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ForCES Model Extension
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Abstract

Forwarding and Control Element Separation (ForCES) defines an architectural framework and associated protocols to standardize information exchange between the control plane and the forwarding plane in a ForCES Network Element (ForCES NE). [RFC5812](#) has defined the ForCES Model provides a formal way to represent the capabilities, state, and configuration of forwarding elements within the context of the ForCES protocol, so that control elements (CEs) can control the FEs accordingly. More specifically, the model describes the logical functions that are present in an FE, what capabilities these functions support, and how these functions are or can be interconnected.

[RFC5812](#) has been around for two years and experience in its use has shown room for extensions without a need to alter the protocol while retaining backward compatibility with older xml libraries.

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1. Terminology and Conventions

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [[RFC2119](#)].

1.2. Definitions

This document follows the terminology defined by the ForCES Model in [[RFC5812](#)]. The required definitions are repeated below for clarity.

FE Model - The FE model is designed to model the logical processing functions of an FE. The FE model proposed in this document includes three components; the LFB modeling of individual Logical Functional Block (LFB model), the logical interconnection between LFBs (LFB topology), and the FE-level attributes, including FE capabilities. The FE model provides the basis to define the information elements exchanged between the CE and the FE in the ForCES protocol [[RFC5810](#)].

LFB (Logical Functional Block) Class (or type) - A template that represents a fine-grained, logically separable aspect of FE processing. Most LFBs relate to packet processing in the data path. LFB classes are the basic building blocks of the FE model.

LFB Instance - As a packet flows through an FE along a data path, it flows through one or multiple LFB instances, where each LFB is an instance of a specific LFB class. Multiple instances of the same LFB class can be present in an FE's data path. Note that we often refer to LFBs without distinguishing between an LFB class and LFB instance when we believe the implied reference is obvious for the given context.

LFB Model - The LFB model describes the content and structures in an LFB, plus the associated data definition. XML is used to provide a formal definition of the necessary structures for the modeling. Four types of information are defined in the LFB model. The core part of the LFB model is the LFB class definitions; the other three types of information define constructs associated with and used by the class definition. These are reusable data types, supported frame (packet) formats, and metadata.

Element - Element is generally used in this document in accordance with the XML usage of the term. It refers to an XML tagged part of an XML document. For a precise definition, please see the full set of XML specifications from the W3C. This term is included in

this list for completeness because the ForCES formal model uses XML.

Attribute - Attribute is used in the ForCES formal modeling in accordance with standard XML usage of the term, i.e., to provide attribute information included in an XML tag.

LFB Metadata - Metadata is used to communicate per-packet state from one LFB to another, but is not sent across the network. The FE model defines how such metadata is identified, produced, and consumed by the LFBs, but not how the per-packet state is implemented within actual hardware. Metadata is sent between the FE and the CE on redirect packets.

ForCES Component - A ForCES Component is a well-defined, uniquely identifiable and addressable ForCES model building block. A component has a 32-bit ID, name, type, and an optional synopsis description. These are often referred to simply as components.

LFB Component - An LFB component is a ForCES component that defines the Operational parameters of the LFBs that must be visible to the CEs.

LFB Class Library - The LFB class library is a set of LFB classes that has been identified as the most common functions found in most FEs and hence should be defined first by the ForCES Working Group.

2. Introduction

The ForCES Model [[RFC5812](#)] presents a formal way to define FEs Logical Function Blocks (LFBs) using XML. [[RFC5812](#)] has been published a little more than two years and current experience in its use has shown some room for adding new and changing existing modeling concepts.

This document extends the ForCES Model by changing and adding new concepts. These extensions do not require any changes on the ForCES protocol [[RFC5810](#)] as they are simply changes of the schema definition. Additionally backward compatibility is ensured as xml libraries produced with the earlier schema are still valid with the new one.

3. ForCES Model Extension overview

The following extensions are considered:

1. Allow complex metadata.
2. Allow optional default values for datatypes.
3. Allow optional access type for struct datatypes.
4. New datatype: Bitmap.
5. New Event Condition: EqualTo.

Additionally this document is also enhancing the XML validation.

4. Extensions

Some of these extensions were product of the work done on the OpenFlow library [[I-D.haleplidis-forces-openflow-lib](#)] document.

