



Agenda

- **Dijkstra Overview**
- **OSPF Structure and Operation**
- **OSPF Scalability**
- **OSPF Implementation**
- **OSPF Design Practices**



Dijkstra

What Is a Link State Anyway?

Dijkstra

Shortest Path First (SPF) Algorithm

- **Link state database**

Created with Link State Packets (LSPs)
from each router

- **TENT database**

Tentative triples (ID, path cost, direction)

Dijkstra (SPF) Overview

- **PATH database**

Best path triples (ID, path cost, direction)

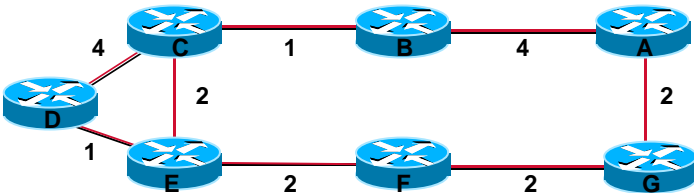
- **Forwarding database**

aka the routing table

Dijkstra (SPF) Overview (Cont.)

- All routers exchange Link State Packets (LSPs)
- Each starts with itself as root
- Tent is built from LSPs
- Path is created by examining and comparing tent triples
- Once path is final the forwarding table is populated

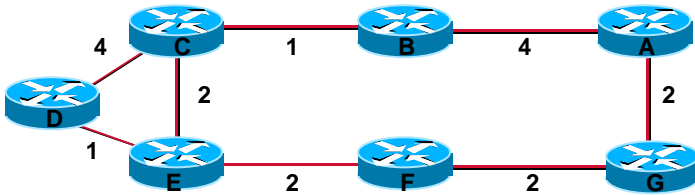
Dijkstra Basics



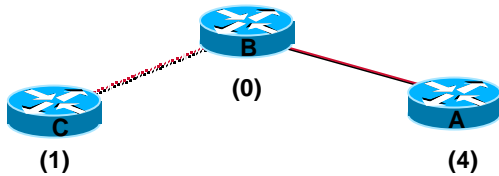
- Router IDs are alphabetic
- Costs are numeric
- Lowest cost best

LSP Data

A	B	C	D	E	F	G
B/4 G/2	A/4 C/1	B/1 D/4 E/2	C/4 E/1	C/2 D/1 F/2	E/2 G/2	A/2 F/2

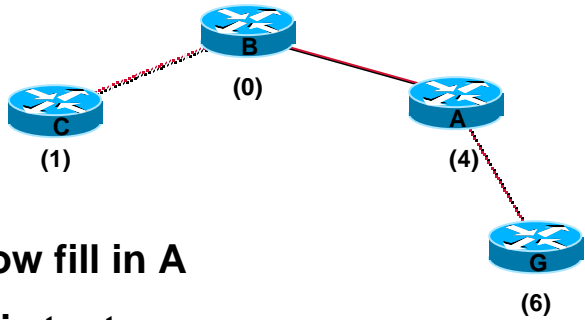


Dijkstra Example—1/7



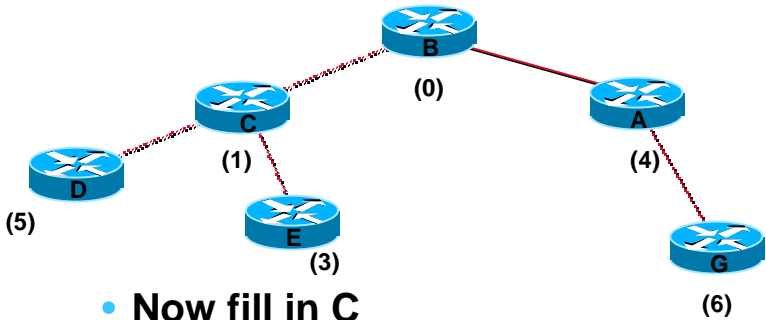
- As an example start with B
- A and C costs are Tent

Dijkstra Example—2/7



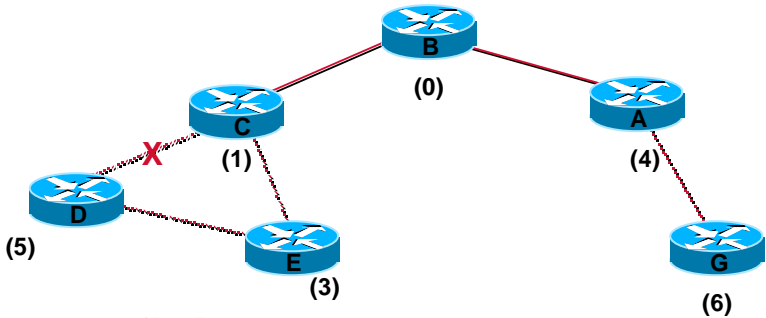
- Now fill in A
- G is tent
- BA is now in path

Dijkstra Example—3/7



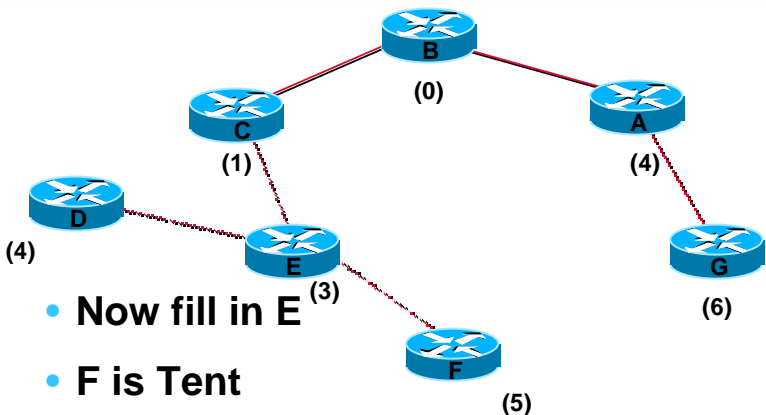
- Now fill in C
- D and E are tent
- BC is now in path

