OSPF (Open Shortest Path First)

- "Open": specification publicly available
  - RFC 1247, RFC 2328
  - Working group formed in 1988
  - Goals:
    - Large, heterogeneous internetworks
- Uses the Link State algorithm
  - Topology map at each node
  - Route computation using Dijkstra's algorithm
- Hierarchy

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OSPF "Advanced" Features (not in RIP)

- Security: All OSPF messages are authenticated (to prevent malicious intrusion); UDP used
- Multiple same-cost paths allowed (only one path in RIP)
- For each link, multiple cost metrics for different TOS (e.g., satellite link cost set "low" for best effort; high for real time)
- Integrated uni- and multicast support:
  - Multicast OSPF (MOSPF) uses same topology data base as OSPF
- Hierarchical OSPF in large domains.

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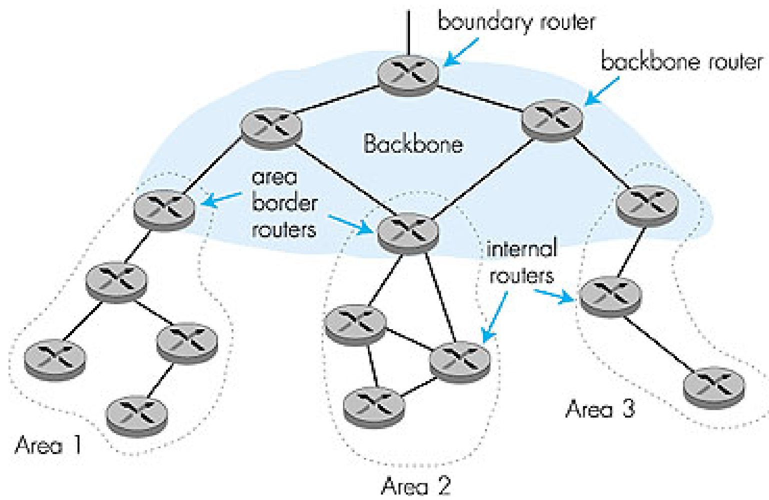
Hierarchical OSPF



Hierarchical OSPF

- Two-level hierarchy: local area and backbone.
  - Link-state advertisements do not leave respective areas.
  - Nodes in each area have detailed area topology; they only know direction (shortest path) to networks in other areas.
- Area Border routers: "summarize" distances to networks in the area and advertise them to other Area Border routers.
- Backbone routers: run an OSPF routing algorithm limited to the backbone.
- Boundary routers: connect to other ASs.

OSPFv2: Tasks (to be filled in)

- Neighbors
  - Discovery
  - Maintenance
- Database
  - Granularity
  - Maintenance
  - Synchronization
- Routing table
  - Metric
  - Calculation

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OSPFv2: Components

- Hello Protocol: "Who is my neighbor?"
- Designated router/Backup designated router (DR/BDR) election: "With whom I want to talk?"
- Database Synch: "What info am I missing?"
- Reliable flooding algo: "How do I distribute info?"
- Route computation
  - From link state database
  - Using Dijkstra's algorithm
  - Supporting equal-cost path routing

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Neighbor Discovery and Maintenance

- Hello Protocol
  - Ensures that neighbors can send packets to and receive packets from the other side: bi-directional communication
  - Ensures that neighbors agree on parameters (HelloInterval and RouterDeadInterval)
- How
  - Hello packet to fixed well-known multicast address
  - Periodic Hellos
  - Broadcast network: electing designated router

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Some Multicast Addresses

- 224.0.0.5 AllSPFRouters OSPF-ALL.MCAST.NET
- 224.0.0.6 AllDRouters OSPF-DSIG.MCAST.NET

- FF02:: 5 and FF02:: 6, respectively for OSPFv3.