4.1. Complex Metadata

[Section 4.6](#). (Element for Metadata Definitions) in the ForCES Model [[RFC5812](#)] limits the datatype use in metadata to only atomic types. Figure 1 shows the xml schema excerpt where only typeRef and atomic are allowed for a metadata definition.

With this extension (Figure 2), complex data types are also allowed, specifically structs and arrays as metadata. The key declarations are required to check for validity of content keys in arrays and componentIDs in structs.

```
<xsd:complexType name="metadataDefsType">
  <xsd:sequence>
    <xsd:element name="metadataDef" maxOccurs="unbounded">
      <xsd:complexType>
        <xsd:sequence>
          <xsd:element name="name" type="xsd:NMTOKEN"/>
          <xsd:element ref="synopsis"/>
          <xsd:element name="metadataID" type="xsd:integer"/>
          <xsd:element ref="description" minOccurs="0"/>
          <xsd:choice>
            <xsd:element name="typeRef" type="typeRefNMTOKEN"/>
            <xsd:element name="atomic" type="atomicType"/>
          </xsd:choice>
        </xsd:sequence>
      </xsd:complexType>
    </xsd:element>
  </xsd:sequence>
</xsd:complexType>
```

Figure 1: Initial MetadataDefType Definition in the schema


```

<xsd:complexType name="metadataDefsType">
  <xsd:sequence>
    <xsd:element name="metadataDef" maxOccurs="unbounded">
      <xsd:complexType>
        <xsd:sequence>
          <xsd:element name="name" type="xsd:NMTOKEN"/>
          <xsd:element ref="synopsis"/>
          <xsd:element name="metadataID" type="xsd:integer"/>
          <xsd:element ref="description" minOccurs="0"/>
          <xsd:choice>
            <xsd:element name="typeRef" type="typeRefNMTOKEN"/>
            <xsd:element name="atomic" type="atomicType"/>
            <xsd:element name="array" type="arrayType">
              <xsd:key name="contentKeyID1">
                <xsd:selector xpath="lfb:contentKey"/>
                <xsd:field xpath="@contentKeyID"/>
              </xsd:key>
            </xsd:element>
            <xsd:element name="struct" type="structType">
              <xsd:key name="structComponentID1">
                <xsd:selector xpath="lfb:component"/>
                <xsd:field xpath="@componentID"/>
              </xsd:key>
            </xsd:element>
          </xsd:choice>
        </xsd:sequence>
      </xsd:complexType>
    </xsd:element>
  </xsd:sequence>
</xsd:complexType>

```

Figure 2: New MetadataDefType Definition for the schema

Two simple use cases can be seen in the OpenFlow switch
[\[OpenFlowSpec1.1\]](#):

1. The Action Set metadata follows a packet inside the Flow Tables. The Action Set metadata is an array of actions to be performed at the end of the pipeline.
2. When a packet is received from a controller it may be accompanied by a list of actions to be performed on it prior to be sent on the flow table pipeline which is also an array.

4.2. DataType Optional Default Value

In the original schema, default values can be defined only in datatypes defined inside LFB components. However when it's a complex datatype or it's a referred datatype, using the default value field is difficult to be used. Additionally there is no option in a complex datatype to use the default value field for only one component in the complex datatype.

This extension allows optionally to add default values to atomic and typeref types, whether they are as simple or complex datatypes. A simple use case would be to have a struct component where one of the components is a counter which the default value would be zero.

This extension alters the definition of the typeDeclarationGroup in the xml schema from Figure 3 to Figure 4 to allow default values to TypeRef.

```
<xsd:element name="typeRef" type="typeRefNMTOKEN"/>
```

Figure 3: Initial Excerpt of typeDeclarationGroup Defintion in the schema

```
<xsd:sequence>
<xsd:element name="typeRef" type="typeRefNMTOKEN"/>
  <xsd:element name="DefaultValue" type="xsd:token"
    minOccurs="0"/>
</xsd:sequence>
```

Figure 4: New Excerpt of typeDeclarationGroup Defintion in the schema

Additionally it appends to the declaration of the AtomicType this xml (Figure 5) to allow default values to Atomic datatypes.

```
<xsd:element name="defaultValue" type="xsd:token" minOccurs="0"/>
```

Figure 5: Appending xml in of AtomicType Defintion in the schema

4.3. Struct Optional Access Type

In the original schema, the access type can be only be defined on components of LFB. However when it's a struct datatype it is not possible to fine-tune access type per component in the struct. With this extension is it allowed to define the access type for a struct component either in the datatype definitions or in the LFB component definitions.