Dijkstra Example—4/7



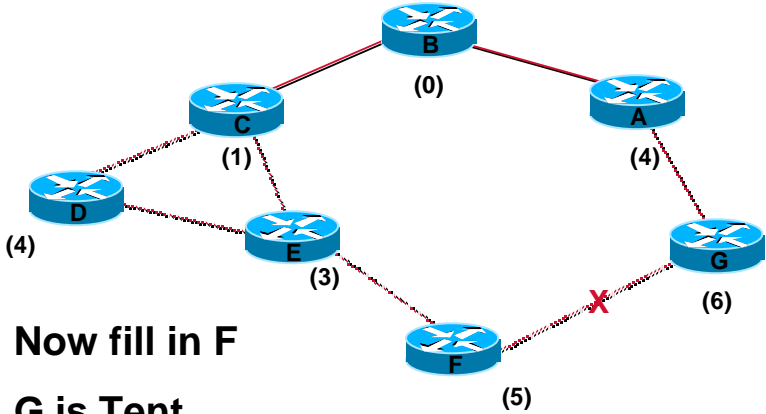
- Now fill in D
- D and E are still tent
- DC does not provide better path

Dijkstra Example—5/7



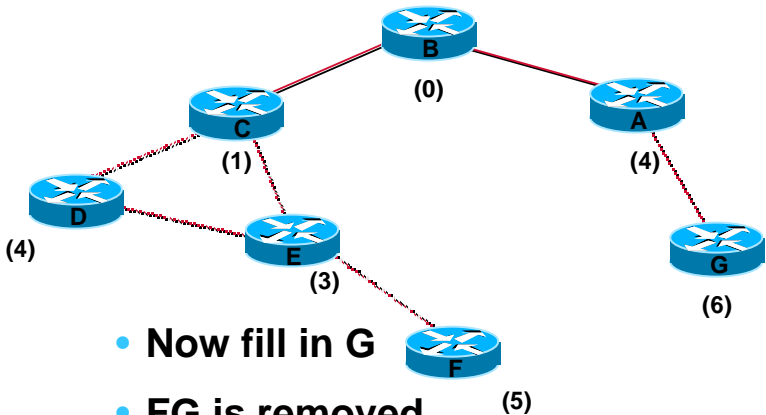
- Now fill in E⁽³⁾
- F is Tent
- CD is removed
- ED and CE are in path

Dijkstra Example—6/7



- Now fill in F
- G is Tent
- EF is in path

Dijkstra Example—7/7



- Now fill in G
- FG is removed
- AG is in path

Dijkstra Concepts

- **SPF is simple :-)**
- **However**

How did each router receive the LSPs?
What happens if a change occurs?

Dijkstra Concepts (Cont.)

- **How?**

We create a protocol

- **What does it do?**

Creates and maintains the path database
Populates the forwarding table

Dijkstra Protocols

- CLNS/DECnet Phase 5
- IS-IS
- **OSPF**
- NLSP



Deploying OSPF

Structure and Operation

OSPF History

- **Development began 1987 by IETF**
- **OSPFv2 established in 1991 with RFC 1247**
- **Goal—a link state protocol more efficient and scaleable than RIP**
- **Latest revision is RFC 2328 April 1998**

OSPF

- **Metric—path cost**
- **Fast convergence**
- **Support for CIDR, VLSM, authentication, multipath and IP unnumbered**
- **Low steady state bandwidth requirement**

OSPF Algorithm

- **Any network change generates link-state advertisements (LSA)**
- **All routers exchange LSAs via MAC layer multicast to build and maintain a consistent database**
- **The protocol remains relatively quiet during steady-state conditions**

Cost = Metric

- **Cost applied on all router link paths**
- **Positive number 1–65, 535**
- **The lower the more desirable**
- **Relevant going out an interface only**
- **Route decisions made on total cost of path**

OSPF Metric

- **Derived from bandwidth**

$100 \div \text{bandwidth}$

Ethernet = 10

T1 (1.544-Mbps serial link) = 65

56-kbps serial link = 1785

64-kbps serial link = 1562

Fast Ethernet/FDDI = 1

- **Configured via:**

Interface subcommand:

Interface subcommand:

Router subcommand:

bandwidth

ip ospf cost

ospf auto-cost reference
bandwidth

Topology/Link State Database

- **A router has a separate LS database for each area to which it belongs**
- **All routers belonging to the same area have identical database**
- **SPF calculation is performed separately for each area**
- **LSA flooding is bounded by area**
- **Router ID unique identifier within OSPF domain**

Router ID

- Router's are identified by a unique ID
- RID: highest IP address from any loopbacks
- RID: if no loopback exists, highest IP address from physical interfaces.

