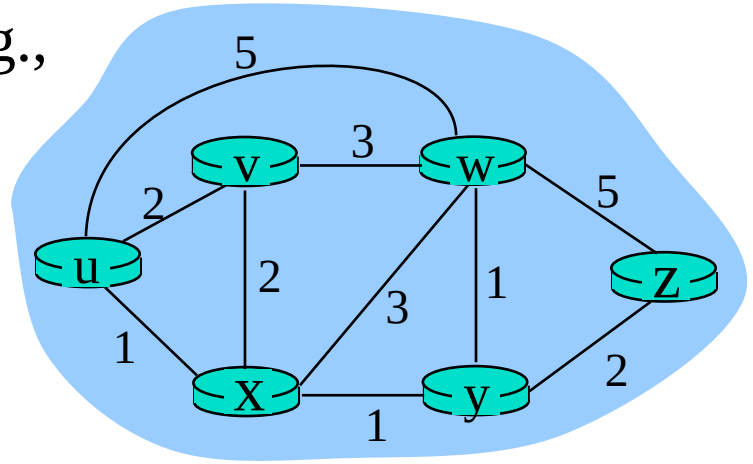
Counting to infinity problem.

©2025 Raj Jain

Distance Vector vs. Link State

Distance Vector:

- Vector of distances to all nodes, e.g., u: {u:0, v:2, w:5, x:1, y:2, z:4}
- Sent to neighbors, e.g., u will send to v, w, x
- Large vectors to a small # of nodes Tell about the world to neighbors.
- Older method. Used in RIP.



Link State:

- Vector of link cost to neighbors, e.g., u: {v:2, w:5, x:1}
- Sent to all nodes, e.g., you will send to v, w, x, y, z
- Small vectors to a large # of nodes Tell about the neighbors to the world
- Newer method. Used in OSPF.

Student Questions

- The book describes link-state as aware of cost of each link in the network, and distance-vector and distance-vector as aware of its neighbor cost which contradicts the slide. Can you clarify distance-vector and link-state and which is Dijkstra vs Bellman-Ford?

The methods are named after what you send out (as discussed in the slide). The book talks about what you receive. There is no contradiction. The book talks about what you receive. Dijkstra is a Link State algorithm.

©2025 Raj Jain

Dijkstra's Algorithm

- Goal: Find the least cost paths from a given node to all other nodes in the network
- Notation:
  c(i,j) = Link cost from i to j if i and j are connected
  D(k) = Total path cost from s to k
  N' = Set of nodes so far for which the least cost path is known
- Method:
  - Initialize: N'={u}, D(v) = c(u,v) for all neighbors of u
  - Repeat until N includes all nodes:
    - Find node $w \notin N'$, whose D(w) is the minimum
    - Add w to N'

Student Questions

- Has Dijkstra's algorithm ever been implemented with a min-priority queue in networking?

Implementations need to be standardized. So yes, someone may implement it using heaps.

- Is there any tradeoff between making it faster vs. the space required?

Yes. That's almost always true. Any computation can be made faster by caching.

- Does Dijkstra's algorithm run on every node in the network or just a subset of the nodes? There might be some re-work to run on every node since the paths might have overlapped when computing different nodes.

*The algorithm is run on every **router.** Paths may **change** while the algorithm is still in progress. If that happens, the router noticing the change will send its new table, and the process will eventually end **iff** the configuration does not change again.*

- Do we need to know the performance of Dijkstra's algorithm or other algorithms in this course?

Yes.

©2025 Raj Jain

Dijkstra's Algorithm

- Goal: Find the least cost paths from a given node to all other nodes in the network
- Notation:
  c(i,j) = Link cost from i to j if i and j are connected
  D(k) = Total path cost from s to k
  N' = Set of nodes so far for which the least cost path is known
- Method:
  - Initialize: N'={u}, D(v) = c(u,v) for all neighbors of u
  - Repeat until N includes all nodes:
    - Find node $w \notin N'$, whose D(w) is the minimum
    - Add w to N'

Student Questions

- How does Dijkstra's algorithm handle network changes or failures, and what strategies does it use to ensure network stability?

See Slide 5.11

- Do we need to know how to write Dijkstra's algorithm in the exam, or do we need to know how it works?

How do you find the path using it in the exam?

- Can you provide more details about how Dijkstra's algorithm determines the least cost paths from a given node to all other nodes in the network?

See the next few slides.

- Considering the Distance Vector routing algorithm, how does it address the "count-to-infinity" problem, and what mechanisms are in place to prevent routing loops?

Discussed in Slide 5.17 (part 2)

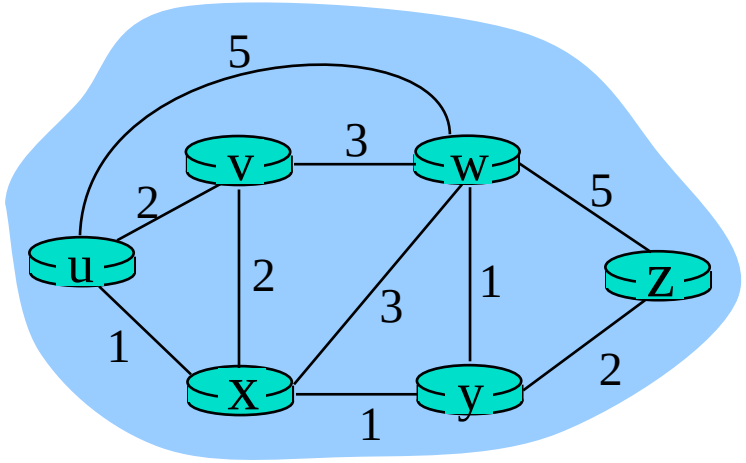
- Is it possible for Dijkstra to return to a path with a cycle? How does it prevent that?

If there is a cycle, the cost cannot be minimal.

- Given that Dijkstra is a form of Breadth First Search, are there any common networking algorithms used that are Depth First Search?

Distance vector

Dijkstra's Algorithm: Example



	N'	D(v)	Path	D(w)	Path	D(x)	Path	D(y)	Path	D(z)	Path
0	{u}	2	u-v	5	u-w	1	u-x	∞	-	∞	-
1	{u, x}	2	u-v	4	u-x-w			2	u-x-y	∞	-
2	{u, x, y}	2	u-v	3	u-x-y-w					4	u-x-y-z
3	{u, x, y, v}			3	u-x-y-w					4	u-x-y-z
4	{u, x, y, v, w}									4	u-x-y-z
5	{u, x, y, v, w, z}										

Student Questions

❑ Could you again review the differences between Dijkstra's and Bellman-Ford's algorithms? It's easy to be confused about how exactly they are different. *Dijkstra broadcasts its link-state table to the entire network, and computation proceeds hop by hop.*
-Bellman-Ford broadcasts its distance vector to its neighbors. Computation continues until the distance vectors do not change.
-Link state tables are smaller than distance vectors.
-Link state tables have to be sent to the entire network. Distance vectors have to be sent only to neighbors.

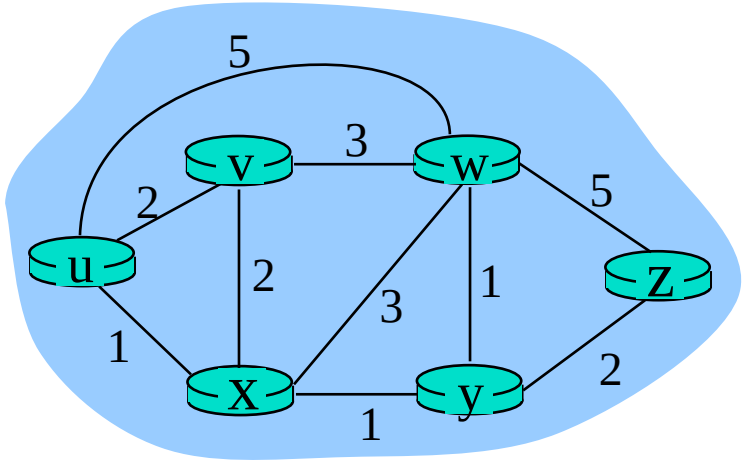
❑ Can we go over another example of Dijkstra's algorithm?
You can make many variations of this graph by changing the costs or source node.

❑ Can we go over P4 on page 439 of the book
This is Homework 5A, done 36 times. Good for practice.

❑ Do we need to know the steps of Dijkstra's link-state routing?
YES

©2025 Raj Jain

Dijkstra's Algorithm: Example



	N'	D(v)	Path	D(w)	Path	D(x)	Path	D(y)	Path	D(z)	Path
0	{u}	2	u-v	5	u-w	1	u-x	∞	-	∞	-
1	{u, x}	2	u-v	4	u-x-w			2	u-x-y	∞	-
2	{u, x, y}	2	u-v	3	u-x-y-w					4	u-x-y-z
3	{u, x, y, v}			3	u-x-y-w					4	u-x-y-z
4	{u, x, y, v, w}									4	u-x-y-z
5	{u, x, y, v, w, z}										

Student Questions

- What did the quiz mean by "not in the set of nodes"? I usually think of Dijkstra's as from one node in the graph to another.

The 2nd column in the table is the set of nodes.

- Does using Dijkstra's algorithm require the links to wait for the results to be propagated to their neighbors before the shortest path overall is found?

Yes.

- Can you explain the process of Dijkstra's Algorithm Example again and why some paths are not filled in?

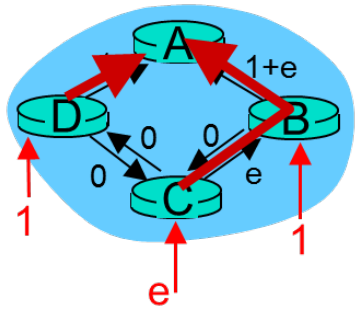
Red entries indicate the minimum cost paths. They are not repeated again.

©2025 Raj Jain

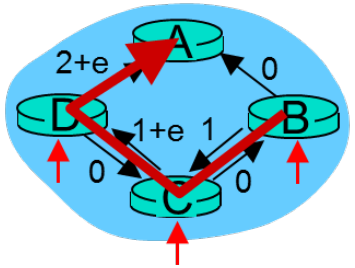
Next Q 16a

Complexity and Oscillations

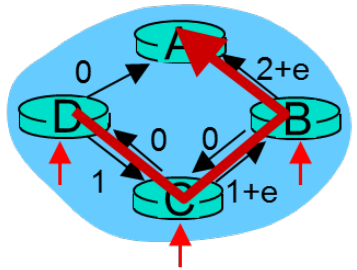
- *Algorithm complexity: n* nodes
  - Each iteration: need to check all nodes, *w*, not in N
  - $n(n+1)/2$ comparisons: $O(n^2)$
  - More efficient implementations possible: $O(n \log n)$
- *Oscillations Possible:* e.g., support link cost equals the amount of carried traffic



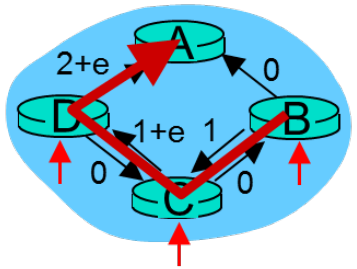
initially



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



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



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

Student Questions

- Why is it *n*+1 in the complexity *n*(*n*+1)/2?

1+2+3+4+…+n = n(n+1)/2

- Is the *n* in the runtime for Djiktra's algorithm the number of routers?

Yes.

n = number of nodes

Will oscillation lead to a change in routing results? *Yes.*

Do we manage the cost dynamically according to the current state?

If necessary, yes.

Can you explain why it is n(n+1)/2 comparisons again?

n+(n-1)+(n-2)+…+1 = n(n+1)/2

- Why is it n+1 in the complexity n(n+1)/2?

1+2+…+n = n(n+1)/2

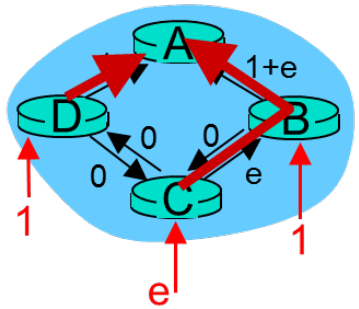
- What is the role of Oscillations?

Disturb traffic flow. Make us unhappy.

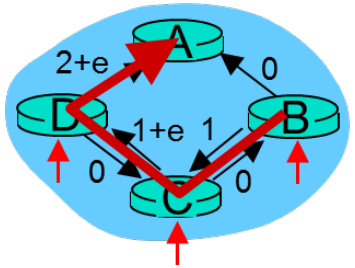
©2025 Raj Jain

Complexity and Oscillations

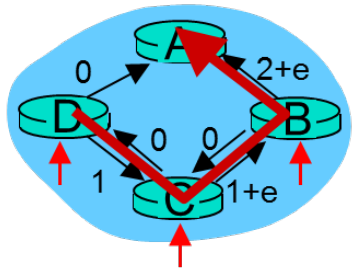
- *Algorithm complexity: n* nodes
  - Each iteration: need to check all nodes, *w*, not in N
  - $n(n+1)/2$ comparisons: $O(n^2)$
  - More efficient implementations possible: $O(n \log n)$
- *Oscillations Possible:* e.g., support link cost equals the amount of carried traffic



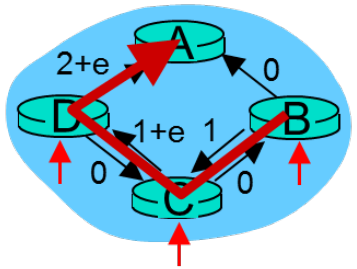
initially



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



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



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

Student Questions

- How does Dijkstra's algorithm adapt to dynamic network changes, such as failures, and what mechanisms ensure continued network stability?

A new algorithm is run after each failure.

- Is the O(n logn) algorithm still Dijkstra's algorithm but with better data structures, or is it an improved algorithm?

It is still Dijkstra with improved data structures.

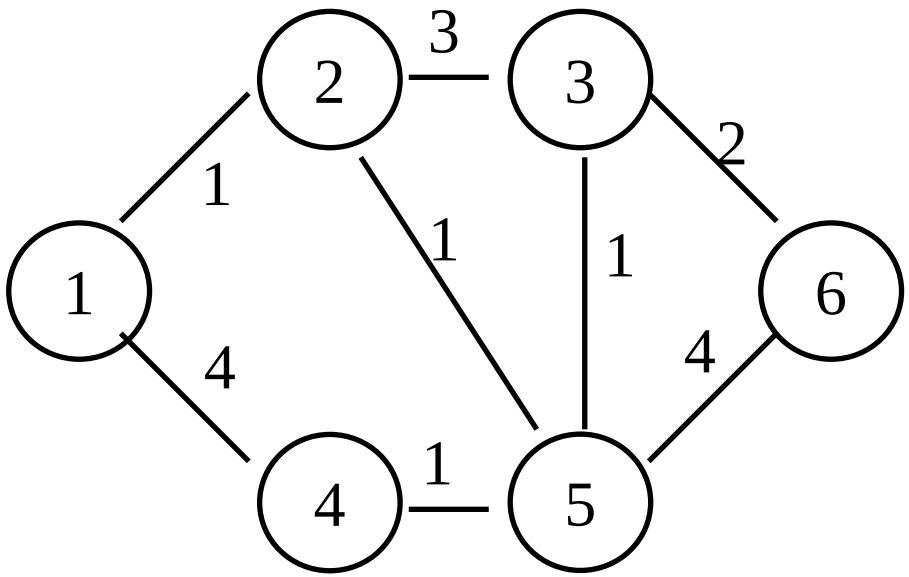
- Can you explain how Dijkstra's oscillations problem occurs again?

Oscillations happen if cost is a function of traffic.

©2025 Raj Jain

Homework 5A

[12 points] Prepare the routing calculation ***table*** for node 1 in the following network using Dijkstra's algorithm. Explain how you computed new entries in each row.



Student Questions

- Should the routing table look like the one on slide 10? Which entries should each node have?

No. Computation is shown in slide 5.10. Routing tables are shown in Slide 4.4.

Prefix	Next Router	Interface
126.23.45.67/32	125.200.1.1	1
128.272.15/24	125.200.1.2	2
128.272/16	125.200.1.1	1

- So for the homework we aren't making a table similar to the example in slide 10?
- No. You are making a table similar to the example in Slide 5.10.