This extension allows to optionally specify access type for struct components. A simple use case would be to have a read-write struct component where one of the components is a counter where the access-type could be read-reset or read-only.

When the optional access type for a struct component is defined it MUST override the access type of the struct. If by accident an access type for a component in a capability is defined, the access type MUST not be taken into account.

This extension alters the definition of the struct in the xml schema from Figure 6 to Figure 7.

```
<xsd:complexType name="structType">
  <xsd:sequence>
    <xsd:element name="derivedFrom" type="typeRefNMTOKEN"
      minOccurs="0"/>
    <xsd:element name="component" maxOccurs="unbounded">
      <xsd:complexType>
        <xsd:sequence>
          <xsd:element name="name" type="xsd:NMTOKEN"/>
          <xsd:element ref="synopsis"/>
          <xsd:element ref="description" minOccurs="0"/>
          <xsd:element name="optional" minOccurs="0"/>
          <xsd:group ref="typeDeclarationGroup"/>
        </xsd:sequence>
        <xsd:attribute name="componentID" type="xsd:unsignedInt"
          use="required"/>
      </xsd:complexType>
    </xsd:element>
  </xsd:sequence>
</xsd:complexType>
```

Figure 6: Initial xml for the struct definition in the schema


```
<xsd:complexType name="structType">
  <xsd:sequence>
    <xsd:element name="derivedFrom" type="typeRefNMTOKEN"
      minOccurs="0"/>
    <xsd:element name="component" maxOccurs="unbounded">
      <xsd:complexType>
        <xsd:sequence>
          <xsd:element name="name" type="xsd:NMTOKEN"/>
          <xsd:element ref="synopsis"/>
          <xsd:element ref="description" minOccurs="0"/>
          <xsd:element name="optional" minOccurs="0"/>
          <xsd:group ref="typeDeclarationGroup"/>
        </xsd:sequence>
        <xsd:attribute name="access" use="optional"
          default="read-write">
          <xsd:simpleType>
            <xsd:list itemType="accessModeType"/>
          </xsd:simpleType>
        </xsd:attribute>
        <xsd:attribute name="componentID" type="xsd:unsignedInt"
          use="required"/>
      </xsd:complexType>
    </xsd:element>
  </xsd:sequence>
</xsd:complexType>
```

Figure 7: New xml for the struct definition in the schema

4.4. New datatype: Bitmap

With the current schema it is valid to create a struct of booleans in order to simulate a bitmap value. However each boolean is sent as 4bytes. This extension adds the bitmap, a set of sequential named bits. The goal is to accompany the bitmap with a TLV for transporting it in a more compact format. A first approach would be to define it as T-L followed by a 16bits that would specify the number of bits, followed by the actual bits and the necessary padding for the 32-bit alignment.

In the new schema, bits are named followed by the bitsize per named bits. An example:


```

<dataTypeDef>
  <name>Bitmap example</name>
  <synopsis>A bitmap field example</synopsis>
  <bitmap>
    <bit bitsize="1" name="Bit0"/>
    <bit bitsize="2" name="Bits12"/>
  </bitmap>
</dataTypeDef>

```

Figure 8: Example of bitmap Defintion

The ordering of the bits MUST be implemented in the order that are defined in the xml library.