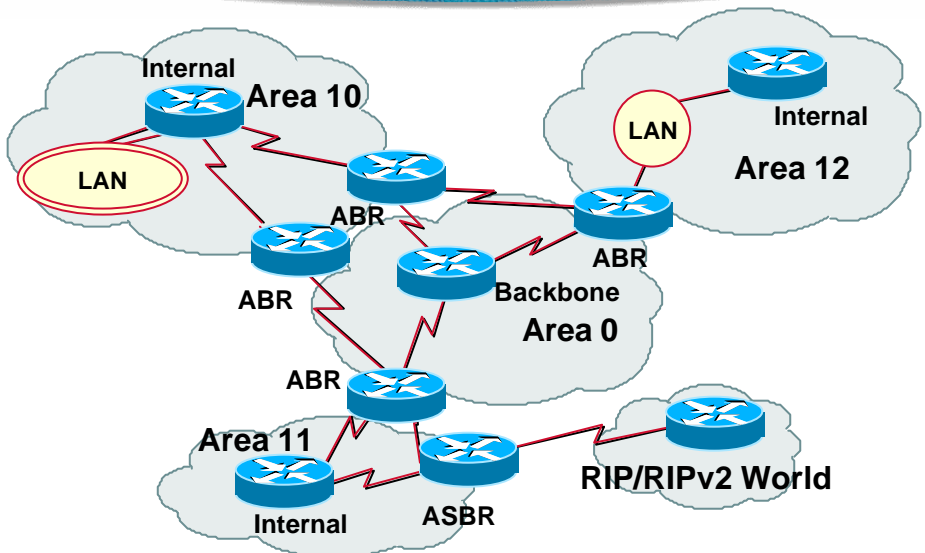
Areas

- OSPF uses a 2 level hierarchical model
- Areas defined with 32 bit number
Defined in IP address format
- 0.0.0.0 reserved for the backbone area
- All areas must connect to area 0.0.0.0

Different Types of Routers

- **Internal routers (inside an area)**
- **Backbone routers (inside area 0)**
- **Area border routers**
 - An ABR sits between two or more areas
 - Must touch area 0
- **Autonomous system boundary routers**
 - Redistribution makes a router an ASBR

Location of Different Routers



Routing Protocol Packets

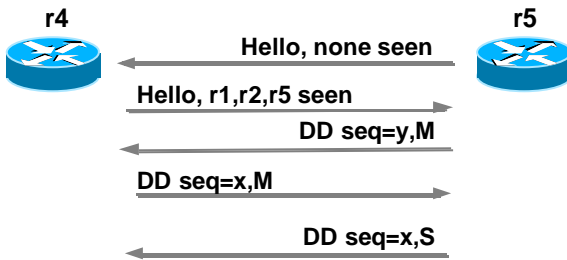
- They share a common protocol header
- Routing protocol packets are sent with type of service (TOS) of 0
- Five types of OSPF routing protocol packets
 - Hello
 - Database description
 - Link-state request
 - Link-state update
 - Link-state acknowledgment

OSPF Hello Packets

- Multicast 224.0.0.5 on all router interfaces
- Hello interval 10 sec. LAN, 30 sec. NBMA
- Used to form adjacencies between routers
- Multicast 224.0.0.6 used with DR and BDR
- Describes the optional capabilities

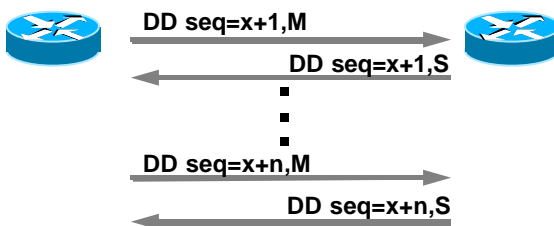
Building the Database

- Hello packets discover neighbors
- **Two-way** stage—communication established
- **Exstart** stage—master and sequence estab.



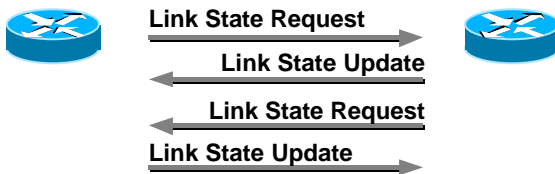
Database Description Packets

- Contain link state database headers
- Describe the current LSDB database
- **Exchange** stage



Link State Request and Update Packets

- Request for specific parts of database
- Send only database updates requested
- Loading stage, labeled full when complete



Different Types of LSAs

- Router link (LSA type 1)
- Network link (LSA type 2)
- Network summary (LSA type 3)
- ASBR (LSA type 4)
- External (LSA type 5)
- NSSA external (LSA type 7)

Opaque LSAs

- **RFC 2370**
 - Used for distribution for applications
- **Opaque link-local (LSA type 9)**
- **Opaque area-local (LSA type 10)**
 - First Cisco implementation with RSVP
- **Opaque AS (LSA type 11)**
 - Similar to type 5

Different Types of LSAs

- **Router LSA (type 1)**
 - Describes the state and cost of the router's links to the area
 - All of the router's links in an area must be described in a single LSA
 - Flooded throughout the particular area and no more
 - Router indicates whether it is an ASBR, ABR, or end point of virtual link

Designated Routers

- Reduce OSPF traffic on multiaccess links
- Store and distribute neighbors LSDBs
- Backup DR for redundancy
- OSPF priority used in DR selection
- Range 1–255 default 1, 0 for noncandidate

Different Types of LSAs

- **Network LSA (type 2)**

Generated for every broadcast network

Describes all the routers attached to the network

Only the designated router originates this LSA

Flooded throughout the area and no more

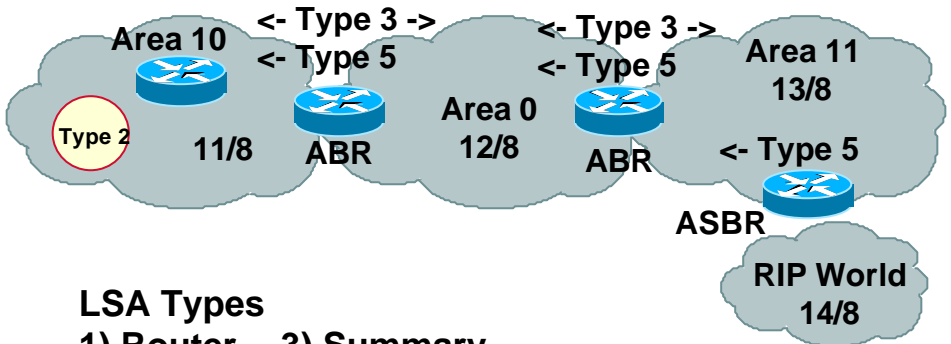
Different Types of LSAs

- **Summary LSA (type 3 and type 4)**
 - Describes the destination outside the area but still in the AS**
 - Flooded throughout a single area**
 - Originated by an ABR**
 - Only intra-area routes are advertised into the backbone**
 - Type 4 is the information about the ASBR**