©2025 Raj Jain

Bellman-Ford Algorithm

- Notation:
  u = Source node
  c(i,j) = link cost from i to j
  h = Number of hops being considered
  $D_u(n)$ = Cost of h-hop path from u to n
- Method:
  1. Initialize: $D_u(n) = \infty$ for all $n \neq u$; $D_u(u) = 0$
  2. For each node: $D_u(n) = \min_j [D_u(j) + c(j, n)]$
  3. If any costs change, repeat step 2

Student Questions

- When do we use Dijkstra's vs. Bellman-Ford's? Is one for distance vector and the other for link state?

Bellman-Ford is a distance vector algorithm. Dijkstra is a link-state algorithm.

- What would the difference between the Bellman-Ford and Dijkstra algorithms be?

See Slide 5.17

- Is Bellman-Ford or Dijkstra more preferred? Which one is implemented in practice?

Dijkstra

©2025 Raj Jain

Bellman Ford Example 1

node x table

from	cost to x	cost to y	cost to z
x	0	2	7
y	∞	∞	∞
z	∞	∞	∞

from	cost to x	cost to y	cost to z
x	0	2	3
y	2	0	1
z	7	1	0

from	cost to x	cost to y	cost to z
x	0	2	3
y	2	0	1
z	3	1	0

node y table

from	cost to x	cost to y	cost to z
x	∞	∞	∞
y	2	0	1
z	∞	∞	∞

from	cost to x	cost to y	cost to z
x	0	2	7
y	2	0	1
z	7	1	0

from	cost to x	cost to y	cost to z
x	0	2	3
y	2	0	1
z	3	1	0

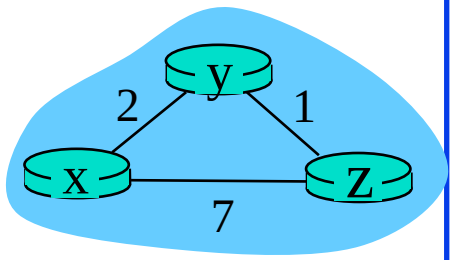
node z table

from	cost to x	cost to y	cost to z
x	∞	∞	∞
y	∞	∞	∞
z	7	1	0

from	cost to x	cost to y	cost to z
x	0	2	7
y	2	0	1
z	3	1	0

from	cost to x	cost to y	cost to z
x	0	2	3
y	2	0	1
z	3	1	0

time



Student Questions

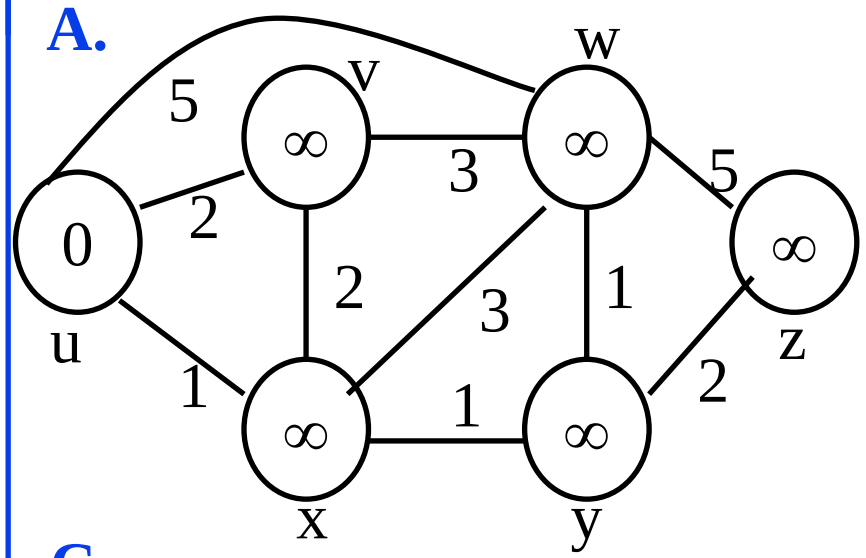
- What part of the graph represents h?

h is the number of hops. In the top row, h=1, 2nd row h=2, 3rd row h=3.

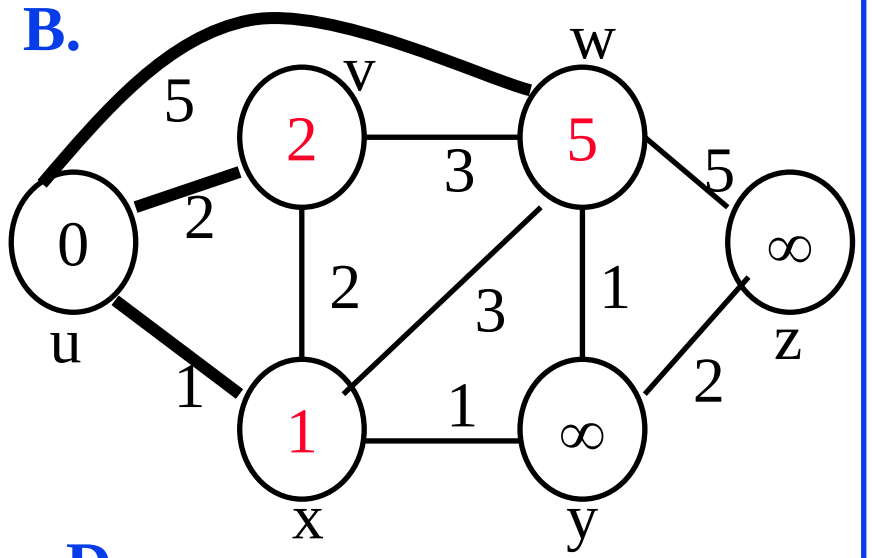
©2025 Raj Jain

Bellman-Ford Example 2

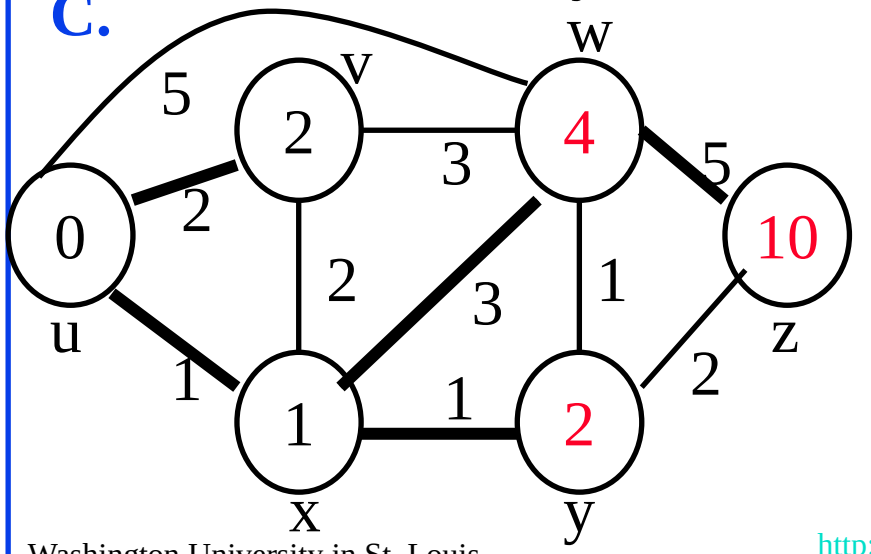
A.



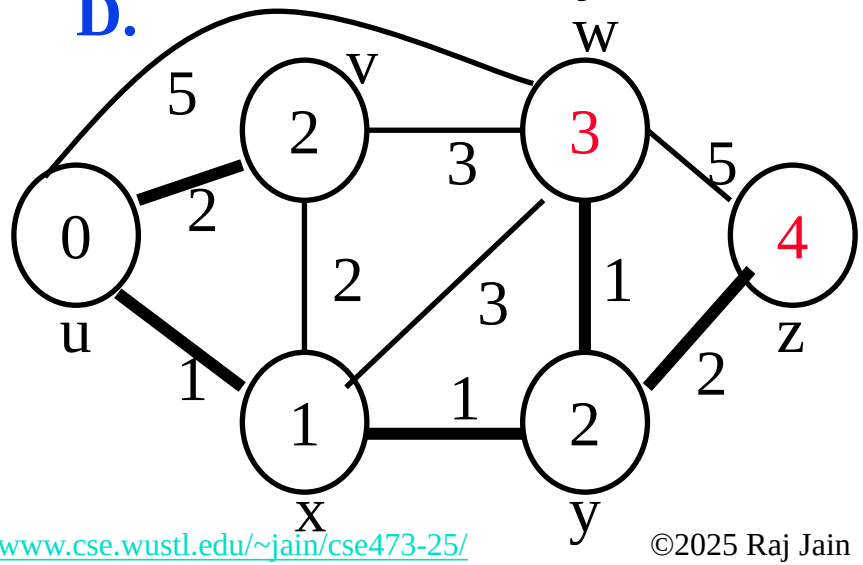
B.



C.



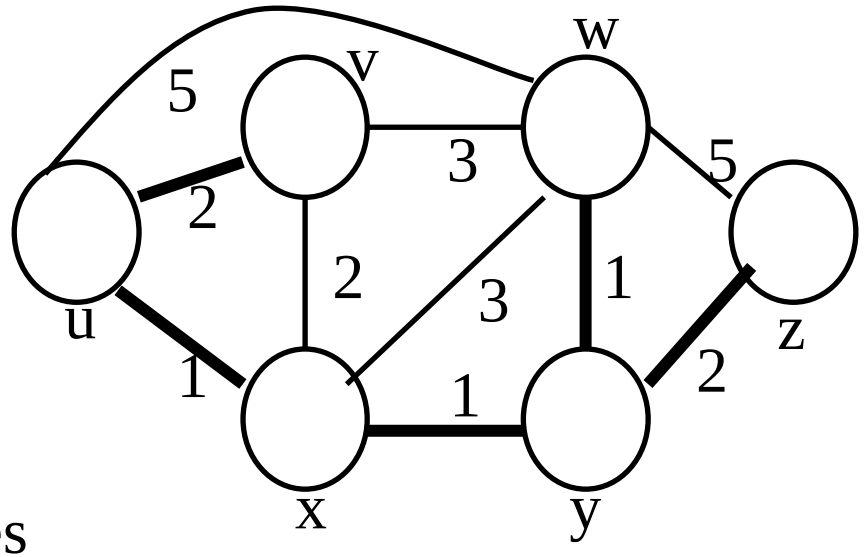
D.



Student Questions

©2025 Raj Jain

Bellman-Ford: Tabular Method



If cost changes

⇒ Recompute the costs to all neighbors

h	D(v)	Path	D(w)	Path	D(x)	Path	D(y)	Path	D(z)	Path
0	∞	-	∞	-	∞	-	∞	-	∞	-
1	2	u-v	5	u-w	1	u-x	∞	-	∞	-
2	2	u-v	4	u-x-w	1	u-x	2	u-x-y	10	u-w-z
3	2	u-v	3	u-x-y-w	1	u-x	2	u-x-y	4	u-x-y-z
4	2	u-v	3	u-x-y-w	1	u-x	2	u-x-y	4	u-x-y-z

Student Questions

- ❑ In the last iteration of the Bellman-Ford Algorithm, there is no update on the distance; what does this last iteration do?

Verifies that there is no update.

- ❑ For what cases is Bellman-Ford used, and for what cases is Dijkstra's better?

Next slide.

- ❑ When we make our table does it need to go in the order of most to least hops?

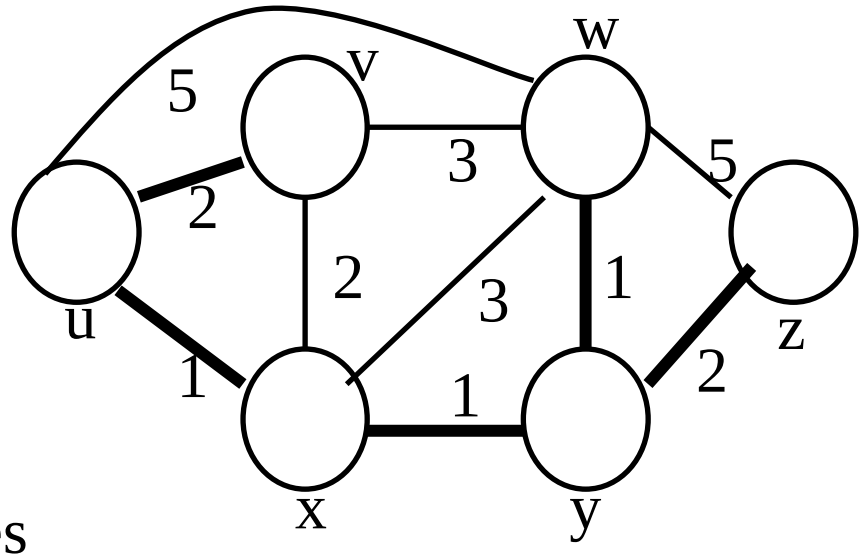
Start from the source. Start with h=0, 1, …, as shown.

- ❖ In terms Bellman-Ford versus Dijkstra's, the final tables would differ if on the same diagram?

The final answers (rows) will be the same. Both algorithms find the shortest paths.

Next Q 16b

Bellman-Ford: Tabular Method



If cost changes

⇒ Recompute the costs to all neighbors

h	D(v)	Path	D(w)	Path	D(x)	Path	D(y)	Path	D(z)	Path
0	∞	-	∞	-	∞	-	∞	-	∞	-
1	2	u-v	5	u-w	1	u-x	∞	-	∞	-
2	2	u-v	4	u-x-w	1	u-x	2	u-x-y	10	u-w-z
3	2	u-v	3	u-x-y-w	1	u-x	2	u-x-y	4	u-x-y-z
4	2	u-v	3	u-x-y-w	1	u-x	2	u-x-y	4	u-x-y-z

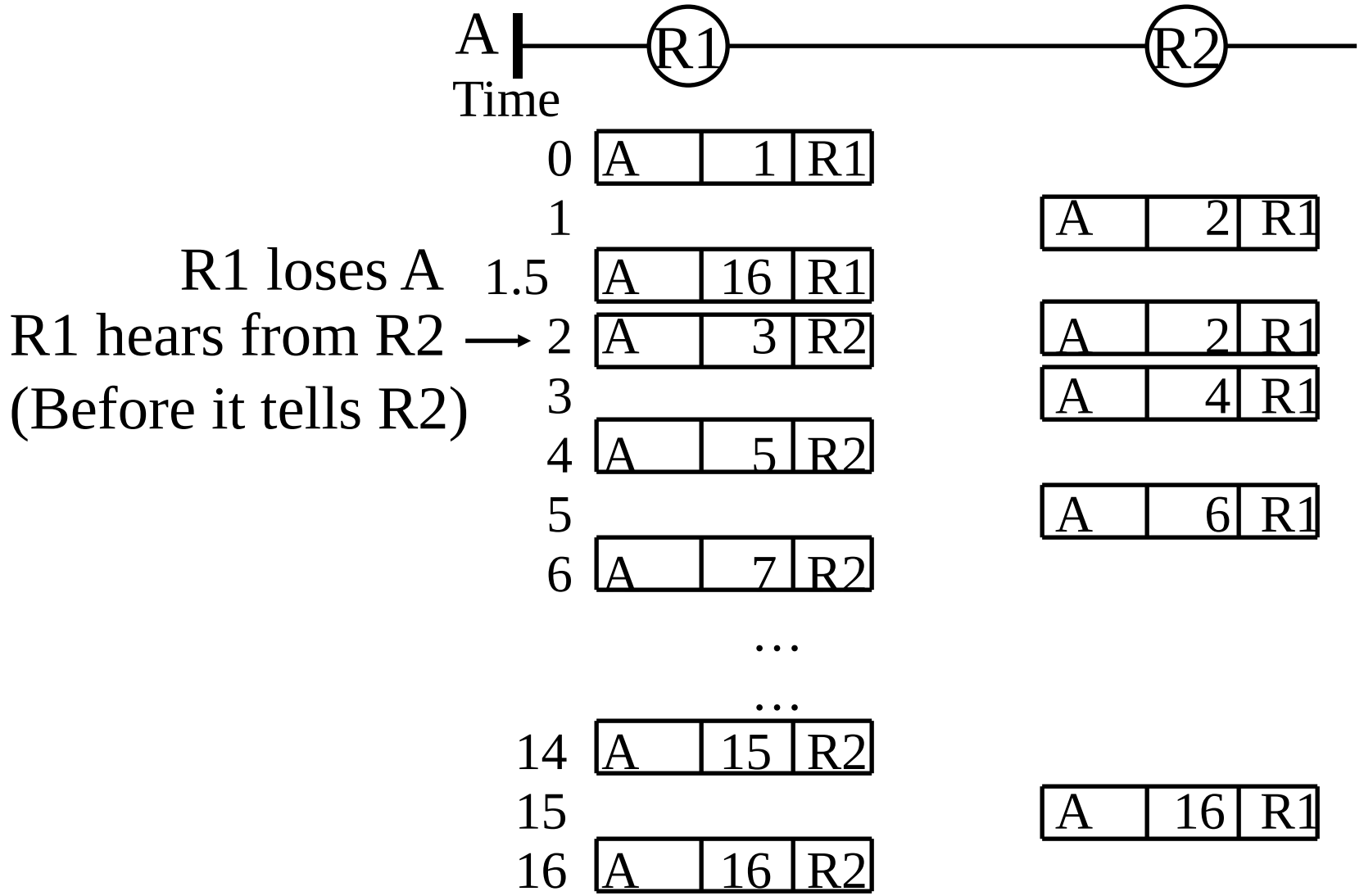
Student Questions

- What's the difference between the Dijkstra's and Bellmon-Ford when they choose the next node to search?

