CIM Network OSPF Sub-Model White Paper

CIM Version 2.8

Version 1.1 December 2, 2003

Abstract

The DMTF Common Information Model (CIM) is a conceptual information model for describing computing and business entities in enterprise and Internet environments. It provides a consistent definition and structure of data, using object-oriented techniques. The CIM Schema establishes a common conceptual framework that describes the managed environment.

The Open Shortest Path First (OSPF) Sub-Model extends the CIM Network Model to enable configuring one of the most widely used Interior Gateway Protocols (IGPs) in the Internet. The purpose of this white paper is to describe the concepts behind the sub-model, and explain how it should be used. The intended audience of this paper is anyone who wants to use this model to configure real OSPF networks, or who would like to extend this work. The reader should already have a working knowledge of OSPF and some familiarity with CIM (especially with the Network Model).

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1. Introduction

1.1 Overview

This white paper describes the CIM OSPF Sub-Model, as defined by the DMTF Network Working Group, initially released in CIM Schema v2.7.

Together with the associated MOF file and Visio drawing, this paper documents the extensions to CIM representing the OSPF configuration of a computer network. This model was influenced by the CIM BGP (Border Gateway Protocol) Model, the OSPF SNMP MIB and by implementation experience. This model also utilizes elements of other CIM Models, such as the IPAddressRange, RemoteServiceAccessPoint and RouteCalculationService classes from the Network Model.

The goal of this model is to enable network management applications (and the network operators) to manage an OSPF network on a higher level than with today's element management applications. This higher level means a more abstract level, but also a configuration with fewer errors. It is worth noting that this model describes only the configuration of the OSPF, it does not describe how OSPF works.

This model is based on the definition of OSPF in the IETF's RFC 2328 and the OSPF MIB in RFC 1850, and also covers the following additional OSPF extensions: Multicast Extensions to OSPF (RFC 1584), OSPF NSSA Option (RFC 1587), OSPF Database Overflow (RFC 1765), Extending OSPF to Support Demand Circuits (RFC 1793). It must be emphasized that although this model covers the configuration of the Multicast Extensions to OSPF, the CIM Network Model does not cover multicast configuration of IP routers, so the current CIM Network Model is not able to fully configure Multicast OSPF.

***Note**: All classes defined by the DMTF in the various models are named using the following syntax: CIM_<Class Name>. For reading convenience, the CIM_ prefix is omitted on class names throughout this paper, unless required for clarity.*

1.2 Background Reference Material

- OSPF Version 2, RFC 2328, http://www.ietf.org/rfc/rfc2328.txt
- OSPF Version 2 Management Information Base, RFC 1850, http://www.ietf.org/rfc/rfc1850.txt
- Multicast Extensions to OSPF, RFC 1584, http://www.ietf.org/rfc/rfc1584.txt
- The OSPF NSSA Option, RFC 1587, http://www.ietf.org/rfc/rfc1587.txt
- OSPF Database Overflow, RFC 1765, http://www.ietf.org/rfc/rfc1765.txt

- Extending OSPF to Support Demand Circuits, RFC 1793, http://www.ietf.org/rfc/rfc1793.txt
- "OSPF: The Anatomy of an Internet Routing Protocol," by John T. Moy, Addison-Wesley Pub Co; ISBN: 0201634724.

1.3 Terminology

Term	Definition
Area	OSPF allows sets of networks to be grouped together. Such a grouping is called an area.
Autonomous System (AS)	A group of routers exchanging routing information via a common routing protocol.
Broadcast networks	Networks supporting more than two attached routers, together with the ability to address a single physical message to all of the attached routers (broadcast).
Interface	The connection between a router and one of its attached networks.
Interior Gateway Protocol (IGP)	The routing protocol spoken by the routers belonging to an Autonomous System.
Link	A network with OSPF adjacency between the routers of the network (i.e., there is a link on the network if the routers of the network form an adjacency to each other).
Link-state routing protocol	In a link-state routing protocol, each router maintains a database describing the Autonomous System's topology. This database is referred to as the link-state database. Each participating router has an identical database. Each individual piece of this database is a particular router's local state (e.g., the router's usable interfaces and reachable neighbors). The router distributes its local state throughout the Autonomous System by flooding.
LSA	Link State Advertisement, a unit of data describing the state of a router or a link.
Network	An IP network/subnet/supernet. It is possible for one physical network to be assigned multiple IP network/subnet numbers. DMTF considers these to be separate networks. Point-to-point physical networks are an exception - they are considered a single network no matter how many (if any at all) IP network/subnet numbers are assigned to them.
Non-broadcast (NBMA) networks	Networks supporting many (more than two) routers, but having no broadcast capability.
OSPF	Open Shortest Path First, an IGP routing protocol using link-state technology.
Point-to-MultiPoint networks	A non-broadcast network configured as a collection of point-to-point links.
Point-to-point networks	A network that joins a single pair of routers.
Router	A level three Internet Protocol packet switch.
SLIP	Serial Line IP, a communications protocol for dial-up

	access to TCP/IP networks.
Stub network	A network thatis connected to only one router (so there cannot be a link over this network).

2. The OSPF Model

2.1 Background and Assumptions

This model was developed to represent a network's OSPF configuration. It contains only classes and attributes, which are used to configure routers.

Although this model was designed to contain the "desired" configuration of the network (the configuration "desired" by the network operator), it may be used to represent the configuration of a working, existing network. In this case, the semantics of some attributes change (e.g., the status attributes are not "administrative" statuses, but "operational" statuses). In addition, there might be further implications, such as when the existing network has an invalid OSPF configuration. For example, if the HelloInterval attribute is set to different values on a subnet, then one OSPFLink object must be used for each different HelloInterval value. (This is valid, however, since according to the OSPF specification there is no adjacency between the routers with different HelloInterval values. They are not connected to the same link.)

2.2 Conceptual Areas Addressed by the Model

This model addresses the configuration of the OSPF routing protocol, not the way it works. Therefore, items such as the LSA database are not modeled. Because OSPF is a hierarchical routing protocol, the model addresses both the inter-area level and the intra-area level configuration of OSPF.

2.3 The Classes/ Concepts on the Intra-area Level

The intra-area level contains the following new classes: OSPFLink, OSPFProtocolEndpointBase, OSPFProtocolEndpoint, OSPFVirtualInterface, OSPFService and OSPFArea.

From our point of view, the computer network is a graph. The vertices of this graph are routers (represented by the **OSPFService** class), interfaces (represented by the descendants of the **OSPFProtocolEndpointBase** class) and links (represented by the **OSPFLink** class). The router objects are connected to interface objects, interface objects are connected to exactly one router object and to at most one link object, and link objects are connected to interface objects. The connection between the OSPFService and the OSPFProtocolEndpointBase objects is not direct, it goes through the hosting ComputerSystem object (this object also represents the router, but on another logical level). An OSPFService object is connected to a ComputerSystem object via the HostedService association, and the ComputerSystem object is connected to the OSPFProtocolEndpointBase object via the HostedAccessPoint association.

A very important point in the DMTF OSPF model is that the link is represented by a class, and this class has configurable attributes. In the OSPF specification, links do not have configurable attributes, however, the interfaces do have some attributes (e.g., HelloInterval), which must be set to the same value at every interface of a network in order to enable OSPF to create adjacencies (and so a link) on the network. DMTF calls these attributes link-scope attributes and the rest of the interface attributes (e.g., Cost, Priority, etc.) interface-scope attributes. These attributes are logically the link's attributes; therefore, DMTF created the OSPFLink class and put those attributes into this class. This enables the network operator to change the value of a link's link-scope attribute at only one place, and not in every interface attached to that link. It is not only convenient, but also reduces the number of configuration errors.

The reader might notice that the OSPFLink does not contain the authentication-related attributes (AuthType and AuthKey), although they are also link-scope attributes. This is to allow the network operator to configure these two attributes on an interface, even if there are no other interfaces attached to the network (i.e., it is a stub network), thereby preventing malicious users from setting up unauthorized OSPF routers that disturb the routing. Another solution for this problem would have been to put these attributes into the OSPFLink class and made OSPFLink objects compulsory to represent stub networks, but it was determined that would add too many unnecessary objects to the model.

The two alternatives are shown in the following figures.

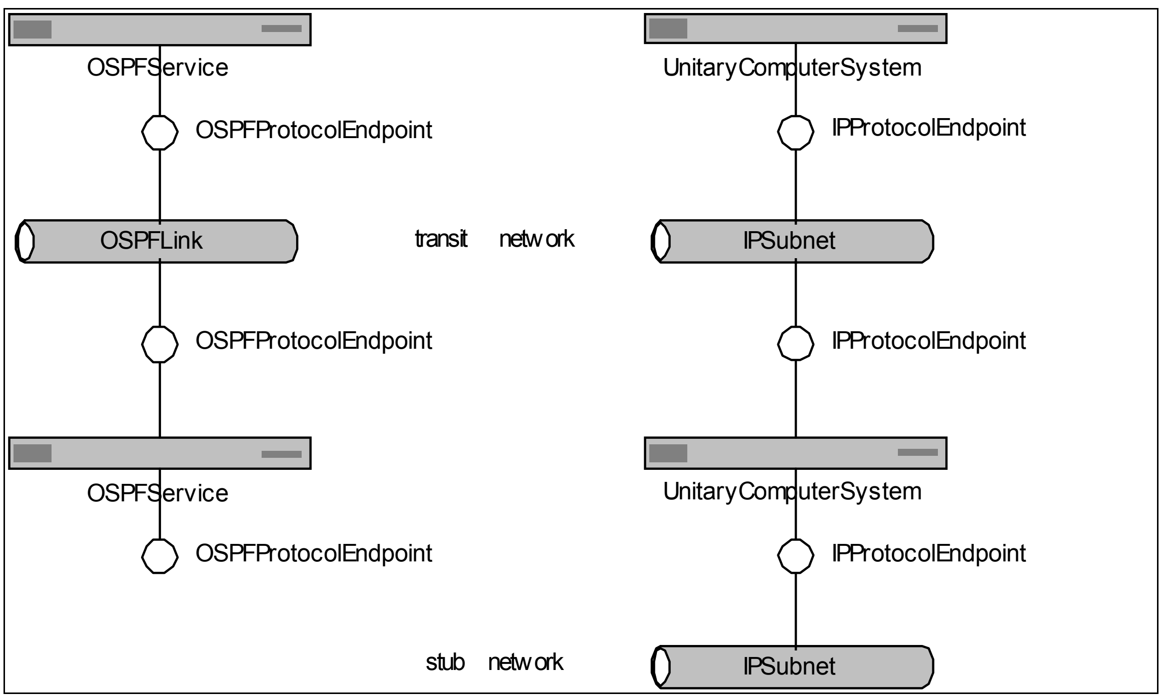


Figure 1 Modeling stub network without OSPF link

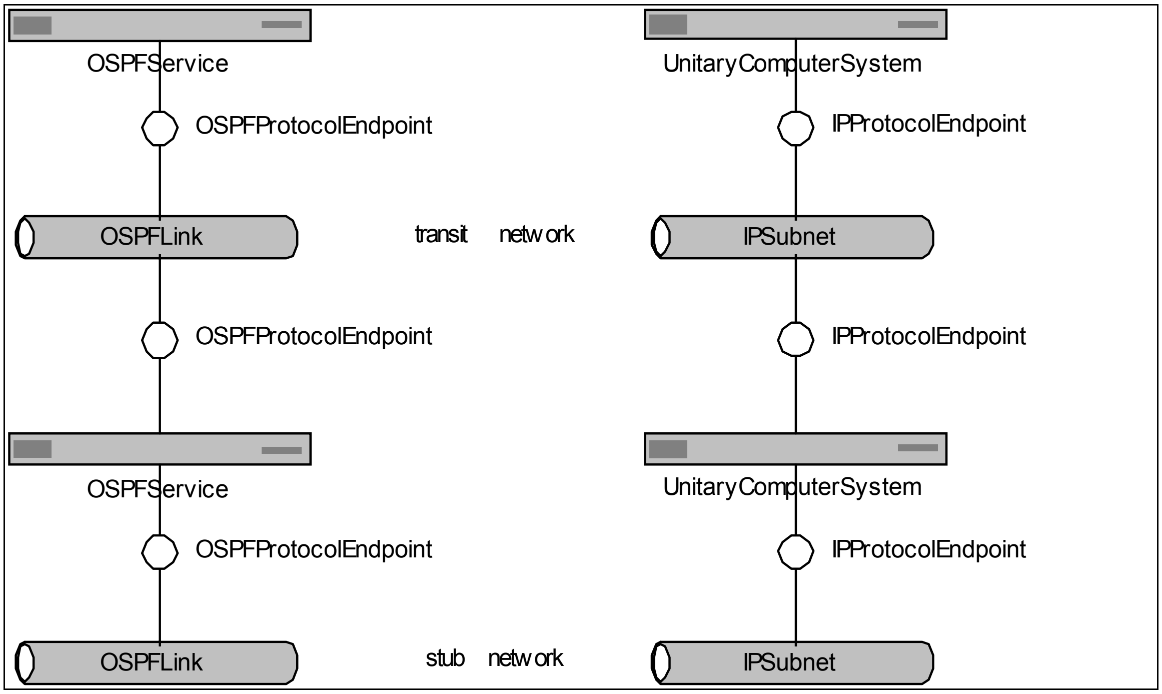


Figure 2 Modeling stub network with OSPF link

On the left hand side of Figures 1 and 2 there are objects representing the OSPF configuration, while on the right hand side there are the objects representing the IP configuration (for drawing convenience, the ComputerSystem objects are omitted on the left hand side of the figures).