Different Types of LSAs

- **External LSA (type 5)**
 - Defines routes to destination external to the AS**
 - Default route is also sent as external**
 - Two types of external LSA:**
 - E1: Consider the total cost up to the external destination**
 - E2: Considers only the cost of the outgoing interface to the external destination**

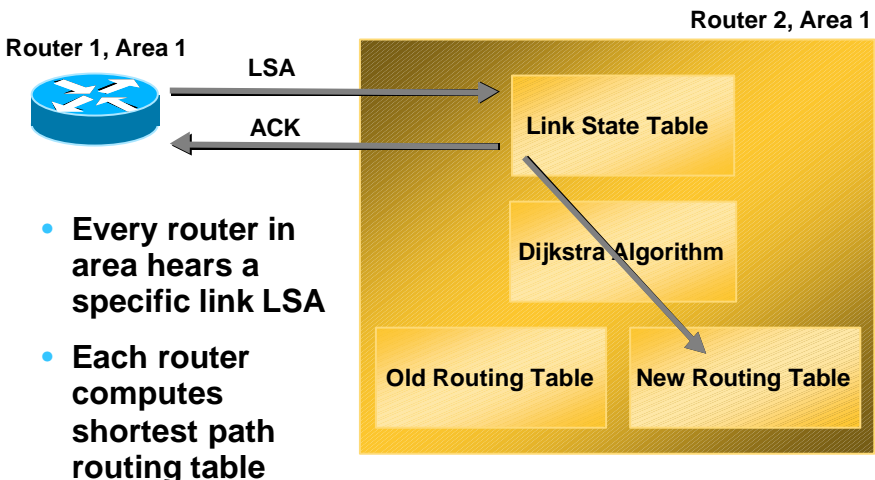
Location of Different LSAs



LSA Types

- 1) Router
- 2) Network
- 3) Summary
- 4) External
- 5) External

When a Link Changes State

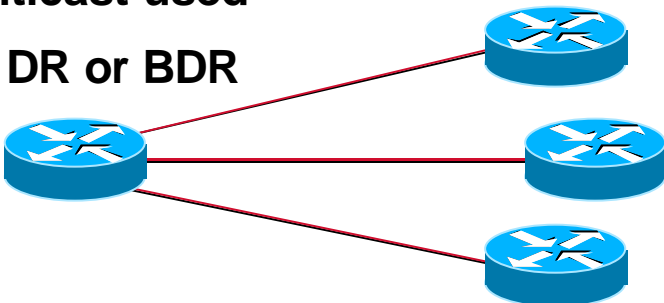


OSPF Media Options

- **Point-to-Point**
- **Non-Broadcast Multi-Access (NBMA)**
- **Multi-access media**
- **Demand circuits (11.2)**

Point-to-Point Media

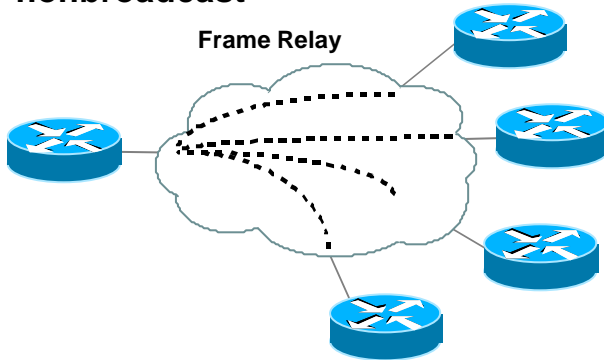
- **Serial links**
- **Multicast used**
- **No DR or BDR**



Non-Broadcast Multi-Access Media (NBMA)

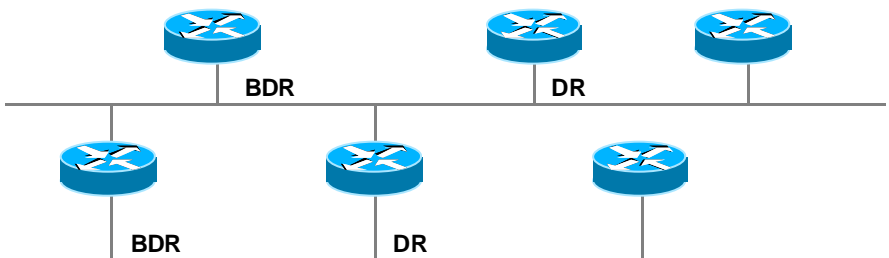
- **Frame Relay (multipoint), X.25**

Several possibilities: point-to-point, broadcast, point-to-multipoint or nonbroadcast



Multi-Access Media

- **Gig/Fast/Ethernet, FDDI, Token Ring**
- **Multicast**
- **DR and BDR**



OSPF Demand Circuits

- **OSPF demand circuit**

 - Additional option in LSAs:
Do not age bit**

 - Suppresses hellos exchange**

 - Suppresses DB synchronization**

- **All new LSA still have to be transmitted in the area**



Deploying OSPF

Scalability Features

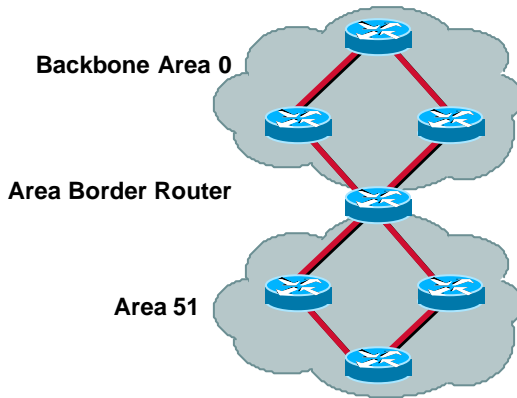
Using Areas

- **The tool to make OSPF scale**
- **One SPF per area, flooding done per area**
- **Different types of areas do different flooding**
 - Normal areas**
 - Stub areas**
 - Totally stubby (stub no summary)**
 - Not so stubby areas (NSSA)**