Dijkstra selects neighbors of the shortest entry. Bellman-Ford computes the costs to all neighbors.

©2025 Raj Jain

Counting to Infinity Problem



Student Questions

- How would routers combat a counting-to-infinity problem?

Using Link-State routing algorithms.

- Is this referring to the Bellman-Ford Algorithm? *Yes*
- Didn't R2 know the cost to A when it sent its cost to A to R1? If so, why couldn't R2 figure out the final state of the network?

R2's cost to A is two at that time. It sends that to R1. This example is highly simplified. Actual cycles may be pretty big.

- How could we prevent counting to infinity?

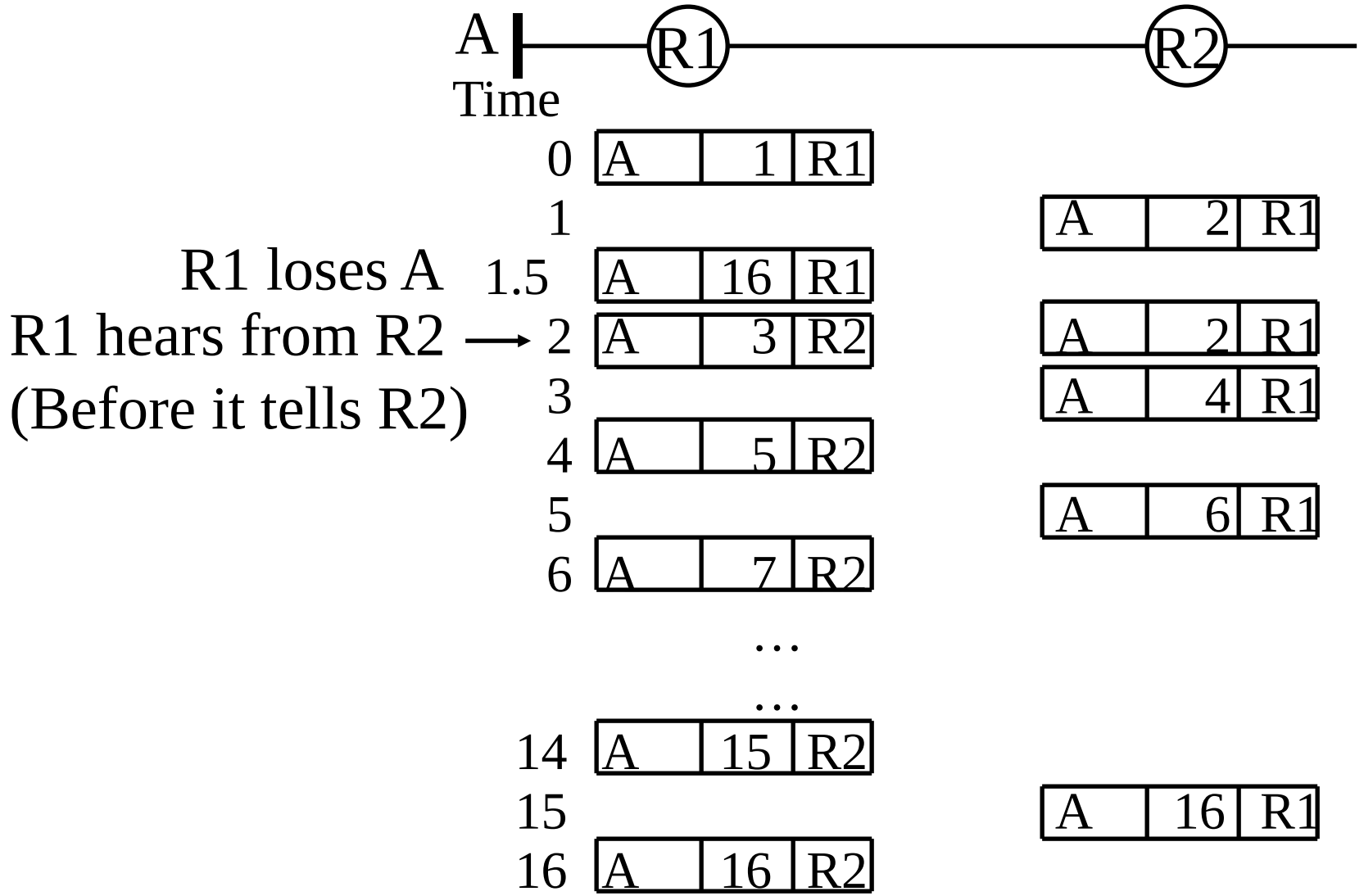
Use link-state algorithms.

- Why does the counting to infinity cause a problem? Isn't it technically true that the cost to the "lost" router is infinite since there is no longer a valid path to it?

It takes a long time for all routers to know that the cost is infinite.

©2025 Raj Jain

Counting to Infinity Problem



Student Questions

- The textbook said the link state routing algorithm has better robustness because the DV algorithm propagates the error of one node to every other node in the network, whereas LS only influences its neighbor. Could you give a concrete example?

This refers to the "Counting to Infinity" problem.

- Do all routers use Link-State algorithms to counter count-to-infinity problems?

Mostly yes. Other routing types, e.g., BGP, still need to be discussed.

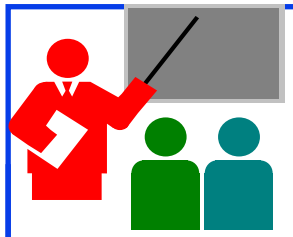
- Why does distance-vector routing still persist if it suffers from counting-to-infinity even with poisoned reverse?

Older implementations (RIP) may still be there.

- What makes Counting to Infinity a problem?

Bad news travels very slowly. A lot of traffic is lost during the confusion.

©2025 Raj Jain



Routing Algorithms: Summary

1. Distance Vectors: Distance to all nodes in the network sent to neighbors. Small # of large messages.
2. Link State: Cost of link to neighbors sent to the entire network. Large # of small messages.
3. Dijkstra's algorithm is used to compute the shortest path using the link state
4. Bellman Ford's algorithm is used to compute shortest paths using distance vectors
5. Distance Vector algorithms suffer from the count-to-infinity problem

Student Questions

- Could you explain again the meaning of link state algorithms sending a "Large # of small messages" and distance vector algorithms sending a "Small # of large messages? "

-Link state tables consist of the cost of each link connected to that router. The size is small. But it has to be broadcast to the entire network.
-Distance vectors consist of distances to all nodes in the network. The size can be huge. But it has to be sent only to neighbors.

- Why does the distance vector suffer from counting to infinity while the link state does not?

In the link state, broken links are immediately announced to the world.

- What is the difference between the routing algorithm and Dijkstra's algorithm?

Dijkstra's algorithm is an example of a routing algorithm.

- Does the link state change as you create the table?

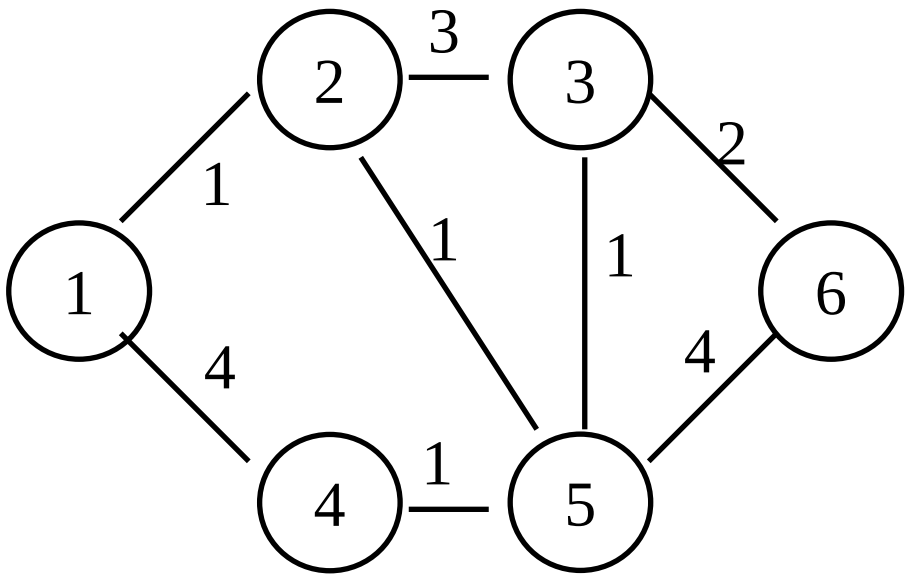
If it does, you have to redo the table.

Ref: Read Section 5.2 of the textbook and try review questions R3-R6.

©2025 Raj Jain

Homework 5B

[10 points] Prepare the routing calculation ***table*** for node 1 in the following network using the Bellman-Ford Algorithm. Explain how you computed new entries in each row.



Student Questions

- Do we also need explanations in words or just our equations?

Yes

- Should I have five rows in total?

Yes

- Can we discuss Bellman-Ford Algorithm homework 5B?

Sure.

©2025 Raj Jain



Routing Protocols

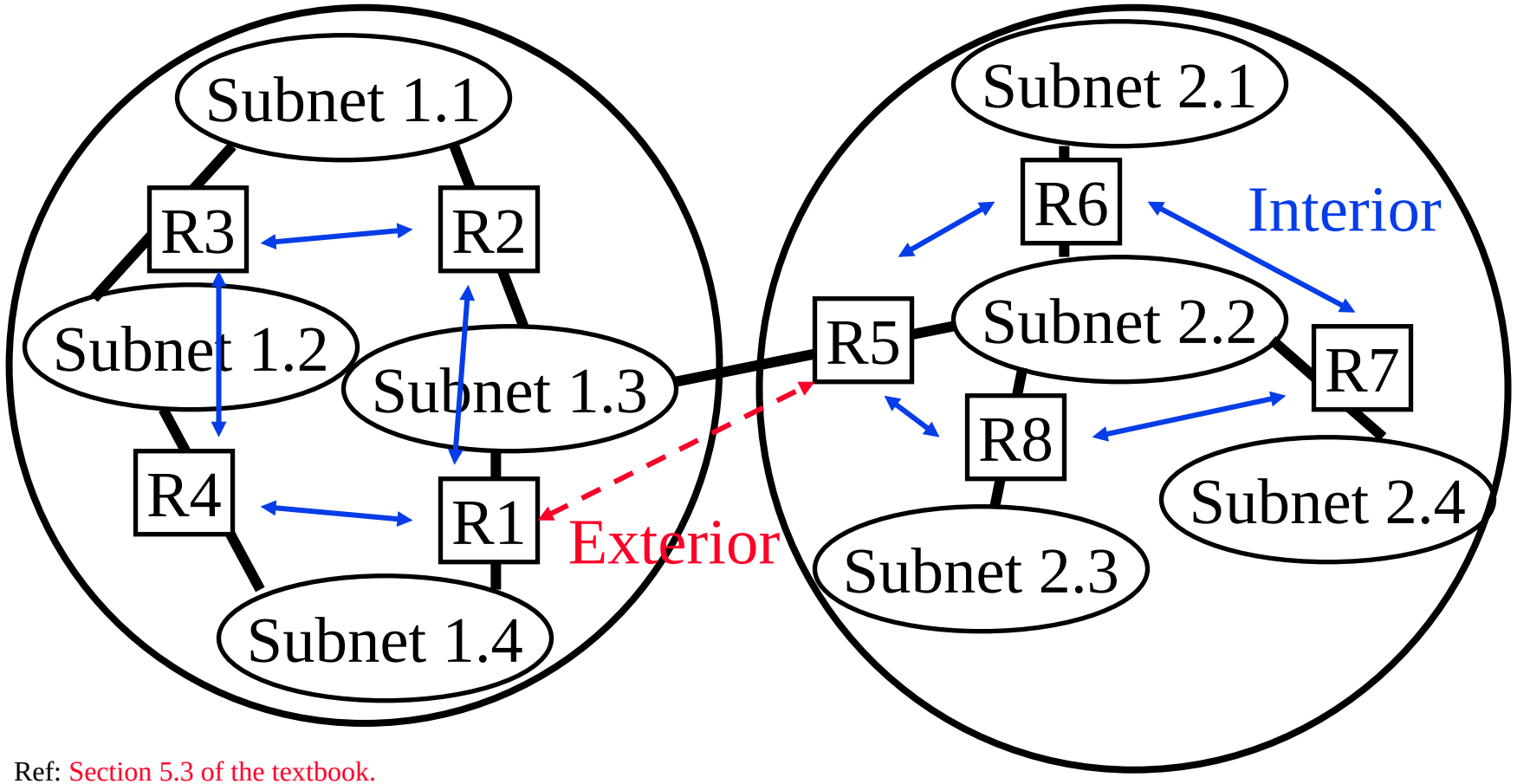
1. Autonomous Systems (AS)
2. Open Shortest Path First (OSPF)
   - OSPF Areas
3. Border Gateway Protocol (BGP)

Student Questions

©2025 Raj Jain

Autonomous Systems

- An internet-connected by homogeneous routers under the administrative control of a single entity



Ref: Section 5.3 of the textbook.

©2025 Raj Jain

Student Questions

- Is an Autonomous System just an area owned by an ISP?

An enterprise or an ISP can own an autonomous system. For example, WUSTL.edu could be one autonomous system. WUSTL is not an ISP. It is an enterprise customer. WUSTL.edu consists of at least two autonomous systems: Med school and Danforth.

- Why are all the subnets in diagram 1.2?

Error corrected. Thank you.

- How do we know which one is interior and which one is exterior

Network administrators know.

- Do Autonomous Systems include access points/Wi-Fi extenders?

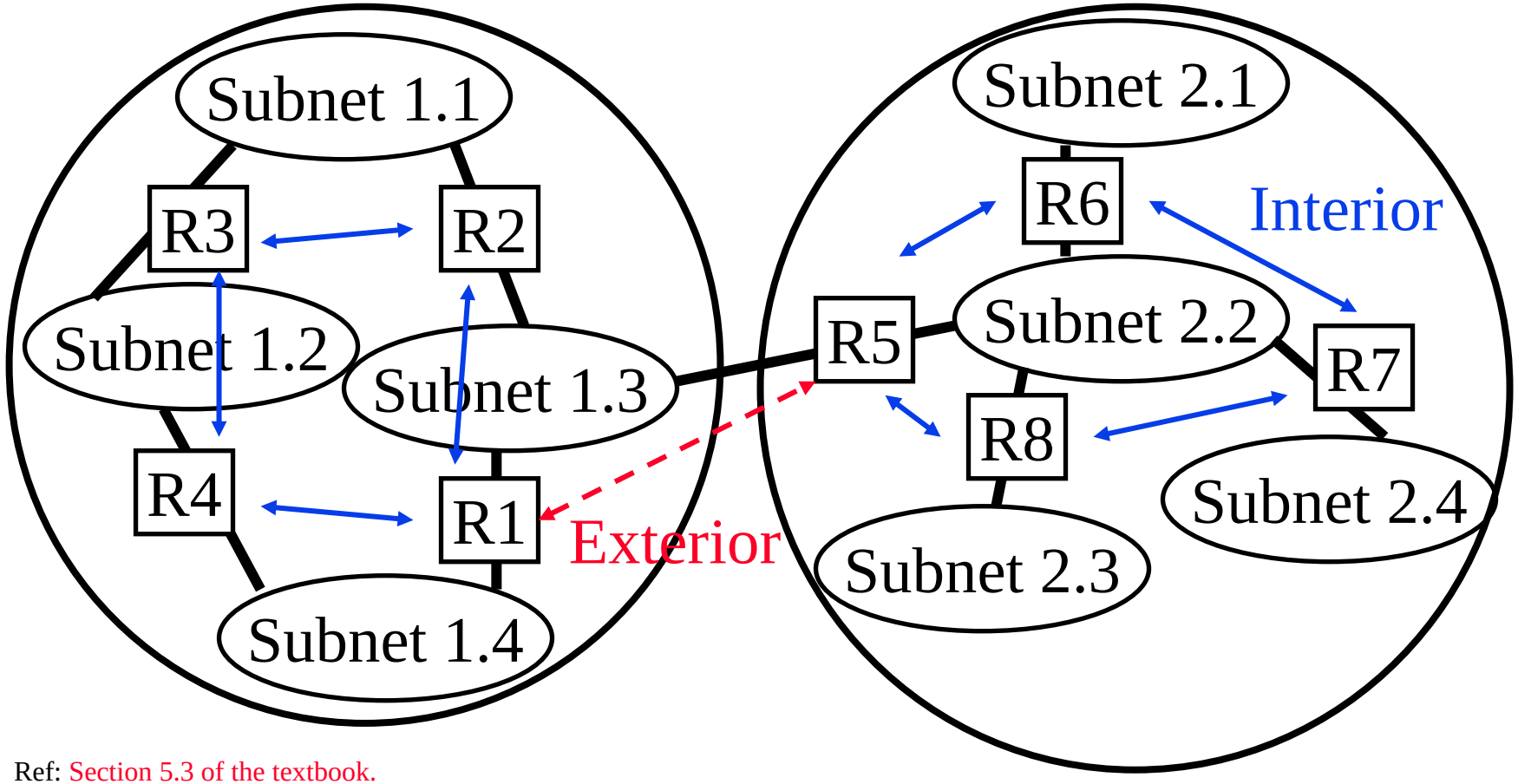
Access points and extenders are layer-2 devices.

