A semantic model for complex computer networks : the network description language

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Appendix A

Translation Specification of OSPFv2 LSAs to NDL

A.1 Introduction

The OSPF protocol is one of the main protocols in use in routers today. It defines a way for routers to discover and communicate with each other, in order to collectively and simultaneously learn the network topology. The routing algorithms in OSPF require that each of the routers maintain a database of the full topology.

Messages between routers are exchanged using OSPF packets. OSPF version 2 defines five different kinds of packets.

1. Hello
2. Database Description
3. Link State Request
4. Link State Update
5. Link State Acknowledgment
6. Opaque Link State Announcements

The first two packets are used in the discovery and first synchronization process. When a new router joins the OSPF topology it sends out a Hello discovery packet. To kick start the joining router an adjacent router sends over his complete database using the Database Description packet.

The next three are used to request and send updated information about the topology. The topology information itself is represented in a structure called a Link State Announcement (LSA). In this appendix we define how we translate all the information in the LSAs to the NDL syntax. The other data in the OSPF packets is only used to ensure correct delivery of the LSAs. We assume that the LSAs we receive have been delivered correctly, so we ignore the other data.

There are different types of LSAs:

1. Router LSA
2. Network LSA
3. Summary LSA (IP Network)
4. Summary LSA (Autonomous System Boundary Router)
5. Autonomous System External LSA

In the rest of this appendix we first examine the generic header of LSAs, and then successively examine each type of LSA.

A.2 Generic LSA Header

The generic LSA Header structure is shown in figure A.1. The diagram shows the fields of the header and their lengths in bits, using lines of 32 bits length.

The first field (LS Age) is an integer value that, together with the LS sequence number, is used to ensure that topology data eventually goes 'stale' and is removed. The Options field is used to relay optional capabilities of routers[1], these are not relevant to the topology, so we ignore them.

The last two fields (LS Checksum, and length) are used to ensure correct delivery of an LSA.

The value of LS type is used to distinguish between the different types of LSAs. The type of the LSA also impacts the interpretation of the Link State ID and the Advertising Router fields.

[1] The options field contains the following bits: `E` (flooding of AS-External-LSAs), `MC` (forwarding of multicast), `N/P` (Handling of type 7 LSAs), `EA` (handling External Attribute LSAs), `DC` (handling demand circuits).

```
 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            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure A.1: *The generic LSA Header*

A.3 LSA Type 1: Router LSAs

Each router describes his links to an area using a single router LSA. The LSA describes the status and metric cost of the interfaces of the router.

The first type of LSAs are Router LSAs. The values of `Link State ID` and `Advertising Router` are in this case identical and set to the sending Router's ID. Following the LSA Header the content of a Router LSA is shown in figure A.2.

The first line contains three bit-flags, surrounded by padding. The bits represent properties of the router sending the LSA:

`V` Virtual link endpoint; The router is an endpoint of virtual links, which have this area as Transit area.

`E` External; This bit is set when the advertising router is an AS boundary router.

`B` Border; The advertising router is an area border router when this bit is set.

In summary these bits are only relevant for distributing routes through different areas, and are not directly related to topology. The flag bits is followed by the specification of the number of links present in the LSA. Each link is of a type between one and four, and the meaning of each field depends on the type:

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    0    |V|E|B|        0      |            # links            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Link ID                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Link Data                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |     # TOS     |            metric             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              ...                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      TOS      |        0      |          TOS  metric          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Link ID                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Link Data                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              ...                              |
```

Figure A.2: *The Router LSA body structure*

1. Point-to-Point connection to another router (unnumbered)

   `Link ID`: Neighboring router's Router ID

   `Link Data`: The interface's MIB-II ifIndex value

2. Connection to a transit network

   `Link ID`: IP Address of the Designated Router

   `Link Data`: The router interface's IP address

3. Connection to a stub network

   `Link ID`: IP network/subnet number

   `Link Data`: The IP network/subnet mask

4. Virtual Link

   `Link ID`: Neighboring router's Router ID

   `Link Data`: Router interface's IP address

Each Link also carries a metric section, which specifies the link metric (`metric`), and the number of additional metrics (`# TOS`). Each TOS is defined on a separate line containing the IP Type of the service (`TOS`), followed by a padding byte and the TOS-specific metric information. The TOS metrics are not used widely, they are only included for backwards compatibility with OSPFv1.

A.3.1 Translation to NDL

From a Router LSA we can extract the following topological information:

- There is a device R with name `dev + Advertising Router`. We add the prefix here to avoid the clash with the interface of the router with that IP-address.
- For each link segment we can conclude that the router R *hasInterface* I with metric `metric`.
- The name of the interface I depends on the link type value:
  1. `p + Advertising Router + p + Link ID` This is an unnumbered interface, and is *connectedTo* an interface I' called `p + Link ID + p + Advertising Router`.