- While we are at it:
  - 224.0.0.1 ALL-SYSTEMS.MCAST.NET
  - 224.0.0.2 ALL-ROUTERS.MCAST.NET
  - 224.0.0.9 RIP2-ROUTERS.MCAST.NET
  - 224.0.0.10 IGRP-ROUTERS.MCAST.NET
  - Look up some more (with dig –x address).

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Hello Protocol: 3 Phases

- Down
  - Neighbor is supposed to be “dead”
  - No communication at all
- Init
  - “I have heard of a Neighbor.”
  - Uni-directional communication
- ExStart or TwoWay
  - Communication is bi-directional

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Hello Protocol: Packet

0 1 2 3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

Version #	1	Packet length	
Router ID			
Area ID			
Checksum		AuType	
Authentication			
Authentication			
Network Mask			
HelloInterval		Options	Router Prio
RouterDeadInterval			
Designated Router			
Backup Designated Router			
Neighbor A			
Neighbor B			
....			

- Hello Interval: 10 seconds (typical default)
- RouterDeadInterval: 4 * Hello Interval (typical default)

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OSPF Packet

- IP Protocol #89
- Directly to neighbors using Multicast address
  - ⇨ TTL 1
- Five packet types
  - Hello
  - Database Description
  - Link State Request
  - Link State Update
  - Link State Acknowledgement

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OSPF Packet (2.)

- Router ID: IP address
- Area ID: configured
- Authentication:
  - 0: no authentication
  - 1: simple password
  - 2: cryptographic authentication

0 1 2 3 4 5 6 7	8 9 0 1 2 3 4 5	6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
Version #	Type	Packet length
Router ID		
Area ID		
Checksum		AuType
Authentication		
Authentication		

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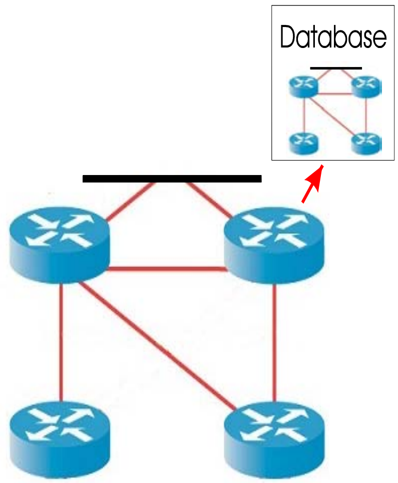
Link State Database

- Based on link-state technology
  - Local view of topology in a database
- Database
  - Consists of Link State Advertisements (LSA)
  - LSA: data unit describing local state of a network/router)
  - Must kept synchronized to react to routing failures



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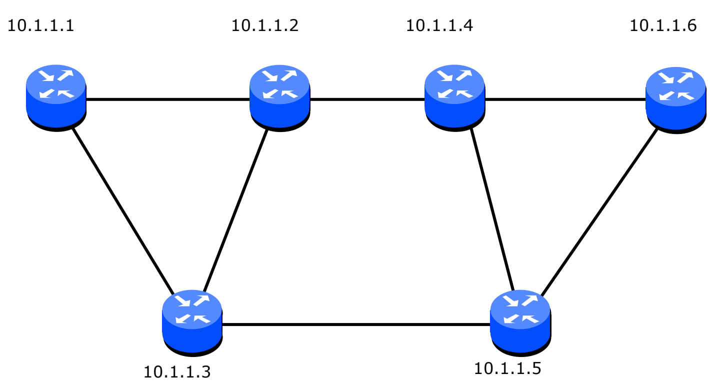
Example Network



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Link State Database: Example

LS-Type	Link State ID	Adv. Router	Checksum	Seq. No.	Age
Router-LSA	10.1.1.1	10.1.1.1	0x9b47	0x80000006	0
Router-LSA	10.1.1.2	10.1.1.2	0x219e	0x80000007	1618
Router-LSA	10.1.1.3	10.1.1.3	0x6b53	0x80000003	1712
Router-LSA	10.1.1.4	10.1.1.4	0xe39a	0x8000003a	20
Router-LSA	10.1.1.5	10.1.1.5	0xd2a6	0x80000038	18
Router-LSA	10.1.1.6	10.1.1.6	0x05c3	0x80000005	1680