Regular Area

- **Regular areas**
 - Summary LSA from other areas injected**
 - Specific links from other areas injected**
 - External links injected**

Regular Area



An Area Forwards the Following
Summary LSAs
Specific LSAs
Default External 0.0.0.0
Specific External Links

- **ABRs forward all LSAs from backbone**

Stub Area

- **Stub area**

Summary LSAs from other areas injected

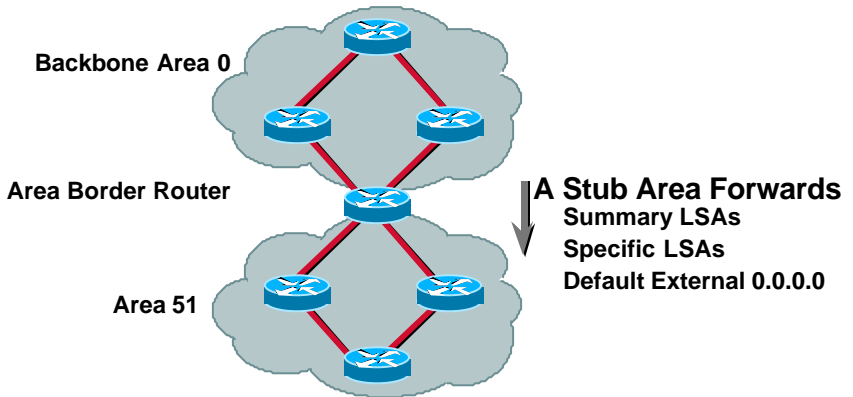
LSA type 5 not injected

**Default LSA injected into area as
summary LSA**

Define all routers in area as stub

External link flaps will not be injected

Stub Area

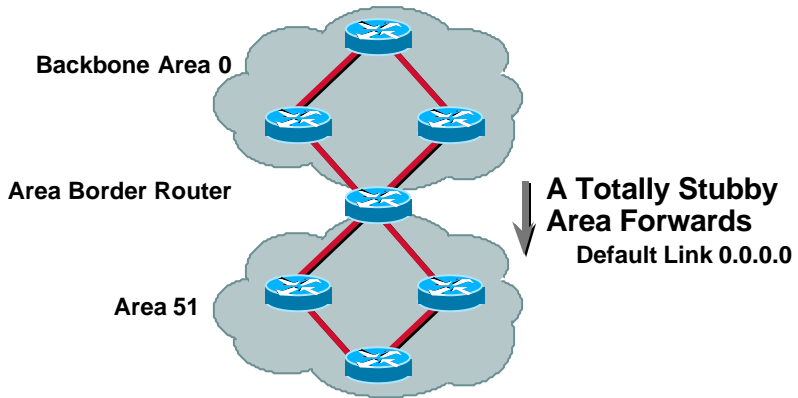


- **Consolidates specific external links—default 0.0.0.0**

Totally Stubby Area

- **Totally stubby area**
 - Default LSA injected into area**
 - Represents all external links**
 - Represents all summarized internal links**
 - Represents non-summarized internal links**
 - Very stable, small LSDB, fewer routes**

Totally Stubby Area

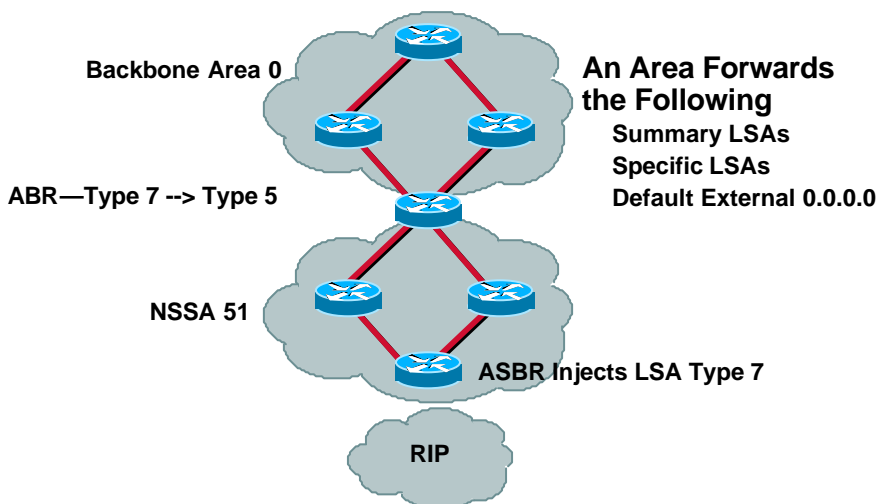


- Use this for stable—scalable internetworks

Not So Stubby Areas (NSSA)

- Benefits of stub area, but ASBR is allowed
- New type external LSA (type 7)
 - Type 7 LSAs flooded throughout the area
 - No type 5 external LSAs in the area
 - Type 7 LSAs will be converted into type 5 LSAs when flooded into area 0 by ABRs
- Filtering and summaries allowed at ABRs

NSSA



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Summarization

- Routing is by longest prefix match
- Instead of advertising many more specific prefixes, advertise only one summary prefix
 - Area-range on ABR to summarize type 3 LSAs
 - Summary-address on ASBR to sum type 5s
- Not only smaller, but also more stable
- Drawback is possible suboptimal routing

