Cabrillo College

CISCO SYSTEMS

NETWORKING ACADEMY

CCNP – Advanced Routing

Ch. 4 - OSPF, Single Area – Part 1 of 3

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Feb. 26, 2002

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Format of the presentation

- Instructors: If you find any misinformation or mistakes, or if you have any questions regarding the content, please email me, Rick Graziani, graziani@cabrillo.cc.ca.us - Thanks!
- I added new information for clarity and interest from Alex Zinin's book, Cisco IP Routing
- Combined different sections of McGregor's Ch. 4 on OSPF, to create a single flow of information. (Tried to.)
- Added some information from Jeff Doyle's "Routing TCP/IP Vol. I," John Moy's book on OSPF and RFC 2328, OSPF version 2 (current version).

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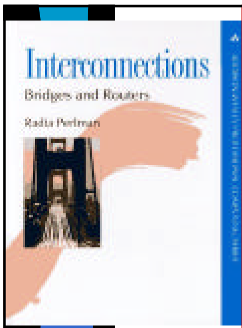
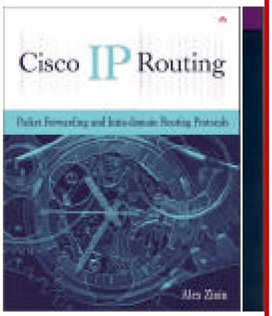
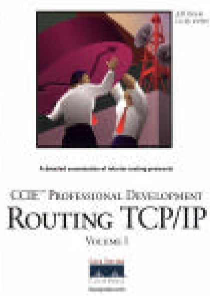


Interconnections : Bridges and Routers by Radia Perlman

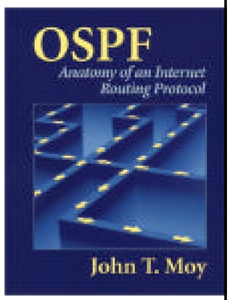


Cisco IP Routing: Packet Forwarding & Intra-domain Routing Protocols by Alex Zinin

This book has been especially helpful for information contained in these presentations.



Routing TCP/IP Volume I by Jeff Doyle



OSPF, Anatomy of an Internet Routing Protocol by John Moy (creator of OSPF)

- **For more information on OSPF, link-state routing protocol, Dijkstra's algorithm and routing in general, check out these sources.**

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OSPF Exam Objectives

- Explain why OSPF is better than RIP in large internetwork
- Explain how OSPF discovers, chooses, and maintains routes.
- Explain how OSPF operates in a single area NBMA environment
- Configure OSPF for proper operation in a single area
- Configure a single-area OSPF environment
- Configure OSPF for an NBMA environment

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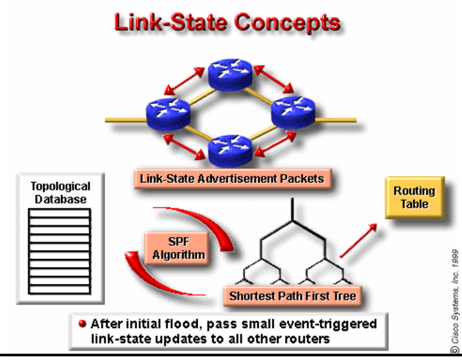
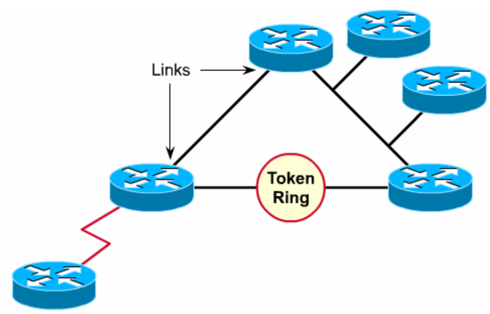
OSPF Overview

- OSPF does not gather routing table information, but routers and the status of their connections, links.
- OSPF routers use this information to build a topological data base (link state database), runs the Shortest Path First (SPF), Dijkstra's algorithm, and creates a SPF tree. From that SPF tree, a routing table is created.