- Are the routers between networks, such as WashU's or my home network, also part of an AS? Are there any routers that are not part of an AS?

Some routers belong to carrier AS, and others to enterprise AS.

Autonomous Systems

- An internet connected by homogeneous routers under the administrative control of a single entity



Ref: Section 5.3 of the textbook.

©2025 Raj Jain

Student Questions

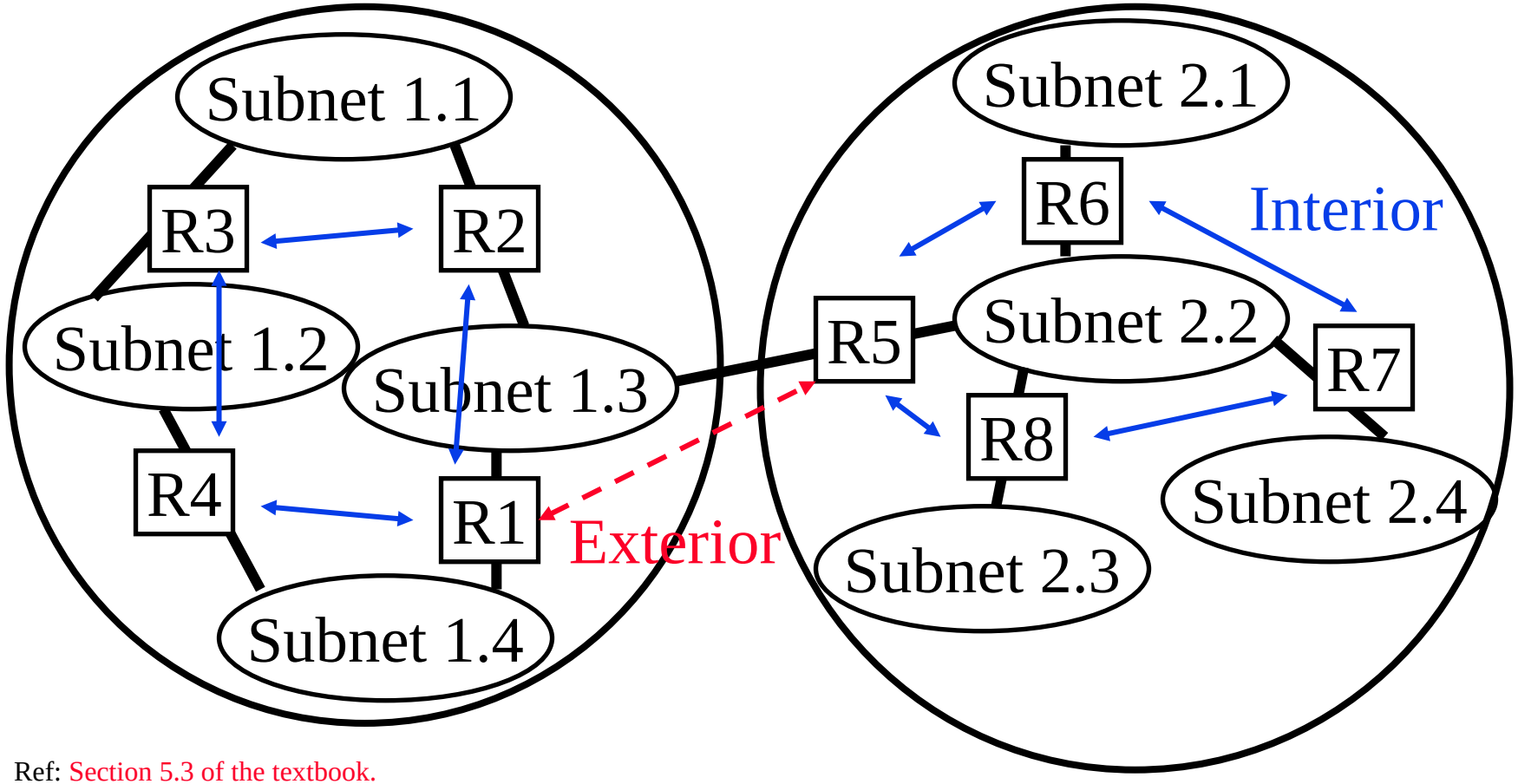
- What are some of the current and emerging applications of autonomous systems in network management and security, and how do these applications improve network performance?

ASs are used for routing.

- Is WashU an autonomous system? And if so, is it considered all one AS?
- *Yes.*
- Is AS the same as ISP? Are there different tiers?
- *An AS could be an ISP or an enterprise. Enterprises do not have tiers.*
- Can there be more than one exterior router?
- *Yes. Quite common.*

Autonomous Systems

- An internet connected by homogeneous routers under the administrative control of a single entity



Ref: Section 5.3 of the textbook.

©2025 Raj Jain

Student Questions

- What are some of the current and emerging applications of autonomous systems in network management and security, and how do these applications improve network performance?

ASs are used for routing.

- Can you point out the Area border route and AS boundary router on this slide? It wasn't visible in the video.

- *R1 and R5 are AS boundary routers. Areas are required in larger networks.*

- Are internal routers or external routers required to be homogeneous?

- *No. They are very different.*

Routing Protocols

- Interior Router Protocol (IRP): Used for passing routing information among routers internal to an autonomous system. Also known as IGP.
  - Examples: RIP, OSPF, IGRP
- Exterior Router Protocol (ERP): Used for passing routing information among routers between autonomous systems. Also known as EGP.
  - Examples: EGP, BGP, IDRP
    Note: EGP is a class as well as an instance in that class.

Student Questions

- Do we combine IRP and ERP for a real-world transmission? How do you switch between two protocols?

OSPF for interior. BGP for exterior.

- Do the class EGP and instance EGP stand for the same thing?

No. One member of the EGP class is EGP.

- The book didn't mention anything about EGP in the instance. What is the difference between EGP and BGP?

BGP is an EGP.

©2025 Raj Jain

Open Shortest Path First (OSPF)

- Uses true metrics (not just hop count)
- Uses subnet masks
- Allows load balancing across equal-cost paths
- Supports type of service (ToS)
- Allows external routes (routes learned from other autonomous systems)
- Authenticates route exchanges
- Quick convergence
- Direct support for multicast
- Link state routing ⇒ Each router broadcasts its connectivity with neighbors to the entire network

Student Questions

- What do you mean by saying using true metrics? The *Hop count does not reflect the cost. Some hops are more expensive than others. True metrics would reflect actual costs.*
- Doesn't IP-anycast violate the rule that computers must have different IP addresses?

-Anycast means "to anyone" in the set. For example, any question "What time is it?" to students in this class will result in a response from any of the students. One response is sufficient in this case.
-Multicast means to "everyone" in the set. For example, "please submit your questions by midnight" needs to be multicast. Anycast will not work. Individual IPs will be too much work.

- What is meant by external routes?

Routes learned from other autonomous systems

- Why does OSPF include external routes? Doesn't it work for routing within an AS?

It tells how to get out of AS.

©2025 Raj Jain

Open Shortest Path First (OSPF)

- Uses true metrics (not just hop count)
- Uses subnet masks
- Allows load balancing across equal-cost paths
- Supports type of service (ToS)
- Allows external routes (routes learned from other autonomous systems)
- Authenticates route exchanges
- Quick convergence
- Direct support for multicast
- Link state routing ⇒ Each router broadcasts its connectivity with neighbors to the entire network

Student Questions

- The textbook says that OSPF uses the link weights, so if the administrator wanted, they could set all link costs to 1 to have minimum-hop routing, while the lecture says that it uses true metrics such as load and speed. Which is correct?

Admin can set weights.

- What is the ToS for in OSPF?

ToS = Low delay, high throughput

- "Quick convergence" refers to the convergence of routing cost table values at different nodes on the network, correct?

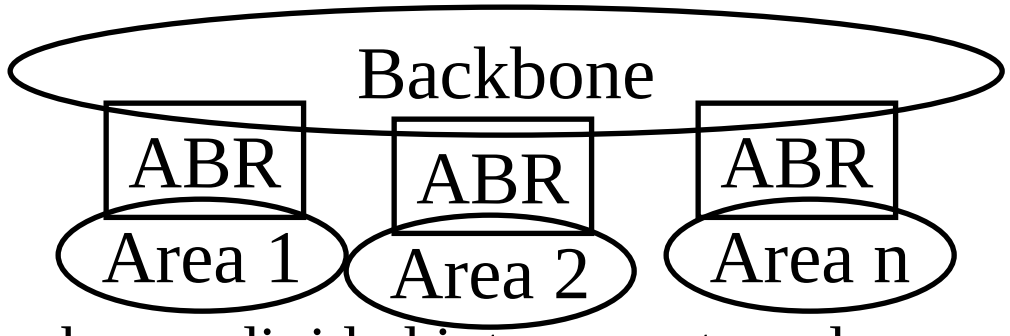
Convergence = All nodes have completed deciding paths to all others in the network.

- How are route exchanges authenticated?

Like any other secure communication.

©2025 Raj Jain

OSPF Areas



- Large networks are divided into areas to reduce routing traffic.
- Link-State Advertisements (LSAs) are flooded throughout the area.
- Area border routers (ABRs) summarize and transmit the topology to the backbone area.
- Backbone routers forward it to other areas
- ABRs connect an area with the backbone area.
  ABRs contain OSPF data for all backbone areas.
- If there is only one area in the AS, there is no backbone area and no ABRs.

Student Questions

- What is LSA?

Link State Advertisements

- How does the flooding of link states in a network affect network congestion?

Not much

- When saying ABR contains data for two areas, which two areas' data does it contain? Are two areas chosen randomly?

The ABR connects the two areas.

- How does an ABR have OSPF areas? Which two areas of information does it have?

See above.

- Does this picture show one autonomous system? Does the AS include the ABR and backbone?

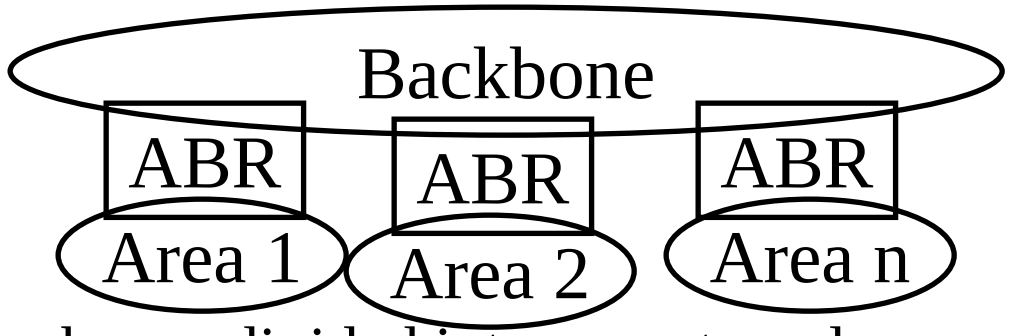
Yes.

- So, can one ABR have information about two other ABRs?

ABR contains OSPF data for all backbone areas.

©2025 Raj Jain

OSPF Areas



- Large networks are divided into areas to reduce routing traffic.
- LSAs are flooded throughout the area.
- Area border routers (ABRs) summarize and transmit the topology to the backbone area.
- Backbone routers forward it to other areas
- ABRs connect an area with the backbone area.
  ABRs contain OSPF data for all areas.
- If only one area in the AS exists, there is no backbone area and no ABRs.

Student Questions

- The lecture slide says "All backbone areas" instead of "the backbone area," implying there can be more than one. Is this correct?

Changed to "all areas"

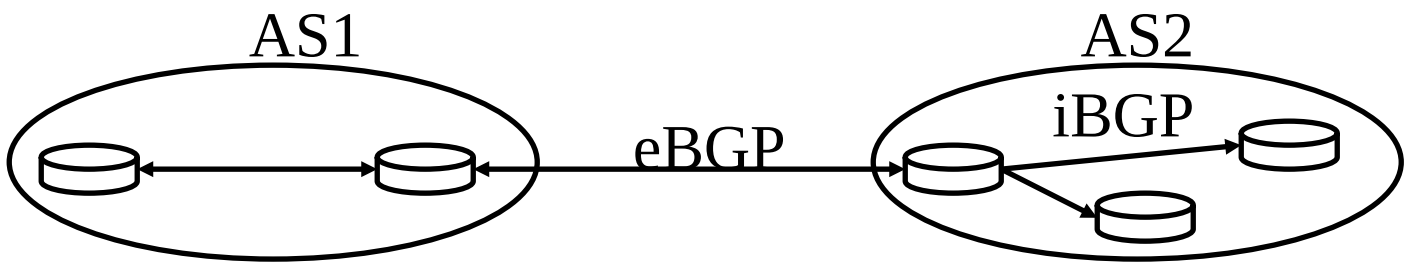
- Can an ABR prioritize one area over another when sending data?

Yes. Traffic could be prioritized based on destination.

©2025 Raj Jain

Border Gateway Protocol

- Inter-autonomous system protocol [RFC 1267]
- Used since 1989 but not extensively until recently
- Runs on TCP (segmentation, reliable transmission)
- Advertises all transit ASs on the path to a destination address
- A router may receive multiple paths to a destination ⇒ Can choose the best path
- iBGP is used to forward paths between two peers in the same AS. eBGP is used to exchange paths between ASs.



Ref: Section 5.4 of the textbook.

Student Questions

- What's the difference between iBGP and OSPF since they work in AS?

If BGP is between peers of an AS, it is called iBGP. Other Ass may separate the two peers.

- If OSPF handles the path, what is the purpose of iBGP?

See above.

- Why does interior BGP exist if there is OSPF?

See above.

- *Why is iBGP needed? Why isn't OSPF used until we hit a gateway router for the AS. (4 other variations of this question)*

See the first question above.

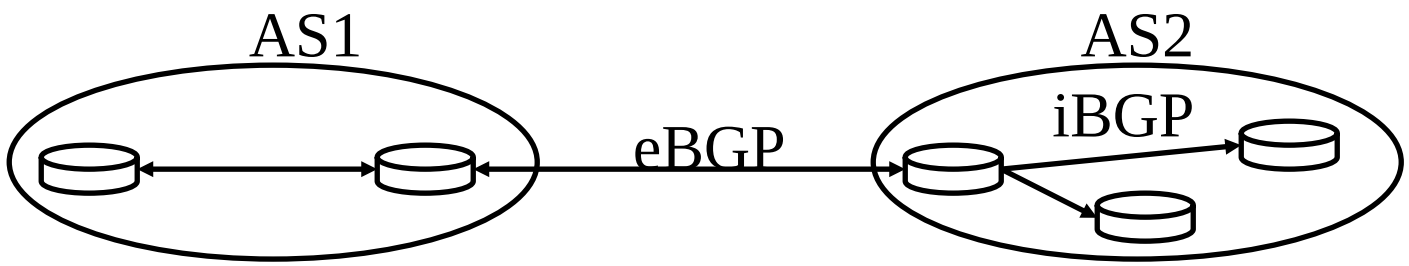
- The textbook mentioned that BGP uses a TCP connection to communicate with edge routers belonging to other AS. I previously thought routers did not have layer four.