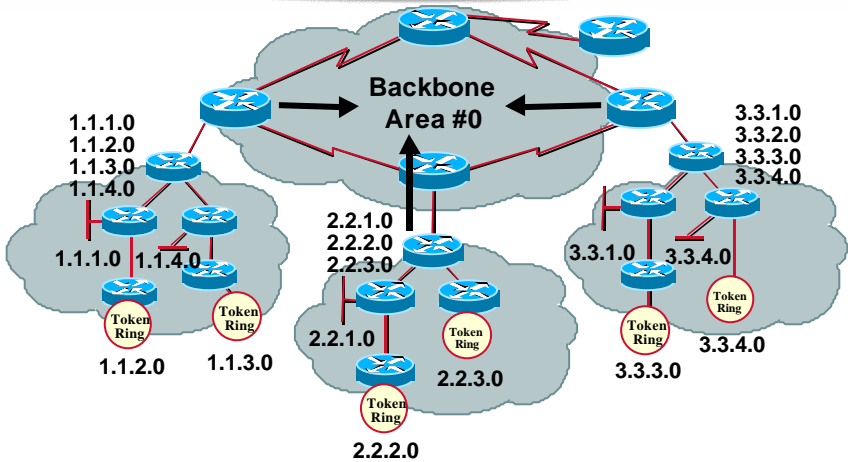
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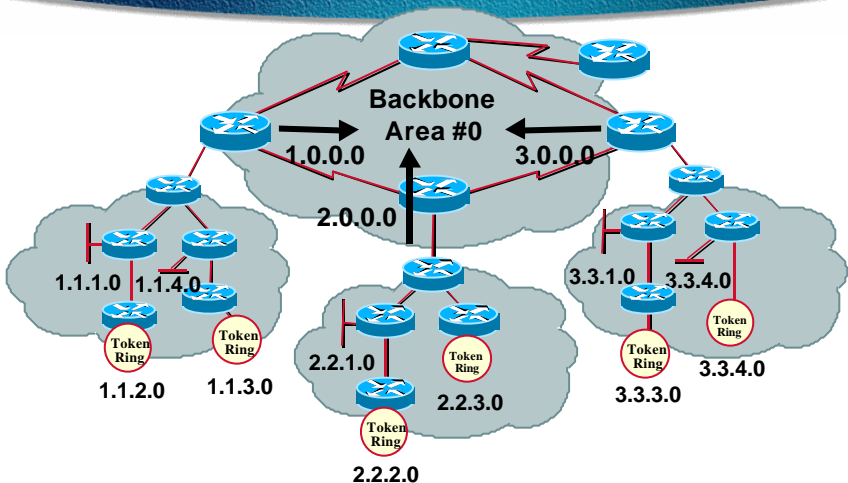
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Not Summarized: Specific Links



- Only summary LSA advertised out
- Link-state changes do not propagate

Summarized: Summary Links

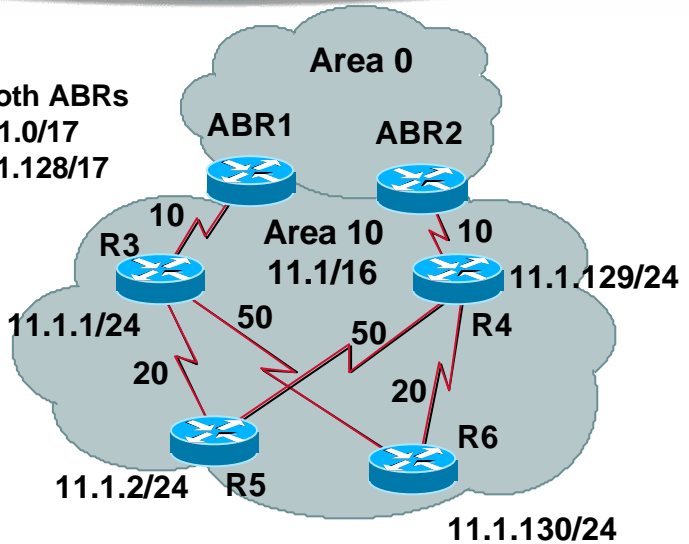


- Only summary LSA advertised out
- Link-state changes do not propagate

Summarization (Cont.)

Configure on Both ABRs
Area-Range 11.1.0/17
Area-Range 11.1.128/17

Cost Range 1:
ABR1 10
ABR2 60
Cost Range 2:
ABR1 60
ABR2 10



Implementing OSPF

Ground Rules

- **Under normal operation, there should be exactly one interior routing protocol on any network segment**

Use “passive-interface” as necessary to ensure this

- **The number of redistribution boundaries should be kept to a minimum**

You have better things in life to do besides build access lists

Ground Rules (Cont.)

- **Addressing should be contiguous with respect to topology**

Not just network topology but routing protocol topology

Allows for summarization

If you've **any** piece of a classfull protocol left, you must keep major network prefixes contiguous and nonVLSM

Preparation

- **Accurate** topology maps
 - Layout new protocol areas
 - Identify redistribution points
- **Create new configs**
 - New configs are simply **installed** during the change window, not created
- **Proof of concept**
 - Lab work with real routers
 - Netsys modeling

Validation

- **All networks should have an acceptance test**
 - What constitutes up?
 - A green network management map is not sufficient
- **Are the route ages appropriate?**
 - If the protocol is periodic, routes should never be older than the update time
 - If the protocol is update based, routes should get old

Validation (Cont.)