It might seem that one class does not make much difference, but it must be noted that the majority of the subnets in a network are stub networks, so in a large network this configuration can be a much simpler. However, the most important reason for this approach is that it is counter-intuitive to have a “link” object that is connected to only one other object.

The fact that DMTF has chosen the first alternative has another important consequence: in OSPF, every interface on a link must be in the same area, so it is another link-scope attribute. This suggests that the OSPFLink class should be connected to the OSPFArea class to represent this relation. However, there is a problem with this approach: interfaces toward stub networks and passive interfaces are not connected to any links, therefore, it is not enough to connect the link class to the area class – the interfaces must be connected to the area, as well. In this case, the association between the link and the area becomes redundant, so DMTF did not add this to the model.

Another OSPF protocol feature is the host route. When, for example, a host is directly connected to an OSPF router via a SLIP line, OSPF does not advertise this host, unless a host route to this host is explicitly configured. This is modeled by an interface connected to a RemoteServiceAccessPoint object (the latter represents the host’s IP interface toward the router).

2.4 The Classes/ Concepts on the Inter-area Level

The inter-area level contains the following additional new classes: OSPFAreaConfiguration, RoutingDomain.

The DMTF OSPF routing protocol supports hierarchical routing. An AS can be divided into areas and the areas contain disjoint sets of interfaces. It is important to notice that a router can be connected to more than one area: these routers are called Area Border Routers (ABR). In addition, there can be more than one ABR between two areas.

The OSPF area is represented by the **OSPFArea** class,a descendant of the new **RoutingDomain** class. RoutingDomain is the only Network class introduced in CIM 2.7 that is not OSPF-specific, but it adds a common base class for other IGP models that might also need a class like the OSPF area to represent their hierarchy. For example, an IS-IS model could use this class to inherit from when it adds a class representing the IS-IS layer. As this kind of class inherits the RoutingDomainInAS association also, their respective models do not need to add a relation between the AutonomousSystem class and their "area-like" class.

A key reason DMTF has introduced areas into OSPF is to allow the network administrator to summarize different networks in an address range into one Summary LSA, so fewer LSAs are needed to describe the whole network. This address range is represented by the **IPAddressRange** class. Typically, a network administrator wants to set the same address ranges in every ABR between two areas, so the obvious modeling choice would be to put the IPAddressRange class between two areas (i.e., create association between OSPFArea and IPAddressRange). However, this solution has two drawbacks: the network administrator might not want use the same set of address ranges in every ABR between the two routers, and the network administrator might want to use the same address range between two different pairs of areas. This second drawback might not sound very significant, but in fact it is important, because OSPF enables other uses of these address ranges (for example, address ranges can be specified to disable advertising networks in that range). It is very useful in hiding private networks (e.g., a network using addresses from the 192.168.0.0/16 range) from the other parts of the network, and it is essential if there are private networks using the same addresses in other areas too.

The conclusion from the above is that there must be an association between the address range and the ABR, which advertises (or hides) the networks in that range. This association must be associated to an area also.

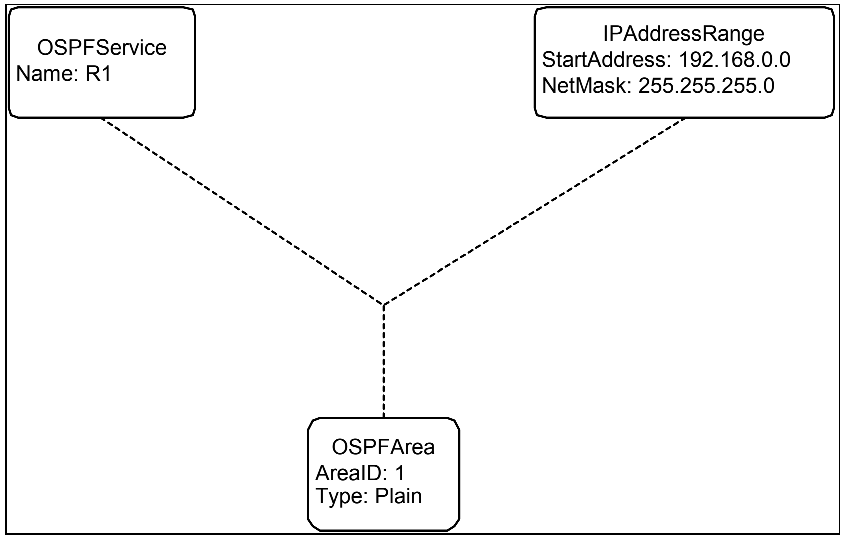


Figure 3 R1 advertises 192.168.0.0/24 (3-way association)

Since there cannot be three-way associations in CIM, the **OSPFAreaConfiguration** class was introduced. An object of this class is connected to exactly one router and one area, and it represents the part of that router's configuration that is relevant to an area. Then, the address ranges, which are configured in this router for this area, are connected to this object. It is worth noting that this class contains the StubDefaultCost and the StubMetricType attributes, which are again area- and router-specific attributes. Their obvious place would be on an association between the area and the router, so it was put into this class (which is used instead of the association).

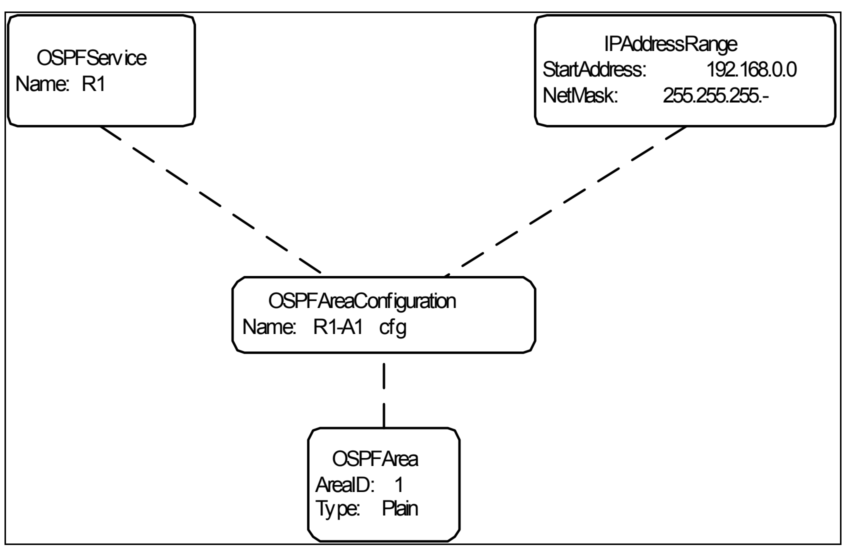


Figure 4 R1 advertises 192.168.0.0/24 (OSPFAreaConfiguration)

In OSPF, the areas must have a special topology: every area must be connected to the backbone area (the area with 0 AreaID), and the backbone must be contiguous. Sometimes the physical topology does not enable this, so the network operator must create a virtual link between two routers of the backbone. From the OSPF point of view, the virtual link is an unnumbered point-to-point link, which connects two routers. This is modeled similarly to a real link: an OSPFLink object is connected to two OSPFVirtualInterface objects, and these two are connected to their respective OSPFService objects (through the appropriate ComputerSystem object).

Rather than use the same class that was used for the real interfaces, the OSPFVirtualInterface class was introduced because many attributes of a real interface are meaningless to a virtual interface. Of course, there are many common attributes to real and virtual interfaces –in the OSPFProtocolEndpointBase class – and the classes of the real and virtual interfaces are inherited from this class.

3. Relationships to Other Standards and Specifications

3.1 Overlapping Standards and Specifications

The RFC 2328 defines the OSPF routing protocol, version 2. The specification was first issued as RFC 1247 in 1991, but it has been revised four times, the last time in 1998, when the RFC2328 was issued. There were only minor changes to the protocol during these revisions, and these changes were always backward compatible.

Our model implements some extensions to the OSPF defined in RFC 1584, 1587, 1765 and 1793. The Multicast Extension to OSPF (defined in RFC 1584) added only a few configurable parameters to OSPF. The OSPF NSSA option (defined in RFC 1587) added a new area type to OSPF. The OSPF Database Overflow (defined in RFC 1765) added a configurable attribute to limit the maximum number of External LSAs in an area. Finally, the RFC 1793 added support for Demand Circuits (two configurable attributes). There are some additional OSPF RFCs, but most of them do not add additional configurable attributes to OSPF, they just alter the way the routing protocol works.

The SNMP MIB for OSPF is defined in RFC 1850. DMTF named most of our attributes after the relevant attributes in this document.

3.2 A Mapping of RFC 2328 into the Model

The configurable attributes of the OSPF Version 2 are specified in appendix C in RFC 2328. In the following table, we specify the corresponding attribute pairs in the RFC and in the DMTF OSPF model:

Attribute name in RFC 2328	Class and attribute in DMTF OSPF model
Router ID (of a router)	CIM_RouteCalculationService.RouterID
RFC1583Compatibility	CIM_OSPFService.RFC1583Compatibility
Area ID (of an area)	CIM_OSPFArea.AreaID
List of address ranges	CIM_IPAddressRange objects
Status (of a range)	CIM_RangesOfConfiguration.EnableAdvertise
ExternalRoutingCapability	CIM_OSPFArea.AreaType (stub area type)
StubDefaultCost	CIM_OSPFAreaConfiguration.StubDefaultCost
Area ID (of an interface)	CIM_EndpointInArea association of the interface
Interface Output Cost	CIM_OSPFProtocolEndpoint.Cost
RxmtInterval	CIM_OSPFProtocolEndpointBase.RetransmitInterval

InfTransDelay	CIM_OSPFProtocolEndpointBase.TransitDelay
Router Priority	CIM_OSPFProtocolEndpoint.Priority
HelloInterval	CIM_OSPFLink.HelloInterval
RouterDeadInterval	CIM_OSPFLink.RouterDeadInterval
AuType	CIM_OSPFProtocolEndpointBase.AuthType
Authentication Key	CIM_OSPFProtocolEndpointBase.AuthKey
List of all other attached routers (on NBMA networks)	CIM_EndpointInLink associations of CIM_OSPFLink
PollInterval	CIM_OSPFProtocolEndpoint.PollInterval
Host IP address (of a host route)	CIM_RemoteServiceAccessPoint.AccessInfo
Cost of link to host	CIM_OSPFProtocolEndpoint.Cost
Area ID (of a host route)	CIM_EndpointInArea association of the interface

3.3 A Mapping of RFC 1584 into the Model

The configurable attributes of the Multicast Extension to OSPF are specified in appendix B in RFC 1584. In the following table, we specify the corresponding attribute pairs in the RFC and in the model:

Attribute name in RFC 1584	**Class and attribute in DMTF OSPF model**
Multicast capability	CIM_OSPFServiceCapabilities.SupportMOSPF
Inter-area multicast forwarder	CIM_OSPFService.IsInterAreaMulticastForwader
Inter-AS multicast forwarder	CIM_OSPFService.IsInterASMulticastForwader
IPMulticastForwarding	CIM_OSPFLink.MulticastForwarding

3.4 A Mapping of RFC 1587 into the Model

The OSPF NSSA option adds only one area type, one possible value to the AreaType attribute of the CIM_OSPFArea class. This is the “NSSA” value.

