Lab 11. Multi-Area OSPF

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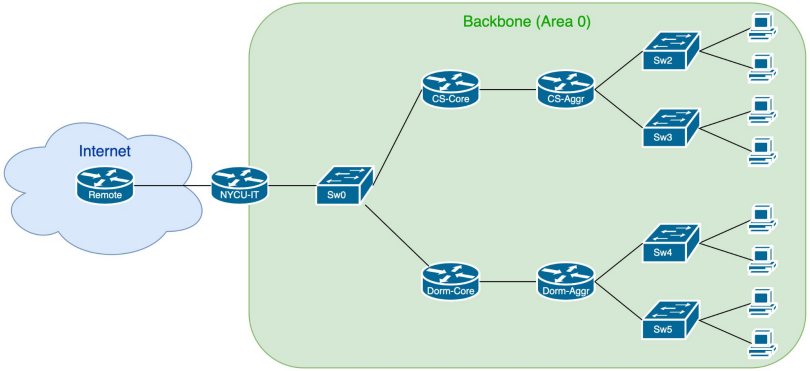
Credit to naich

Slide: https://tg.pe/Mtu

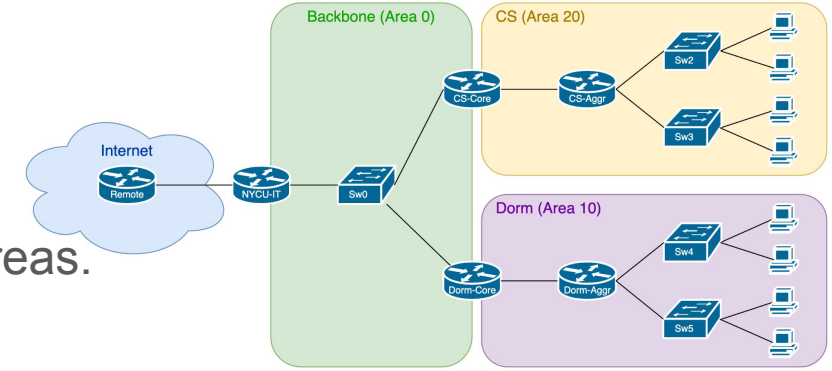
Last Week: Single-Area OSPF



- A widely-used link-state routing protocol.
- How do routers establish OSPF neighbors.
- How to configure OSPF in Cisco routers.
- Packet Types, LSA Types
- Constraints of Single-Area OSPF
  - Large routing table
  - Large Link-State Database (LSDB)
  - Frequent SPF algorithm re-calculations

※ Link State Advertisement (LSA), Shortest-Path First (SPF)