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LSAs

- Consists of a Header and a Body
- Header size is 20 Byte and consists of

<table>
<tr><td colspan="4">0 1 2 3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1</td></tr>
<tr><td colspan="2">LS Age</td><td>Options</td><td>LS Type</td></tr>
<tr><td colspan="4">Link State ID</td></tr>
<tr><td colspan="4">Advertising Router</td></tr>
<tr><td colspan="4">LS sequence number</td></tr>
<tr><td>LS Checksum</td><td colspan="3">Length</td></tr>
</table>

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LSAs (2.)

- Identifying LSAs
  - LS Type Field
  - Link State ID Field
  - Advertising Router Field
- Verifying LSA Contents
  - LS Checksum Field
- Identifying LSA Instances
  (keeping in mind that the topology changes)
  - LS Sequence Number Field
    - Linear sequence space
    - Max Seq ⇨ new instance

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LSAs (3.)

- LS Age Field
  (to ensure consistency)
  - Goal: new sequence number every 30 minutes
  - Maximum value 1 hour
  - Age > 1 hour ⇨ invalid ⇨ removal
  - Enables premature aging
  - Ensures removal of outdated information

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Example LSA: Router-LSA

0 1 2 3

0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1

LS Age		Options	LS Type
Link State ID			
Advertising Router			
LS sequence number			
LS Checksum		Length	
0 V E B	0	# Link	
Link ID			
Link Data			
Type	# TOS	Metric	
....			

Example: Router LSA

- Link-Cost: integers (configured)

32 Bits

8	8	8	8
Alter = 0		Optionen	Typ = 1
Link State ID = 10.1.1.1			
Advertising Router = 10.1.1.1			
Sequence Number = 0x80000006			
Checksum = 0x9b47		Length = 60	
00000 0 0 0	0x00	Number of Links = 3	
Link ID =10.1.1.2			
Link Data = Interf. Index 1			
Link Typ = 1	# TOS = 0	Link-Cost = 3	
Link ID =10.1.1.3			
Link Data = Interf. Index 2			
Link Typ = 1	# TOS = 0	Link-Cost = 5	
Link ID =10.1.1.1			
Link Data = 255.255.255.255			
Link Typ = 3	# TOS = 0	Link-Cost = 0	

Link Typ 1: Peer-to-peer
Link Typ 3: Stub Network

Link-State Database (2.)

- Is the database synchronized?
  - Same number of LSAs?
  - Sums of LSA LS Checksums are equal?

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Database synchronization

- Central aspect:
  all routers need to have identical databases!
- 2 types of synchronization
  - Initial synchronization
    - After hello
  - Continuos synchronization
    - Flooding

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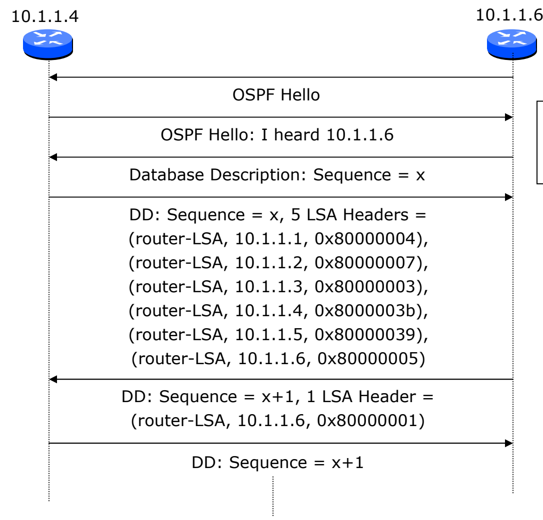
Initial Synchronization

- Explicit transfer of the database upon establishment of neighbor ship
- Once bi-directional communication exists
- Send all LS header from database to neighbor
  - OSPF database description packets (DD pkt)
  - Flood all future LSA's

Initial Synchronization (2.)