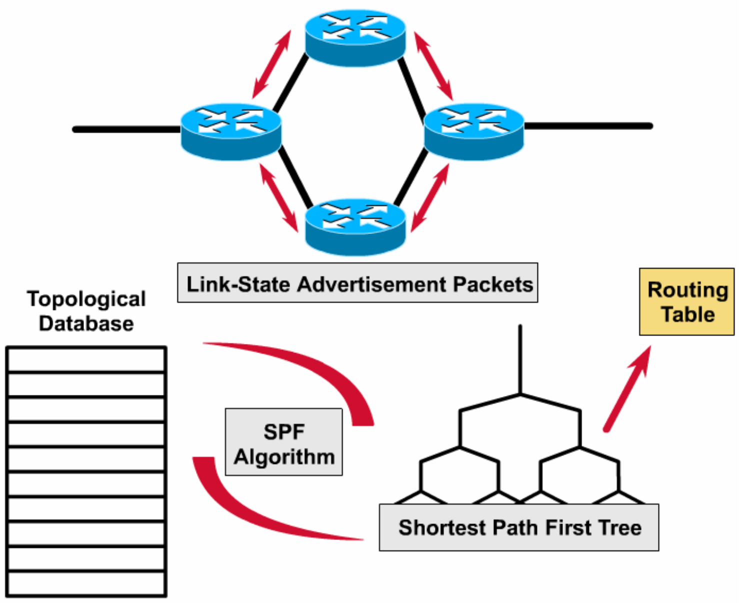


OSPF is a link state protocol

- ***Link***: interface on a router
- ***Link state***: the status of a link between two routers.



Link-State Concepts



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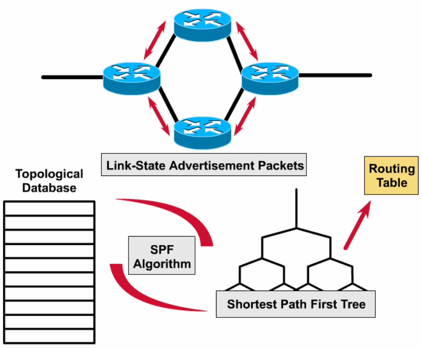
Link-State Concepts



Link-State Routing Protocols

- The first type of routing protocol we discussed was **distance vector**.
- The second type of routing protocol that we will examine is **link-state**.
- In this presentation we will only examine the very basic concepts of link-state routing protocols.
- In **CCNP Advanced Routing** we examine the link state routing protocol **OSPF** in detail.
- I have added a presentation, ***Introduction to OSPF***, which we will discuss at the end of this semester.

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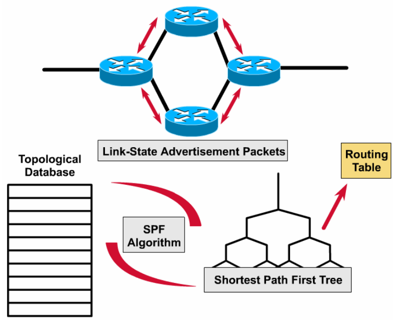
Link-State Concepts



Distance Vector Routing Protocols

- Distance vector routing protocols like RIP and IGRP do not know the exact topology of a network.
- All distance vector routing decisions are made from information from neighboring routers – routing by rumor.
- The only information the router has about a route is how far away the network is in hops or using another cost (**distance**) and which interface to send forward the packet out of (**vector**).
- The router has no way to make its own decision on which direction is ultimately the best way to send the packets.

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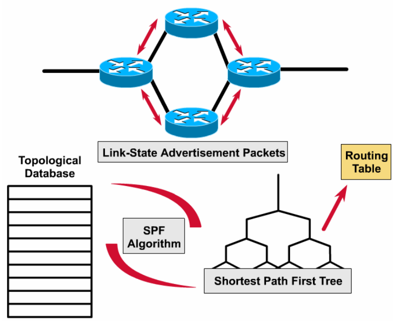
Link-State Concepts



Link-State Routing Protocols - History

- The first link-state routing protocol was implemented and deployed in the **ARPANET** (Advanced Research Project Agency Network), the predecessor to later link-state routing protocols.
- Next, DEC (Digital Equipment Corporation) proposed and designed a link-state routing protocol for ISO's OSI networks, **IS-IS (Intermediate System-to-Intermediate System).**
  - The OSI protocol stack is what the OSI model was based on. The OSI protocol stack was designed to be the protocol of the Internet, but to make a long story short, TCP/IP became the Internet protocol instead.
- Later, IS-IS was extended by the IETF to carry IP routing information.