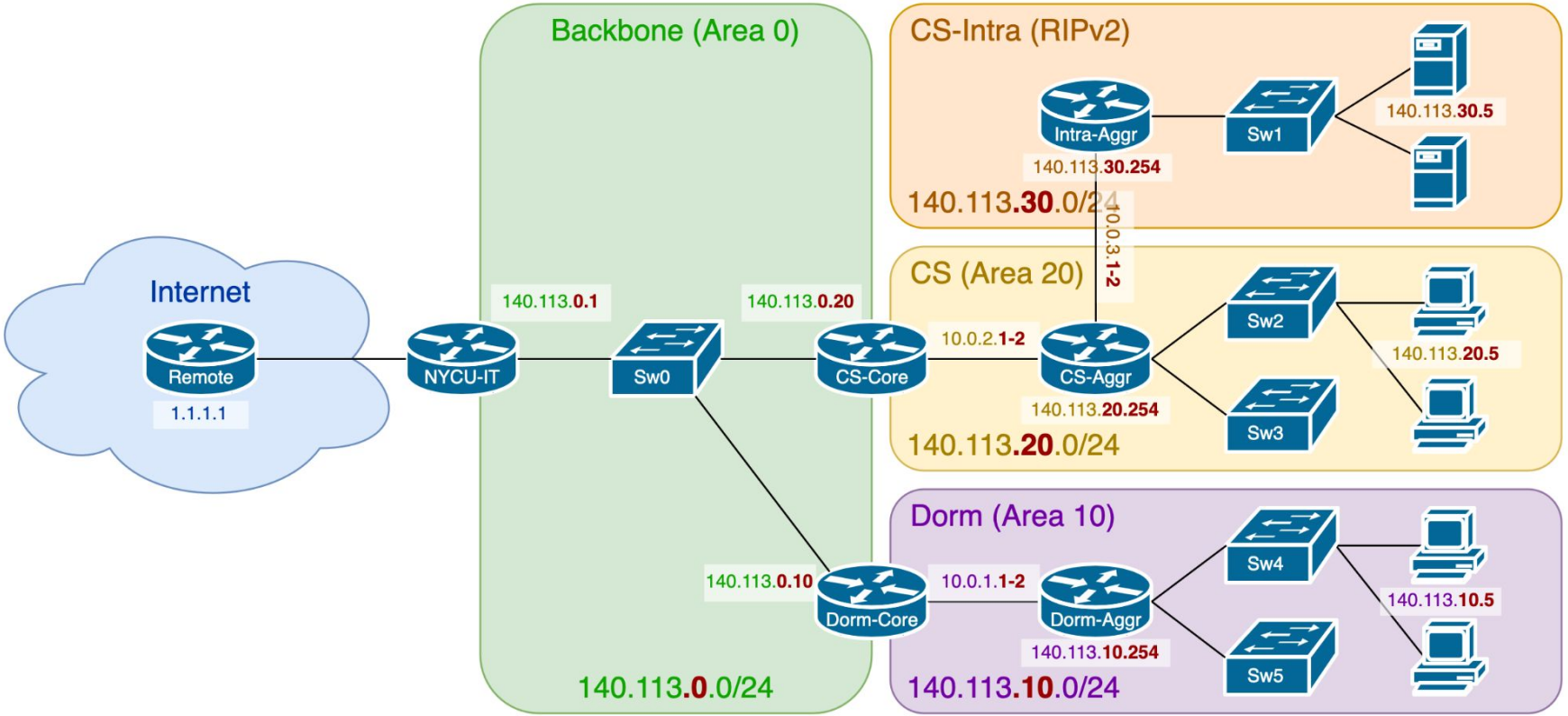
Advantage of Multi-Area OSPF



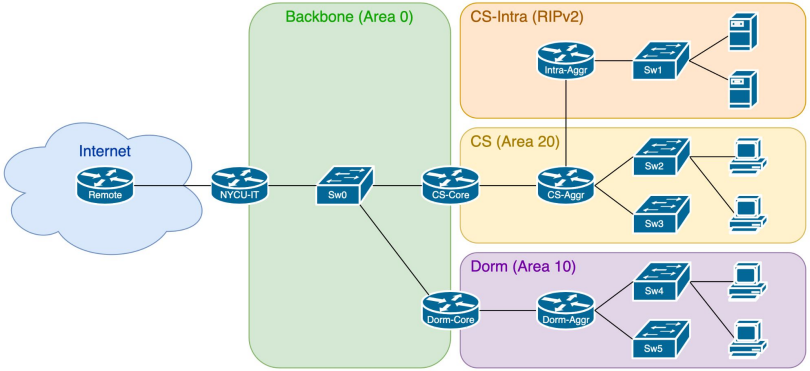
- Divide a large OSPF domain into small areas.
- Smaller routing tables.
  - Route entries can be summarized between areas.
  - Routers in an area may only receive a default route for destinations outside their area.
- Reduce link-state update overhead.
  - LSA flooding stops at the area boundary.
  - Fewer routers are exchanging detailed topology information.
- Reduce the frequency of shortest-path calculations.
  - SPF algorithm is CPU-intensive; the time it takes depends on the size of the area.

※ Shortest-Path First (SPF)

Topology (Lab11-OSPF.pkt)



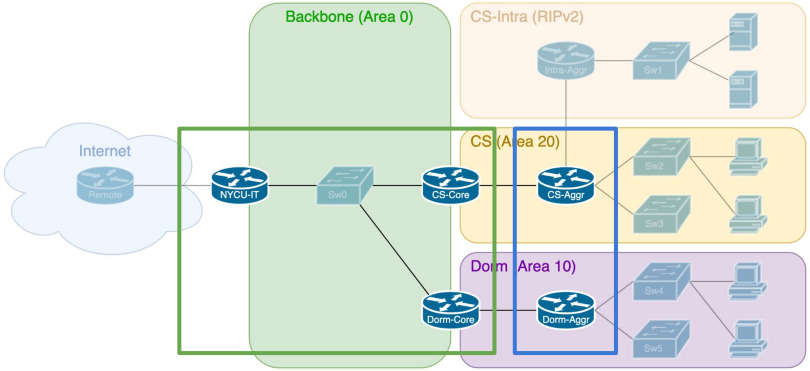
Explore the topology



- What is the **Router ID** for every router?
- How about **neighbors** and their states?
- How do we plan the **subnets**?
- Which networks are **advertised**?
- Can all devices reach others?
- Familiar with the routing table. (Optional)

※ Link-State Database (LSDB), Link State Advertisement (LSA)

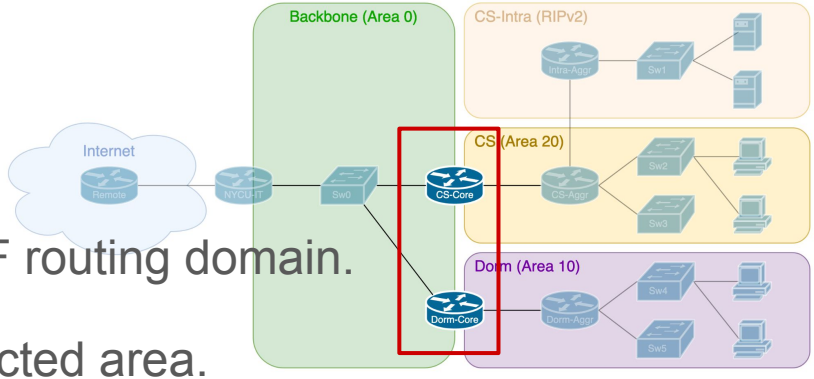
Router Types



- Backbone Router
  - A router connected to the OSPF backbone area.
  - It could be ABR, ASBR, or just a backbone router.
- Internal Router
  - A router that only connected to **the same area**.
  - All internal routers in the same area have the identical LSDB.
- Area Border Router (ABR)
- AS Boundary Router (ASBR)