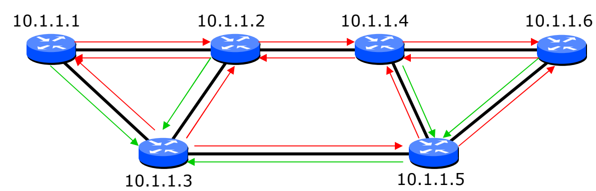
- Database description (DD) exchange
  - Only one DD at a time
  - Wait for Ack
- Control of DD exchange
  - Determine Master/Slave for DD exchange
  - Determine which LSA's are missing in own DB
  - Request those via link state request packets
  - Neighbor sends these in link state update packets
- Result:
  - Fully adjacent OSPF neighbors

Example: Database Synchronization



- Router from previous example are synchronized
- 10.1.1.6 is restarted

Reliable Flooding



- 10.1.1.3 sends LS Update
- Same copy of an LSA is an implicit Ack
- Use delayed Ack's
- All LSA's must be acknowledged
  either implicit or explicit

Robustness of Flooding

- More robust than a spanning tree
- LSA refreshes every 30 minutes
- LSAs have checksums
- LSAs are aged
- LSAs cannot be send at arbitrary rate: there are timers

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OSPF LSA Timers

MinLSArrival	1 second
MinLSInterval	5 seconds
CheckAge	5 minutes
MaxAgeDiff	15 minutes
LSRefreshTime	30 minutes
MaxAge	1 hour

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Calculation of routing table

- Link state database is a directed graph with costs for each link
- Dijkstra's SPF algorithms
  - Add all routers to shortest-path-tree
  - Add all neighbors to candidate list
  - Add routers with the smallest cost to tree
  - Add neighbors of this router to candidate list
    - If not yet on it
    - If cost smaller
  - Continue until candidate list empty

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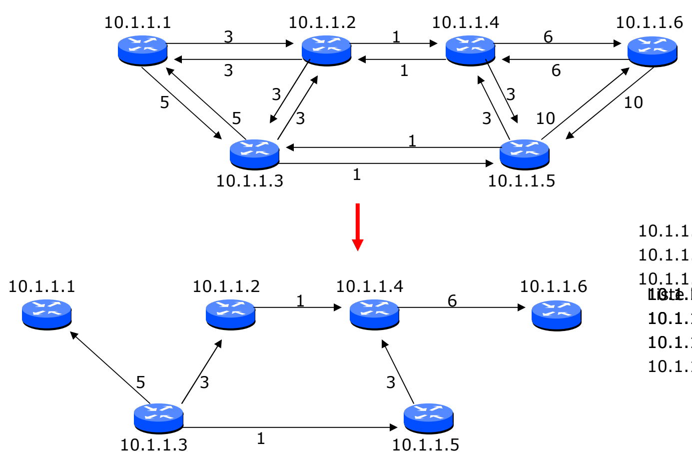
Example



10.1.1.4 (4, 10.1.1.5/2)
10.1.1.1 (5, 10.1.1.1)
10.1.1.6 (11, 10.1.1.5)
[illegible]
[illegible]
10.1.1.1 (5, 10.1.1.1)
10.1.1.6 (11, 10.1.1.5)

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Network Types

- So far only point-to-point
- Many other technologies
- Specific requirements for OSPF
  - Neighbor relations
  - Synchronization
  - Representation in DB
- Kinds
  - Point-to-point
  - Broadcast
  - Nonbroadcast multiaccess
  - Point-to-multipoint

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IP subnets

- Address plus subnet mask
- IP-routing for subnets not hosts
- Traffic between subnets via routers
- No router ⇨ same subnet

⇨ OSPF Hello's only accepted
  - If both have the same subnet mask
  - If both interfaces are in the same subnet

