14.5

OSPF:
Open Shortest Path First
Areas in an autonomous system

Autonomous system

Area 0 (backbone)
- Backbone router
- net

Area 1
- Area border router
- net
- net

Area 2
- Area border router
- net
- net

To other ASs
Types of links

- Point-to-point
- Transient
- Stub
- Virtual
Figure 14-21

Point-to-point link
Figure 14-22

**Transient link**

*Figure 14-22: Transient link.*

(a) Transient network

(b) Unrealistic representation

(c) Realistic representation
Figure 14-23

**Stub link**

A

Ethernet

a. Stub network

A

Designated router

b. Representation
Example of an AS
Figure 14-24b

Graphical representation of an AS
Shortest path calculation

Dijkstra’s Algorithm shortest path tree is created by each router.
Shortest path calculation

e. Make B permanent, add its neighbors

f. Make N2 permanent

g. Make D permanent, add its neighbors

h. Make E permanent, add its neighbors
Shortest path calculation

i. Make N3 permanent, add its neighbors

j. Make F permanent, add its neighbors

k. Make N4 permanent

l. Make N5 permanent
OSPF Hello Protocol

- OSPF routers use the Hello Protocol to learn about other routers with interfaces on the same network (“neighbors”)
- On all multi-access networks (broadcast and nonbroadcast) the Hello Protocol also elects a Designated Router
Neighbors and Adjacency

- OSPF creates *adjacencies* between neighbors to facilitate exchange of routing information
- Neighbors on point-to-point networks and virtual links always become adjacent
- On multi-access networks, all routers become adjacent to the Designated Router
- Adjacencies control the distribution of routing protocol packets
OSPF Designated Router

- Each multi-access network has a Designated Router, elected by the Hello Protocol.
- The Designated Router generates Link State Advertisements (LSA) for the multi-access network and has other responsibilities in the running of the protocol.
- The Designated Router concept enables a reduction in the number of adjacencies required.
- The reduction in the number of adjacencies reduces the amount of routing traffic and the size of the topological database.
Link State Advertisements

- Link State Advertisements are flooded throughout an area ensuring all routers in the area have exactly the same topological database.
- The topological database consists of the LSAs from each router belonging to the area.
- From the topological database, each router calculates a shortest-path tree, with itself as root.
- This shortest-path tree in turn yields a routing table for *intra-area routing* (inside area).
Inter-Area Routing (between areas)

• Each Area Border Router summarizes the topology of its attached areas for transmission to all other Area Border Routers via the backbone.
• This process allows all ABRs to calculate paths to destinations not contained in its attached areas.
• ABRs then advertise these paths to its attached areas to enable routing to other areas.
Autonomous System External Routes

• Routers that have information regarding other ASs flood this information throughout the AS
• To utilize external routing information: the path to all routers advertising external information must be known throughout the AS
• The location of AS Boundary Routers are summarized by Area Border Routers
Types of OSPF packets

- Hello
- Database description
- Link state request
- Link state update
- Link state acknowledgment

- Router link
- Network link
- Summary link to network
- Summary link to AS boundary router
- External link
Open Shortest Path First

First OSPF RFC Oct 1989
Final RFC 2328 April 1998

OSPF Components
1) Hello Protocol - Detect neighbors and confirm still there
2) “Reliable Flooding” Mechanism - ensures all routers in an OSPF area have a consistent link state database

OSPF is “Encapsulated” in IP and the IP protocol field is set to 0X59. Immediately following the IP header is a common 24 - Byte packet header.

OSPF's common header.
OSPF packets are encapsulated in IP datagrams.
### OSPF Packet Header

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Version</strong></td>
<td><strong>Type</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Message length</strong></td>
</tr>
<tr>
<td></td>
<td>Source router IP address</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Area ID</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Checksum</td>
<td>Authentication type</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Authentication</td>
</tr>
</tbody>
</table>
Hello Protocol

Destination address is always 224.0.0.5 which is multicast and is represented in Ethernet as 0X01-00-5E-00-00-05

This is a MAC layer multicast address. OSPF hellos are transmitted every 10 seconds (By Default).