They do not change headers of higher layers for datagrams being forwarded. However, they use all layers for internal operation and management.

©2025 Raj Jain

Border Gateway Protocol

- Inter-autonomous system protocol [RFC 1267]
- Used since 1989 but not extensively until recently
- Runs on TCP (segmentation, reliable transmission)
- Advertises all transit ASs on the path to a destination address
- A router may receive multiple paths to a destination ⇒ Can choose the best path
- iBGP is used to forward paths between two peers in the same AS. eBGP is used to exchange paths between ASs.



Student Questions

- How does the concept of Autonomous Systems (AS) facilitate routing in large-scale networks like the internet, and what role does BGP play in inter-AS routing?

ASs are large enterprises. They handle their internal networks. The external traffic requires payment to/between carriers. BGP allows routing based on path costs.

- Does BGP maintain a persistent TCP connection?

Yes, during the exchange of path vectors.

- How does BGP know who to connect?

When a link is established between two ASs, BGP is started.

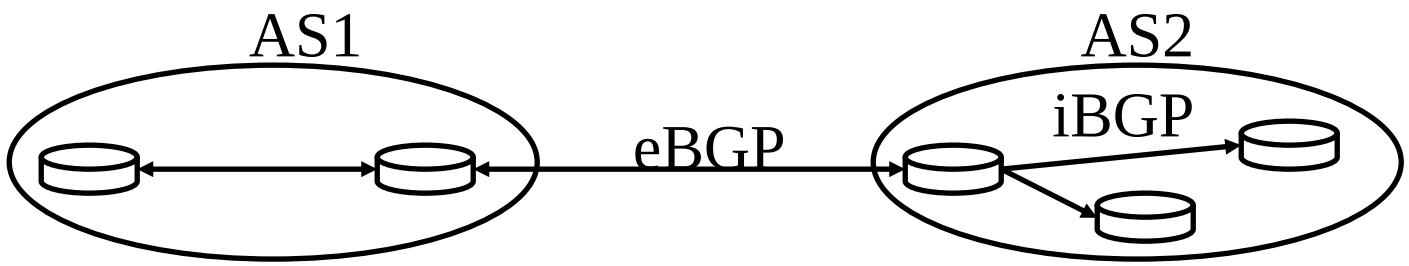
- When does the BGP advertise its existence? Does it send UDP packets, or does it open TCP connections?

All routing algorithms advertise when there is a change, a problem, or a fixed period expires. BGP uses TCP.

©2025 Raj Jain

Border Gateway Protocol

- Inter-autonomous system protocol [RFC 1267]
- Used since 1989 but not extensively until recently
- Runs on TCP (segmentation, reliable transmission)
- Advertises all transit ASs on the path to a destination address
- A router may receive multiple paths to a destination ⇒ Can choose the best path
- iBGP is used to forward paths between two peers in the same AS. eBGP is used to exchange paths between ASs.



Student Questions

- Does BGP belong to the network layer protocol or the application layer protocol?

All routing protocols use transport layers, which could be called application layers. However, they are used only by the network layer, so they are designed and discussed with the network layer.

Ref: Section 5.4 of the textbook.

©2025 Raj Jain

BGP Operations

- BGP systems initially exchange all the routing tables. Afterward, only updates are exchanged.
- BGP messages have the following information:
  - Origin of path information: RIP, OSPF, …
  - AS_Path: List of ASs on the path to reach the dest
  - Next_Hop: IP address of the border router to be used as the next hop to reach the dest
  - Unreachable: If a previously advertised route has become unreachable
- BGP speakers generate update messages to all peers when they select a new route or some route becomes unreachable.

Student Questions

- When BGP hops between ABRs, do the datagrams enter the AS or remain on the exterior? If BGP only sends updates to neighbors, is it also susceptible to a count-to-infinity problem?

BGP is not a distance vector algorithm. It belongs to another class called "path vector" algorithms. It does not have a count-to-infinity problem.

- Could you explain the "origin of path information" field? If BGP is being used between ASs, would we want to avoid revealing information about the internal workings of an AS?

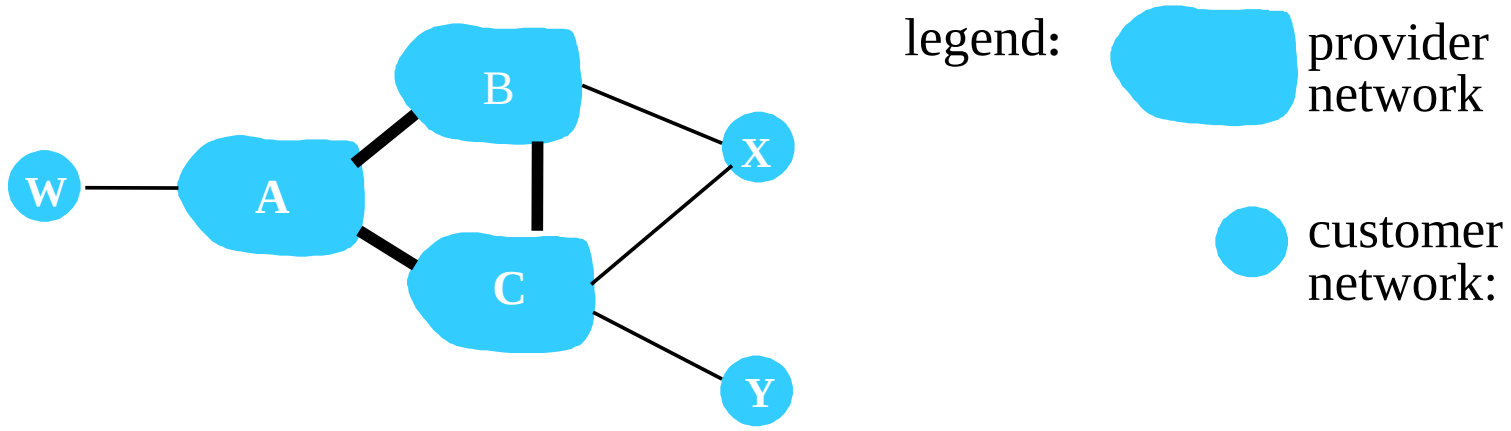
The field is used when transmitting BGP information internally.

- How do BGP systems detect if a route becomes unreachable?

Periodic hello messages.

©2025 Raj Jain

BGP Routing Policy Example

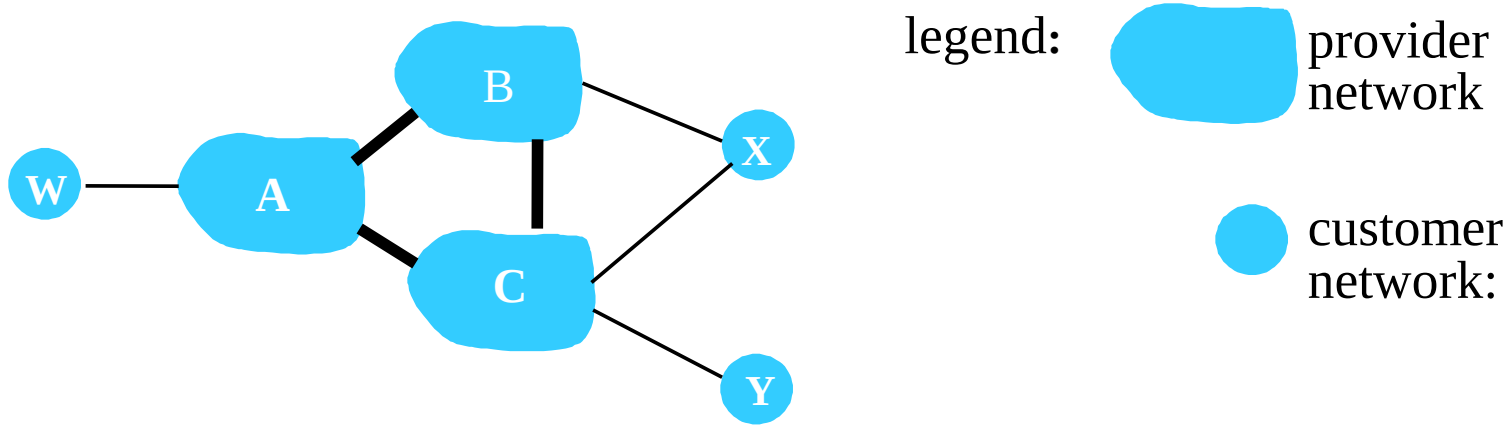


- A,B, C are provider networks
- X,W, and Y are customers (of provider networks)
- X is dual-homed: attached to two networks
  - X does not want to route from B via X to C
  - .. so X will not advertise to B a route to C

Student Questions

©2025 Raj Jain

BGP Routing Policy Example (Cont)



- A advertises path A-W to B
- B advertises path B-A-W to X
- Should B advertise path B-A-W to C?
  - No way! B gets no "revenue" for routing C-B-A-W since neither W nor C are B's customers
  - B wants to force C to route to W via A
  - B wants to route *only* to/from its customers!

Student Questions

- What is the relationship between the routing protocols and the path algorithms like Dijkstra's and Bellman Ford's? Is one used by the other?

Protocols use algorithms.

- Does this type of routing policy apply to both eBGP and iBGP?

No. iBGP is simpler since there is no payment.

©2025 Raj Jain

Intra- vs. Inter-AS Routing

- **Policy:**
  - Inter-AS: The admin wants control over how its traffic is routed and who routes through its net.
  - Intra-AS: single admin, so no policy decisions are needed
- **Scale**:
  - Hierarchical routing saves table size, reduces update traffic
- **Performance**:
  - Intra-AS: can focus on performance
  - Inter-AS: policy may dominate over performance

Student Questions

- What is hierarchical routing?

ISPs of various Tiers, ASs, and Areas inside ASs form a hierarchy.

©2025 Raj Jain

Routing Protocols: Summary

1. OSPF uses link-state routing and divides the autonomous systems into multiple areas.
   Area border router, AS boundary router
2. BGP is an inter-AS protocol ⇒ Policy driven

Student Questions

- Can you again point in graph 5.21 about the three kinds of routers?

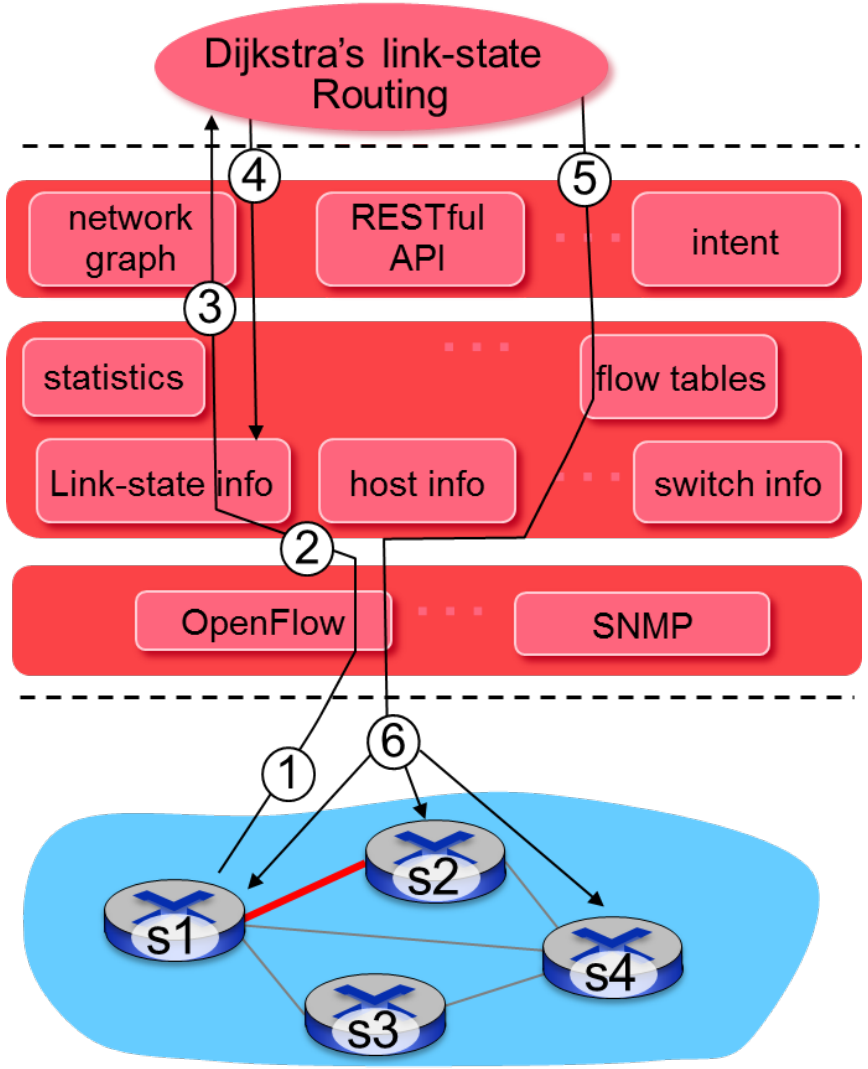
Designated routers were not shown. Used when there are multiple routers on a single Local Area Network.



Ref: Read Section 5.3 and 5.4 of the textbook and try review questions R7-R13.

©2025 Raj Jain

SDN Control Plane



① S1, experiencing link failure using OpenFlow port status message to notify controller

② SDN controller receives OpenFlow message, updates link status info

③ Dijkstra's routing algorithm application has previously registered to be called when ever link status changes. It is called.

④ Dijkstra's routing algorithm access network graph info, link state info in controller, computes new routes

⑤ Controller distributes revised tables. ⑥ Uses OpenFlow

Student Questions

- Are any special techniques used to optimize Dijkstra's performance in practice?

Yes. But beyond the scope of this course.

- How long does it take to go through steps 1-4 in the real world on average?

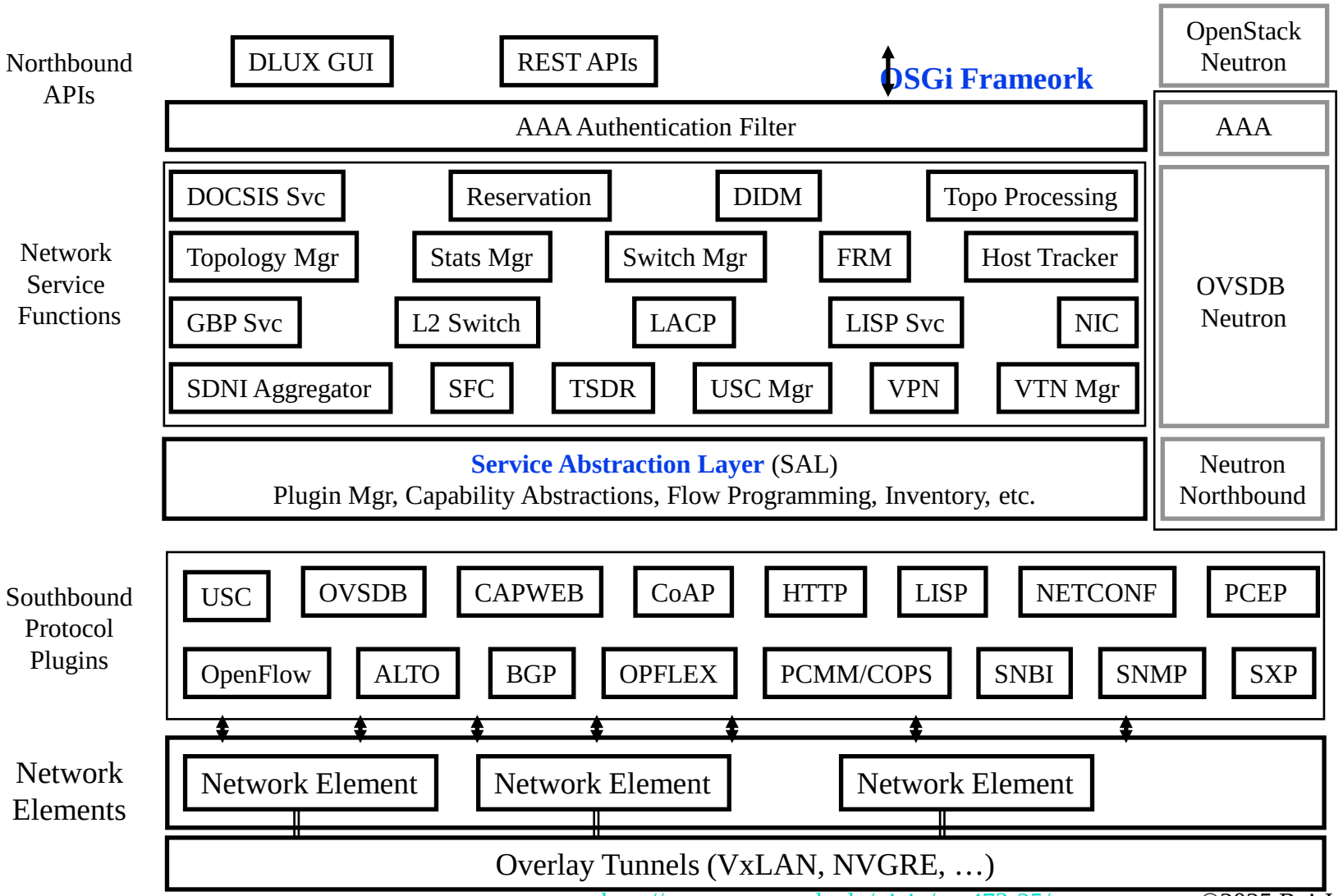
With a centralized controller, this process takes only a few seconds.