- **Is the number of routes stable?**
- **If you have the luxury, fail a link, allow the network to converge then restore the link and let the network converge**

Are convergence times appropriate for the protocol

Remember to account for differentials in convergence time

Validation OSPF

- **Do I have all the neighbors I should?**
show ip ospf neighbors
- **Are routes getting old**
show ip route
look at the age of the route



Design Practices

How Do I Use All This Anyway?

OSPF Design

- **Attack addressing first**
 - Create address hierarchy to match topology**
 - Can be geographic or organizational**
- **Examine physical topology**
 - Is it meshed or hub and spoke?**

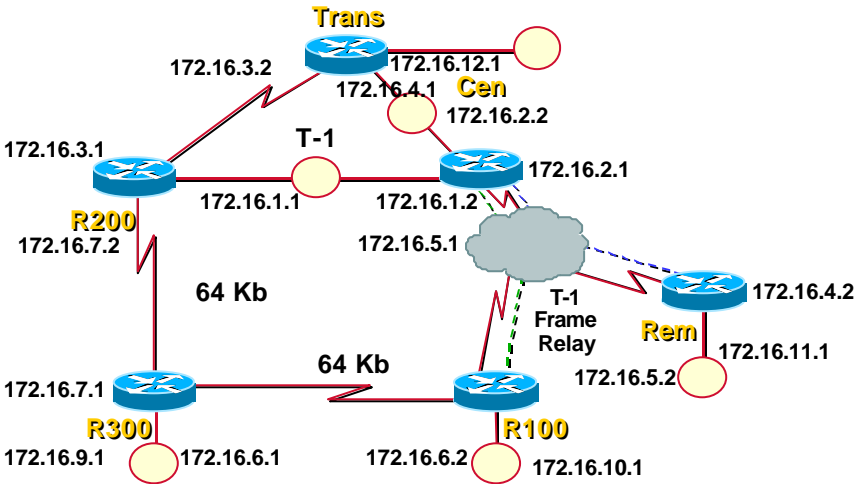
Meshed

- **OSPF may not be the right choice**
 - We only get a two-layer hierarchy**
 - Using Virtual Links for a fix is bad**
- **However we can engineer anything**
 - Pruning some links**
 - Adding a few**

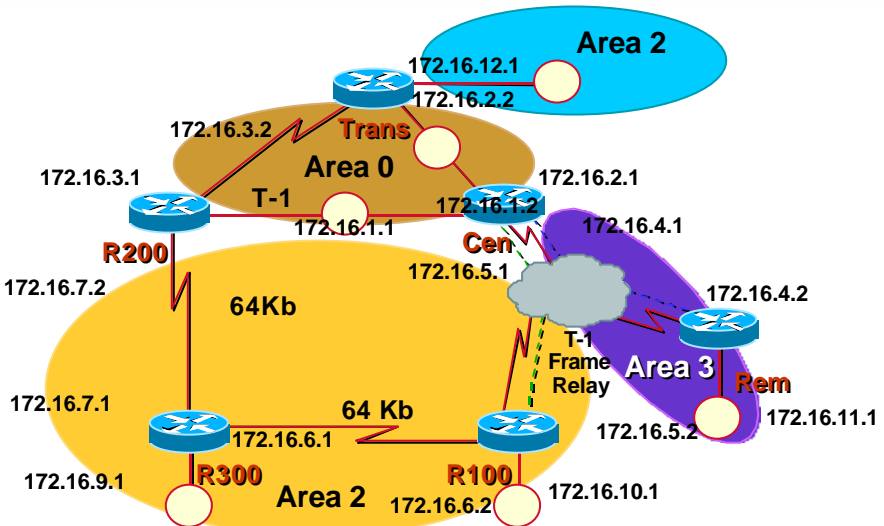
Meshed (Cont.)

- **Try to use as stubby an area as possible**
 - It reduces overhead and LSA counts**
- **Push the creation of a backbone**
 - Reduces mesh and promotes hierarchy**

Example Network



OSPF Overlay



Virtual Links

- **Not recommended**
- **So what's it for?**

Tunnel ABR summaries to area 0

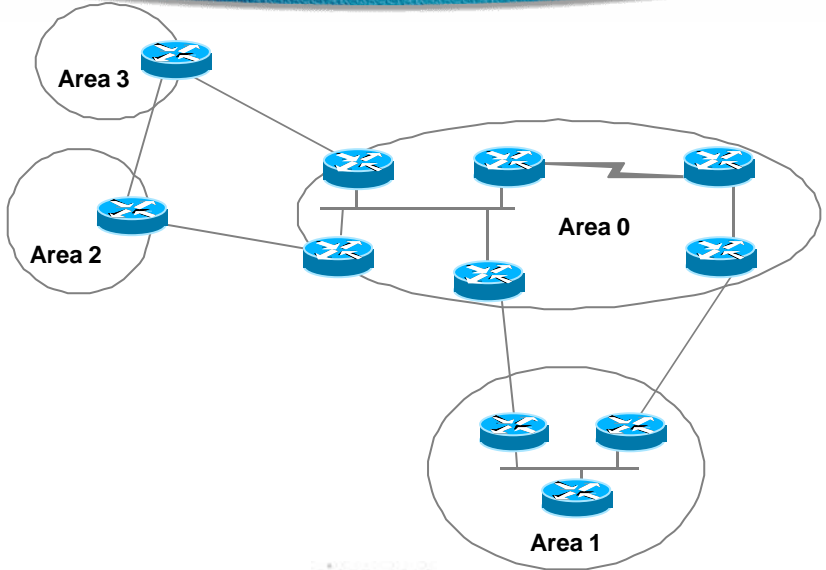
Allow areas to connect to areas other than 0

Repair a discontinuous area 0

Virtual Links (Cont.)