If 4 hello intervals pass (40 seconds) without hearing a hello from a neighbor that neighbor is declared to be down

Hello Protocol:
1. Advertises a router’s “Aliveness”
2. Verifies two-way connectivity
3. Avoids one-way connectivity
4. Elects designated and backup designated routers
5. Maintains OSPF adjacencies once established

OSPF hello protocol allows detection of one-way links. Protocol lists neighbor routers router ID’s in hello packets.

OSPF routers will not attempt to form an adjacency (IE Synchronize Link State Databases) until they see themselves as sharing a two way link (and they are both members of the same IP prefix - IP address anded with mask)
OSPF HELLO PACKET

Typical 10 Sec must be same to form adjacency

HelloInterval
RouterDeadInterval
Designated Router IP
Backup Designated Router IP
Neighbor
Neighbor

Example / 18
Network Mask 0XFF-FF-C0-00

Router Priority for DR elections
Typically 40 Sec must be same to form adjacency

Not Shown
IP Header
Common OSPF Header
Not Shown

24
**Hello packet**

<table>
<thead>
<tr>
<th>Common header</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 bytes</td>
</tr>
<tr>
<td>Type: 1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Network mask</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hello interval</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dead interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designated router IP address</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Backup designated router IP address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neighbor IP address</td>
</tr>
</tbody>
</table>
Hello packet’s network mask field is set by transmitting router to be the mask of the interface on which the hello is being transmitted. Used by neighbors with transmitter router source IP address to decide if within same prefix as transmitting router. If not will not attempt to form an OSPF adjacency.

Forming an OSPF adjacency means a pair of routers exchange, and maintain the common link state database.

Instead of every one doing this with every one we use a designated router (DR) and a backup designated router.

A new router learns about this from just one hello packet and forms an OSPF adjacency only with designated router, and back up designated router.

Multicast address 224.0.0.6 used to communicate updates to designated routers and backup designated routers. Then DR and BDR communicate to all others.
Designated Router and Backup Designated Router election.

Once elected DR and BDR remain even if a “Better” choice comes along.

The first router that is active on a LAN declares itself to be the DR after waiting “Router Dead Internal which is a field in hello packet.

DR fills in its own “ Router ID ” in the “Designated Router” field of hello packet.

Second router in LAN will become BDR after waiting “Router Dead Interval.”

If several routers all come on at the same time, router with the numerically largest “Router ID” will become DR, next higher BDR. (Router ID- A 32-bit number that uniquely identifies this router in the AS. One possible implementation strategy would be to use the smallest IP interface address belonging to the router.)

The “Router Priority” field in hello can be used to control who wins election 8 bits 0 to 255, higher is “Better” if set to 0 administrator never wants this router to become DR or BDR.

Typically value is set to 1.

Highest router priority used first, if several with same value, highest ID used next.
OSPF Scaling: Maximum # of Neighbors Per Router Interface (In one Hello Packet)

Given a Worst Case
- 60 Byte IP Header
- 24 Byte OSPF Header
- 20 Byte Hello Header

Given An MTU (Maximum Transfer Unit) 1500 Bytes

1500 - 60 - 24 - 20 = 1,396

It Takes 4 Bytes Per Neighbor Entry

1,396/4 = 349 Maximum number of neighbors that can fit into a single hello packet.
What do we mean by Reliable Flooding Algorithm?

Each update must be acknowledged so that the routers are sure that the change has been reliably handed off to the next router.

Sending router retransmits until update has been acknowledged.

The entire process of spreading the update reliably over a spanning tree that includes all the Area’s routers is known as the OSPF’s reliable flooding algorithm.
Types of LSAs

- Link state advertisements
  - Router link
  - Network link
  - Summary link to network
  - Summary link to AS boundary router
  - External link
Link State Advertisement (LSA) Packets

Common Part

<table>
<thead>
<tr>
<th>LS Age</th>
<th>Options</th>
<th>LS Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS Age : 0x0000 - 0x0E10  (i.e., 0-3600) seconds</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LS Type Description

1 Router - LSA
2 Network - LSA
3 Summary - LSA (IP network)
4 Summary - LSA (ASBR)
5 AS - External - LSA

Common LSA header.