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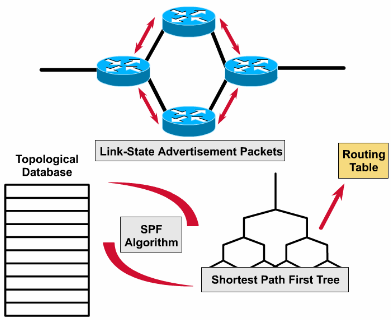
Link-State Concepts



Link-State Routing Protocols - History

- An IETF working group designed a routing protocol specifically for IP routing, **OSPF (Open Shortest Path First).**
- For most network administrators they had two open-standard routing protocols to choose from: RIP, simple but very limited, or OSPF, robust but more sophisticated to implement.
  - IGRP and EIGRP are Cisco proprietary
  - IS-IS is used in IP networks, but not as common as OSPF

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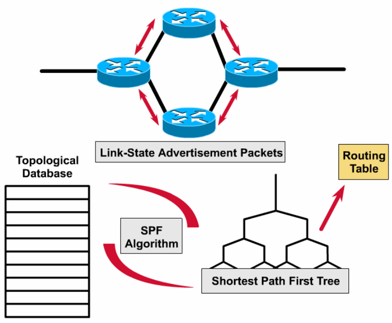
Link-State Concepts



OSPF - Open Shortest Path First

- OSPF is covered in detail in CCNP Advanced Routing.
- We will have a presentation on an Introduction to OSPF later this semester, just enough to give you a taste.

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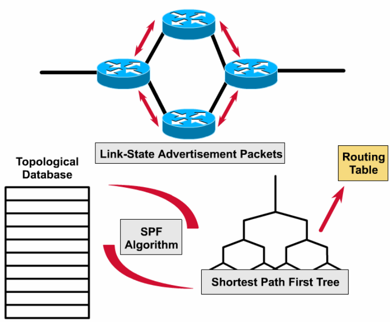
Link-State Concepts



Theory of Link-State Routing Protocols

- In this presentation we will examine "some" of the theory behind link-state routing protocols.
- This will only be a brief introduction to the link-state theory, requiring much more time and perhaps even some requisite knowledge of algorithms.
- At the end of this presentation will be some suggested resources for leaning more about the theory of link-state routing and Dijkstra's algorithm.

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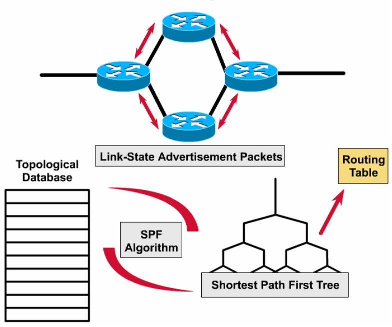
Link-State Concepts



Mathematical point of view

- Link-state routing is <u>not</u> based on IP addresses, subnets and network information!
- Link-state routing has a mathematical point of view, looking at the network as nothing more than a graph with vertices and the costs to these vertices.
- *Okay, I'm losing you and I said I wouldn't get mathematical*.
- Link-state routing is based on a very simple algorithm known as **Dijkstras's algorithm**, invented by Edsger Wybe Dijkstra
- This algorithm can and has been used in many areas of human activity, not just for routing.

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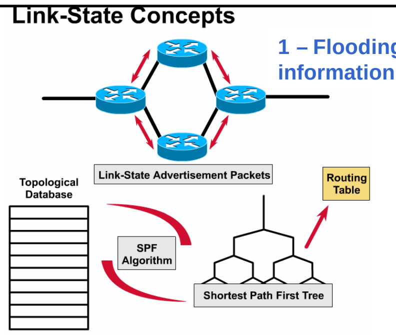
Link-State Concepts

1 – Flooding of link-state information



Link-State Theory

- The network is viewed as a graph, showing the complete topology of the network.
- How do routers build this topology?

1 – Flooding of link-state information

- The first thing that happens is that each node, router, on the network announces its own piece of **link-state information** to other all other routers on the network: who their neighboring routers are and the cost of the link between them.
- Example: "Hi, I'm RouterA, and I can reach RouterB via a T1 link and I can reach RouterC via an Ethernet link."
- Each router sends these announcements to all of the routers in the network.