The bitmap is defined in the model extension schema is as follows:

```

<xsd:complexType name="bitmapType">
  <xsd:sequence>
    <xsd:element name="bit" minOccurs="1" maxOccurs="unbounded">
      <xsd:complexType>
        <xsd:attribute name="name" type="xsd:NMTOKEN"
          use="required"/>
        <xsd:attribute name="bitsize" type="xsd:integer"
          use="required"/>
      </xsd:complexType>
    </xsd:element>
    <xsd:element name="defaultValue" type="xsd:token"
      minOccurs="0"/>
  </xsd:sequence>
</xsd:complexType>

```

Figure 9: New Excerpt of bitmap Defintion in the schema

Along with the needed addition to the typeDeclarationGroup Definition:

```

<xsd:element name="bitmap" type="bitmapType"/>

```

Figure 10: New Excerpt of typeDeclarationGroup Defintion in the schema

4.5. New Event Condition: EqualTo

This extensions adds one more event condition in the model schema, that of EqualTo. The difference between Greater Than and Less Than, is that when the value is exactly that of the EqualTo, the event is triggered. This event condition is particular useful when there is a need to monitor one or more states of an LFB or the FE. For example

in the CEHA [[I-D.ietf-forces-ceha](#)] document it may be useful for the master CE to know which backup CEs have just become associated in order to connect to them and begin synchronizing the state of the FE. The master CE could always poll for such information but getting such an event will speed up the process and the event may be useful in other cases as well for monitoring state.

A user subscribing to such an event SHOULD always set the Event Time Filtering for the EqualTo event condition in order to avoid getting a large amount of generated events.

The EqualTo is appended to the schema as follows:

```
<xsd:element name="eventEqualTo"
substitutionGroup="eventCondition"/>
```

Figure 11: New Excerpt of EqualTo event condition definition in the schema

[4.6.](#) Enhancing XML Validation

As specified earlier this is not an extension but an enhancement of the schema to provide additional validation rules. This includes adding new key declarations to provide uniqueness as defined by the ForCES Model [[RFC5812](#)]. Such validations work only on within the same xml file.

The following validation rules have been appended in the original schema in [[RFC5812](#)]:

1. Each metadata ID must be unique.
2. LFB Class IDs must be unique.
3. Component ID, Capability ID and Event Base ID must be unique per LFB.
4. Event IDs must be unique per LFB.
5. Special Values in Atomic datatypes must be unique per atomic datatype.