Aside: The entries in OSPF’s Link State Database are known as “Link State Advertisements”
## LSA header

<table>
<thead>
<tr>
<th>Field</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link state age</td>
<td></td>
</tr>
<tr>
<td>Reserved</td>
<td>E</td>
</tr>
<tr>
<td>Link state ID</td>
<td></td>
</tr>
<tr>
<td>Advertising router</td>
<td></td>
</tr>
<tr>
<td>Link state sequence number</td>
<td></td>
</tr>
<tr>
<td>Link state checksum</td>
<td>Length</td>
</tr>
</tbody>
</table>
From a router’s perspective: Advertises all the individual links’ network addresses. One address for each link connected to the router.
From an individual Network’s perspective: Advertises one network mask and all the router IP addresses connected to that individual network.
Figure 14-38

Summary link to network

Area 1
Flooded by the area border router into the area

R1

Summary link to network

Area 2
Flooded by the area border router into the area

R2

N1

Autonomous system
Figure 14-40

**Summary link to AS boundary router**

- **Area 1**: Flooded by the area border router into the area
- **Area 2**: Flooded by the area border router into the area
- **Area 0**: Summary link to AS boundary router

Autonomous system

AS boundary router
Figure 14-42

External link

Flooded by the AS boundary router into the AS

Network

External link
Types of LSAs

- Link state advertisements
  - Router link
  - Network link
  - Summary link to network
  - Summary link to AS boundary router
  - External link
Example 3

In Figure 14.37 (next slide), which router(s) sends out router link LSAs?
Example 5 and Example 6
Solution

All routers advertise router link LSAs.

R1 has two links, Net1 and Net2.
R2 has one link, Net2 in this AS.
R3 has two links, Net2 and Net3.
Router - LSA

Sent out as zero. Routers that received this LSA keep time by incrementing this field up to one hour at which point the entry is discarded.

LS Age
Link State ID
LS Type
Advertisement Router
LS Sequence Number
LS Checksum
Reserved
Length
Number of Links
Link ID
Link Data
Link Type
# TOS Metrics
Metric
Link ID
Link Data
Link Type
# TOS Metrics
Metric

Router-LSA.

Link ID
This is the network / subnet prefix

Link Data
This is the mask for that prefix

Link State ID
This is set to originating Routers Router ID also true for advertising Router field
Router - LSA:

Link Type:

Stub Network => Link Type = 3 stub network is a network that is not used to reach destinations beyond the network itself.

- Link ID = Network / Subnet “IP” prefix
- Link Data = Mask for that prefix

Transit Network => Link Type = 2 transit network connect multiple OSPF routers

- Link ID = Designated Router’s “Router ID”
- Link Data = Router’s Interface IP address within that prefix.

Point to Point => Link Type = 1

- Link ID = Address of Neighbor router
- Link Data = Interface Number

In Router - LSA’s common LSA Header info: Link State ID and advertising router fields are both set to the originating routers Router ID.
### Router link LSA

<table>
<thead>
<tr>
<th>Link state header</th>
<th>20 bytes</th>
<th>Type: 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserved</td>
<td>E</td>
<td>B</td>
</tr>
</tbody>
</table>

- **Link ID**
- **Link data**

<table>
<thead>
<tr>
<th>Link type</th>
<th># of TOS</th>
<th>Metric for TOS</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOS</td>
<td>Reserved</td>
<td>Metric</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 14-30*
Example

Give the router link LSA sent by router 10.24.7.9 in next figure.
Example

10.24.7.0/24

10.24.7.9

metric: 2

10.24.7.10

metric: 4

dashed line point-to-point

10.24.7.11

metric: 6

dashed line point-to-point
This router has three links: two of type 1 (point-to-point) and one of type 3 (stub network). The next figure shows the router link LSA.
Solution to Example

<table>
<thead>
<tr>
<th>OSPF Header</th>
<th>Type: 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSA Header</td>
<td>Type: 1</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>10.24.7.10</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
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<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>10.24.7.11</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>10.24.7.0</td>
<td></td>
</tr>
<tr>
<td>255.255.255.0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Diagram showing OSPF and LSA headers with IP addresses and types.
Types of LSAs

- Link state advertisements
  - Router link
  - Network link
  - Summary link to network
  - Summary link to AS boundary router
  - External link
Example 4

In next figure, which router(s) sends out the network link LSAs?
Solution

All three networks must advertise network links:

Advertisement for Net1 is done by R1 because it is the only router and therefore the designated router.