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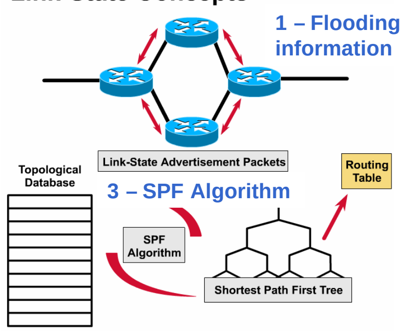
Link-State Concepts

1 – Flooding of link-state information

2 – Building a Topological Database



2. Building a Topological Database

- Each router collects all of this link-state information from other routers and puts it into a topological database.

3. Shortest-Path First (SPF), Dijkstra's Algorithm

- Using this information, the routers can recreate a topology graph of the network.
- Believe it or not, this is actually a very simple algorithm and I highly suggest you look at it some time, or even better, take a class on algorithms. (Radia Perlman's book, Interconnections, has a very nice example of how to build this graph – she is one of the contributers to the SPF and Spanning-Tree algorithms.)

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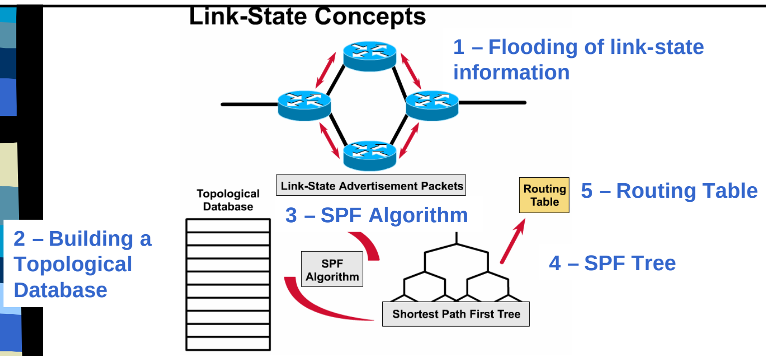
Link-State Concepts



4. Shortest Path First Tree

- This algorithm creates an SPF tree, with the router making itself the root of the tree and the other routers and links to those routers, the various branches.
  - Note: Just a reminder that the link-state algorithm and graph it creates is mathematically based and although we are mentioning routers and their links, it has nothing to do with IP addresses or other network information.

5. Routing Table

- Using this information, the router creates a routing table.

I bet you can create this tree given the link-state information!

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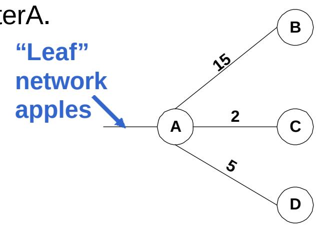
Exercise: From link-state flooding to routing tables - Lets try it …

- For this exercise we will not worry about the individual, leaf, networks attached to each node or router (shown as a blank line), but focus on how the topology is built to find the the shortest path between each router.
- ***In order to keep it simple, we will take some liberties with the actual process and algorithm, but you will get the basic idea!***
- You are RouterA and you have a link to RouterB with a cost of 15, a link to RouterC with a cost of 2, a link to RouterD with a cost of 5, and a leaf network "apple."
- This is your **own link-state information**, which you will flood to all other routers so they can do the same thing we will be doing for RouterA.



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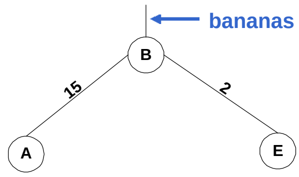
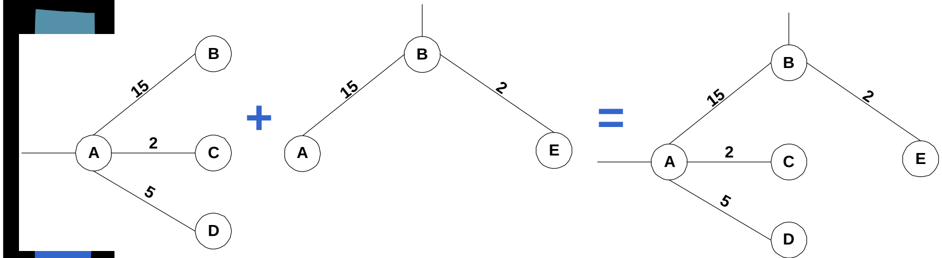
We now get the following link-state information from RouterB

- RouterB has a link to RouterA with a cost of 15.
- RouterB has a link to RouterE with a cost of 2.
- And information about its own “leaf” network “bananas.”