※ Link-State Database (LSDB), Autonomous System (AS)

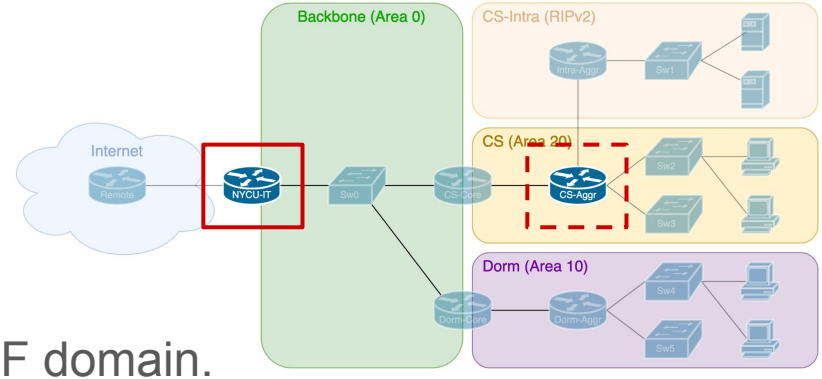
Area Border Router (ABR)



- Connects **different areas** within the OSPF routing domain.
- Maintains **separate LSDB** for each connected area.
- It can be configured to summarize the Link-States.

※ Link-State Database (LSDB)

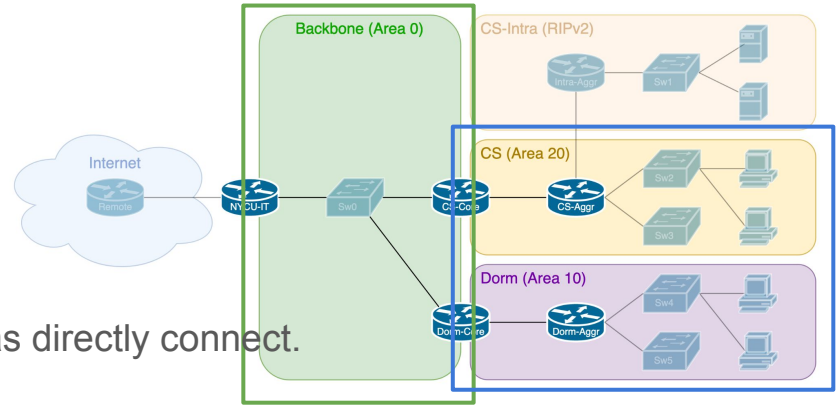
AS Boundary Router (ASBR)



- Connects OSPF with external networks.
- **Advertises external routes** into the OSPF domain.
- Vital for OSPF's inter-operability with other routing domains.

※ Autonomous System (AS)

Two-layer Area Hierarchy



- Backbone (Transit) Area
  - The core network is Area 0, where all other areas directly connect.
  - Fast and efficient delivery of IP packets.
  - Contains none of the end users.
- Non-backbone (Internal) Area
  - Must directly connect to the Backbone Area.
  - Connect end users and network resources.
  - Grouping by functions or geography.
  - There are five types: normal area, stub area, totally stubby area, NSSA, and Totally NSSA.

Inter-area routing: Non-backbone area -> Backbone area -> Non-backbone area

※ Not-So-Stubby Area (NSSA)

Verify ASBR

```
NYCU-IT# show ip protocols
[...]
  Router ID 140.113.0.1
  It is an autonomous system boundary router
  Redistributing External Routes from,
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
[...]
```

📝 Quiz: ABR must connect to…

A. the Backbone Area

B. the Non-backbone Area

C. both the Backbone Area and the Non-backbone Area

D. either the Backbone Area or the Non-backbone Area (Cannot be determined)

Hint: refer to Two-layer Area Hierarchy

※ Area Border Router (ABR)

Recap: What is LSA?

- **L**ink **S**tate **A**dvertisement
  - Individually, LSA acts as database records and provides specific OSPF network details.
- An LSDB (**L**ink **S**tate **D**ata**b**ase) contains many LSA.
  - In combination, LSA describes the entire topology of an OSPF network/area.
- There are 11 different LSA types.
  - Type 1 - 2: Single-Area
  - Type 3 - 5: Multi-Area
  - Type 6: Multicast (deprecated)
  - Type 7: Multi-Area (Not-So-Stubby Area)
  - Type 8 - 11: OSPFv3 (for IPv6)

LSA Types

#	Name	Sender	Receiver	Information
Type 1	Router LSA	Any OSPF Router	All other routers in the same area	Link / Network information
Type 2	Network LSA	DR	All other routers in the same area	List of routers that DR connects with
Type 3	Summary LSA	ABR	All routers in the different area	Network information of other areas
Type 4	ASBR Summary LSA	ABR	All routers in the different area	Information of ASBR
Type 5	AS External LSA	ASBR	All routers in OSPF routing domain	External network
Type 7	NSSA External LSA	ASBR	All the routers in the NSSA	External network