Advertisement for Net2 can be done by either R1, R2, or R3, depending on which one is chosen as the designated router.

Advertisement for Net3 is done by R3 because it is the only router and therefore the designated router.
Network - LSA:

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<tr>
<td>LS Age</td>
<td>Options</td>
<td>LS Type (= 2)</td>
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<td>Link State ID</td>
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<tr>
<td>Advertising Router</td>
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<td>LS Sequence Number</td>
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<tr>
<td>Network Mask</td>
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<tr>
<td>Attached Router</td>
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</tbody>
</table>

Network - LSA

Only originated by the **Designated Router**.

Listed routers (Attached Routers) will be those adjacent to the Designated Router.

The Router ID along with both the Router - LSA’s and network LSA’s are used to determine the subnet prefixes attached to each router.

IN NETWORK - LSA

Link State ID = Originating routers interface address anded with network mask which is contained in “Network Mask” field.

Attached router fields are other router interface addresses within that prefix.
Network link advertisement format

- Link state header
  - 20 bytes
  - Type: 2
- Network mask
- Attached router
Example 6

Give the network link LSA in Figure 13.44.
Example 4
Solution

The network, for which the network link advertises, has three routers attached. The LSA shows the mask and the router addresses. See Figure 14.36.

Note that only one of the routers, the designated router, advertises the network link.
### Solution to Example 4

<table>
<thead>
<tr>
<th>OSPF Header</th>
<th>Type: 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSA Header</td>
<td>Type: 2</td>
</tr>
<tr>
<td>255.255.255.0</td>
<td></td>
</tr>
<tr>
<td>10.24.7.14</td>
<td></td>
</tr>
<tr>
<td>10.24.7.15</td>
<td></td>
</tr>
<tr>
<td>10.24.7.16</td>
<td></td>
</tr>
</tbody>
</table>
Types of LSAs

- Router link
- Network link
- Summary link to network
- Summary link to AS boundary router
- External link
Summary link to network

Area 1
Flooded by the area border router into the area

Area 2
Flooded by the area border router into the area

Area 0

R1  Summary link to network  N1  Summary link to network  R2

Autonomous system
Summary Link to Network LSA

Outside of the OSPF area summary - LSA’s are used to advertise networks (but not exact connections) inside one OSPF area to another adjacent area. (See Forouzan Figure 13-28 our slide 34)

Only non zero TOS fields are used so first zero TOS Byte is end of summary-LSA packet. In practice TOS is not used so end after TOS X Metric field which is usually zero.

An area border router needs to originate one summary-LSA for each of its area’s reachable network prefixes. Only one network contained in each advertisement.

Aggregation of IP addresses may be used to reduce the number of summary-LSA’s that need to be injected into the backbone area, but only when an area boundary aligns with an IP address prefix.
Summary link to network LSA
Types of LSAs

- Link state advertisements
  - Router link
  - Network link
  - Summary link to network
  - Summary link to AS boundary router
  - External link
Figure 14-40

Summary link to AS boundary router

Area 1
Flooded by the area border router into the area

Area 2
Flooded by the area border router into the area

Area 0
Summary link to AS boundary router

Autonomous system

AS boundary router
Summary link to AS boundary LSA

Used to announce the route to an AS boundary router.
Types of LSAs
Figure 14-42

External link

Area 1

Area 2

Area 0

Autonomous system

Flooded by the AS boundary router into the AS

Network

External link
External link LSA

Used to advertise networks that are outside the AS.
Types of OSPF packets

- Hello
- Database description
- Link state request
- Link state update
- Link state acknowledgment

- Router link
- Network link
- Summary link to network
- Summary link to AS boundary router
- External link
Figure 14-47

**Link state acknowledgment packet**

- **Common header**
  - 24 bytes
  - Type: 5

- **Link state header**
  - 20 bytes
  - Corresponding type
OSPF Summary

OSPF is never a bad choice over either version of RIP

RIPv2 at least supports VLSM and CIDR but is still a distance-vector protocol and converges slowly in large networks

Link state protocols converge much more quickly than distance-vector protocols especially as network size increases

In small networks there is probably no compelling reason to choose OSPF