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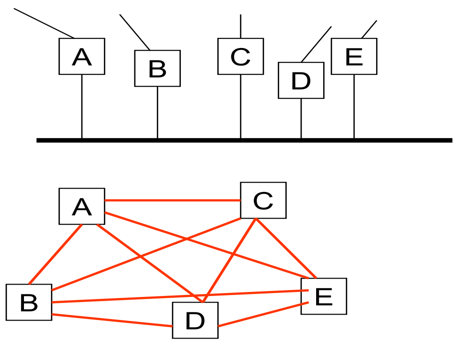
Adjacencies on Broadcast Networks



- If n routers are on a broadcast link, $n(n-1)/2$ adjacencies can be formed.
- n^2 LSAs would be originated for this network.

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Adjacencies (2.)

- If routers formed pair wise adjacencies:
  - Each would originate $(n-1)+1=n$ LSAs for the link.
  - Out of the network, n^2 LSAs would be emanating.
- Routers also send received LSAs to their neighbors
  - $(n-1)$ copies of each LSA present on the network
  - Even with multicast: $(n-1)$ responses
- Solution: elect Designated Router (DR)
  - Routers form adjacencies only with DR:
  - Link acts as a (multi-interface) virtual router to the rest of the area

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Designated Router Election

- When router joins:
  - Listen to hellos; if DR and BDR advertised, accept them
    - All Hello packets agree on who the DR and BDR are
    - Status quo is not disturbed
- If there is no elected BDR, router with highest priority becomes BDR
- Ties are broken by highest RouterID
  - RouterIDs are unique (IP address of interface)
- If there is no DR, BDR is promoted to DR
- Elect new BDR

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Designated Router Election Details

- Routers who believe can be BDRs or DRs put their own Ids in their Hello packets.
- Once 2-way communication has been established, all routers know who the candidates are.
- They can now all pick a BDR
  - Highest priority, then Router ID.
- And then a DR
- If only one router claims he's the DR, he becomes the DR.
- First two routers to come up become DR/BDR.
- On NMBA networks use unicast Hellos

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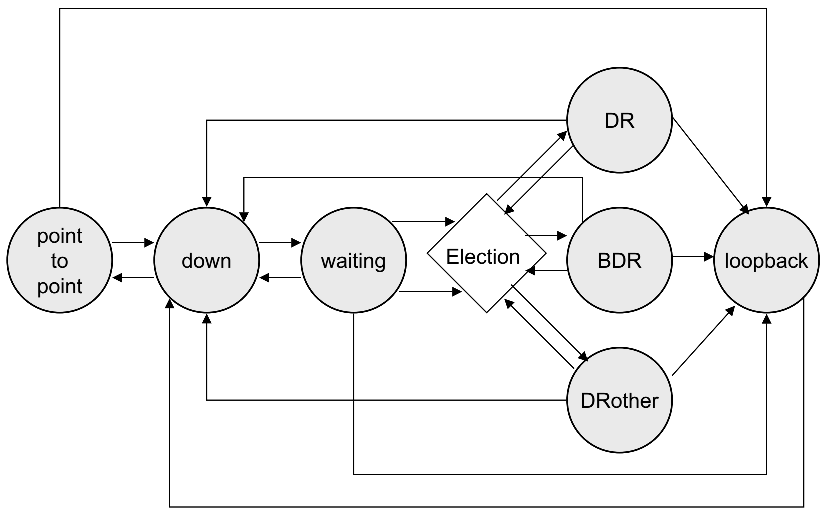
OSPF Interface State Machine