Verify Type 1 Router LSA and Type 2 Network LSA

```
Dorm-Aggr# show ip ospf 42 database router
       OSPF Router with ID (140.113.0.15)
               (Process ID 42)
           Router Link States (Area 10)

LS Type: Router Links
Link State ID: 140.113.0.15
Advertising Router: 140.113.0.15
Number of Links: 2

Link State ID: 140.113.0.10
Advertising Router: 140.113.0.10
Area Border Router
Number of Links: 1
```

```
Dorm-Aggr# show ip ospf 42 database network
       OSPF Router with ID (140.113.0.15)
               (Process ID 42)
           Net Link States (Area 10)

LS Type: Network Links
Link State ID: 10.0.1.2
Advertising Router: 140.113.0.15
Network Mask: /24
    Attached Router: 140.113.0.10
    Attached Router: 140.113.0.15
```

Type 3 Summary LSA (1/2)

#	Name	Sender	Receiver	Information
Type 1	Router LSA	Any OSPF Router	All other routers in the same area	Link / Network information
Type 2	Network LSA	DR	All other routers in the same area	List of routers that DR connects with
Type 3	Summary LSA	ABR	All routers in the different area	Network information of other areas
Type 4	ASBR Summary LSA	ABR	All routers in the different area	Information of ASBR
Type 5	AS External LSA	ASBR	All routers in OSPF routing domain	External network
Type 7	NSSA External LSA	ASBR	All the routers in the NSSA	External network

Type 3 Summary LSA (2/2)

- Generated by ABR to advertise networks from other areas.
  - Used to advertise inter-area routes.
  - It flooded throughout a single area only, not across area boundaries.
- In large networks, too many Type 3 LSA can cause traffic jams.
  - Manually configured router summarization is recommended on the ABR.
- Type 3 LSA is appropriately added to or deleted from the routing table.
  - Receiving a type 3 LSA into an area does not trigger the SPF algorithm.

※ Area Border Router (ABR), Shortest-Path First (SPF)

Verify Type 3 Summary LSA

```
Dorm-Aggr# show ip ospf 42 database summary
       OSPF Router with ID (140.113.0.15) (Process ID42)
           Summary Net Link States (Area 10)

LS Type: Summary Links(Network)
Link State ID: 140.113.0.0 (summary Network Number)
Advertising Router: 140.113.0.10
Network Mask: /24

Link State ID: 10.0.2.0 (summary Network Number)
Advertising Router: 140.113.0.10

Link State ID: 140.113.20.0 (summary Network Number)
Advertising Router: 140.113.0.10
```

Type 4 Summary LSA (1/2)

#	Name	Sender	Receiver	Information
Type 1	Router LSA	Any OSPF Router	All other routers in the same area	Link / Network information
Type 2	Network LSA	DR	All other routers in the same area	List of routers that DR connects with
Type 3	Summary LSA	ABR	All routers in the different area	Network information of other areas
Type 4	ASBR Summary LSA	ABR	All routers in the different area	Information of ASBR
Type 5	AS External LSA	ASBR	All routers in OSPF routing domain	External network
Type 7	NSSA External LSA	ASBR	All the routers in the NSSA	External network

Type 4 Summary LSA (2/2)

- The format of Type 3 LSA and Type 4 LSA is identical.
- Type 4 LSA describes routes to AS boundary routers.
  - While Type 3 LSA describes routes to networks.

Verify Type 4 Summary LSA

```
Dorm-Aggr# show ip ospf 42 database asbr-summary
       OSPF Router with ID (140.113.0.15) (Process ID 42)
           Summary ASB Link States (Area 10)

LS Type: Summary Links(AS Boundary Router)
Link State ID: 140.113.0.1 (AS Boundary Router address)
Advertising Router: 140.113.0.10
Network Mask: /0
```

Type 5 AS External LSA (1/2)

#	Name	Sender	Receiver	Information
Type 1	Router LSA	Any OSPF Router	All other routers in the same area	Link / Network information
Type 2	Network LSA	DR	All other routers in the same area	List of routers that DR connects with
Type 3	Summary LSA	ABR	All routers in the different area	Network information of other areas
Type 4	ASBR Summary LSA	ABR	All routers in the different area	Information of ASBR
Type 5	AS External LSA	ASBR	All routers in OSPF routing domain	External network
Type 7	NSSA External LSA	ASBR	All the routers in the NSSA	External network

Type 5 AS External LSA (2/2)

- Originated by AS Boundary Routers.
- Advertise routes to external destinations of the OSPF routing domain.
  - Typically learned via other routing protocols (e.g., BGP) or static routes.
- Flooded throughout the entire routing domain, except in stub areas.
- Help to propagate external routing information throughout the OSPF domain.
- It can be used to advertise a default route for the AS.