Now lets attach the two graphs …



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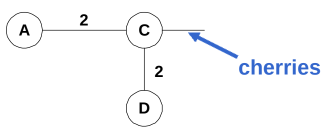
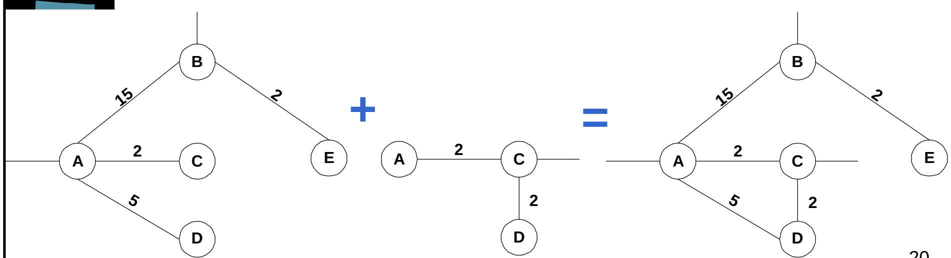
We now get the following link-state information from RouterC

- RouterC has a link to RouterA with a cost of 2.
- RouterC has a link to RouterD with a cost of 2.
- And information about its own “leaf” network “cherries.”



Now lets attach the two graphs …



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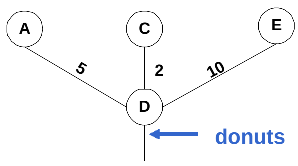
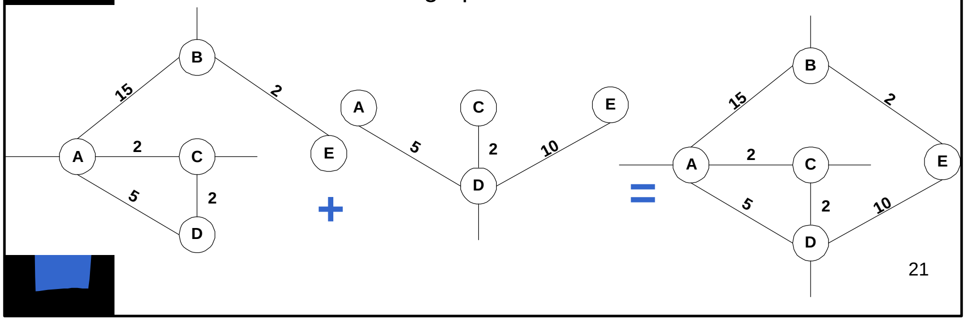
We now get the following link-state information from RouterD

- RouterD has a link to RouterA with a cost of 5.
- RouterD has a link to RouterC with a cost of 2.
- RouterD has a link to RouterE with a cost of 10.
- And information about its own "leaf" network "donuts."



Now lets attach the two graphs …



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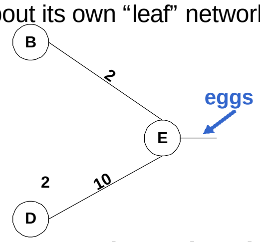
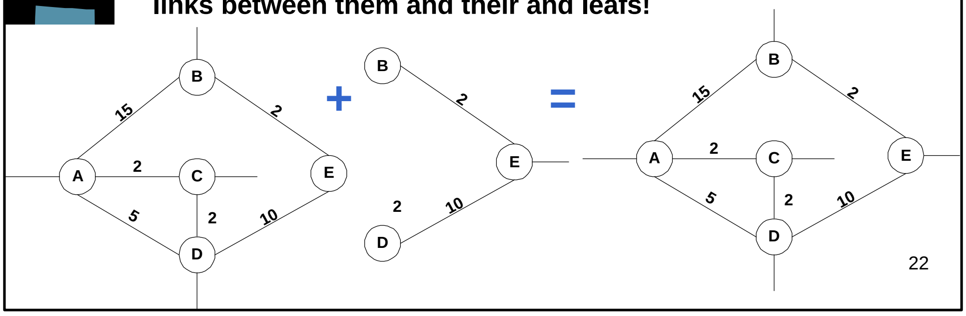
We now get the following link-state information from RouterE

- RouterE has a link to RouterB with a cost of 2.
- RouterE has a link to RouterD with a cost of 10.
- And information about its own "leaf" network "eggs."