3.5 A Mapping of RFC 1765 into the Model

The configurable attributes of the OSPF Database Overflow specification are in section 2.1 in RFC 1765. In the following table, we specify the corresponding attribute pairs in the RFC and in the model:

Attribute name in RFC 1765	Class and attribute in DMTF OSPF model
ospfExtLsdbLimit	CIM_OSPFArea.ExtLsdbLimit
ospfExitOverflowInterval	CIM_OSPFService.ExitOverflowInterval

3.6 A Mapping of RFC 1793 into the Model

The configurable attributes of the Extending OSPF to Support Dynamic Circuits specification are in appendix B in RFC 1793. In the following table, we specify the corresponding attribute pairs in the RFC and in the model:

Attribute name in RFC 1793	Class and attribute in DMTF OSPF model
ospfIfDemand	CIM_OSPFProtocolEndpoint.IfDemand

3.7 A Mapping of RFC 1850 into the Model

The OSPF Version 2 Management Information Base contains most of the attributes already mentioned. This RFC contains not only configurable attributes, but statistical attributes, as well. Naturally, the attributes of the latter kind are not in the model. In the following table, we specify the corresponding attribute pairs in the RFC and in the model:

Attribute name in RFC 1850	Class and attribute in DMTF OSPF model
ospfRouterId	CIM_RouteCalculationService.RouterID
ospfAdminStat	CIM_ManagedSystemElement.Status
ospfExtLsdbLimit	CIM_OSPFArea.ExtLsdbLimit
ospfMulticastExtensions	CIM_OSPFService.RunningMOSPF CIM_OSPFService.IsInterAreaMulticastForwader CIM_OSPFService.IsInterAsMulticastForwader
ospfExitOverflowInterval	CIM_OSPFService.ExitOverflowInterval
ospfDemandExtensions	CIM_OSPFServiceCapabilities.SupportOndemand
ospfAreaId	CIM_OSPFArea.AreaId
ospfAuthType	CIM_OSPFProtocolEndpoint.AuthType
ospfImportAsExtern	CIM_OSPFArea.AreaType (stub area type)
ospfStubMetric	CIM_OSPFAreaConfiguration.StubDefaultCost
ospfStubMetricType	CIM_OSPFAreaConfiguration.StubMetricType

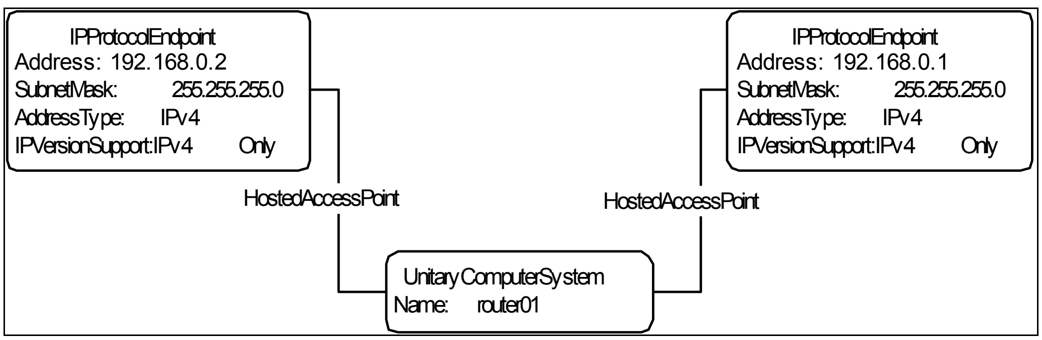
ospfHostIpAddress	CIM_RemoteServiceAccessPoint.AccessInfoString
ospfHostMetric	CIM_OSPFProtocolEndpoint.Cost
ospfHostAreaID	CIM_EndpointInArea association of the interface
ospfIfAreaId	CIM_EndpointInArea association of the interface
ospfIfType	CIM_OSPFLink.LinkType
ospfIfAdminStat	CIM_ProtocolEndpoint.EnabledStatus
ospfIfRtrPriority	CIM_OSPFProtocolEndpoint.Priority
ospfIfTransitDelay	CIM_OSPFProtocolEndpointBase.TransitDelay
ospfIfRetransInterval	CIM_OSPFProtocolEndpointBase.RetransmitInterval
ospfIfHelloInterval	CIM_OSPFLink.HelloInterval
ospfIfRtrDeadInterval	CIM_OSPFLink.RouterDeadInterval
ospfIfPollInterval	CIM_OSPFProtocolEndpoint.PollInterval
ospfIfAuthKey	CIM_OSPFProtocolEndpointBase.AuthKey
ospfIfDemand	CIM_OSPFProtocolEndpoint.IfDemand
ospfIfAuthType	CIM_OSPFProtocolEndpointBase.AuthType
ospfIfMetricValue	CIM_OSPFProtocolEndpoint.Cost
ospfVirtIfAreaId	CIM_EndpointInArea association of the interface
ospfVirtIfNeighbor	CIM_RouteCalculationService.RouterID
ospfVirtIfTransitDelay	CIM_OSPFProtocolEndpointBase.TransitDelay
ospfVirtIfRetransInterval	CIM_OSPFProtocolEndpointBase.RetransmitInterval
ospfVirtIfHelloInterval	CIM_OSPFLink.HelloInterval
ospfVirtIfRtrDeadInterval	CIM_OSPFLink.RouterDeadInterval
ospfVirtIfAuthKey	CIM_OSPFProtocolEndpoint.AuthKey
ospfVirtIfAuthType	CIM_OSPFProtocolEndpoint.AuthType
ospfAreaAggregateAreaID	CIM_RangesOfConfiguration, CIM_AreaOfConfiguration association of the range
ospfAreaAggregateNet	CIM_IPAddressRange.StartAddress
ospfAreaAggregateMask	CIM_IPAddressRange.NetMask
ospfAreaAggregateEffect	CIM_RangesOfConfiguration.EnableAdvertise

4. Model Use Case

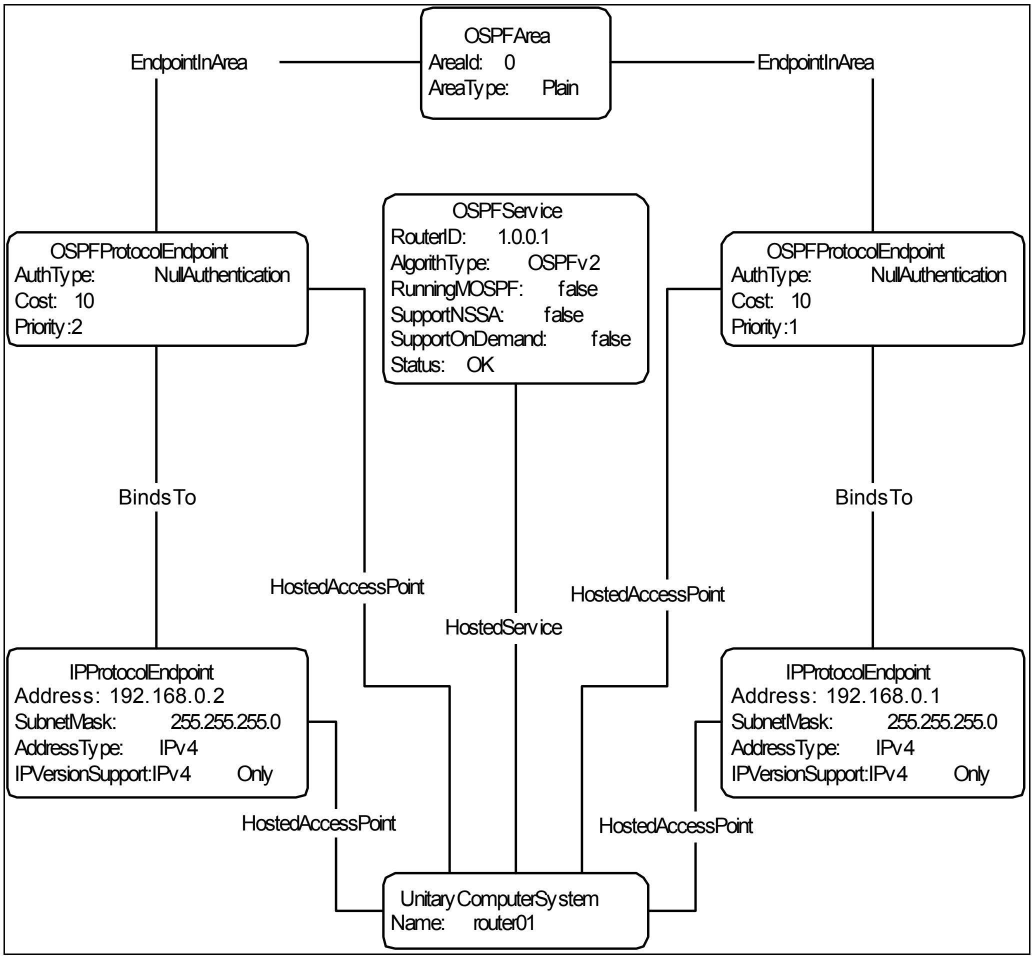
In the following sections some use cases are provided to demonstrate how our model can be used to configure OSPF routers. For drawing convenience, some attributes have been omitted from the objects.

4.1 Enabling OSPF on a router

In this scenario, the network operator wants to enable OSPF on an IP router with two interfaces. Both of the interfaces of the router will be in the backbone area. The original configuration can be seen in the following figure:



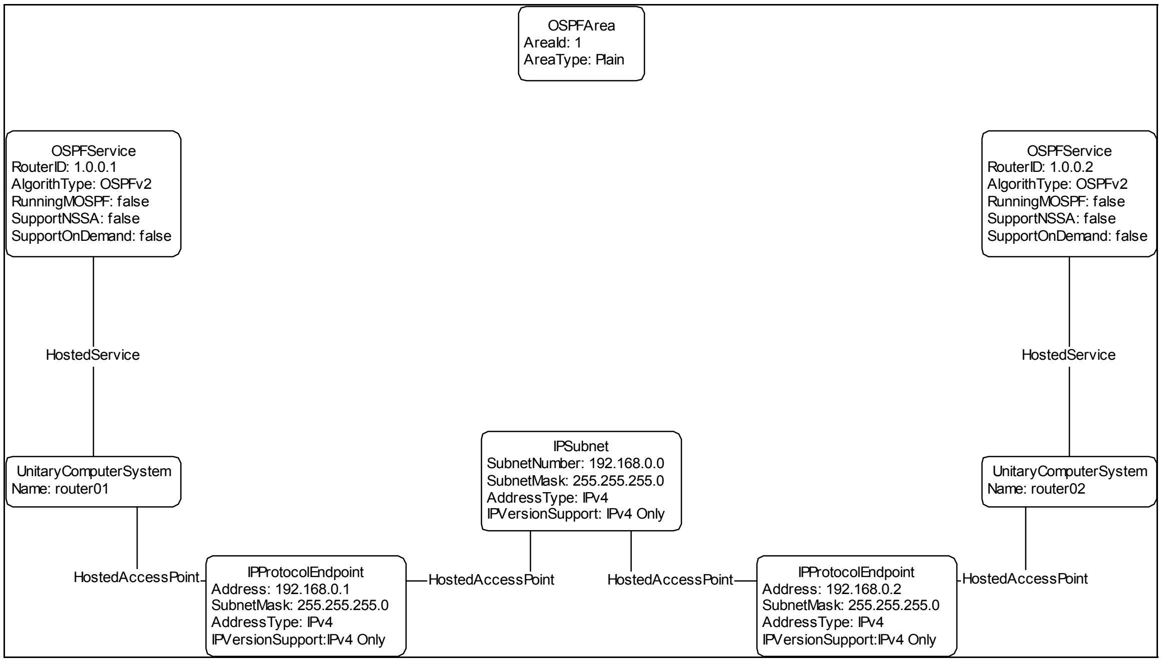
To enable OSPF on the router, the network management application must add an OSPFService object to the router, and then connect it to the ComputerSystem object using the HostedRoutingService association. Then the OSPFProtocolEndpoint objects must be created and connected to their underlying IPProtocolEndpoint objects, to their hosting ComputerSystem objects and to the object representing the backbone OSPF area. The new configuration can be seen in the following figure:



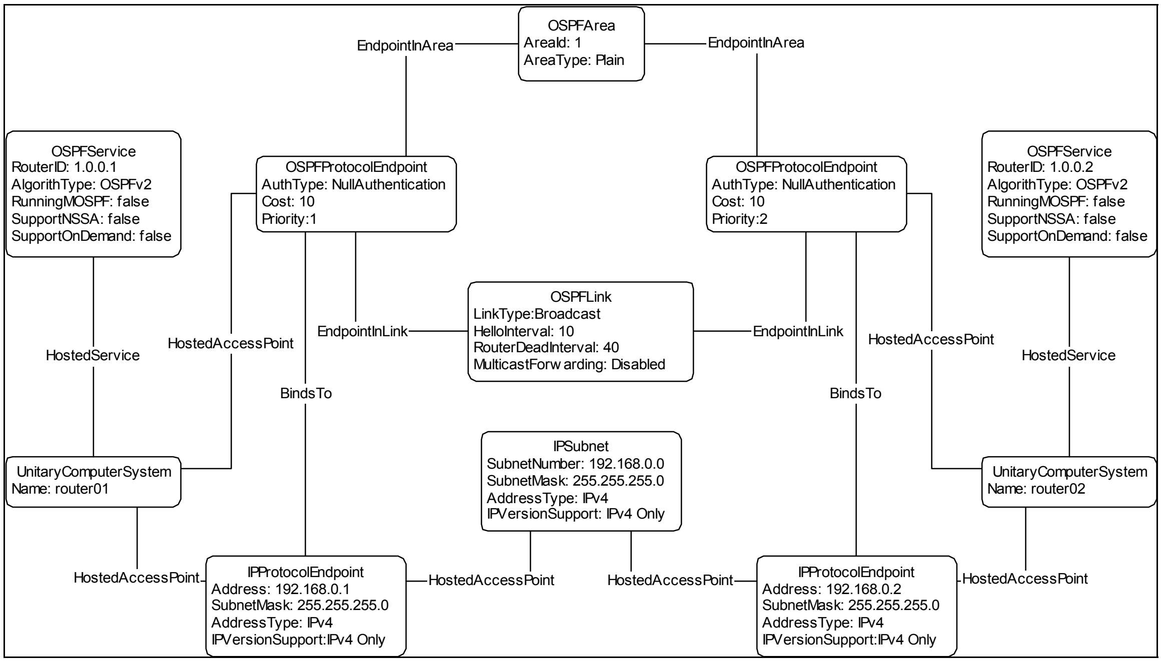
Of course, this object creation is only necessary if the OSPFService, OSPFProtocolEndpoint, etc., objects did not exist before. The network operator can disable the OSPF routing protocol on a router via setting the Status attribute of the OSPFService object to “Stopped.” In this case, the operator has to set only the Status attribute to “OK” to enable OSPF.

4.2 Adding an OSPF link

In this scenario, the network operator wants to define an OSPF link over the 192.168.0.0/24 subnet. The original configuration can be seen in the following figure:

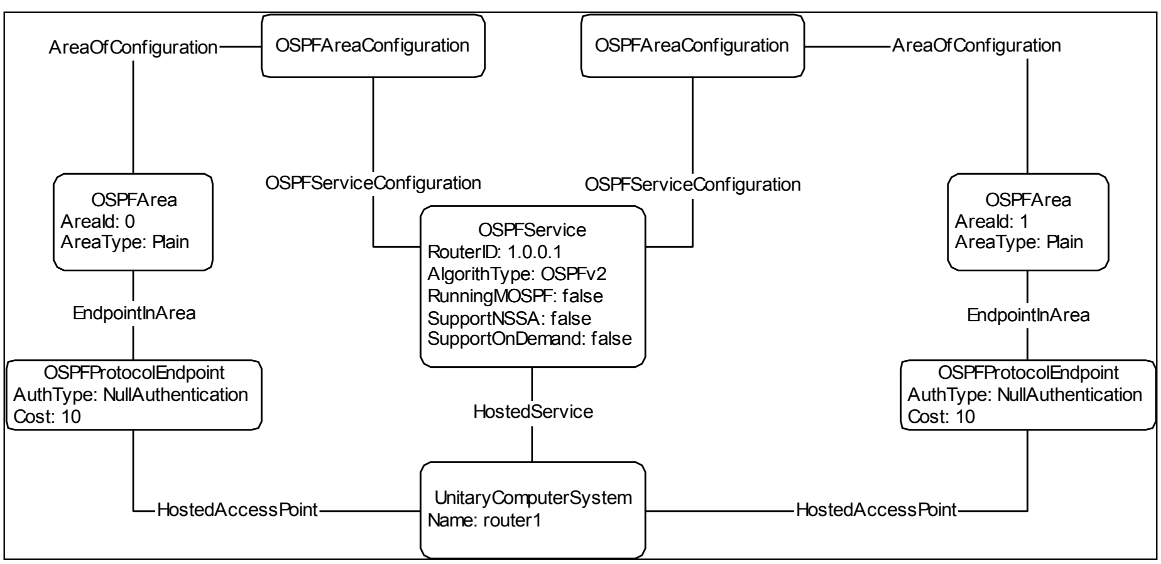


To define the OSPF link, the network management application must add one OSPFProtocolEndpoint object for each router, and connect them to the routers and to the IPProtocolEndpoints (using the BindsTo association), as well. Then, these objects must be connected to the area object, and a new OSPFLink object must be created. Finally, the OSPFProtocolEndpoint objects must be connected to the OSPFLink object. The new configuration can be seen in the following figure:

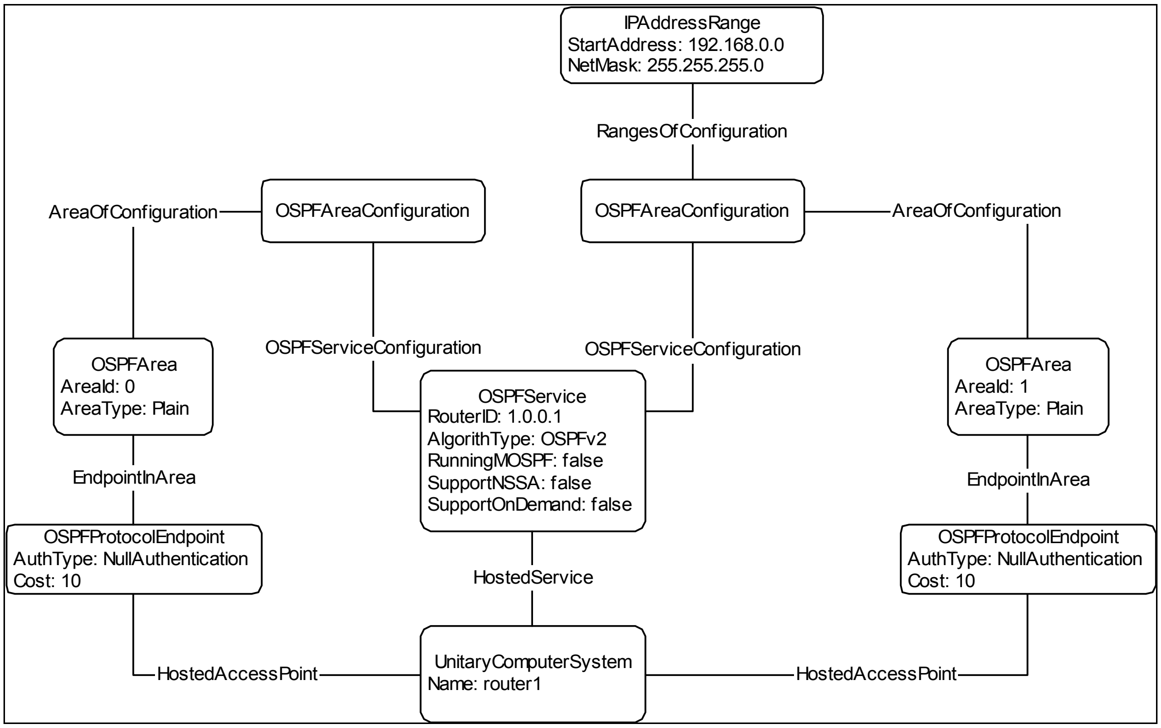


4.3 Adding a range

In this scenario, the network operator wants to configure router1 to advertise the 192.168.0.0/24 address range from the area 1 into the other areas. The original configuration can be seen in the following figure:

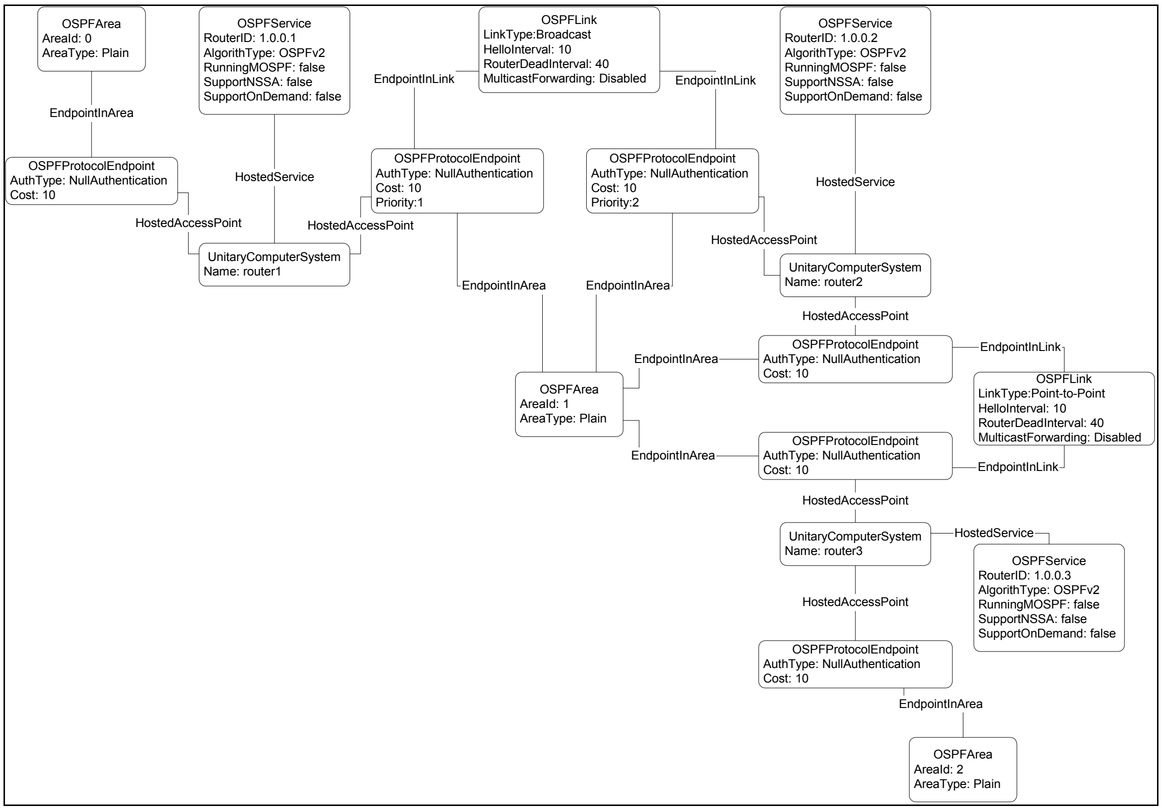


To add the range, the network management application must simply add a new IPAddressRange object to the model, and connect it to the OSPFAreaConfiguration object between the area 1 and the router with a RangesOfConfiguration association. Then, the EnableAdvertise attribute of the RangesOfConfiguration association must be set to “True.” The new configuration can be seen in the following figure:



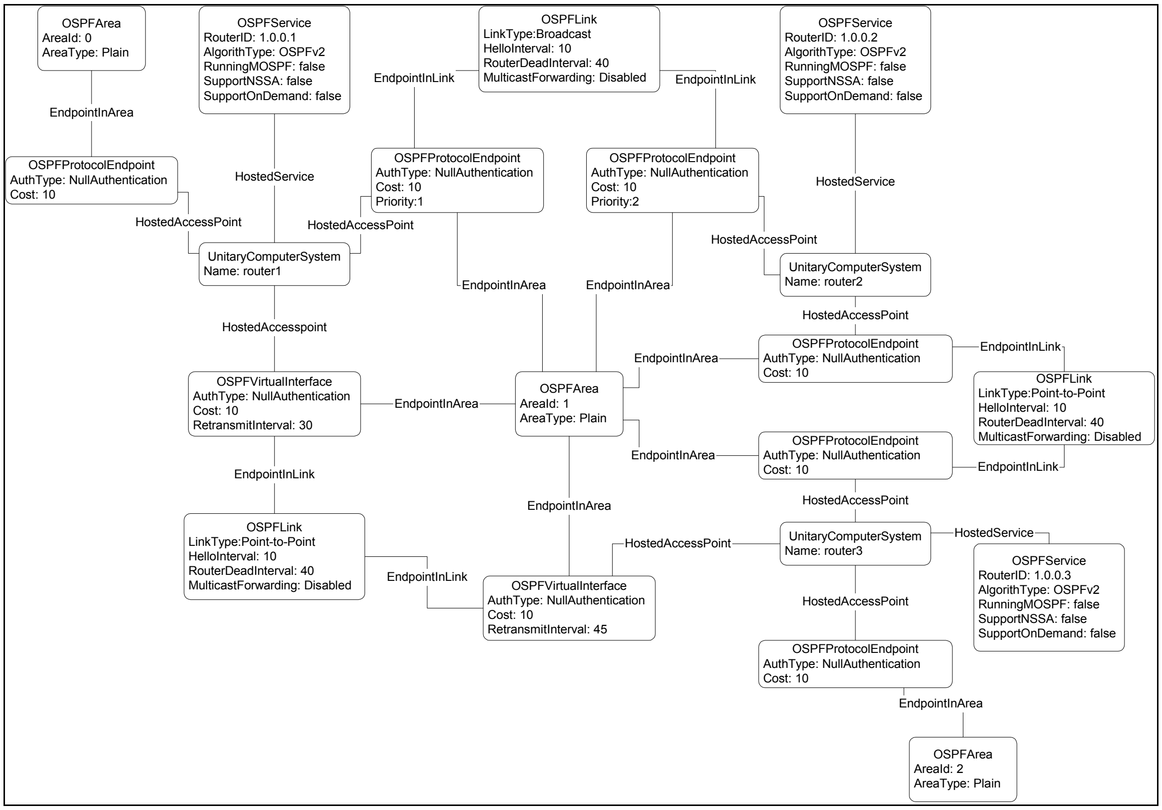
4.4 Adding a virtual link

In this scenario, the network operator wants to create a virtual link between router1 and router3 through area 1. The original configuration can be seen in the following figure:



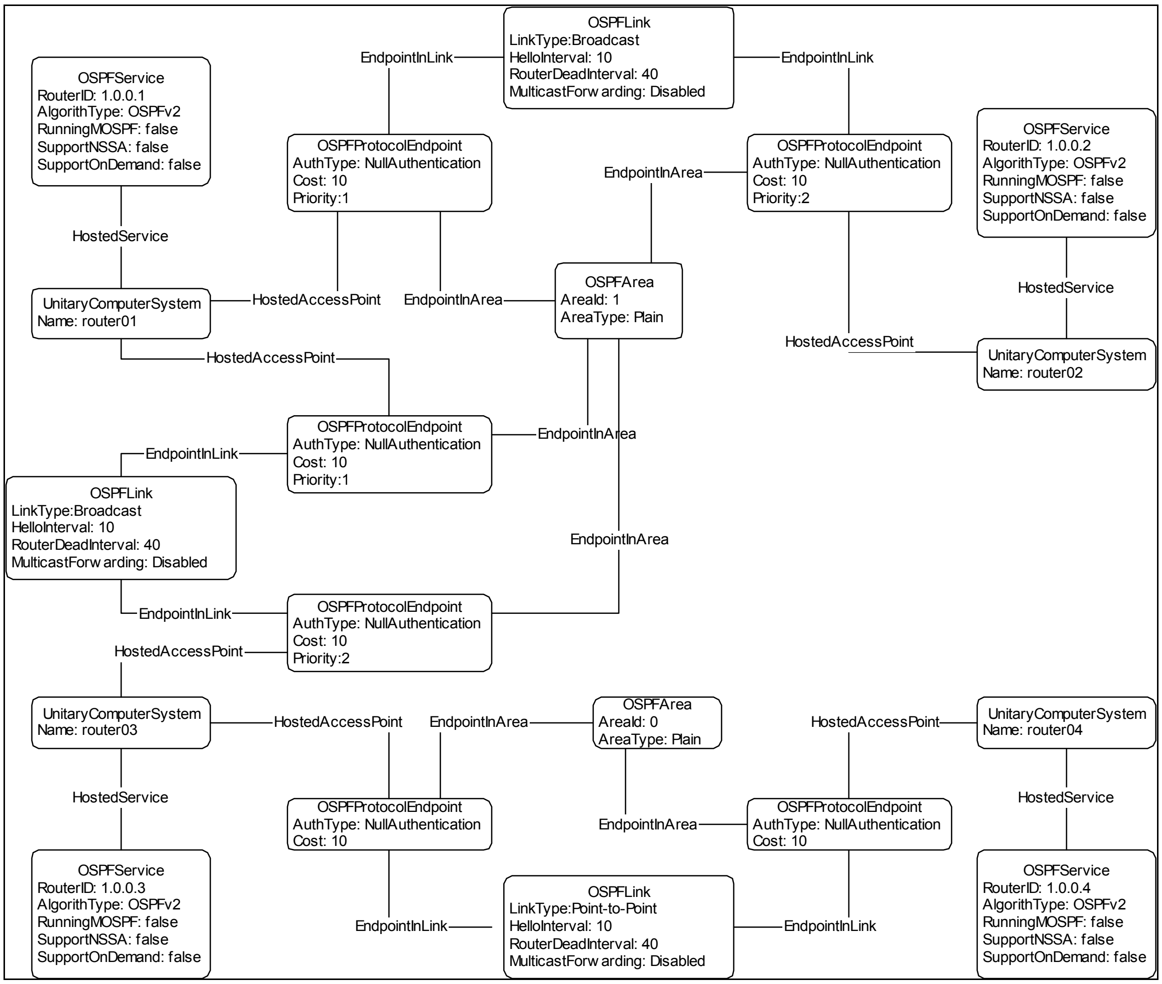
To create the virtual link, the network management application must connect two new OSPFVirtualInterface objects to the routers; they must be connected to a new OSPFLink object, as well as to the object representing the area 1. It is a very similar operation to the one specified in section

4.2 Adding an OSPF link. This new configuration can be seen in the following figure:

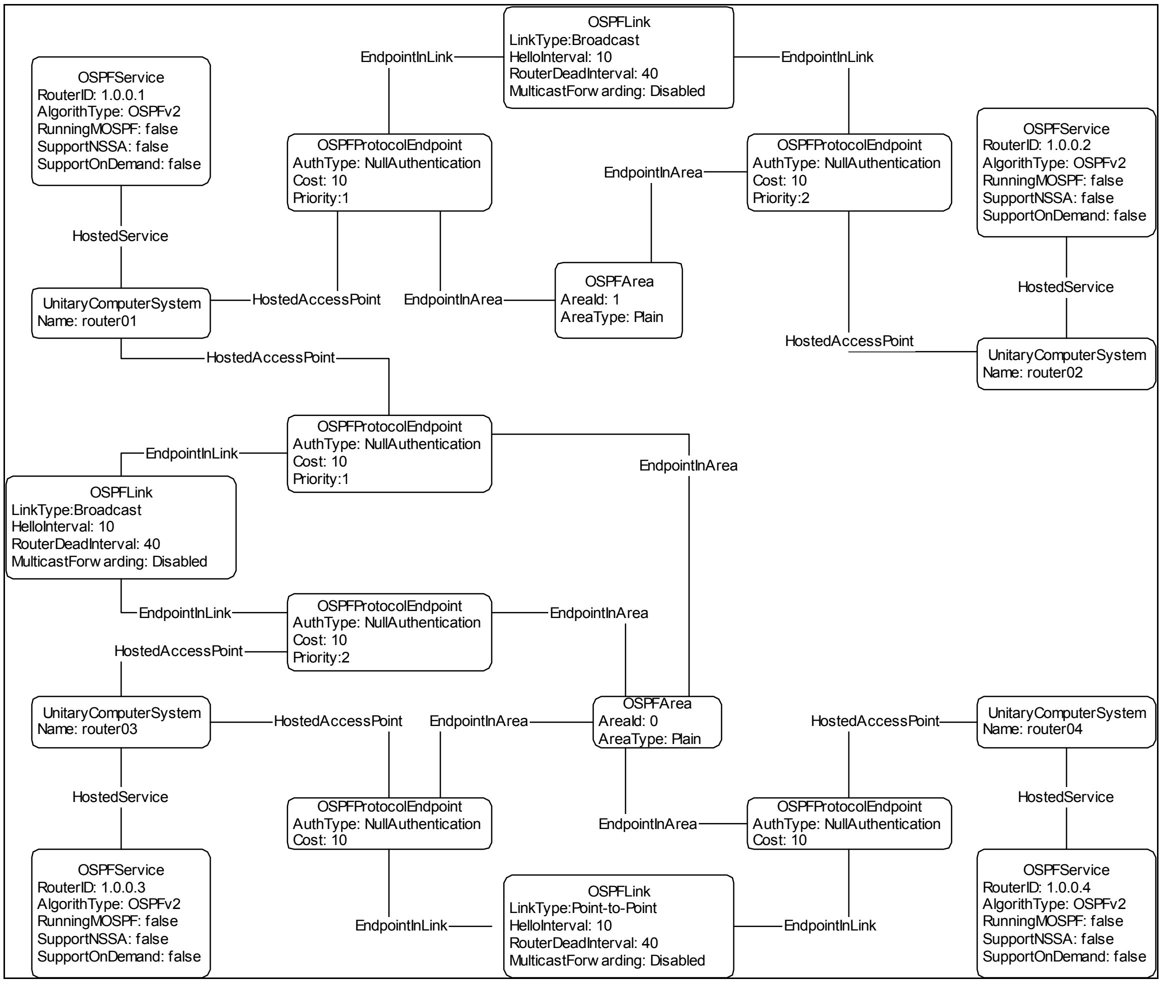


4.5 Transfer OSPF link

In this scenario, the network operator wants to transfer the link between router01 and router03 from the area 1 into the backbone area. The original configuration can be seen in the following figure:



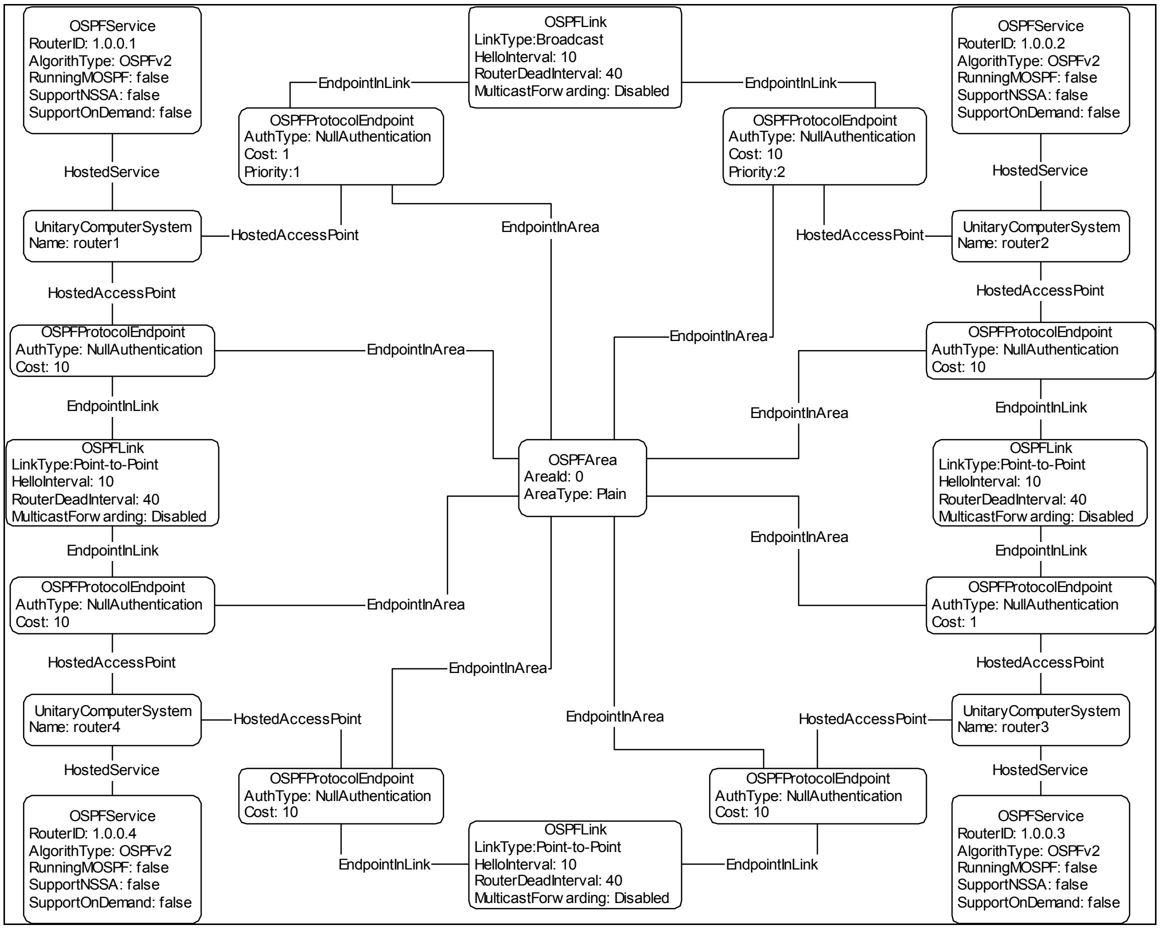
To transfer the link, the network management application must remove the EndpointInArea association between the endpoints of the link and the area 1, and then create EndpointInArea associations between the endpoints of the link and the backbone area. This new configuration can be seen in the following figure:



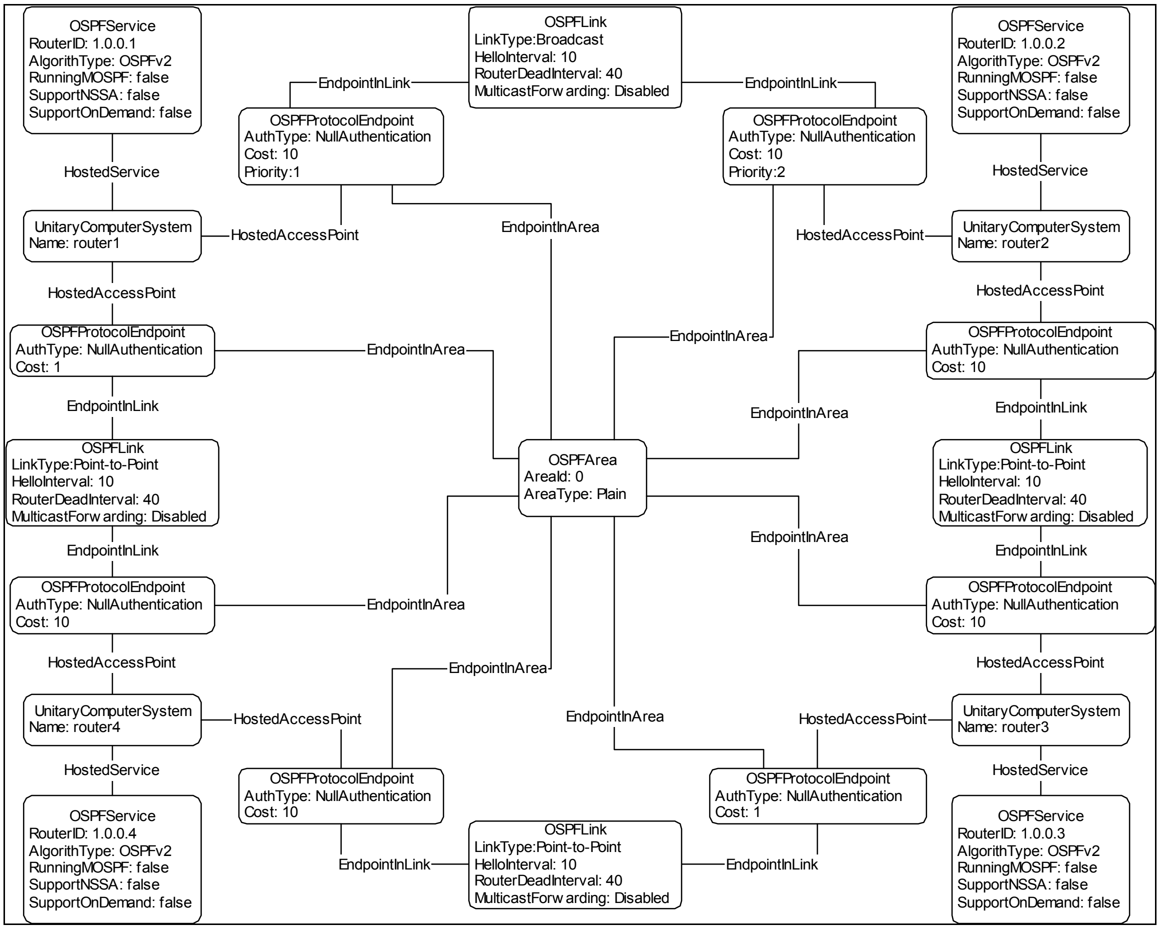
We must remind the reader that according to the OSPF specification, an area must be connected, but the DMTF OSPF model cannot enforce it, so the network management application must check the correctness of the new configuration.

4.6 A traffic-engineering example

In this scenario, the network operator wants to change the preferred path between router1 and router3. In the original configuration, the traffic between router1 and router3 goes through router2, but the network operator wants to change it to go through router4. The original configuration can be seen in the following figure:

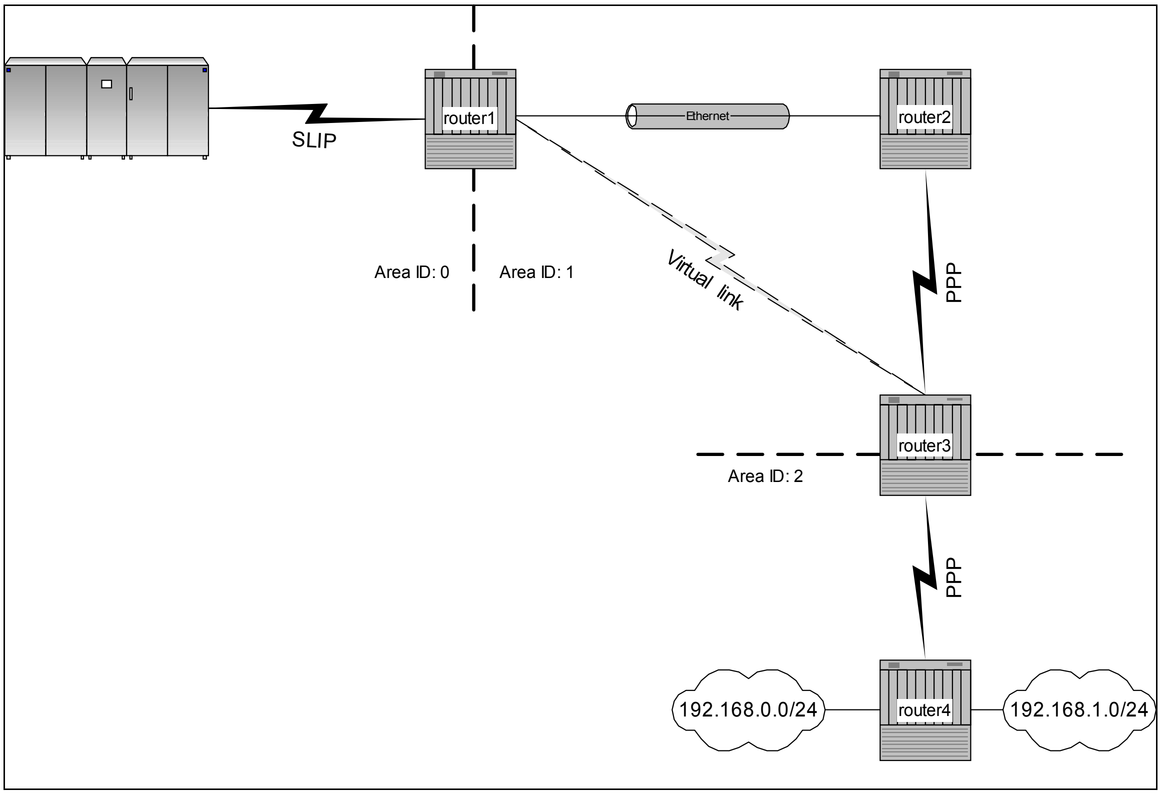


To change the preferred path, the network management application must change the cost attributes of router1 and router3's OSPFProtocolEndpoint objects. The cost of the objects toward router2 must be set to 10, while the cost of the objects toward router4 must be set to 1. This new configuration can be seen in the following figure:


OSPFService
RouterID: 1.0.0.1
AlgorithType: OSPFv2
RunningMOSPF: false
SupportNSSA: false
SupportOnDemand: false
OSPFLink
LinkType:Broadcast
HelloInterval: 10
RouterDeadInterval: 40
MulticastForwarding: Disabled
OSPFService
RouterID: 1.0.0.2
AlgorithType: OSPFv2
RunningMOSPF: false
SupportNSSA: false
SupportOnDemand: false
EndpointInLink
EndpointInLink
OSPFProtocolEndpoint
AuthType: NullAuthentication
Cost: 10
Priority:1
OSPFProtocolEndpoint
AuthType: NullAuthentication
Cost: 10
Priority:2
HostedService
HostedService
UnitaryComputerSystem
Name: router1
HostedAccessPoint
EndpointInArea
HostedAccessPoint
UnitaryComputerSystem
Name: router2
HostedAccessPoint
HostedAccessPoint
OSPFProtocolEndpoint
AuthType: NullAuthentication
Cost: 1
EndpointInArea
EndpointInArea
OSPFProtocolEndpoint
AuthType: NullAuthentication
Cost: 10
EndpointInLink
EndpointInArea
EndpointInLink
OSPFLink
LinkType:Point-to-Point
HelloInterval: 10
RouterDeadInterval: 40
MulticastForwarding: Disabled
OSPFArea
AreaId: 0
AreaType: Plain
OSPFLink
LinkType:Point-to-Point
HelloInterval: 10
RouterDeadInterval: 40
MulticastForwarding: Disabled
EndpointInLink
EndpointInArea
EndpointInLink
OSPFProtocolEndpoint
AuthType: NullAuthentication
Cost: 10
EndpointInArea
OSPFProtocolEndpoint
AuthType: NullAuthentication
Cost: 10
HostedAccessPoint
EndpointInArea
HostedAccessPoint
UnitaryComputerSystem
Name: router4
HostedAccessPoint
EndpointInArea
HostedAccessPoint
UnitaryComputerSystem
Name: router3
HostedService
OSPFProtocolEndpoint
AuthType: NullAuthentication
Cost: 10
OSPFProtocolEndpoint
AuthType: NullAuthentication
Cost: 1
HostedService
OSPFService
RouterID: 1.0.0.4
AlgorithType: OSPFv2
RunningMOSPF: false
SupportNSSA: false
SupportOnDemand: false
EndpointInLink
OSPFLink
LinkType:Point-to-Point
HelloInterval: 10
RouterDeadInterval: 40
MulticastForwarding: Disabled
EndpointInLink
OSPFService
RouterID: 1.0.0.3
AlgorithType: OSPFv2
RunningMOSPF: false
SupportNSSA: false
SupportOnDemand: false