※ Open Shortest Path First (OSPF), Border Gateway Protocol (BGP), Autonomous System (AS)

Verify Type 5 AS External LSA

```
Dorm-Aggr# show ip ospf 42 database external

       OSPF Router with ID (140.113.0.15) (Process ID 42)

           Type-5 AS External Link States

Routing Bit Set on this LSA
LS Type: AS External Link
Link State ID: 0.0.0.0 (External Network Number)
Advertising Router: 140.113.0.1
Network Mask: /0
```

LSA Types

#	Name	Sender	Receiver	Information
Type 1	Router LSA	Any OSPF Router	All other routers in the same area	Link / Network information
Type 2	Network LSA	DR	All other routers in the same area	List of routers that DR connects with
Type 3	Summary LSA	ABR	All routers in the different area	Network information of other areas
Type 4	ASBR Summary LSA	ABR	All routers in the different area	Information of ASBR
Type 5	AS External LSA	ASBR	All routers in OSPF routing domain	External network
Type 7	NSSA External LSA	ASBR	All the routers in the NSSA	External network

Go Through the LSDB Summary

```
Dorm-Aggr# show ip ospf 42 database

  OSPF Router with ID (140.113.0.15)
            (Process ID 42)

    Router Link States (Area 10)
Link ID         ADV Router      Link count
140.113.0.15    140.113.0.15    2
140.113.0.10    140.113.0.10    1

    Net Link States (Area 10)
Link ID         ADV Router
10.0.1.2        140.113.0.15
```

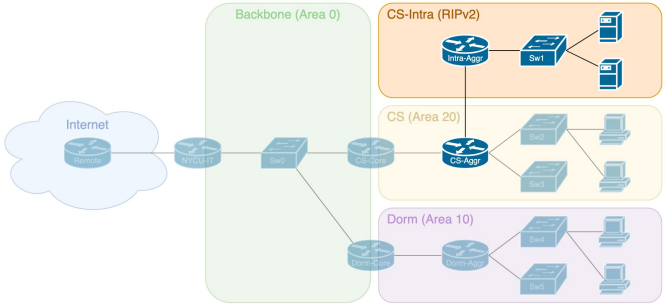
```
[...]

    Summary Net Link States (Area 10)
Link ID         ADV Router
140.113.0.0     140.113.0.10
10.0.2.0        140.113.0.10
140.113.20.0    140.113.0.10

    Summary ASB Link States (Area 10)
Link ID         ADV Router
140.113.0.1     140.113.0.10

    Type-5 AS External Link States
Link ID         ADV Router      Tag
0.0.0.0         140.113.0.1     1
```

Integrate with RIPv2




```
CS-Aggr(config)# router ospf 42
CS-Aggr(config-router)# redistribute rip subnets
```

```
CS-Core# show ip route
Codes: L - local, C - connected, O - OSPF, R - RIP, * - candidate default
  E1 - OSPF external type 1, E2 - OSPF external type 2 , IA - OSPF inter area

140.113.0.0/16 is variably subnetted, 5 subnets, 2 masks
C       140.113.0.0/24 is directly connected, GigabitEthernet0/0
O IA    140.113.10.0/24 [110/3] via 140.113.0.10, 00:00:12,
GigabitEthernet0/0
O       140.113.20.0/24 [110/2] via 10.0.2.2, 00:00:24, GigabitEthernet0/1
O E2    140.113.30.0/24 [110/20]  via 10.0.2.2, 00:00:32, GigabitEthernet0/1
O*E2    0.0.0.0/0       [110/1] via 140.113.0.1, 00:00:24, GigabitEthernet0/0
```

※ Routing Information Protocol version 2 (RIPv2)

Verify ASBR

```
CS-Aggr# show ip protocols
[...]
  Router ID 140.113.0.15
  It is an autonomous system boundary router
  Redistributing External Routes from,
    rip
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
[...]
```