- What are steps 5 and 6?

See the updated figure.

©2025 Raj Jain

Controller Example: OpenDaylight



Student Questions

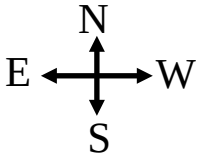
- ❑ Is the SAL responsible for translating Northbound APIs into Southbound Protocol Plugins?

*It translates and submits **network service function** requests to southbound protocol plugins. Also, it is responsible for translating and submitting **responses** from southbound protocol plugins to network service functions.*

- ❑ Why are so many protocols needed? Do they all do similar things?

No, they solve different problems.

- ❑ What exactly are northbound and southbound?



North is upward on a map.

- ❑ What are network elements?

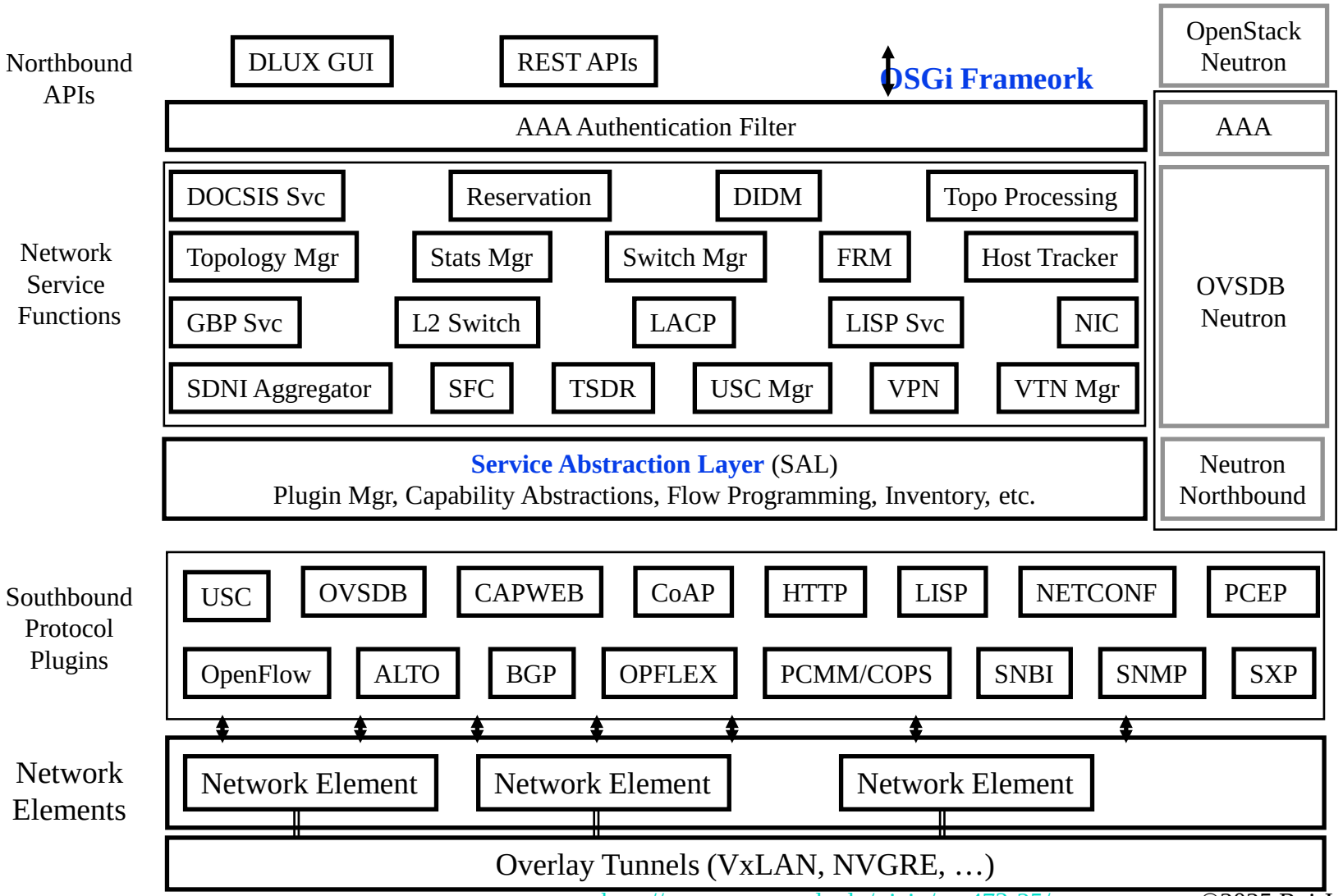
Network Hardware

- ❑ Is "northbound" equivalent to higher abstraction layers (like applications) and "southbound" equivalent to lower layers (like hardware)?

Higher = upper = North

©2025 Raj Jain

Controller Example: OpenDaylight



Student Questions

- What is the OSGi framework (denoted in blue)?

Open Source Gateway Initiative is a set of specifications for dynamically creating new applications using reusable Java components. It is covered in a bit more detail in CSE570S. Ref: https://en.Wikipedia.org/wiki/OSGi

- What are the overlay tunnels?

These are the LAN virtualization protocols. Again, it is covered in CSE570S.

- Can you provide some examples of a service that might be requested through the northbound APIs?

Virtual Private Network (VPN)

- Can you go over this example again?

Sure.

©2025 Raj Jain

OpenDaylight SDN Controller

- Multi-company collaboration under the Linux Foundation
- Many projects, including OpenDaylight Controller
- Dynamically linked into a Service Abstraction Layer (SAL)
  ⇒ SAL determines how to fulfill the service requested by higher layers irrespective of the southbound protocol.
- Modular design
- A rich set of North-bound APIs via RESTful (Web page-like) services

Student Questions

- Can you explain SAL a little more?

Sure

- What exactly does "RESTful" mean?

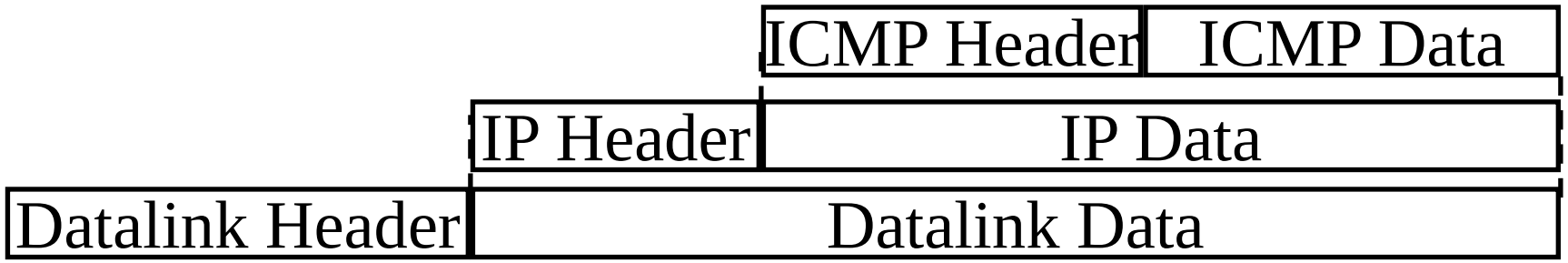
Representational State Transfer = State-less like Web

Ref: Read Section 5.5 and try review questions R14-R18.

©2025 Raj Jain

ICMP

- Internet Control Message Protocol
- Required companion to IP. Provides feedback from the network.
- ICMP: Used by IP to send error and control messages
- ICMP uses IP to send its messages (Not UDP)
- ICMP does not report errors on ICMP messages.
- ICMP reports error only on the first fragment



Student Questions

- Can we say ICMP is a layer 3.5 protocol?

Not really. It is a component of the Layer 3 protocol. IP cannot run without ICMP. Generally, each layer needs its management and security protocols. Sometimes, these are built-in. In other cases, separate and many different standards (protocols) exist.

- What if an error starts to occur on the second fragment? Is this possible? If so, how will ICMP handle this, then?

Those errors are handled by TCP/UDP checksum.

- Can you explain why an error is only reported on the first fragment?

The first fragment contains the original IP header.

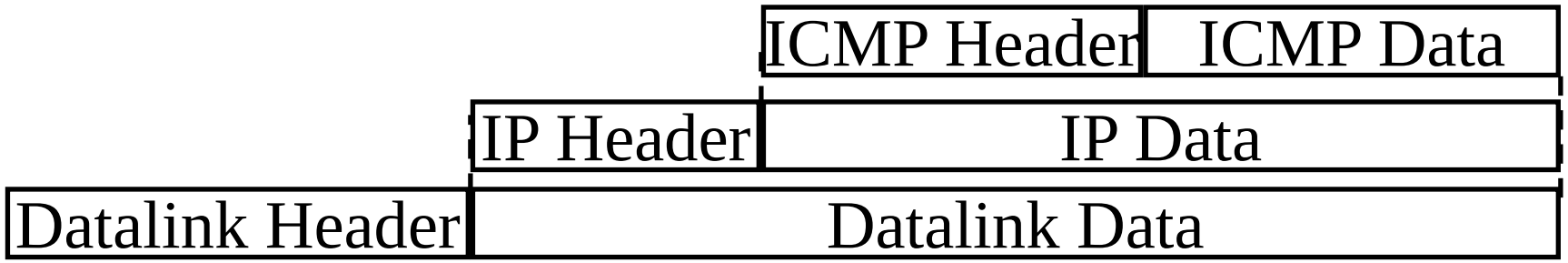
- Is everything after the "IP header" an IP datagram payload containing the ICMP header and message?

Yes.

©2025 Raj Jain

ICMP

- Internet Control Message Protocol
- Required companion to IP. Provides feedback from the network.
- ICMP: Used by IP to send error and control messages
- ICMP uses IP to send its messages (Not UDP)
- ICMP does not report errors on ICMP messages.
- ICMP reports error only on the first fragment



Student Questions

- The book, page 423, says that ICMP is commonly used for error reporting. What motivates using ICMP messages that describe router advertisement and discovery? Could OpenFlow implement the same functionality that ICMP does with sending messages?

OpenFlow works in one management domain. ICMP is worldwide.

- How would NAT handle ICMP messages?

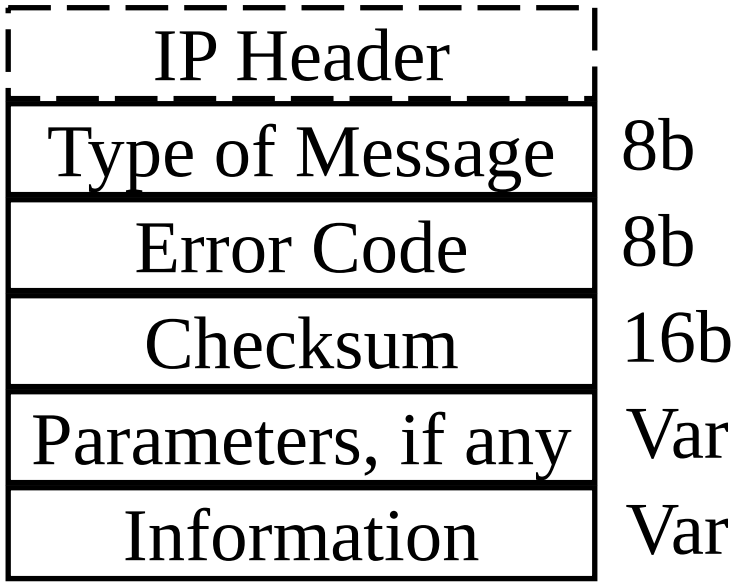
ICMP data includes the initial part of the packet that was dropped. It may contain the TCP header.

- Can you talk about why ICMP was needed?

All protocols contain messages to report errors and faults. In the case of IP, a separate protocol ICMP was designed for this.

©2025 Raj Jain

ICMP: Message Types



Type	Message
0	Echo reply
3	Destination unreachable
4	Source quench
5	Redirect
8	Echo request
11	Time exceeded
12	Parameter unintelligible
13	Time-stamp request
14	Time-stamp reply
15	Information request
16	Information reply
17	Address mask request
18	Address mask reply

Student Questions

- Can you explain more about the error packet?

*ICMP **Messages** have "Type," which indicates what that message is for. Not all ICMP messages are "Error messages." The error code field indicates the type of error encountered while processing a datagram.*

- If all necessary information is included in the ICMP header (type of message, error code), what is included in ICMP data?

ICMP data consists of the IP header and some parts of the IP data.

- For ICMP Information request/reply, do we specify the information in the ICMP data field?

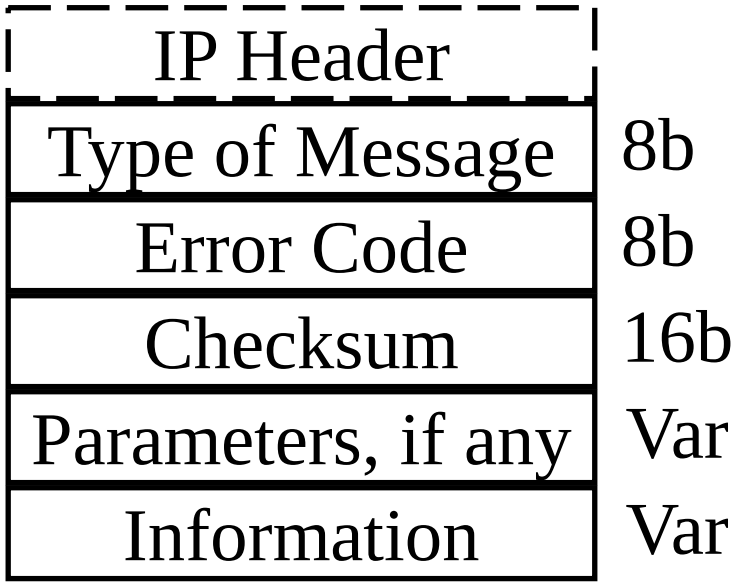
See above.

- Should I check ICMP and IP checksum when receiving an ICMP packet?

Yes.

©2025 Raj Jain

ICMP: Message Types



Type	Message
0	Echo reply
3	Destination unreachable
4	Source quench
5	Redirect
8	Echo request
11	Time exceeded
12	Parameter unintelligible
13	Time-stamp request
14	Time-stamp reply
15	Information request
16	Information reply
17	Address mask request
18	Address mask reply

Student Questions

- So, will the router throwing away a packet due to TTL expiry notify its sender via ICMP? *Yes.*
- When is the information request/reply used?

For example, to find the maximum datagram size.

- Are there no messages with types 1, 2, 6, 7, 8, 9, and 10?

Yes, there are. This is just a common subset. Some are reserved.

- What is the point of having multiple codes per ICMP type rather than another ICMP type?

Code=Subtype. For example, the destination unreachable may be due to the network/ host/ protocol/ port being unreachable.

©2025 Raj Jain

ICMP Messages

- Source Quench: Please slow down!
  I just dropped one of your datagrams.
- Time Exceeded: Time to live field in one of your packets became zero." or "Reassembly timer expired at the destination.
- Fragmentation Required: Datagram was longer than MTU, and "No Fragment bit" was set.
- Address Mask Request/Reply: What is the subnet mask on this net? Replied by "Address mask agent".
- PING uses ICMP echo
- Tracert uses TTL expired

Student Questions

- What is the type code for fragmentation required? Why does it not appear in the chart in the previous slide?