5. XML Extension Schema for LFB Class Library Documents

```
<?xml version="1.0" encoding="UTF-8"?>
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema"
  xmlns="urn:ietf:params:xml:ns:forces:lfbmodel:1.0"
  xmlns:lfb="urn:ietf:params:xml:ns:forces:lfbmodel:1.0"
  targetNamespace="urn:ietf:params:xml:ns:forces:lfbmodel:1.0"
  elementFormDefault="qualified" attributeFormDefault="unqualified">
  <xsd:annotation>
    <xsd:documentation xml:lang="en">
      Schema for Defining LFB Classes and associated types (frames,
      data types for LFB attributes, and metadata).
    </xsd:documentation>
  </xsd:annotation>
  <xsd:element name="description" type="xsd:string" />
  <xsd:element name="synopsis" type="xsd:string" />
  <!-- Document root element: LFBLibrary -->
  <xsd:element name="LFBLibrary">
    <xsd:complexType>
      <xsd:sequence>
        <xsd:element ref="description" minOccurs="0" />
        <xsd:element name="load" type="loadType"
          minOccurs="0" maxOccurs="unbounded" />
        <xsd:element name="frameDefs" type="frameDefsType"
          minOccurs="0" />
        <xsd:element name="dataTypeDefs" type="dataTypeDefsType"
          minOccurs="0" />
        <xsd:element name="metadataDefs" type="metadataDefsType"
          minOccurs="0" />
        <xsd:element name="LFBClassDefs" type="LFBClassDefsType"
          minOccurs="0" />
      </xsd:sequence>
      <xsd:attribute name="provides" type="xsd:Name"
        use="required" />
    </xsd:complexType>
  <!-- Uniqueness constraints -->
  <xsd:key name="frame">
    <xsd:selector xpath="lfb:frameDefs/lfb:frameDef" />
    <xsd:field xpath="lfb:name" />
  </xsd:key>
  <xsd:key name="dataType">
    <xsd:selector xpath="lfb:dataTypeDefs/lfb:dataTypeDef" />
    <xsd:field xpath="lfb:name" />
  </xsd:key>
  <xsd:key name="metadataDef">
    <xsd:selector xpath="lfb:metadataDefs/lfb:metadataDef" />
    <xsd:field xpath="lfb:name" />
  </xsd:key>
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```
</xsd:key>
<xsd:key name="metadataDefID">
  <xsd:selector xpath="lfb:metadataDefs/lfb:metadataDef" />
  <xsd:field xpath="lfb:metadataID" />
</xsd:key>
<xsd:key name="LFBCClassDef">
  <xsd:selector xpath="lfb:LFBCClassDefs/lfb:LFBCClassDef" />
  <xsd:field xpath="lfb:name" />
</xsd:key>
<xsd:key name="LFBCClassDefID">
  <xsd:selector xpath="lfb:LFBCClassDefs/lfb:LFBCClassDef" />
  <xsd:field xpath="@LFBCClassID" />
</xsd:key>
</xsd:element>
<xsd:complexType name="loadType">
  <xsd:attribute name="library" type="xsd:Name" use="required" />
  <xsd:attribute name="location" type="xsd:anyURI"
    use="optional" />
</xsd:complexType>
<xsd:complexType name="frameDefsType">
  <xsd:sequence>
    <xsd:element name="frameDef" maxOccurs="unbounded">
      <xsd:complexType>
        <xsd:sequence>
          <xsd:element name="name" type="xsd:NMTOKEN" />
          <xsd:element ref="synopsis" />
          <xsd:element ref="description"
            minOccurs="0" />
        </xsd:sequence>
      </xsd:complexType>
    </xsd:element>
  </xsd:sequence>
</xsd:complexType>
<xsd:complexType name="dataTypeDefsType">
  <xsd:sequence>
    <xsd:element name="dataTypeDef" maxOccurs="unbounded">
      <xsd:complexType>
        <xsd:sequence>
          <xsd:element name="name" type="xsd:NMTOKEN" />
          <xsd:element name="derivedFrom" type="xsd:NMTOKEN"
            minOccurs="0" />
          <xsd:element ref="synopsis" />
          <xsd:element ref="description"
            minOccurs="0" />
          <xsd:group ref="typeDeclarationGroup" />
        </xsd:sequence>
      </xsd:complexType>
    </xsd:element>
```



```
</xsd:sequence>
</xsd:complexType>
<!-- Predefined (built-in) atomic data-types are: char, uchar,
      int16, uint16, int32, uint32, int64, uint64, string[N], string,
      byte[N], boolean, octetstring[N], float32, float64 -->
<xsd:group name="typeDeclarationGroup">
  <xsd:choice>
    <!-- Extension -->
    <xsd:sequence>
      <!-- /Extension -->
      <xsd:element name="typeRef" type="typeRefNMTOKEN" />
      <!-- Extension -->
      <xsd:element name="DefaultValue" type="xsd:token"
        minOccurs="0" />
    </xsd:sequence>
    <xsd:element name="bitmap" type="bitmapType"/>