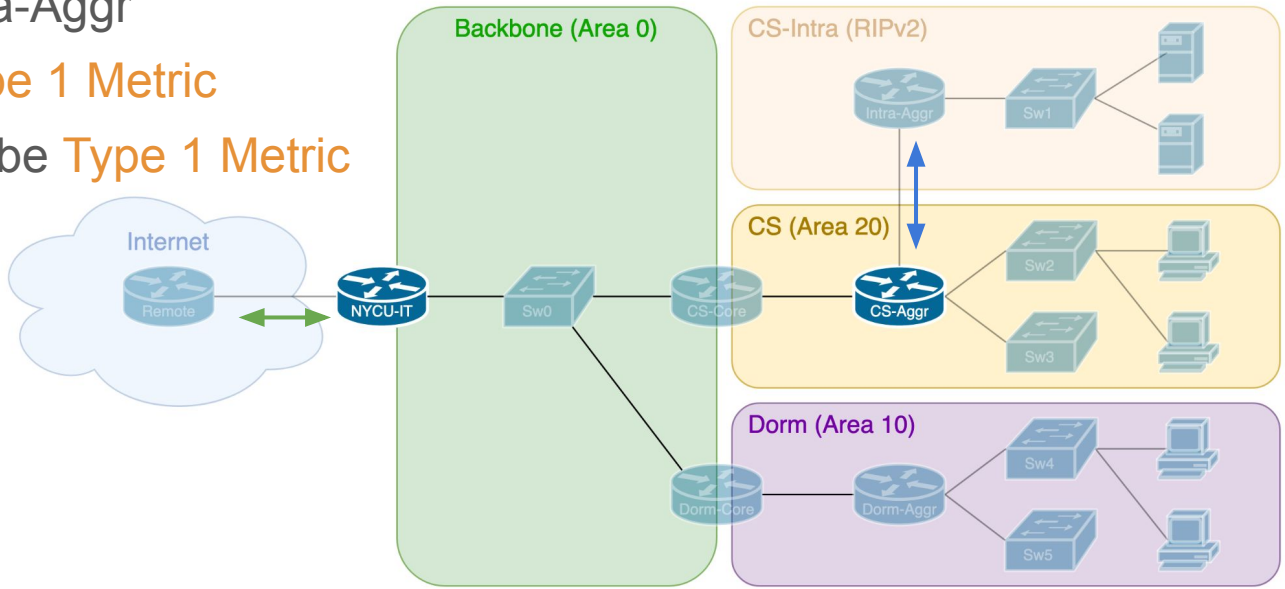
Metric Types for Type 5 LSA

- The metric for external routes can be Type 1 Metric or Type 2 Metric.
- What are the internal cost and the external cost?
- Type 1 Metric is comparable to the link state metric.
  - The total (internal + external) cost is used when calculating the routing table.
- Type 2 Metric is assumed to be larger than the cost of any intra-AS path.
  - The external cost dominates the total path cost.
  - The internal cost is considered only if multiple paths have the same external cost.
- Resulting `E1` and `E2` in routing table.

📝 Quiz: Metric Type

In our scenario, which external route is more suitable for Type 1 Metric?

A. NYCU-IT → Internet
B. CS-Aggr → Intra-Aggr
C. Both can be Type 1 Metric
D. Neigher should be Type 1 Metric

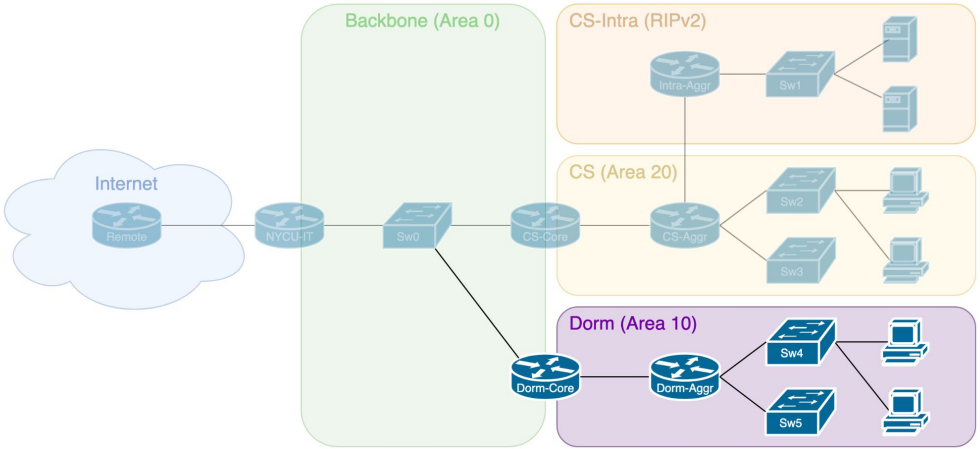


⏳ Break Time

- We learned: Router Types, LSA Types 3 - 5
- Next section: Stub Area, NSSA, Quiz Answer & QA

Stub Area

- Prevents the advertisement of external routes within the stub area.
  - Blocks Type 4 ASBR Summary LSA and Type 5 AS External LSA.
- Use the default route to reach external networks from the stub area.
- Simplifies routing and reduces routing table size.



Convert to Stub Area

- It must be configured consistently for all routers within the area.
  - The neighbor relationships cannot be established if the configurations mismatch.

```
Dorm-Core(config)# router ospf 42
Dorm-Core(config-router)# area 10 stub
```

```
Dorm-Aggr(config)# router ospf 42
Dorm-Aggr(config-router)# area 10 stub
```

Routing Table Difference for Stub Area

- Show the routing table and OSPF database.

```
Dorm-Aggr# show ip route

Codes: O - OSPF, E2 - OSPF external type 2, IA - OSPF inter area

-O E2 140.113.30.0/24 [110/4] via 10.0.1.1, 00:00:42, GigabitEthernet0/0
-O*E2 0.0.0.0/0 [110/1] via 10.0.1.1, 00:00:42, GigabitEthernet0/0
+O*IA 0.0.0.0/0 [110/2] via 10.0.1.1, 00:00:42, GigabitEthernet0/0
```

LSDB Difference for Stub Area

- Eliminates Type 4, 5 LSA.
- ABR will send a default route as Type 3 LSA.

```
 Dorm-Aggr# show ip ospf 42 database

   Summary Net Link States (Area 10)
 Link ID         ADV Router      Seq#
 140.113.0.0     140.113.0.10    0x80000001
 10.0.2.0        140.113.0.10    0x80000002
 140.113.20.0    140.113.0.10    0x80000003
+0.0.0.0         140.113.0.10    0x80000006

[...]
```

```
[...]
-   Summary ASB Link States (Area 10)
-Link ID         ADV Router      Seq#
-140.113.0.1     140.113.0.10    0x80000004
-140.113.0.25    140.113.0.10    0x80000005

-   Type-5 AS External Link States
-Link ID         ADV Router      Seq#       Tag
-0.0.0.0         140.113.0.1     0x80000001 1
-10.0.3.0        140.113.0.15    0x80000001 0
-140.113.30.0    140.113.0.15    0x80000001 0
```