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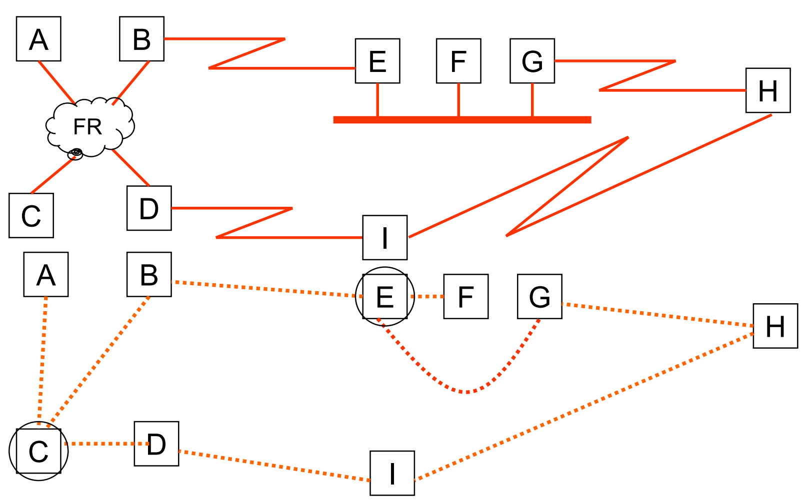
Adjacencies (3.)



Routers connected by data links ⇔ nodes connected by adjacencies.

Network LSA's

- A network LSA represents a broadcast subnet
- Router LSA's have links to network LSA
- Reduction of links
- DR responsible for network LSA
- Link State ID = IP-address of DR

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Areas

- An AS (or Routing Domain) is divided into areas.
- Group of routers
- "Close" to each other.
- Reduce the extend of LSA flooding
- Intra-area traffic
- Inter-area traffic
- External traffic: injected from a different AS
- OSPF requires a backbone area (Area 0)
  - Routing between areas only via backbone area
  - Strict area hierarchie (no loops allowed)

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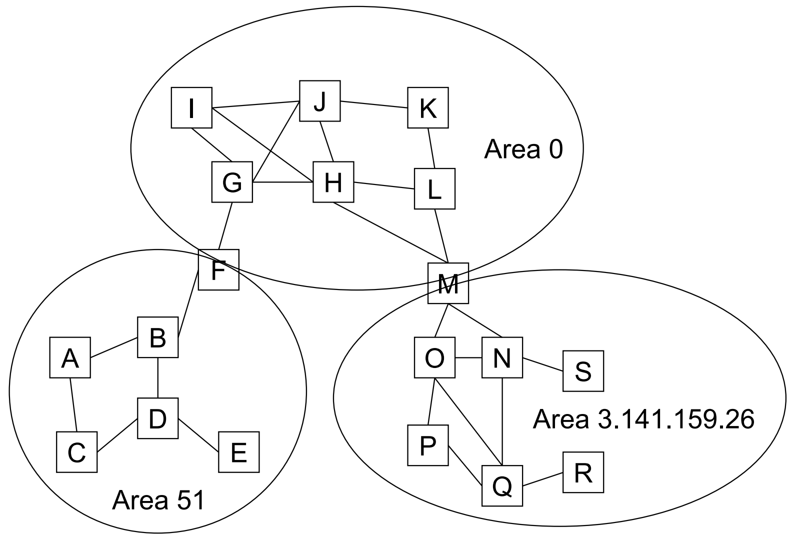
Areas: Example



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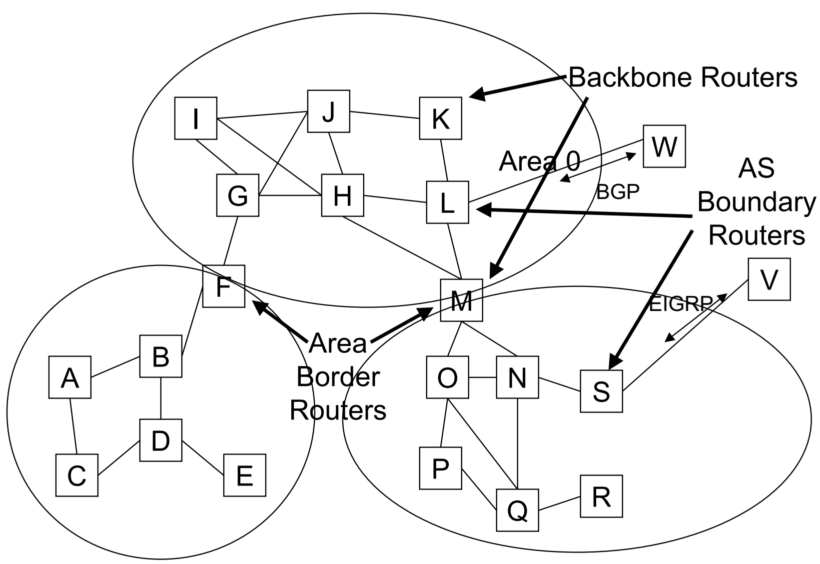
Areas: Router Types