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Network Mask                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Attached Router                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              ...                              |
```

Figure A.3: *The body structure of a Network LSA*

2. `Link Data` *connectedTo* a broadcast segment BC called `bc + Link ID`.
3. `stub + Advertising Router + net + Link Id` The interface is *connectedTo* a broadcast segment BC called `stub + Link ID`.
4. `Link Data` *connectedTo* interface I' of device R', called `dev + Link ID`. The name of interface I' can only be determined once we receive a matching Link description of R'.

Note that we have ignored the TOS metric. While the TOS metric fields are still present in OSPFv2 LSAs, they are only supported for backward compatibility and are never used in practice.

A.4 LSA Type 2: Network LSAs

Network LSAs are originated for broadcast and NBMA networks in areas where there are two or more routers. The Network LSA is sent by the designated router for the area. The `Link State ID` is in this case set to the IP address of the DR's interface in the network, and the `Advertising Router` is the DR's router ID. Following the LSA header, the Network LSA is rather simple, as shown in figure A.3.

The `Network Mask` contains the mask for the network, after which the IDs of the attached routers are listed, including the DR.

A.4.1 Translation to NDL

From a Network LSA we can extract the following topological information:

- There is a router R with router ID `Advertising Router`, which we call `dev + Advertising Router`.

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Network Mask                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      0        |                  metric                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     TOS       |                TOS  metric                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              ...                              |
```

Figure A.4: *The body structure of a Summary LSA*

- R *hasInterface* I, which is called `Link State ID`. This interface is connected to the broadcast segment BC called `bc + Link State ID`.
- For each of the values of `Attached Router` we can conclude:
  - There is a device R' called `dev + Attached Router`.
  - R' has also sent out a Type 1 LSA, listing (an) interface(s) I', which is already *connectedTo* broadcast segment BC.
  - For each of the above interfaces I' of R' we add a *connectedTo* from the broadcast segment BC to that interface.

A.5 LSA Type 3 & 4: Summary LSAs

LSA Types 3 and 4 are summary LSAs. These LSAs are originated by area border routers and are used to distribute network routes to destinations outside the area. Note that this means that these LSAs are only sent when the OSPF network contains multiple areas. Type 3 LSAs are used for routes to other areas , while type 4 are used for AS external routes. An example is a default route to an AS border router, which means that any traffic for which no other route is defined is routed to that AS border router.

The only difference in the summary LSAs is in the meaning of the `LSA Link ID`, for type 3 this contains the IP network number, while in type 4 this contains the AS boundary router's Router ID. The `Advertising Router` field is always the area's border router. The structure of the summary LSAs after the generic header is shown in figure A.4.

The `Network Mask` contains the mask of the route that is being advertised, and the `metric`, `TOS`, and `TOS metric` are of the same format as in type 2 LSAs.

A.5.1 Translation to NDL

From a type 3 Summary LSA we can extract the following topological information:

- There is a device R with router ID `Advertising Router`, which we call `dev + Advertising Router`.
- R *hasInterface* I called `Advertising Router + if + LSA Link ID`. This interface has a *metric* of `metric`.
- Interface I is *connectedTo* a Network Domain ND called `nd + LSA Link ID`.

From a type 4 Summary LSA we can extract the following:

- There is a device R named `dev + Advertising Router`, and a device R' named `dev + LSA Link ID`.
- R is connected through an abstracted link with R', with interface I .
- I has a *metric* of `metric`.

Note that we have ignored the TOS metric. While the TOS metric fields are still present in OSPFv2 LSAs, they are onlly supported for backward compatibility and are never used in practice.

A.6 LSA Type 5: AS External LSAs

The last type of OSPF v2 LSAs are AS External LSAs. These LSAs are originated by AS boundary routers to describe destinations external to the AS. Contrary to other LSAs the AS External LSAs are flooded over the entire routing domain. When multiple areas are used, the information from a type 5 LSA is not sufficient, because routers in other areas will not know how to reach the boundary router. In this case the type 4 LSAs are used to distribute additional reachability information.

The `Advertising Router` is the router ID of the AS boundary router, and the `Link State ID` is used to describe the destination network number, or `0.0.0.0` for the default route. The structure of the AS External LSA after the header is shown in figure A.5

The fields have the following meaning:

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Network Mask                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|E|     0       |                  metric                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Forwarding address                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      External Route Tag                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|E|    TOS      |                TOS  metric                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Forwarding address                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      External Route Tag                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              ...                                |
```

Figure A.5: *The body structure of an AS External LSA*

`Network Mask` The network mask for the destination network or `0.0.0.0` in case of the default route.

`E` This flag signals whether the metric is a Type 1 (off) or 2 (on) external metric. In case of type 2, the metric is always considered to be higher than any internal metric.

`metric` The value of the metric.

`Forwarding Address` Data for the described destination should be forwarded to this address. If it is set to `0.0.0.0`, use the address `Advertising Router`.

`External Route Tag` This field is not used by the OSPF protocol itself, but is used for communication between AS boundary routers.

`TOS` For each TOS value, different destinations can be defined, using the similar fields as above.

A.6.1 Translation to NDL

From a type 5 AS External LSA we can extract the following topological information:

- There is a device R with Router ID `Advertising Router`, which we call `dev + Advertising Router`.
- If `Forwarding Address` equals `0.0.0.0`, the router is in the same area, and we already know how R is connected to the rest of the network.
- R *hasInterface* I with an abstract connection to the interface I' `Forwarding Address` a router R'.
- A Network Domain ND called `nd + Link State ID`.
- I has a *metric* of `metric`.

Note that we have ignored the TOS metric. While the TOS metric fields are still present in OSPFv2 LSAs, they are only supported for backward compatibility and are never used in practice.