Further Reduce the LSA info

- Convert Area 10 to Totally Stubby Area.
  - Eliminates Type 3, 4, 5 LSA.
- It only needs to be configured on ABR.
  - Why?

```
Dorm-Core(config)# router ospf 42
Dorm-Core(config-router)# area 10 stub no-summary
```

Routing Table Difference for Totally Stubby Area

- Show the routing table and OSPF database.

```
Dorm-Aggr# show ip route
Codes: C - connected, O - OSPF,  IA - OSPF inter area
    140.113.0.0/16 is variably subnetted, 6 subnets, 2 masks
-O IA   140.113.0.0/24  [110/2] via 10.0.1.1, 00:00:42, GigabitEthernet0/0
C       140.113.10.0/24 is directly connected, GigabitEthernet0/1
-O IA   140.113.20.0/24 [110/4] via 10.0.1.1, 00:00:42, GigabitEthernet0/0
O*IA    0.0.0.0/0       [110/1] via 10.0.1.1, 00:00:42, GigabitEthernet0/0
```

LSDB Difference for Totally Stubby Area

- Eliminates Type 3, 4, 5 LSA.
- ABR will send a default route as Type 3 LSA.

```
Dorm-Aggr# show ip ospf 42 database

  Summary Net Link States (Area 10)
Link ID         ADV Router      Seq#
-140.113.0.0    140.113.0.10    0x80000001
-10.0.2.0       140.113.0.10    0x80000002
-140.113.20.0   140.113.0.10    0x80000003
 0.0.0.0        140.113.0.10    0x80000006

[...]
```

```
[...]
-  Summary ASB Link States (Area 10)
-Link ID         ADV Router      Seq#
-140.113.0.1     140.113.0.10    0x80000004
-140.113.0.25    140.113.0.10    0x80000005

-  Type-5 AS External Link States
-Link ID         ADV Router      Seq#       Tag
-0.0.0.0         140.113.0.1     0x80000001 1
-10.0.3.0        140.113.0.15    0x80000001 0
-140.113.30.0    140.113.0.15    0x80000001 0
```

📝 Quiz: Type 1, 2 LSA in Totally Stubby Area

- Totally Stubby Area only eliminates Type 3, 4, 5 LSA.
- How about Type 1 Router-LSA and Type 2 Network-LSA?

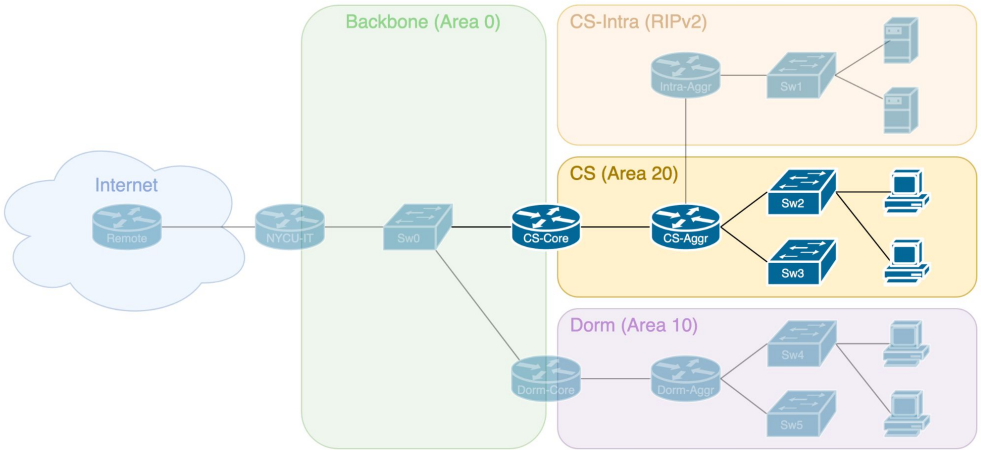
Summary LSA Comparison

LSA Type	Type 3 Network Summary LSA	Type 4 ASBR Summary LSA	Type 3 Default Summary Route
Purpose	Advertises routes between OSPF areas (inter-area)	Advertises the location of an ASBR to other areas	Advertises a default route to areas that do not have full routing information
Contents	Network address, subnet mask, cost	Router ID of the ASBR, cost to ASBR	Default route (0.0.0.0/0), cost
Usage	Used by ABR to share routes between areas, helping OSPF routers determine routes to networks in other areas.	Enables routers in other areas to locate the ASBR and use it for routing to external destinations.	Used in stub areas to provide a path to external networks without needing specific external routes.

※ Area Border Router (ABR), AS Boundary Router (ASBR), Autonomous System (AS)

Convert Area 20 to Stub Area

- Reduce overall network load.
- What can go wrong? Can we still connect to CS-Intra?



Not-So-Stubby Area (NSSA)

- We need Type 5 AS External LSA, but Stub Area forbids it.
  - Define Type 7 **NSSA** External LSA to bypass.
- Extension of OSPF Stub Area.
  - Like stub area, prevent Type 5 AS External LSA flooding in Not-So-Stubby Area.
  - Rely on the default summary route for external destinations.
- More flexible than Stub Area.
  - Can import external routes into the OSPF routing domain.
  - Provide transit service to small routing domains that are not part of the OSPF routing domain.