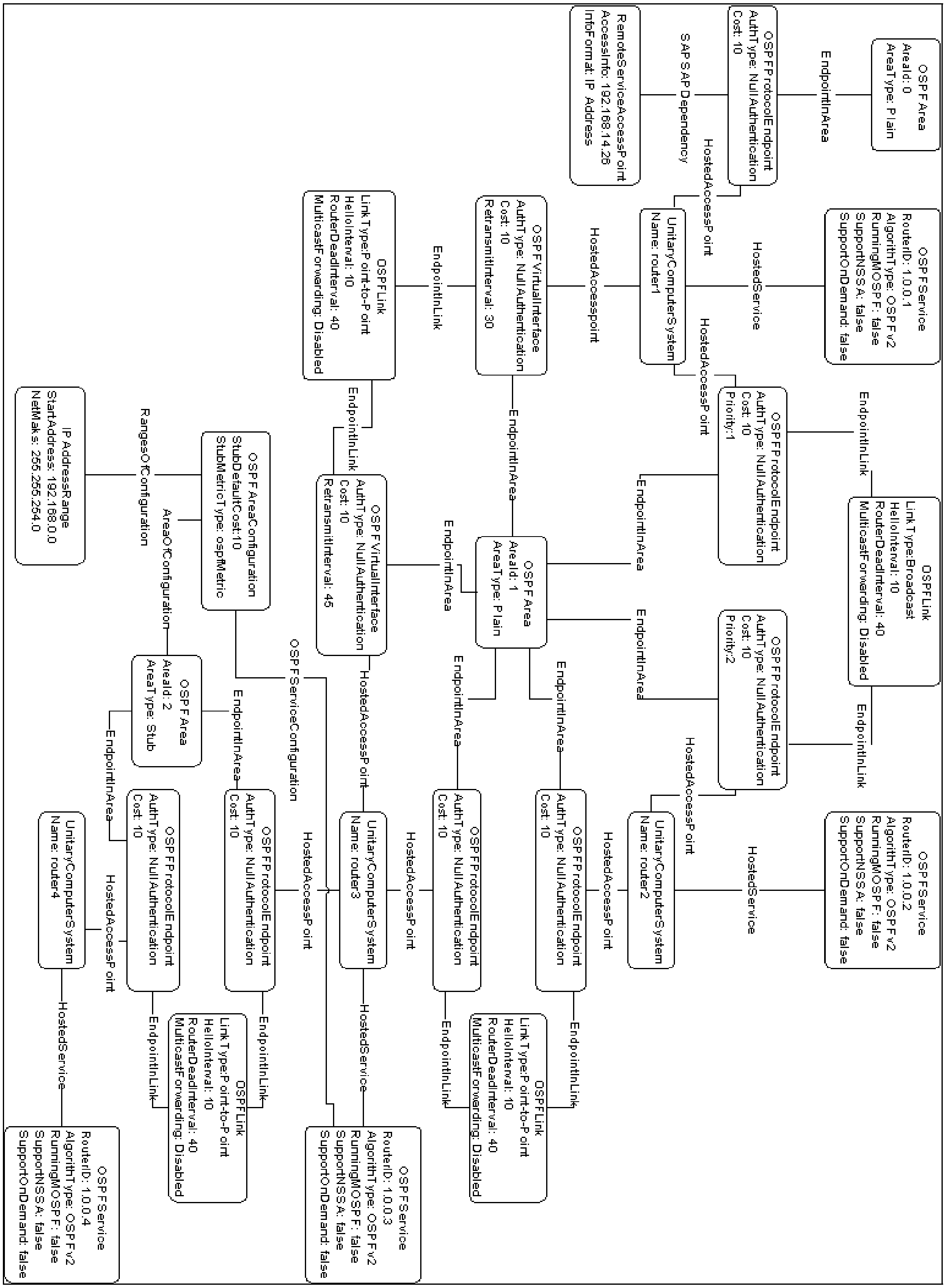
4.7 A network

The topology of the network in the following figure contains every feature of our model:



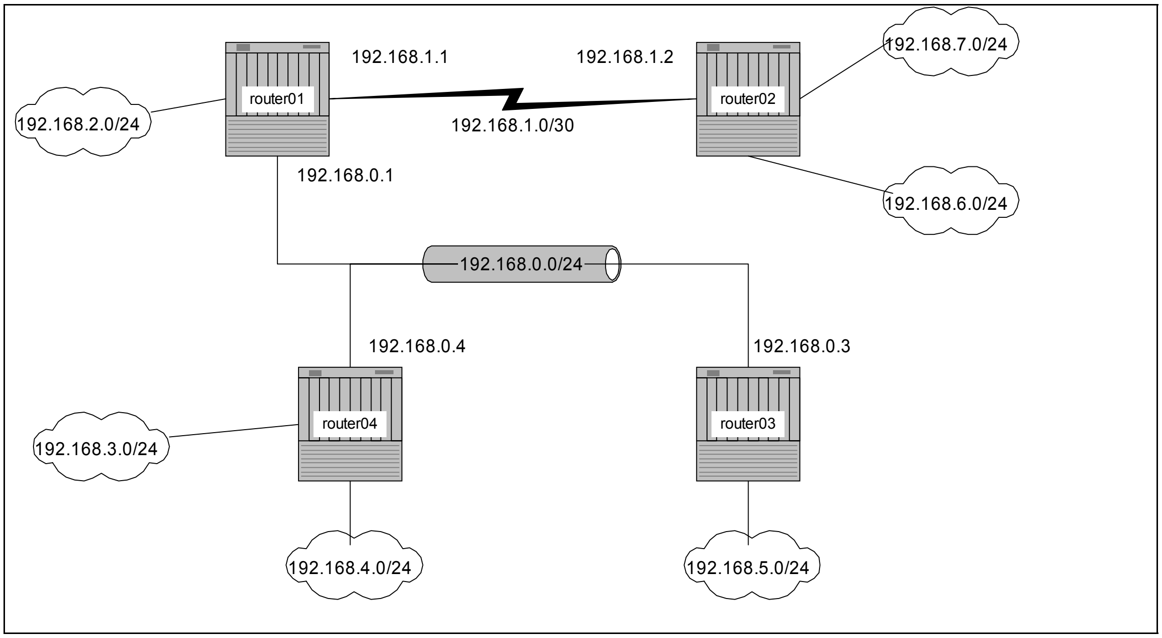
There are four routers in the network in three areas. Router1 is connected to a non-router computer via a SLIP line. Router1 and router2 are connected via an Ethernet network, while router2 and router3 are connected via a PPP network. These two networks are in area 1. Router3 is connected to router4 via a PPP network, and two stub networks are attached to router4. These three networks are in area 2. Router3 is configured to summarize the 192.168.0.0/23 into area 1 and area 0. Because router3 is an ABR, it must be connected to the backbone also. It leads to a non-contiguous backbone, so there is a virtual link between router1 and router3.

The model of the network above can be seen in the following figure:

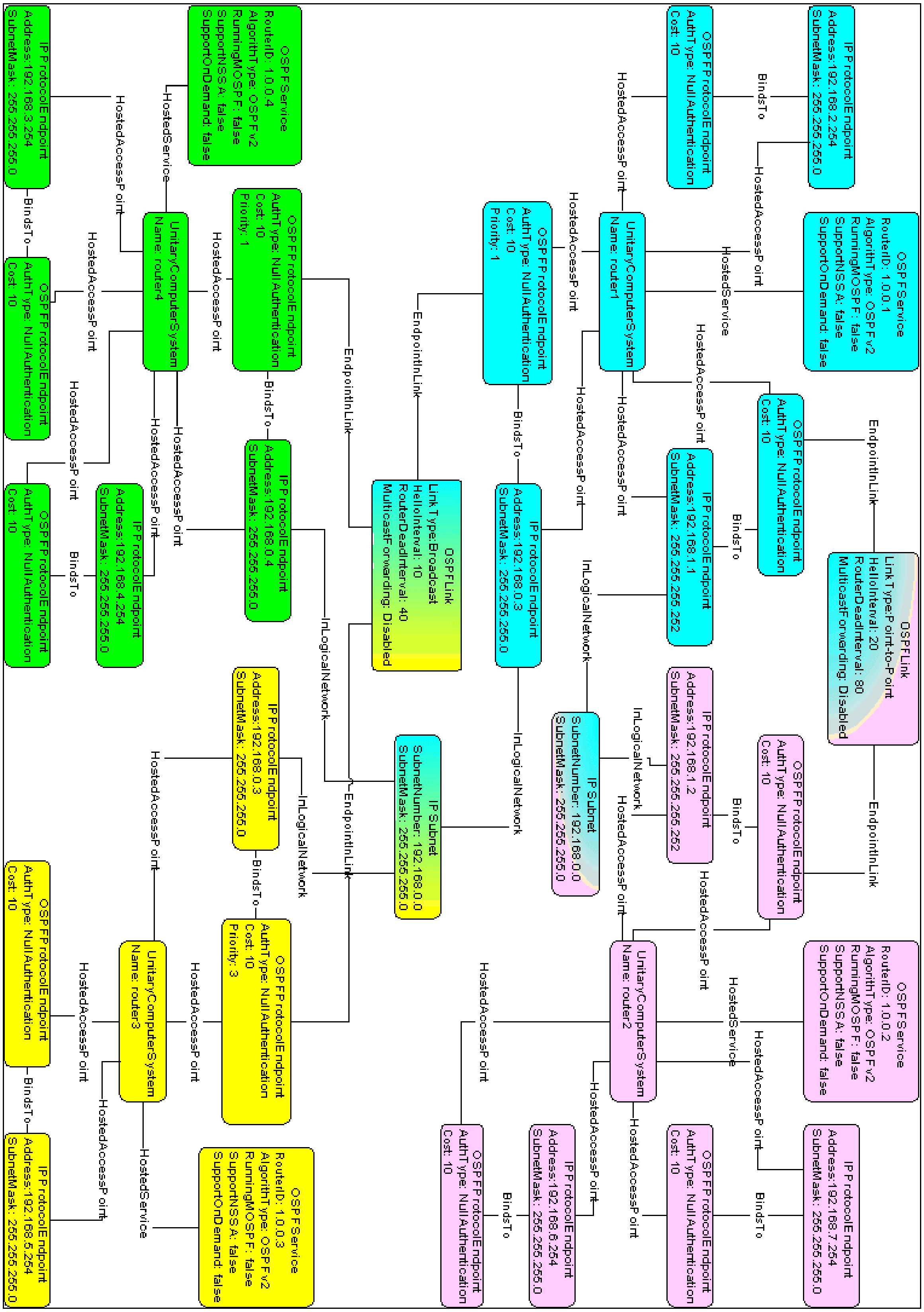

OSPFArea
AreaId: 0
AreaType: Plain
EndpointInArea
OSPFProtocolEndpoint
AuthType: NullAuthentication
Cost: 10
SAPSAPDependency
RemoteServiceAccessPoint
AccessInfo: 192.168.14.26
InfoFormat: IP Address
HostedAccessPoint
OSPFService
RouterID: 1.0.0.1
AlgorithType: OSPFv2
RunningMOSPF: false
SupportNSSA: false
SupportOnDemand: false
HostedService
UnitaryComputerSystem
Name: router1
HostedAccesspoint
OSPFVirtualInterface
AuthType: NullAuthentication
Cost: 10
RetransmitInterval: 30
EndpointInLink
OSPFLink
LinkType:Point-to-Point
HelloInterval: 10
RouterDeadInterval: 40
MulticastForwarding: Disabled
HostedAccessPoint
OSPFProtocolEndpoint
AuthType: NullAuthentication
Cost: 10
Priority:1
EndpointInLink
OSPFLink
LinkType:Broadcast
HelloInterval: 10
RouterDeadInterval: 40
MulticastForwarding: Disabled
EndpointInArea
IP AddressRange
StartAddress: 192.168.0.0
NetMaks: 255.255.254.0
RangesOfConfiguration
OSPFAreaConfiguration
StubDefaultCost:10
StubMetricType: ospfMetric
EndpointInLink
OSPFVirtualInterface
AuthType: NullAuthentication
Cost: 10
RetransmitInterval: 45
OSPFArea
AreaId: 1
AreaType: Plain
OSPFProtocolEndpoint
AuthType: NullAuthentication
Cost: 10
Priority:2
AreaOfConfiguration
OSPFServiceConfiguration
OSPFArea
AreaId: 2
AreaType: Stub
HostedAccessPoint
EndpointInArea
OSPFProtocolEndpoint
AuthType: NullAuthentication
Cost: 10
UnitaryComputerSystem
Name: router4
OSPFProtocolEndpoint
AuthType: NullAuthentication
Cost: 10
UnitaryComputerSystem
Name: router3
OSPFProtocolEndpoint
AuthType: NullAuthentication
Cost: 10
OSPFProtocolEndpoint
AuthType: NullAuthentication
Cost: 10
UnitaryComputerSystem
Name: router2
OSPFService
RouterID: 1.0.0.2
AlgorithType: OSPFv2
RunningMOSPF: false
SupportNSSA: false
SupportOnDemand: false
OSPFLink
LinkType:Point-to-Point
HelloInterval: 10
RouterDeadInterval: 40
MulticastForwarding: Disabled
OSPFLink
LinkType:Point-to-Point
HelloInterval: 10
RouterDeadInterval: 40
MulticastForwarding: Disabled
OSPFService
RouterID: 1.0.0.4
AlgorithType: OSPFv2
RunningMOSPF: false
SupportNSSA: false
SupportOnDemand: false
OSPFService
RouterID: 1.0.0.3
AlgorithType: OSPFv2
RunningMOSPF: false
SupportNSSA: false
SupportOnDemand: false