The list on the previous slide is partial. For a complete list of possibilities, please see the RFC.

- It says ICMP will only report on the first fragment, but will it send duplicate 'source quench' responses if multiple packets in a row are dropped?

No. Not in a row.

- How does the source reply to receiving the source quench message? Will flow control or congestion control window change because of ICMP?

The source should reduce the window use using its congestion control protocol.

Ref: Read Section 5.6 of the textbook and try erview questions R19-R20.

©2025 Raj Jain

Trace Route Example

C:\>tracert www.google.com

Tracing route to www.l.google.com [74.125.93.147]
over a maximum of 30 hops:

1	3 ms	1 ms	1 ms	192.168.0.1
2	12 ms	10 ms	9 ms	bras4-l0.stlsmo.sbcglobal.net [151.164.182.113]
3	10 ms	8 ms	8 ms	dist2-vlan60.stlsmo.sbcglobal.net [151.164.14.163]
4	9 ms	7 ms	7 ms	151.164.93.224
5	25 ms	22 ms	22 ms	151.164.93.49
6	25 ms	22 ms	22 ms	151.164.251.226
7	30 ms	28 ms	28 ms	209.85.254.128
8	61 ms	57 ms	58 ms	72.14.236.26
9	54 ms	52 ms	51 ms	209.85.254.226
10	79 ms	160 ms	67 ms	209.85.254.237
11	66 ms	57 ms	68 ms	64.233.175.14
12	60 ms	58 ms	58 ms	qw-in-f147.google.com [74.125.93.147]

Trace complete.

Student Questions

- If the route changes during a traceroute, is there any way to know? Is a change prevented? Or is it not necessary?

Traceroute gives the actual route used for the message. It can change between two traceroutes.

©2025 Raj Jain

Lab 5A: ICMP

- [14 points] Download the Wireshark traces from http://gaia.cs.umass.edu/wireshark-labs/wireshark-traces.zip
- Open *icmp-ethereal-trace-1* in Wireshark. Select **View → Expand All**. Answer the following questions:

1. Examine Frame 3.
   A. What is the IP address of your host? What is the IP address of the destination host?
   B. Why does an ICMP packet not have source and destination port numbers?
   C. What are the ICMP type and code numbers? What other fields does this ICMP packet have? How many bytes are the checksum, sequence number, and identifier fields?

Student Questions

Lab 5A (Cont)

2. Examine Frame 4. What are the ICMP type and code numbers?

- Open *icmp-ethereal-trace-2* in Wireshark. Answer the following questions:

3. Examine Frame 2. What fields are included in this ICMP error packet?
4. Examine Frames 100, 101, and 102. How are these packets different from the ICMP error packet 2? Why are they not error packets?

Student Questions

©2025 Raj Jain



Network Management

- What is Network Management?
- Components of Network Management
- How is Network Managed?
- SNMP protocol

Student Questions

- On page 426 of the textbook, the framework for network management is described very in depth. To what extent are we expected to know the definitions for each part of the framework for the exam?

Everything in the book and slides.

©2025 Raj Jain

What is Network Management?

- Traffic on Network = Data + Control + Management
- **Data** = Bytes/Messages sent by users
- **Control** = Bytes/messages added by the system to properly transfer the data (e.g., routing messages)
- **Management** = Optional messages to ensure that the network functions correctly and to handle the issues arising from the malfunction of any component
- If all components function properly,
  Control is still required, but management is optional.
- Examples:
  - Detecting failures of an interface card at a host or a router
  - Monitoring traffic to aid in resource deployment
  - Intrusion Detection

Student Questions

©2025 Raj Jain

Components of Network Management

1. **Fault Management**:
   Detect, log, and respond to fault conditions
2. **Configuration Management**:
   Track and control which devices are on or off
3. **Accounting Management**:
   Monitor resource usage for records and billing
4. **Performance Management**:
   Measure, report, analyze, and control traffic, messages
5. **Security Management**:
   Enforce a policy for access control, authentication, and authorization

❑ **FCAPS**

Student Questions

❑ Can performance measurements also be used for accounting management if performance includes resource usage/reports?

Yes, any data can be used for multiple purposes.

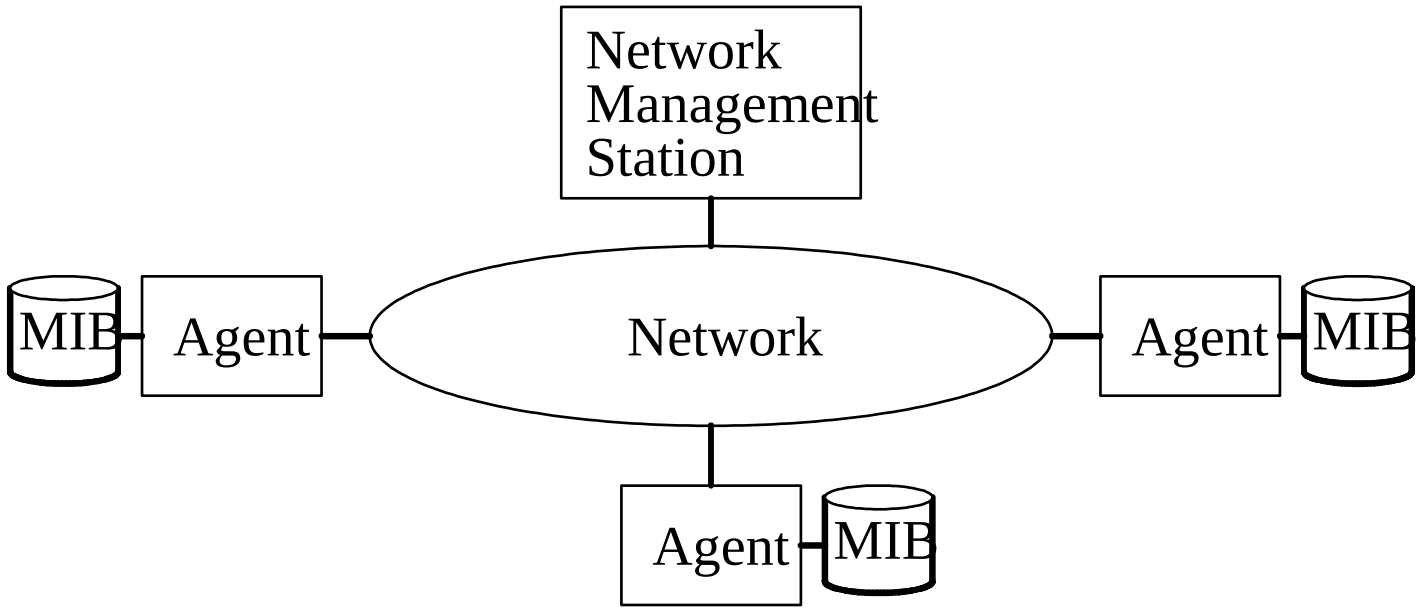
❑ Which component is most critical for network management?

Security, Fault, Performance, Configuration, accounting.

©2025 Raj Jain

How is Network Managed?

- Management = Initialization, Monitoring, Control
- Manager, Agents, and Management Information Base (MIB)



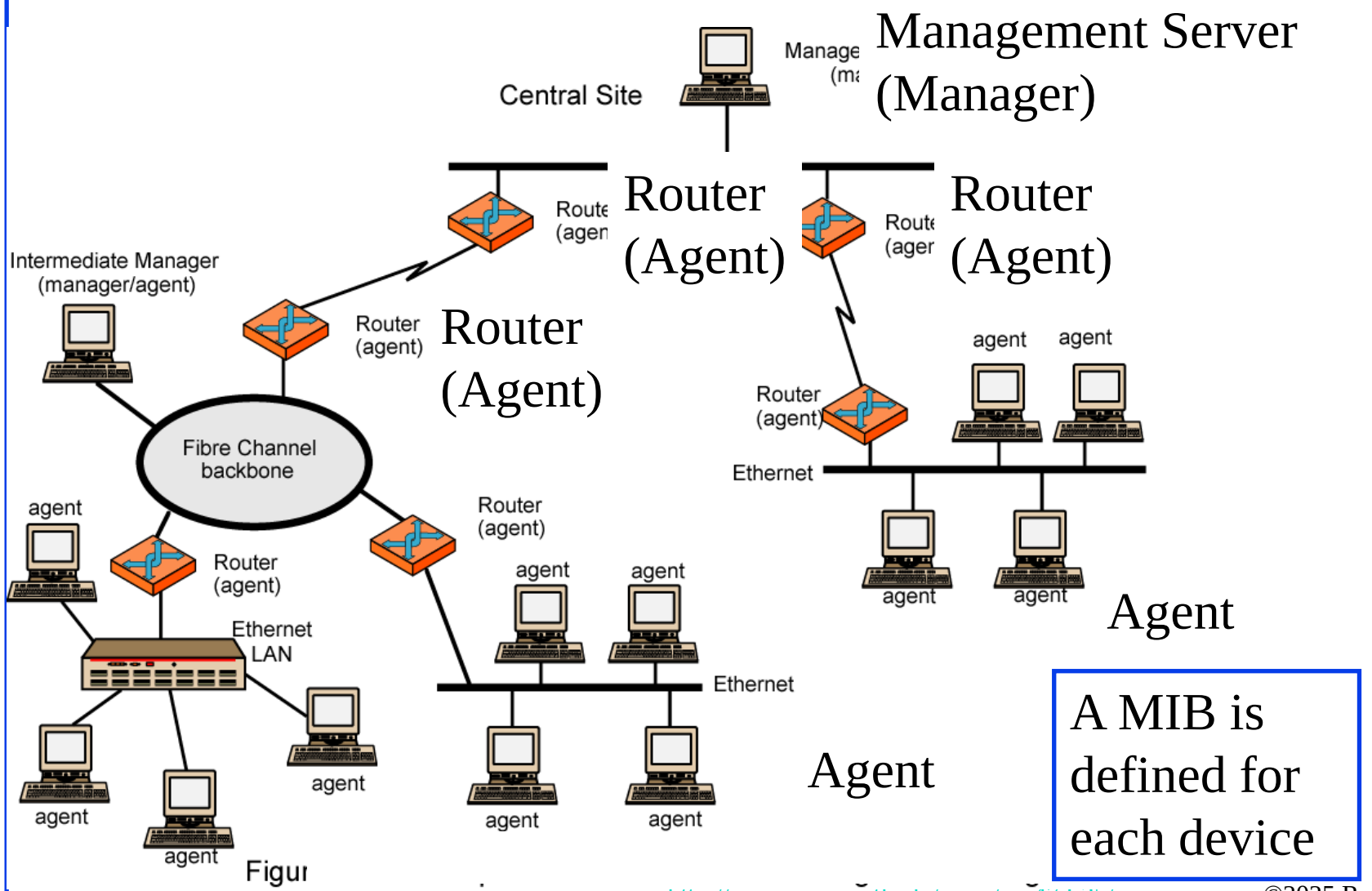
Student Questions

- Can you go over what MIB does?

MIB is a database to keep all counters and parameters.

End of Q

Example of Network Management



A MIB is defined for each device

Student Questions

SNMP

- Based on Simple Gateway Management Protocol (SGMP) – RFC 1028 – Nov 1987
- SNMP = **S**imply ***N***ot ***M***y ***P***roblem [Marshall Rose]
  Simple Network Management Protocol
- RFC 1058, April 1988
- Only Five commands

Command	Meaning
get-request	Fetch a value
get-next-request	Fetch the next value (in a tree)
get-response	Reply to a fetch operation
set-request	Store a value
trap	An event

Student Questions

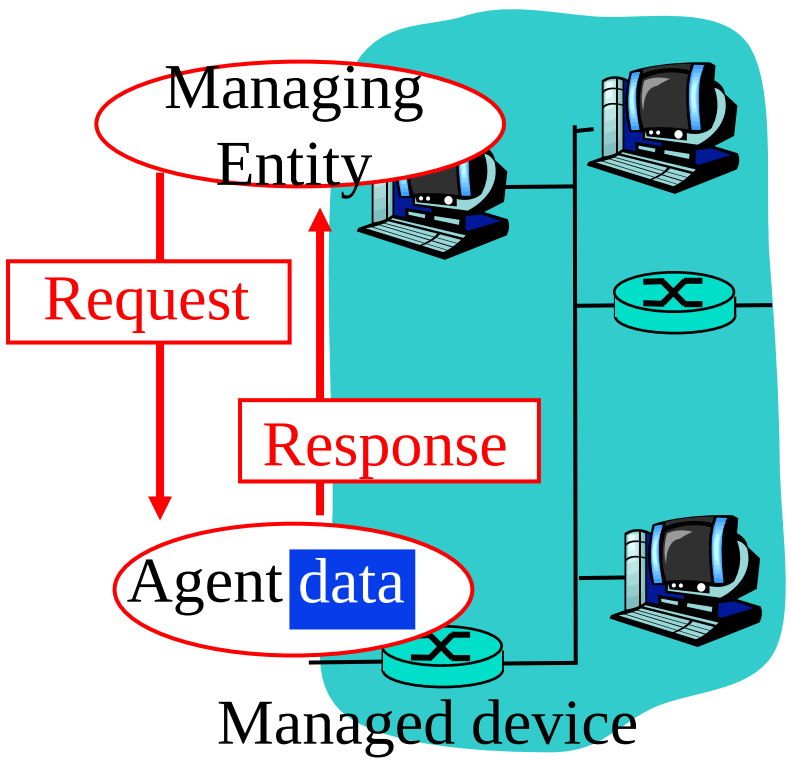
- What is the meaning of value here? What do they represent?

Generally, counters and parameters

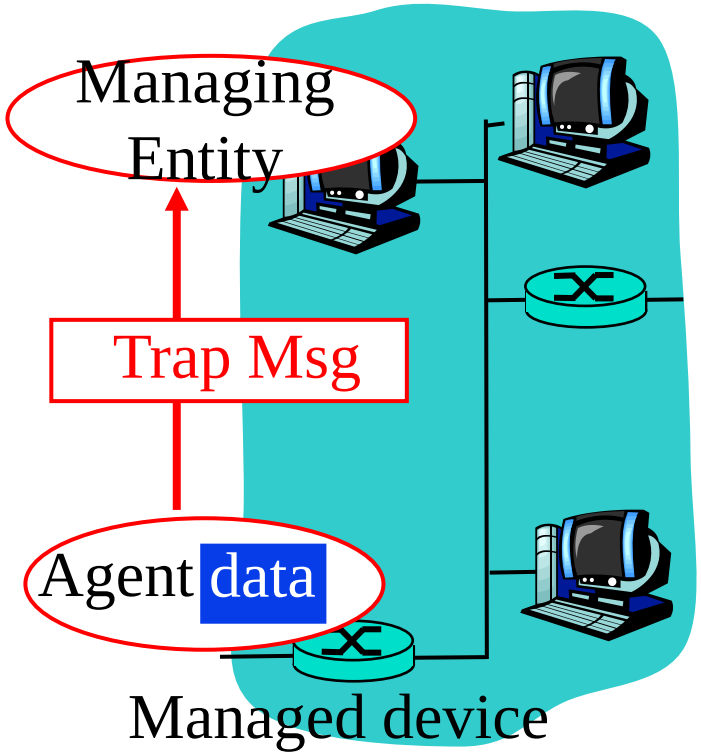
©2025 Raj Jain

SNMP protocol

Two ways to convey MIB info, commands:



Request/response mode



Trap mode

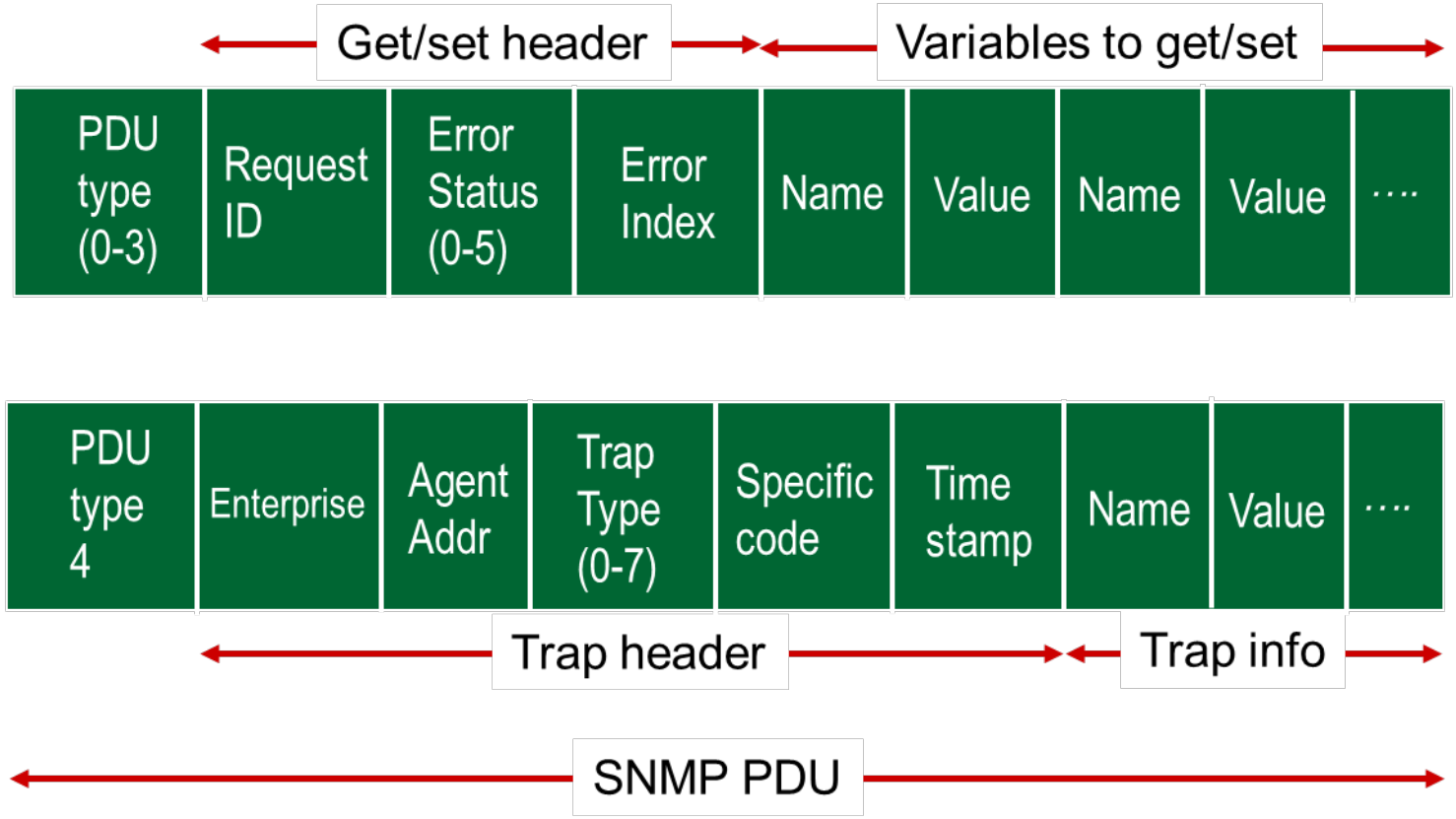
Student Questions

- Are there SNMP version differences that can lead to issues, or does most hardware usually run the same version?

SNMP is now in V3. They are backward compatible.

©2025 Raj Jain

SNMP Message Formats



Student Questions

- *How many variables are there to get/set? Is the length standard and padded if unused or dynamically allocated?*

Dynamic.

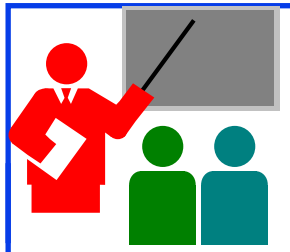
- I've heard the term "OID" denote the data in the tree. Would that correspond to the Name or value?

Object ID (OID) uniquely identifies each object type in the world using a standard method.

- Ref: https://www.dpstele.com/snmp/what-does-oid-network-elements.php
- Why are there two different message types for SNMP?

The first type is the standard processing. The second type is like an interrupt.

©2025 Raj Jain



Network Management: Summary

1. Management = Initialization, Monitoring, and Control
2. Standard MIBs are defined for each object
3. SNMP = Only five commands in the first version

Student Questions

- *What kinds of fields does an MIB contain?*

Parameters and counters

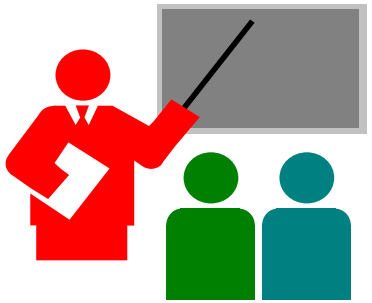
- What does MIB contain?

It is a database definition. Each product has an MIB document that allows standard SNMP managers to get various pieces of information. For example, Packets lost due to checksum errors could be 1.3.5.6.7.

Ref: Read Section 5.7 of the textbook and try review questions R21-R23.

©2025 Raj Jain

Network Layer Control Plane: Summary



1. Dijkstra's algorithm allows path computation using link state
2. Bellman Ford's algorithm allows path computation using distance vectors.
3. OSPF is a link state IGP.
4. BGP is an EGP and uses path vectors
5. SDN controllers use various algorithms for the centralized computation of paths and other policies
6. ICMP is an IP control protocol used to convey errors
7. SNMP is the simple network management protocol to manage all devices and protocols in a network

Student Questions

- ❑ What are the hardware and software advantages and disadvantages between decentralized and centralized routing algorithms?

Centralization makes management more effortless.

- ❑ From the textbook page 437 HW problem, What is meant by a control plane that is based on logically centralized control?

SDN, e.g., OpenFlow, was discussed in Chapter 4

©2025 Raj Jain

Lab 5B: ICMP Ping Programming

[25 points] In this lab, you will better understand Internet Control Message Protocol (ICMP). You will learn to implement a Ping application using ICMP request and reply messages.

Ping is a computer network application that tests whether a particular host is reachable across an IP network. It is also used to self-test the computer's network interface card or as a latency test. It works by sending ICMP "echo reply" packets to the target host and listening for ICMP "echo reply" replies. The "echo reply" is sometimes called a pong. Ping measures the round-trip time, records packet loss, and prints a statistical summary of the echo reply packets received (the minimum, maximum, and mean of the round-trip times and, in some versions, the standard deviation of the mean).

Your task is to develop your own Ping application in Python. Your application will use ICMP, but to keep it simple, it will not exactly follow the official specification in RFC 1739. Note that you will only need to write the client side of the program, as the functionality needed on the server side is built into almost all operating systems.

You should complete the Ping application so that it sends ping requests to a specified host separated by approximately one second. Each message contains a payload of data that includes a timestamp. After sending each packet, the application waits up to one second to receive a reply. If one second goes by without a reply from the server, the client assumes that either the ping packet or the pong packet was lost in the network (or the server is down).

Student Questions

- Should I check the ICMP type and code in Lab 5B? Is it enough to only check the ICMP type?

Code gives a reason for type. It is required for some types, e.g., destination unreachable. You may get the destination unreachable to some echo requests. So yes, you should check both.

©2025 Raj Jain

Lab 5B (Cont)

Code

Below, you will find the skeleton code for the client. You are to complete the skeleton code. The places where you need to fill in the code are marked with **#Fill in start** and **#Fill in end**. Each place may require one or more lines of code. This code was written for **Python V2.7** and may not run on higher versions.

Additional Notes

In the "receiveOnePing" method, you must receive the structure ICMP_ECHO_REPLY and fetch the necessary information, such as checksum, sequence number, time to live (TTL), etc. Study the "sendOnePing" method before trying to complete the "receiveOnePing" method.

You do not need to be concerned about the checksum, as it is already in the code.

This lab requires the use of raw sockets. In some operating systems, you may need **administrator/root privileges** to run your Pinger program.

Testing the Pinger

First, test your client by sending packets to localhost, 127.0.0.1.

Then, you should see how your Pinger application communicates across the network by pinging servers on different continents. See additional hints on slide 5.62.

What to Hand in

- You will hand in the complete client code and screenshots of your Pinger output for four target hosts: north-america.pool.ntp.org, europe.pool.ntp.org, asia.pool.ntp.org, south-america.pool.ntp.org

Student Questions

©2025 Raj Jain

Lab 5B (Cont)

Skeleton Python Code for the ICMP Pinger

```
from socket import *
import os
import sys
import struct
import time
import select
import binascii
ICMP_ECHO_REQUEST = 8

def checksum(string):
	csum = 0
	countTo = (len(string) // 2) * 2
	count = 0
	while count < countTo:
		thisVal = ord(string[count+1]) * 256 + ord(string[count])
		csum = csum + thisVal
		csum = csum & 0xffffffff
		count = count + 2

	if countTo < len(string):
		csum = csum + ord(string[len(string) - 1])
		csum = csum & 0xffffffff

	csum = (csum >> 16) + (csum & 0xffff)
	csum = csum + (csum >> 16)
	answer = ~csum
	answer = answer & 0xffff
	answer = answer >> 8 | (answer << 8 & 0xff00)
	return answer
```

Student Questions

©2025 Raj Jain

Lab 5B (Cont)

```
def receiveOnePing(mySocket, ID, timeout, destAddr):
    timeLeft = timeout
    while 1:
        startedSelect = time.time()
        whatReady = select.select([mySocket], [], [], timeLeft)
        howLongInSelect = (time.time() - startedSelect)
        if whatReady[0] == []: # Timeout
            return "Request timed out."
        timeReceived = time.time()
        recPacket, addr = mySocket.recvfrom(1024)
        #Fill in start
        #Fetch the ICMP header from the IP packet
        #Fill in end
        timeLeft = timeLeft - howLongInSelect
        if timeLeft <= 0:
            return "Request timed out."
```

Student Questions

©2025 Raj Jain

Lab 5B (Cont)

```
def sendOnePing(mySocket, destAddr, ID):
    # Header is type (8), code (8), checksum (16), id (16), sequence (16)
    myChecksum = 0
    # Make a dummy header with a 0 checksum
    # struct -- Interpret strings as packed binary data
    header = struct.pack("bbHHh", ICMP_ECHO_REQUEST, 0, myChecksum, ID, 1)
    data = struct.pack("d", time.time())
    # Calculate the checksum on the data and the dummy header.
    myChecksum = checksum(str(header + data))

    # Get the right checksum, and put in the header
    if sys.platform == 'darwin':
        # Convert 16-bit integers from host to network byte order
        myChecksum = htons(myChecksum) & 0xffff
    else:
        myChecksum = htons(myChecksum)
    header = struct.pack("bbHHh", ICMP_ECHO_REQUEST, 0, myChecksum, ID, 1)
    packet = header + data

    mySocket.sendto(packet, (destAddr, 1)) # AF_INET address must be tuple, not str
    # Both LISTS and TUPLES consist of a number of objects
    # which can be referenced by their position number within the object.
```

Student Questions

©2025 Raj Jain

Lab 5B (Cont)

```
def doOnePing(destAddr, timeout):
    icmp = getprotobyname("icmp")
    # SOCK_RAW is a powerful socket type. For more details: http://sock-raw.org/papers/sock_raw
    mySocket = socket(AF_INET, SOCK_RAW, icmp)
    myID = os.getpid() & 0xFFFF     # Return the current process i
    sendOnePing(mySocket, destAddr, myID)
    delay = receiveOnePing(mySocket, myID, timeout, destAddr)
    mySocket.close()
    return delay

def ping(host, timeout=1):
    # timeout=1 means: If one second goes by without a reply from the server,
    # the client assumes that either the client's ping or the server's pong is lost
    dest = gethostbyname(host)
    print("Pinging " + dest + " using Python:")
    print("")
    # Send ping requests to a server separated by approximately one second
    while 1 :
            delay = doOnePing(dest, timeout)
            print(delay)
            time.sleep(1)# one second
    return delay
```

Student Questions

©2025 Raj Jain

Acronyms

- ABR — Area border router
- API — Application Programming Interface
- AS — Autonomous System
- ASBR — Autonomous System Boundary Router
- BDR — Backup Designated Router
- BGP — Border Gateway Protocol
- BR — Backbone Router
- CAPWAP — Control and Provisioning of Wireless Access Points
- CCITT — Consultative Committee for International Telegraph and Telephone (now ITU-T)
- CoAP — Constrained Application Protocol
- COPS — Common Open Policy Service
- DIDM — Device Identifier and Driver Management
- DLUX — OpenDaylight User Interface
- DOCSIS — Data over Cable Service Interface Specification
- DR — Designated Router
- eBGP — exterior BGP

Student Questions

©2025 Raj Jain

Acronyms (Cont)

EGP	Exterial Gateway Protocol
ERP	Exterior Router Protocol
FCAPS	Fault Configuration Accounting Performance and Security
FRM	Forwarding Rules Manager
GBP	Group Based Policy
GUI	Graphical User Interface
HTTP	Hyper-Text Transfer Protocol
iBGP	interior BGP
ICMP	IP Control Message Protocol
ID	Identifier
IDRP	ICMP Router Discovery Protocol
IGP	Interior Gateway Protocol
IGRP	Interior Gateway Routing Protocol
IP	Internet Protocol
IRP	Interior Router Protocol
ISO	International Standards Organization

Student Questions

©2025 Raj Jain

Acronyms (Cont)

LACP	Link Aggregation Control Protocol
LSA	Link State Advertisements
MIB	Management Information Base
MTU	Maximum Transmission Unit
NETCONF	Network Configuration Protocol
NIC	Network Interface Card
OSGi	Open Service Gateway Initiative
OSI	Open Service Interconnection
OSPF	Open Shortest Path First
OVSDB	Open V-Switch Database
PCEP	Path Computation Element Protocol
PCMM	Packet Cable Multimedia
REST	Representational State Transfer
RESTful	Representational State Transfer
RFC	Request for Comments
RIP	Routing Information Protocol
SAL	Service Abstraction Layer

Student Questions

©2025 Raj Jain

Acronyms (Cont)

SDN	Software Defined Networking
SDNI	SDN domains interface
SFC	Service Function Chaining
SGMP	Simple Gateway Management Protocol
SNBI	Secure Network Bootstrapping Interface
SNMP	Simple Network Management Protocol
SXP	SGT (Security Group Tags) Exchange Protocol
TCP	Transmission Control Protocol
ToS	Type of Service
TSDR	Time Series Data Repository
TTL	Time to Live
UDP	User Datagram Protocol
USC	Unified Secure Channel
VPN	Virtual Private Network
VTN	Virtual Tenant Network

Student Questions

©2025 Raj Jain

Scan This to Download These Slides





Raj Jain
http://rajjain.com

http://www.cse.wustl.edu/~jain/cse473-25/i_5nlc.htm

Student Questions

- Can you explain how collisions are avoided by randomizing the execution of LS algorithms at each node and only running it at one node at a single time?

Collision avoidance usually requires someone to wait a random amount of time. However, clocks at different nodes are not synchronized and are already random.

©2025 Raj Jain

Related Modules



CSE 567: The Art of Computer Systems Performance Analysis
https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof

CSE473S: Introduction to Computer Networks (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcgy5e_10TiDw





CSE 570: Recent Advances in Networking (Spring 2013)
https://www.youtube.com/playlist?list=PLjGG94etKypLHyBN8mOgwJLHD2FFIMGq5

CSE571S: Network Security (Spring 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypKvzfVtutHcPFJXumyyg93u





Video Podcasts of Prof. Raj Jain's Lectures,
https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw

Student Questions

©2025 Raj Jain

Lab5B Hints

- You only need to fill out the unpacking of the ICMP reply, check ICMP header fields, and return RTT time.
  The program is supposed to hear the ICMP_ECHO_REPLY. And in the fill area, you should check the ICMP type, code, and ID. Measure the RTT using the sent time inside the data field of the ICMP_ECHO_REPLY. The code will print timeout if you don't return the RTT time inside the receiveOnePing function.
- You should have a socket object or something inside the whatReady list
- You do not need to verify the checksum of the ICMP packet.
- Do not run the program on a virtual machine. Otherwise, you may always get Received ICMP packet type 8.
- If you copy the code from the slide, the compiler may miss some indents, resulting in all pings giving timeouts. So make sure that all indents are correct.
- Ensure that the destination node is up by pinging it first.

Student Questions

©2025 Raj Jain

Lab5B Hints (Cont)

- If you remove the calls to ord() in checksum and subsequently don't call str(header + data) and just pass in header + data to checksum it will work in Python 3. What changed between Python 2 and 3 for this was converting bytes to string didn't assume any encoding whereas it looks like it assumed some form of 2-byte encoding in Python 2.7.

Student Questions

©2025 Raj Jain