Now lets attach the two graphs and we have all the nodes, their links between them and their and leafs!



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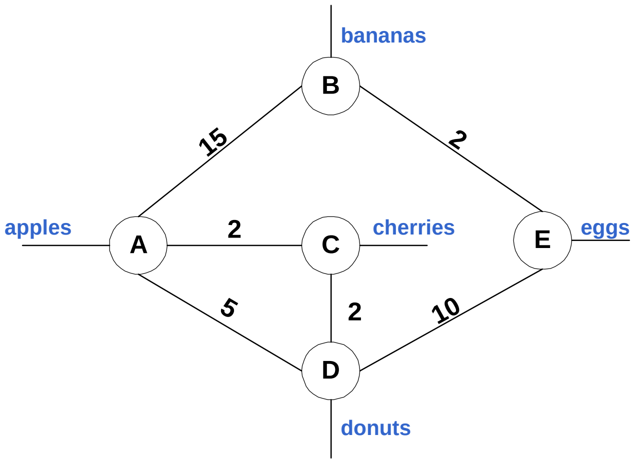
Topology

- Using the topological information we listed, RouterA has now built a complete topology of the network.
- The next step is for the link-state algorithm to find the best path to each node and leaf network.



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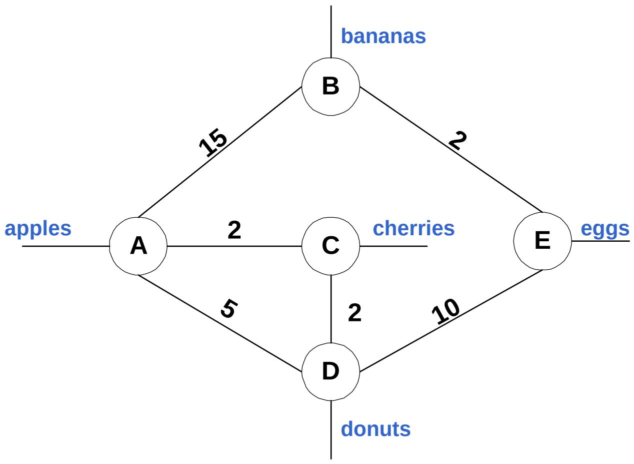
Choosing the best path

- Using the link-state algorithm RouterA can now proceed to find the shortest path to each leaf network.
- Try doing it on your own!



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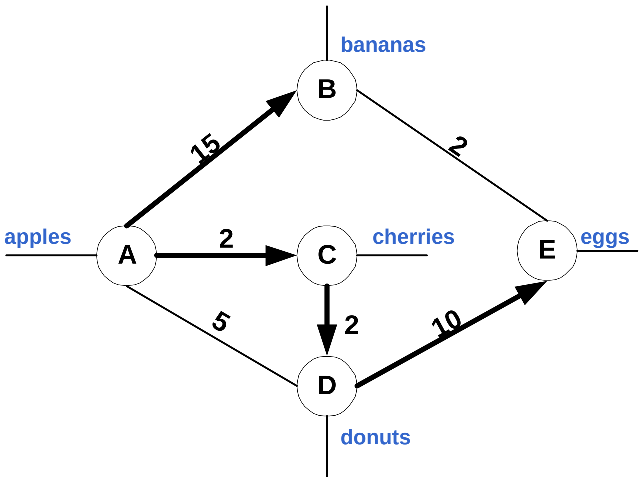
Choosing the best path

- Now RouterA knows the best path to each network.