- **May be required in backup scenarios**
- **Configured at each ABR**
- **Should use loopback interfaces**
- **area [area-#] virtual-link [router-ID]**

Virtual Links—Example 1



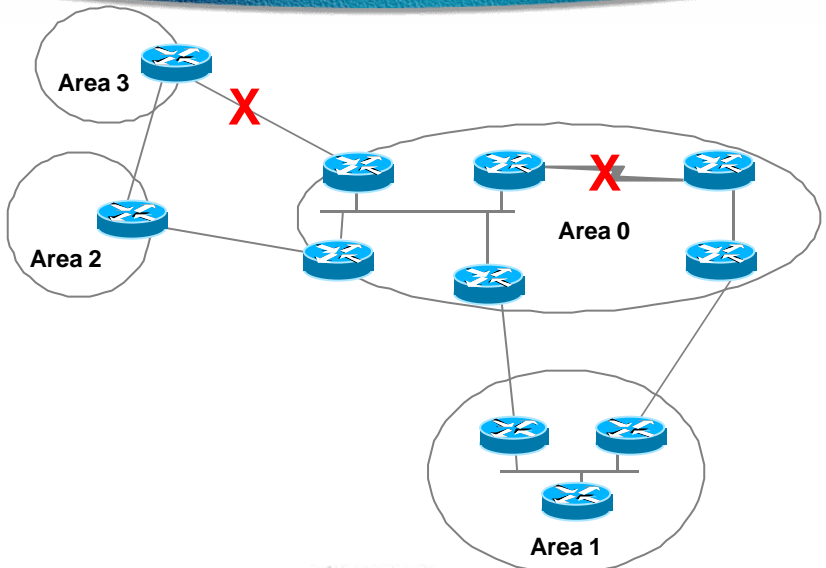
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Virtual Links—Example 1



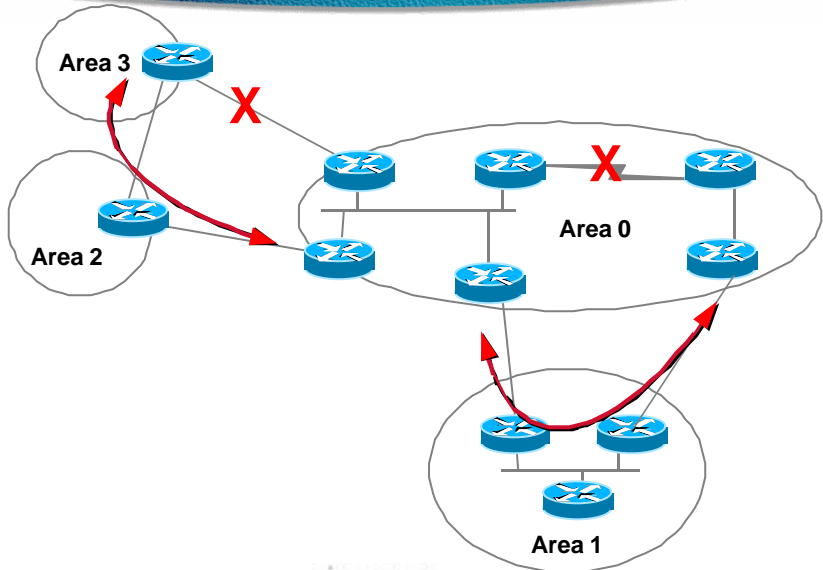
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Virtual Links—Example 1



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Hub and Spoke

- **Scalability**

But any dynamic routing protocol is unnecessary if there is only one path and no dial backup

ODR/static?

- **Hub routers are the ABRs**

Spoke routers are totally stubby wherever possible

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Hub and Spoke (Cont.)

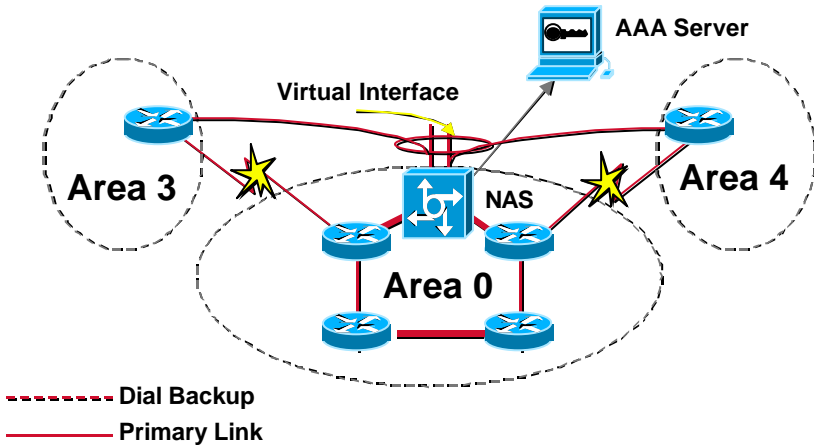
- **Group branch offices by capability for**
 - Totally stubby, stub, NSSA and regular**
- **Define area's and addressing to these groups**
- **How big:**
 - Always a tough question!**

Dial on Demand

- **Dial-on-Demand Techniques:**
 - Use virtual profiles**
 - Virtual interface gets assigned to the area associated with the calling router**
 - Area configuration and IP address for virtual interface are dynamic**

Dial Backup and OPSF

Virtual Profiles



Recommended Reading

- **OSPF : Anatomy of An Internet Routing Protocol** By John T. Moy, ISBN: 0201634724
- **OSPF Network Design Solutions** By Thomas M. Thomas, ISBN: 1578700469
- **Large-Scale IP Network Solutions : CCIE Professional Development** by Khalid Raza, Mark Turner, Salmad Asad, ISBN: 1578700841
- **RFC 2328 and others**
- **Routing in the Internet** By Christian Huitema, ISBN: 0130226475
- **and of course:** <http://www.cisco.com>



Deploying OSPF

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