Type 7 AS External LSA

#	Name	Sender	Receiver	Information
Type 1	Router LSA	Any OSPF Router	All other routers in the same area	Link / Network information
Type 2	Network LSA	DR	All other routers in the same area	List of routers that DR connects with
Type 3	Summary LSA	ABR	All routers in the different area	Network information of other areas
Type 4	ASBR Summary LSA	ABR	All routers in the different area	Information of ASBR
Type 5	AS External LSA	ASBR	All routers in OSPF routing domain	External network
Type 7	NSSA External LSA	ASBR	All the routers in the NSSA	External network

Convert to Not-So-Stubby Area Area

- Just use the `nssa` keyword instead of the `stub`.

```
CS-Core(config)# router ospf 42
CS-Core(config-router)# no area 20 stub
CS-Core(config-router)# area 20 nssa
```

```
CS-Aggr(config)# router ospf 42
CS-Aggr(config-router)# no area 20 stub
CS-Aggr(config-router)# area 20 nssa
```

LSDB Difference for Normal Area → NSSA

- Eliminates Type 4 ASBR Summary LSA. Converts Type 5 to Type 7.
- No Type 3 Default Summary LSA.

```
CS-Aggr# show ip ospf 42 database

    Summary Net Link States (Area 20)
Link ID         ADV Router      Seq#
140.113.0.0     140.113.0.20    0x80000001
10.0.1.0        140.113.0.20    0x80000002
140.113.10.0    140.113.0.20    0x80000003

-   Summary ASB Link States (Area 20)
-Link ID         ADV Router      Seq#
-140.113.0.1     140.113.0.20    0x80000004
-140.113.0.20    140.113.0.20    0x80000005
```

```
[...]

-   Type-5 AS External Link States
+   Type-7 AS External Link States (Area 20)
 Link ID         ADV Router      Seq#       Tag
-0.0.0.0         140.113.0.1     0x80000001 1
 10.0.3.0        140.113.0.25    0x80000001 0
 140.113.30.0    140.113.0.25    0x80000001 0
-10.0.3.0        140.113.0.20    0x80000001 0
-140.113.30.0    140.113.0.20    0x80000001 0
```

3-Way Diff: Stub Area / Normal Area / NSSA

```
CS-Aggr# show ip ospf 42 database

  Summary Net Link States (Area 20)
Link ID       ADV Router     Seq#
140.113.0.0   140.113.0.20   0x80000001
10.0.2.0      140.113.0.20   0x80000002
140.113.10.0  140.113.0.20   0x80000003
0.0.0.0       140.113.0.20   0x80000006
```

```
CS-Aggr# show ip ospf 42 database

  Summary Net Link States (Area 20)
Link ID       ADV Router     Seq#
140.113.0.0   140.113.0.20   0x80000001
10.0.2.0      140.113.0.20   0x80000002
140.113.10.0  140.113.0.20   0x80000003

  Summary ASB Link States (Area 20)
Link ID       ADV Router     Seq#
140.113.0.1   140.113.0.20   0x80000004
140.113.0.20  140.113.0.20   0x80000005

  Type-5 AS External Link States
Link ID       ADV Router     Seq#
0.0.0.0       140.113.0.1    0x80000001
10.0.3.0      140.113.0.25   0x80000001
140.113.30.0  140.113.0.25   0x80000001
10.0.3.0      140.113.0.20   0x80000001
140.113.30.0  140.113.0.20   0x80000001
```

```
CS-Aggr# show ip ospf 42 database

  Summary Net Link States (Area 20)
Link ID       ADV Router     Seq#
140.113.0.0   140.113.0.20   0x80000001
10.0.2.0      140.113.0.20   0x80000002
140.113.10.0  140.113.0.20   0x80000003

  Type-7 AS External Link States
Link ID       ADV Router     Seq#

10.0.3.0      140.113.0.25   0x80000001
140.113.30.0  140.113.0.25   0x80000001
```

Totally NSSA

- Further reduce the table by eliminating Type 3, 4, 5 LSA.
- Note: Totally Stubby Area and Totally NSSA is a vendor-specific feature, not part of the OSPF standard.

```
CS-Core(config)# router ospf 42
CS-Core(config-router)# area 20 nssa no-summary
```

Stub Area Comparison (1/2)

Area	**External Routes** (Type 4, 5 LSA)	**Inter-Area Routes** (Type 3 LSA)
Normal Area	Yes	Yes
Stub Area	No	Yes
Totally Stubby Area	No	No
Not-So-Stubby Area (NSSA)	Yes (as Type 7 LSA)	Yes
Totally NSSA	Yes (as Type 7 LSA)	No

Stub Area Comparison (2/2)

Area	Restriction
Normal Area	● None
Stub Area	● No Type 4 and Type 5 LSA allowed.
Totally Stubby Area	● No Type 3, 4, 5 LSA allowed. ○ Except for the default summary route.
Not-So-Stubby Area (NSSA)	● No Type 4 and Type 5 LSA allowed. ○ Utilize Type 7 LSA for external routes.
Totally NSSA	● No Type 3, 4, 5 LSA allowed. ○ Except for the default summary route. ○ Utilize Type 7 LSA for external routes.

Thanks

Lab 11. Multi-Area OSPF

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