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OSPF vs RIP (no contest)

- OSPF is link-state, where RIP is distance-vector.
- OSPF has faster convergence - Because of RIP's hold-down timer, RIP can be quite slow to converge.
- OSPF has no hop restriction - RIP to limited to 15 hops, OSPF does not use hops.
- OSPF supports VLSM; RIPv1 doesn't
- Cisco's OSPF metric is based on bandwidth, RIP's is based on hop count
- Update efficiency - RIP sends entire routing table every 30 seconds, where OSPF only sends out changes when they occur.
  - Note: OSPF does flood LSAs when it age reaches 30 minutes (later)
- OSPF also uses the concept of area to implement hierarchical routing

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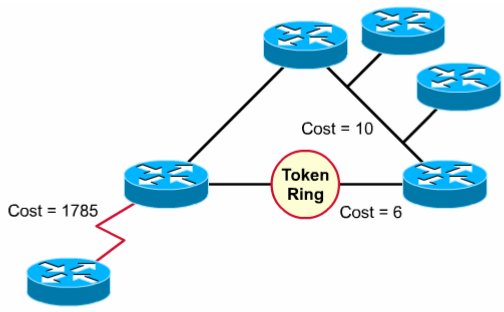
Cisco's OSPF's metric is based on cost

Cost: The outgoing cost for packets transmitted from this interface.

- Cost is an OSPF metric expressed as an unsigned 16-bit integer, from 1 to 65,535.



Cisco's OSPF's metric is based on cost

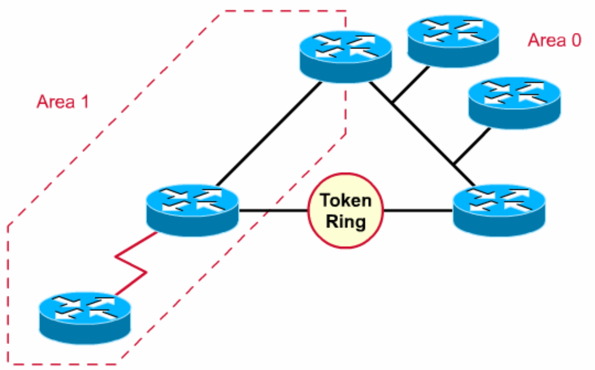
- Cisco uses a default cost of 10^8/BW, where BW is the configured bandwidth (bandwidth command) of the interface and 10^8 (100,000,000) as the reference bandwidth.
- **Example**: A serial link with a configured bandwidth of 128K would have a cost of: 100,000,000/128,000 = **781**
- More on the cost metric later …
- **Note**: Bay and some other vendors use a default cost of 1 on all interfaces, essentially making the OSPF cost reflect hop counts.

RFC 2328, OSPF version 2, J. Moy

- "A cost is associated with the output side of each router interface. This cost is configurable by the system administrator. The lower the cost, the more likely the interface is to be used to forward data traffic."
- RFC 2328 does not specify any values for cost.

Areas make OSPF scalable

- ***Area***: collection of OSPF routers.
- Every OSPF router must belong to at least one area
- Every OSPF network must have an Area 0 (backbone area)
- All other Areas should “touch” Area 0
  - There are exceptions to this rule – virtual link (later)
- Routers in the same area have the same link-state information
- Much more on areas in the next chapter, OSPF Multiple Areas



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OSPF neighbor relationships

- OSPF is capable of sophisticated communication between neighbors.
- OSPF uses 5 different types of packets to communicate information.

Type	Description
1	Hello (establishes and maintains adjacency relationships with neighbors)
2	Database description packet (describes the contents of an OSPF router's link-state database)
3	Link-state request (requests specific pieces of a neighbor router's link-state database)
4	Link-state update (transports link-state advertisements (LSAs) to neighbor routers)
5	Link-state acknowledgement (Neighbor routers acknowledge receipt of the LSAs)

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OSPF packet types

Type	Description
1	Hello (establishes and maintains adjacency relationships with neighbors)
2	Database description packet (describes the contents of an OSPF router's link-state database) **OSPF Type-2 (DBD)**
3	Link-state request (requests specific pieces of a neighbor router's link-state database) **OSPF Type-3 (LSR)**
4	Link-state update (transports link-state advertisements (LSAs) to neighbor routers) **OSPF Type-4 (LSU)**
5	Link-state acknowledgement (Neighbor routers acknowledge receipt of the LSAs) **OSPF Type-5 (LSAck)**

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OSPF packet types – More later