    <!-- /Extension -->
    <xsd:element name="atomic" type="atomicType" />
    <xsd:element name="array" type="arrayType">
      <!-- Extension -->
      <!--declare keys to have unique IDs -->
      <xsd:key name="contentKeyID">
        <xsd:selector xpath="lfb:contentKey" />
        <xsd:field xpath="@contentKeyID" />
      </xsd:key>
      <!-- /Extension -->
    </xsd:element>
    <xsd:element name="struct" type="structType">
      <!-- Extension -->
      <!-- key for componentIDs uniqueness in a struct -->
      <xsd:key name="structComponentID">
        <xsd:selector xpath="lfb:component" />
        <xsd:field xpath="@componentID" />
      </xsd:key>
      <!-- /Extension -->
    </xsd:element>
    <xsd:element name="union" type="structType" />
    <xsd:element name="alias" type="typeRefNMTOKEN" />
  </xsd:choice>
</xsd:group>
<xsd:simpleType name="typeRefNMTOKEN">
  <xsd:restriction base="xsd:token">
    <xsd:pattern value="\c+" />
    <xsd:pattern value="string\[\\d+\\]" />
    <xsd:pattern value="byte\[\\d+\\]" />
    <xsd:pattern value="octetstring\[\\d+\\]" />
  </xsd:restriction>
</xsd:simpleType>
```



```
<xsd:complexType name="atomicType">
  <xsd:sequence>
    <xsd:element name="baseType" type="typeRefNMTOKEN" />
    <xsd:element name="rangeRestriction"
      type="rangeRestrictionType" minOccurs="0" />
    <xsd:element name="specialValues" type="specialValuesType"
      minOccurs="0">
      <!-- Extension -->
      <xsd:key name="SpecialValue">
        <xsd:selector xpath="specialValue" />
        <xsd:field xpath="@value" />
      </xsd:key>
      <!-- /Extension -->
    </xsd:element>
    <!-- Extension -->
    <xsd:element name="defaultValue" type="xsd:token"
      minOccurs="0" />
    <!-- /Extension -->
  </xsd:sequence>
</xsd:complexType>
<xsd:complexType name="rangeRestrictionType">
  <xsd:sequence>
    <xsd:element name="allowedRange" maxOccurs="unbounded">
      <xsd:complexType>
        <xsd:attribute name="min" type="xsd:integer"
          use="required" />
        <xsd:attribute name="max" type="xsd:integer"
          use="required" />
      </xsd:complexType>
    </xsd:element>
  </xsd:sequence>
</xsd:complexType>
<xsd:complexType name="specialValuesType">
  <xsd:sequence>
    <xsd:element name="specialValue" maxOccurs="unbounded">
      <xsd:complexType>
        <xsd:sequence>
          <xsd:element name="name" type="xsd:NMTOKEN" />
          <xsd:element ref="synopsis" />
        </xsd:sequence>
        <xsd:attribute name="value" type="xsd:token" />
      </xsd:complexType>
    </xsd:element>
  </xsd:sequence>
</xsd:complexType>
<!-- Extension -->
<xsd:complexType name="bitmapType">
  <xsd:sequence>
```



```
<xsd:element name="bit" minOccurs="1" maxOccurs="unbounded">
  <xsd:complexType>
    <xsd:attribute name="name" type="xsd:NMTOKEN"
      use="required"/>
    <xsd:attribute name="bitsize" type="xsd:integer"
      use="required"/>
  </xsd:complexType>
</xsd:element>
<xsd:element name="defaultValue" type="xsd:token" minOccurs="0"/>
</xsd:sequence>
</xsd:complexType>
<!-- /Extension -->
<xsd:complexType name="arrayType">
  <xsd:sequence>
    <xsd:group ref="typeDeclarationGroup" />
    <xsd:element name="contentKey" minOccurs="0"
      maxOccurs="unbounded">
      <xsd:complexType>
        <xsd:sequence>
          <xsd:element name="contentKeyField"
            type="xsd:string" maxOccurs="unbounded" />
        </xsd:sequence>
        <xsd:attribute name="contentKeyID" type="xsd:integer"
          use="required" />
      </xsd:complexType>
    </xsd:element>
  </xsd:sequence>
  <xsd:attribute name="type" use="optional"
    default="variable-size">
    <xsd:simpleType>
      <xsd:restriction base="xsd:string">
        <xsd:enumeration value="fixed-size" />
        <xsd:enumeration value="variable-size" />
      </xsd:restriction>
    </xsd:simpleType>
  </xsd:attribute>
  <xsd:attribute name="length" type="xsd:integer"
    use="optional" />
  <xsd:attribute name="maxLength" type="xsd:integer"
    use="optional" />
</xsd:complexType>
<xsd:complexType name="structType">
  <xsd:sequence>
    <xsd:element name="derivedFrom" type="typeRefNMTOKEN"
      minOccurs="0" />