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Area Partitions

- Link and router failures can cause areas to be partitioned
- Some partitions are healed automatically
- Some need manual intervention.
  - Virtual Links.
- Isolated area: link failure results in no path to the rest of the network
  - Obviously, cannot be healed at all.
  - Redundancy is important!

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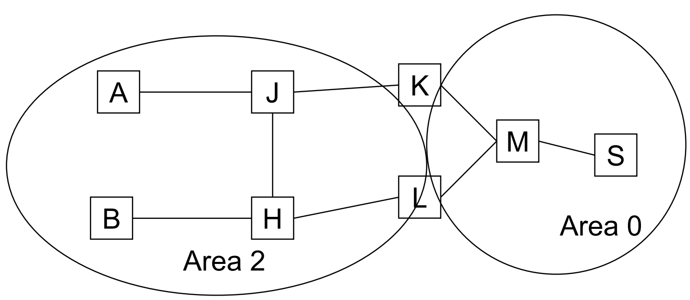
Example Partition



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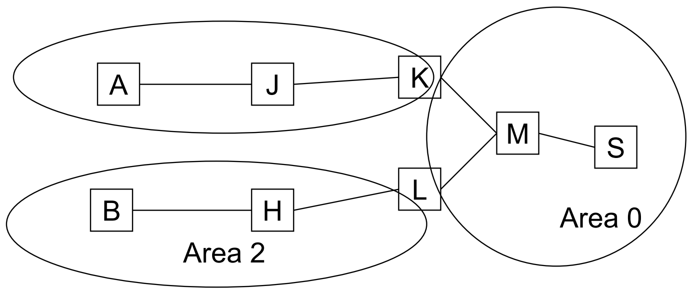
Example Partition (cont.)



- Area 2 gets partitioned, but all its routers can reach an ABR, so traffic is not disrupted.

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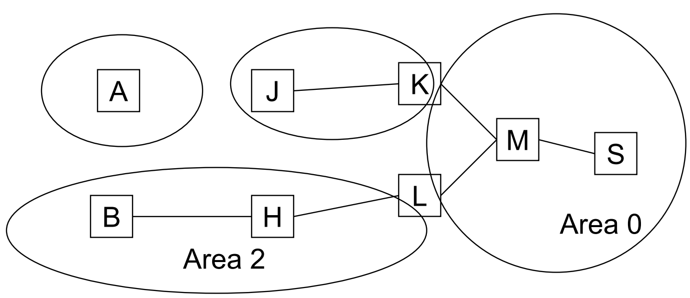
Example Partition (cont.)



- IF AJ fails, A becomes isolated.

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Virtual Links

- Link to the backbone through a non-backbone area
- Unnumbered
- Connect an area to the BB through a non-BB area
- Heal a partitioned BB through a non-BB area.
- No physical wires.
  - Solely result of configuration
  - A tunnel without encapsulation
- Configured between two ABRs
- Transit Area: area through which VL is configures
- Routers "connected" with VLs become adjacent.

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OSPF: Summary

- Neighbors
  - Discovery — Multicast group
  - Maintenance — Hello protocol
- Database
  - Granularity — Link state advertisements (LSA)
  - Maintenance — LSA-updates flooding protocol
  - Synchronization — Synchronization protocol
- Routing table
  - Metric — Fixed values
  - Calculation — Local shortest path calculation

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