Type	Description
1	Hello (establishes and maintains adjacency relationships with neighbors)
2	Database d… router's link-state database)
3	Link-state request (requests link-state database)
4	Link-state update (transport neighbor routers)
5	Link-state acknowledgemen receipt of the LSAs)

OSPF Type-4 packets have 7 LSA packets (later)

LSA Type	Name	Description
1	Router link entry (record) (O-OSPF)	Generated by each router for each area it belongs to. It describes the states of the router's link to the area. These are only flooded within a particular area.The link status and cost are two of the descriptors provided.
2	Network link entry (O-OSPF)	Generated by Designated Router in multiaccess networks. They describe the set of routers attached to a particular network. LSA Type 2 messages are flooded only within the area that contains the network.
3 or 4	Summary link entry (IA-OSPF Inter area)	Originated by ABRs. They describes the links between the ABR and the internal routers of a local area. These entries are flooded throughout the backbone area to the other ABRs. Type-3 message s describe routes to networks within the local area and are sent to the backbone area. Type-4 messages describe reachability to ASBRs. These link entries are not flooded through totally stubby areas.
5	Autonomous system external link entry (E1-OSPF external type-1)	Originated by the ASBR. Describes routes to destinations external to the autonomous system. Flooded throughout an OSPF autonomous system except for stub and totally stubby areas.

OSPF Hello Subprotocol

Version	Type	Packet Length	
Router ID			
Area ID			
Checksum		Authentication Type	
Authentication Data			
Network Mask			
Hello Interval		Options	Router Priority
Dead Interval			
Designated Router			
Backup Designated Router			
Neighbor Router ID			
Neighbor Router ID			
(additional Neighbor Router ID fields can be added to the end of the header, if necessary)			

OSPF Header (Version through Authentication Data)

Hello Header (Network Mask through additional Neighbor Router ID fields)

Example Hello packet (Type 1 OSPF packet)

OSPF Packet Header

```
Version:                  2
Type:                     1
Packet Length:            52
Router ID:                10.202.16.1
Area ID:                  0.0.0.0
Checksum:                 0x9F0A
Authentication Type:      0
Authentication Data:      0
```

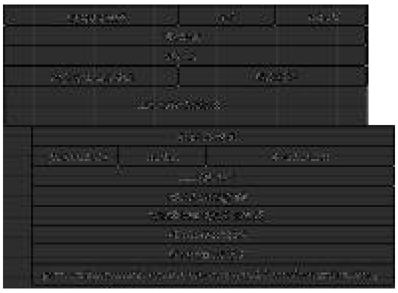
The OPSF packet header is used by all 5 types of OSPF packets.

Hello Header

```
Network Mask:             255.255.255.0
Hello Interval:           10 seconds
Options (in bits):        00000010
Router Priority:          1
Dead Interval:            40 seconds
Designated Router (DR):   206.202.16.254
Backup DR:                10.202.16.1
  Neighbor:               206.255.255.254
  Neighbor:               206.202.16.254
```

The Hello header is exclusive to Type-1 packets.

OSPF Hello Subprotocol



Hello subprotocol is intended to perform the following tasks within OSPF:

- Means for dynamic neighbor discovery
- Detect unreachable neighbors within a finite period of time
- Ensure two-way communications between neighbors
- Ensure correctness of basic interace parameters between neighbors
- Provide necessary information for the election of the Designated and Backup Designated routers on a LAN segement

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The OSPF Hello Protocol

- OSPF routers send Hellos on OSPF enabled interfaces:
  - default **every 10 seconds** on broadcast and point-to-point segments
  - Default **every 30 seconds** on NBMA segments
- Most cases OSPF Hello packets are sent as multicast to ALLSPFRouters (224.0.0.5)
- **HelloInterval** - Cisco default = 10 seconds/30 seconds and can be changed with the command **ip ospf hello-interval**.
- **RouterDeadInterval** - The period in seconds that the router will wait to hear a Hello from a neighbor before declaring the neighbor down.
  - Cisco uses a default of four-times the HelloInterval (4 x 10 sec. = 40 seconds) and can be changed with the command **ip ospf dead-interval**.
- **Note**: For routers to become adjacent, the **Hello**, **DeadInterval** and **network types** must be identical between routers or Hello packets get dropped!

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Ch. 4 - OSPF, Single Area

Rick Graziani, Instructor

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