    <xsd:element name="component" maxOccurs="unbounded">
      <xsd:complexType>
        <xsd:sequence>
```



```
<xsd:element name="name" type="xsd:NMTOKEN" />
<xsd:element ref="synopsis" />
<xsd:element ref="description"
  minOccurs="0" />
<xsd:element name="optional" minOccurs="0" />
<xsd:group ref="typeDeclarationGroup" />
</xsd:sequence>
<!-- Extension -->
<xsd:attribute name="access" use="optional"
  default="read-write">
  <xsd:simpleType>
    <xsd:list itemType="accessModeType"/>
  </xsd:simpleType>
</xsd:attribute>
<!-- /Extension -->
<xsd:attribute name="componentID"
  type="xsd:unsignedInt" use="required" />
</xsd:complexType>
</xsd:element>
</xsd:sequence>
</xsd:complexType>
<xsd:complexType name="metadataDefsType">
  <xsd:sequence>
    <xsd:element name="metadataDef" maxOccurs="unbounded">
      <xsd:complexType>
        <xsd:sequence>
          <xsd:element name="name" type="xsd:NMTOKEN" />
          <xsd:element ref="synopsis" />
          <xsd:element name="metadataID" type="xsd:integer"/>
          <xsd:element ref="description"
            minOccurs="0" />
          <xsd:choice>
            <xsd:element name="typeRef"
              type="typeRefNMTOKEN" />
            <xsd:element name="atomic" type="atomicType" />
            <!-- Extension -->
            <xsd:element name="array" type="arrayType">
              <!-- declare keys to have unique IDs -->
              <xsd:key name="contentKeyID1">
                <xsd:selector xpath="lfb:contentKey" />
                <xsd:field xpath="@contentKeyID" />
              </xsd:key>
              <!-- /Extension -->
            </xsd:element>
            <xsd:element name="struct" type="structType">
              <!-- Extension -->
              <!-- key declaration to make componentIDs
                unique in a struct -->
```



```
        <xsd:key name="structComponentID1">
            <xsd:selector xpath="lfb:component" />
            <xsd:field xpath="@componentID" />
        </xsd:key>
        <!-- /Extension -->
    </xsd:element>
</xsd:choice>
</xsd:sequence>
</xsd:complexType>
</xsd:element>
</xsd:sequence>
</xsd:complexType>
<xsd:complexType name="LFBClassDefsType">
    <xsd:sequence>
        <xsd:element name="LFBClassDef" maxOccurs="unbounded">
            <xsd:complexType>
                <xsd:sequence>
                    <xsd:element name="name" type="xsd:NMTOKEN" />
                    <xsd:element ref="synopsis" />
                    <xsd:element name="version" type="versionType" />
                    <xsd:element name="derivedFrom" type="xsd:NMTOKEN"
                        minOccurs="0" />
                    <xsd:element name="inputPorts"
                        type="inputPortsType"
                        minOccurs="0" />
                    <xsd:element name="outputPorts"
                        type="outputPortsType"
                        minOccurs="0" />
                    <xsd:element name="components"
                        type="LFBComponentsType"
                        minOccurs="0" />
                    <xsd:element name="capabilities"
                        type="LFBCapabilitiesType"
                        minOccurs="0" />
                    <xsd:element name="events" type="eventsType"
                        minOccurs="0" />
                    <xsd:element ref="description"
                        minOccurs="0" />
                </xsd:sequence>
                <xsd:attribute name="LFBClassID" type="xsd:unsignedInt"
                    use="required" />
            </xsd:complexType>
            <!-- Key constraint to ensure unique attribute names
                within a class: -->
            <xsd:key name="components">
                <xsd:selector xpath="lfb:components/lfb:component" />
                <xsd:field xpath="lfb:name" />
            </xsd:key>
```



```
<xsd:key name="capabilities">
  <xsd:selector xpath="lfb:capabilities/lfb:capability"/>
  <xsd:field xpath="lfb:name" />
</xsd:key>
<xsd:key name="events">
  <xsd:selector xpath="lfb:events/lfb:event" />
  <xsd:field xpath="lfb:name" />
</xsd:key>
<xsd:key name="eventsIDs">
  <xsd:selector xpath="lfb:events/lfb:event" />
  <xsd:field xpath="@eventID" />
</xsd:key>