4.8 A configuration comparison

In this section, the configuration of a small network is shown, comparing two ways to specify it: one configuration described by a CIM-based object model, and another configuration described by Cisco-like configuration files. The topology of the network is the following:



Every interface is in the backbone OSPF area. The addresses of the interfaces toward the stub networks are 192.168.2.254, 192.168.3.254, 192.168.4.254, 192.168.5.254, 192.168.6.254 and 192.168.7.254. The 192.168.0.0/24 network is an Ethernet network, while the 192.168.1.0/30 network is a Point-to-Point link. The following figure shows the OSPF configuration of the above network:


IPProtocolEndpoint Address:192.168.2.254 SubnetMask: 255.255.255.0
OSPFProtocolEndpoint AuthType: NullAuthentication Cost: 10
OSPFService RouterID: 1.0.0.1 AlgorithmType: OSPFv2 RunningMOSPF: false SupportNSSA: false SupportOnDemand: false
UnitaryComputerSystem Name: router1
OSPFProtocolEndpoint AuthType: NullAuthentication Cost: 10 Priority: 1
OSPFProtocolEndpoint AuthType: NullAuthentication Cost: 10
OSPFLink LinkType:Point-to-Point HelloInterval: 20 RouterDeadInterval: 80 MulticastForwarding: Disabled
IPProtocolEndpoint Address:192.168.1.1 SubnetMask: 255.255.255.252
IPProtocolEndpoint Address:192.168.0.3 SubnetMask: 255.255.255.0
IPProtocolEndpoint Address:192.168.1.2 SubnetMask: 255.255.255.252
IPSubnet SubnetNumber: 192.168.0.0 SubnetMask: 255.255.255.0
OSPFProtocolEndpoint AuthType: NullAuthentication Cost: 10
OSPFService RouterID: 1.0.0.2 AlgorithmType: OSPFv2 RunningMOSPF: false SupportNSSA: false SupportOnDemand: false
UnitaryComputerSystem Name: router2
IPProtocolEndpoint Address:192.168.7.254 SubnetMask: 255.255.255.0
OSPFProtocolEndpoint AuthType: NullAuthentication Cost: 10
IPProtocolEndpoint Address:192.168.6.254 SubnetMask: 255.255.255.0
OSPFProtocolEndpoint AuthType: NullAuthentication Cost: 10
OSPFService RouterID: 1.0.0.4 AlgorithmType: OSPFv2 RunningMOSPF: false SupportNSSA: false SupportOnDemand: false
IPProtocolEndpoint Address:192.168.3.254 SubnetMask: 255.255.255.0
UnitaryComputerSystem Name: router4
OSPFProtocolEndpoint AuthType: NullAuthentication Cost: 10 Priority: 1
OSPFProtocolEndpoint AuthType: NullAuthentication Cost: 10
OSPFLink LinkType:Broadcast HelloInterval: 10 RouterDeadInterval: 40 MulticastForwarding: Disabled
IPProtocolEndpoint Address:192.168.0.4 SubnetMask: 255.255.255.0
IPProtocolEndpoint Address:192.168.4.254 SubnetMask: 255.255.255.0
OSPFProtocolEndpoint AuthType: NullAuthentication Cost: 10
IPSubnet SubnetNumber: 192.168.0.0 SubnetMask: 255.255.255.0
IPProtocolEndpoint Address:192.168.0.3 SubnetMask: 255.255.255.0
OSPFProtocolEndpoint AuthType: NullAuthentication Cost: 10 Priority: 3
UnitaryComputerSystem Name: router3
OSPFProtocolEndpoint AuthType: NullAuthentication Cost: 10
OSPFService RouterID: 1.0.0.3 AlgorithmType: OSPFv2 RunningMOSPF: false SupportNSSA: false SupportOnDemand: false
IPProtocolEndpoint Address:192.168.5.254 SubnetMask: 255.255.255.0
BindsTo
HostedAccessPoint
HostedService
EndpointInLink
InLogicalNetwork

For drawing convenience, the OSPFArea object and the EndpointInArea associations between the OSPFArea and the OSPFProtocolEndpoint objects are not drawn on the figure. The blue colored objects contain attributes thatmust be set in router1, the green colored objects contain attributes that must be set in router2, etc. The multicolored objects contain attributes that must be set in more than one router. The OSPFArea object has four colors.

In the following section, the OSPF-related parts of the four router configuration is specified:

```
!
interface Ethernet0/0
 ip address 192.168.0.1 255.255.255.0
 ip ospf cost 10
 ip ospf priority 1
 ip ospf hellointerval 10
 ip ospf deadinterval 40
!
interface Ethernet0/1
 ip address 192.168.2.254 255.255.255.0
 ip ospf cost 10
!
interface Serial 1/0
 ip address 192.168.1.1 255.255.255.252
 ip ospf cost 10
 ip ospf hellointerval 20
 ip ospf deadinterval 80
!
router ospf 1
 ospf router-id 1.0.0.1
 network 192.168.0.0 0.0.0.255 area 0
 network 192.168.1.0 0.0.0.3 area 0
 network 192.168.2.0 0.0.0.255 area 0
!
```

The configuration of router01

```
!
interface Ethernet0/0
 ip address 192.168.6.254 255.255.255.0
 ip ospf cost 10
!
interface Ethernet0/1
 ip address 192.168.7.254 255.255.255.0
 ip ospf cost 10
!
interface Serial 1/0
 ip address 192.168.1.2 255.255.255.252
 ip ospf cost 10
 ip ospf hellointerval 20
 ip ospf deadinterval 80
!
router ospf 1
 ospf router-id 1.0.0.2
 network 192.168.1.0 0.0.0.3 area 0
```

```
 network 192.168.6.0 0.0.0.255 area 0
 network 192.168.7.0 0.0.0.255 area 0
!
```

The configuration of router02

```
!
interface Ethernet0/0
 ip address 192.168.0.3 255.255.255.0
 ip ospf cost 10
 ip ospf priority 1
 ip ospf hellointerval 10
 ip ospf deadinterval 40
!
interface Ethernet0/1
 ip address 192.168.5.254 255.255.255.0
 ip ospf cost 10
!
router ospf 1
 ospf router-id 1.0.0.3
 network 192.168.0.0 0.0.0.255 area 0
 network 192.168.5.0 0.0.0.255 area 0
!
```

The configuration of router03

```
!
interface Ethernet0/0
 ip address 192.168.0.4 255.255.255.0
 ip ospf cost 10
 ip ospf priority 1
 ip ospf hellointerval 10
 ip ospf deadinterval 40
!
interface Ethernet0/1
 ip address 192.168.3.254 255.255.255.0
 ip ospf cost 10
!
interface Ethernet0/2
 ip address 192.168.4.254 255.255.255.0
 ip ospf cost 10
!
router ospf 1
 ospf router-id 1.0.0.4
 network 192.168.0.0 0.0.0.255 area 0
 network 192.168.3.0 0.0.0.255 area 0
 network 192.168.4.0 0.0.0.255 area 0
!
```

The configuration of router04

It can be seen that the HelloInterval and the RouterDeadInterval values of the links are specified at each interface on a link in the configuration, while in the CIM-based object model it is stored in only one place. This means that when the network operator wants to change the configuration he must change only one value in the object model, instead of the two or four values in the configuration files.

5. Future Work

There are many fields where our model can evolve. First, it might be extended to cover the OSPF for IPv6 specification (RFC 2740). Because OSPF is quite independent of its underlying protocol, this RFC did not changed considerably the way OSPF works, so its configuration is very similar to OSPF version 2. At first glance, only some new attributes should be added to some classes, and possibly the cardinalities of some associations should be changed.

Another interesting field is the interoperation of routing protocols, in particular, the interoperation between BGP and OSPF. BGP is the most widely deployed Exterior Routing Protocol, and at many sites the biggest configuration challenge is to control the importing of routes from BGP into OSPF, and vice versa. Now that both protocols have a CIM model, it would be nice to have the possibility to configure this relationship with standard CIM classes. This configuration might be possible by using already existing classes only in the Network Model, but some work on this field is inevitable.

There is also an extension to OSPF, which supports a kind of Quality of Service routing mechanism (RFC 2676). Because it is only an experimental RFC, it shows that there must be some research done in this field to have good QoS support in OSPF, but in the future the DMTF model should be able to configure this OSPF extension, as well.

Finally, the DMTF model might be extended to represent statistical information about OSPF. Obviously, this is not needed to configure OSPF, but a full-featured network management application has to collect statistics about the OSPF routing in the network. If that application uses the CIM model to store the configuration of the routers, it would be beneficial to use the same model (for the sake of simplicity) to collect statistics.

Appendix A – Change History

Version 0.9	June 19, 2003	Initial Draft
Version 1.0	August 26, 2003	Preliminary
Version 1.1	December 2, 2003	Cleanup based on review comments

Appendix B – References

Common Information Model (CIM) Specification, V2.2, June 14, 1999 - Downloadable from http://www.dmtf.org/standards/standard_cim.php

Unified Modeling Language (UML) from the Open Management Group (OMG) - Downloadable from http://www.omg.org/uml/

OSPF Version 2, RFC 2328, http://www.ietf.org/rfc/rfc2328.txt

OSPF Version 2 Management Information Base, RFC 1850, http://www.ietf.org/rfc/rfc1850.txt

Multicast Extensions to OSPF, RFC 1584, http://www.ietf.org/rfc/rfc1584.txt

The OSPF NSSA Option, RFC 1587, http://www.ietf.org/rfc/rfc1587.txt

OSPF Database Overflow, RFC 1765, http://www.ietf.org/rfc/rfc1765.txt

Extending OSPF to Support Demand Circuits, RFC 1793, http://www.ietf.org/rfc/rfc1793.txt

"OSPF: The Anatomy of an Internet Routing Protocol," by John T. Moy, Addison-Wesley Pub Co; ISBN: 0201634724.

Appendix C – Extending the Model

The DMTF model can be extended if a router supports additional OSPF-related configuration attributes (e.g., logging, packet dumping, etc.). For example, if the additional configuration option is to enable logging of every OSPF packet sent from an interface, the vendor could define an Acme_OSPFProtocolEndpoint subclass of OSPFProtocolEndpoint, and add a LogOSPFPackets property.

Appendix D – Considerations for Implementation

Although the goal was to create a model that does not permit invalid OSPF configurations, the complexity of the OSPF protocol and the limitations of CIM modeling did not enable this. This means that the network management application that implements this OSPF model must examine whether the configuration represented by a set of objects is valid or not. The following rules must be observed:

- An OSPFProtocolEndpoint object cannot be connected to a ComputerSystem object unless this ComputerSystem object is connected to an OSPFService object also.
- The AreaID attributes of the OSPFArea objects must be unique.
- If there is more than one OSPFArea object, one of them must be the backbone (its AreaID is 0), and it must be connected to every other area through ABRs.
- A virtual link cannot go through a stub or NSSA area (i.e., the type of the virtual link's endpoint's area must be "Plain").
- OSPFProtocolEndpoint objects cannot be connected to the same OSPFLink object if their respective IPProtocolEndpoint objects (those that are connected to the OSPFProtocolEndpoint objects with the BindsTo association) are in different subnet.
- Every OSPF area must be contiguous (especially the backbone).