<xsd:key name="componentIDs">
  <xsd:selector xpath="lfb:components/lfb:component" />
  <xsd:field xpath="@componentID" />
</xsd:key>
<xsd:key name="capabilityIDs">
  <xsd:selector xpath="lfb:capabilities/lfb:capability"/>
  <xsd:field xpath="@componentID" />
</xsd:key>
<xsd:key name="ComponentCapabilityComponentIDUniqueness">
  <xsd:selector
    xpath="lfb:components/lfb:component|
    lfb:capabilities/lfb:capability|lfb:events" />
  <xsd:field xpath="@componentID|@baseID" />
</xsd:key>
</xsd:element>
</xsd:sequence>
</xsd:complexType>
<xsd:simpleType name="versionType">
  <xsd:restriction base="xsd:NMTOKEN">
    <xsd:pattern value="[1-9][0-9]*\.[1-9][0-9]*|0" />
  </xsd:restriction>
</xsd:simpleType>
<xsd:complexType name="inputPortsType">
  <xsd:sequence>
    <xsd:element name="inputPort" type="inputPortType"
      maxOccurs="unbounded" />
  </xsd:sequence>
</xsd:complexType>
<xsd:complexType name="inputPortType">
  <xsd:sequence>
    <xsd:element name="name" type="xsd:NMTOKEN" />
    <xsd:element ref="synopsis" />
    <xsd:element name="expectation" type="portExpectationType"/>
    <xsd:element ref="description" minOccurs="0" />
  </xsd:sequence>
  <xsd:attribute name="group" type="xsd:boolean"
```



```
        use="optional" default="0" />
</xsd:complexType>
<xsd:complexType name="portExpectationType">
  <xsd:sequence>
    <xsd:element name="frameExpected" minOccurs="0">
      <xsd:complexType>
        <xsd:sequence>
          <!-- ref must refer to a name of a defined
               frame type -->
          <xsd:element name="ref" type="xsd:string"
                minOccurs="unbounded" />
        </xsd:sequence>
      </xsd:complexType>
    </xsd:element>
    <xsd:element name="metadataExpected" minOccurs="0">
      <xsd:complexType>
        <xsd:choice maxOccurs="unbounded">
          <!-- ref must refer to a name of a defined
               metadata -->
          <xsd:element name="ref"
                type="metadataInputRefType" />
          <xsd:element name="one-of"
                type="metadataInputChoiceType" />
        </xsd:choice>
      </xsd:complexType>
    </xsd:element>
  </xsd:sequence>
</xsd:complexType>
<xsd:complexType name="metadataInputChoiceType">
  <xsd:choice minOccurs="2" maxOccurs="unbounded">
    <!-- ref must refer to a name of a defined metadata -->
    <xsd:element name="ref" type="xsd:NMTOKEN" />
    <xsd:element name="one-of" type="metadataInputChoiceType" />
    <xsd:element name="metadataSet" type="metadataInputSetType"/>
  </xsd:choice>
</xsd:complexType>
<xsd:complexType name="metadataInputSetType">
  <xsd:choice minOccurs="2" maxOccurs="unbounded">
    <!-- ref must refer to a name of a defined metadata -->
    <xsd:element name="ref" type="metadataInputRefType" />
    <xsd:element name="one-of" type="metadataInputChoiceType"/>
  </xsd:choice>
</xsd:complexType>
<xsd:complexType name="metadataInputRefType">
  <xsd:simpleContent>
    <xsd:extension base="xsd:NMTOKEN">
      <xsd:attribute name="dependency" use="optional"
            default="required">
```



```
<xsd:simpleType>
  <xsd:restriction base="xsd:string">
    <xsd:enumeration value="required" />
    <xsd:enumeration value="optional" />
  </xsd:restriction>
</xsd:simpleType>
</xsd:attribute>
<xsd:attribute name="defaultValue" type="xsd:token"
  use="optional" />
</xsd:extension>
</xsd:simpleContent>
</xsd:complexType>
<xsd:complexType name="outputPortsType">
  <xsd:sequence>
    <xsd:element name="outputPort" type="outputPortType"
      maxOccurs="unbounded" />
  </xsd:sequence>
</xsd:complexType>
<xsd:complexType name="outputPortType">
  <xsd:sequence>
    <xsd:element name="name" type="xsd:NMTOKEN" />
    <xsd:element ref="synopsis" />
    <xsd:element name="product" type="portProductType" />
    <xsd:element ref="description" minOccurs="0" />
  </xsd:sequence>
  <xsd:attribute name="group" type="xsd:boolean"
    use="optional" default="0" />
</xsd:complexType>
<xsd:complexType name="portProductType">
  <xsd:sequence>
    <xsd:element name="frameProduced" minOccurs="0">
      <xsd:complexType>
        <xsd:sequence>
          <!-- ref must refer to a name of a defined
            frame type -->
          <xsd:element name="ref" type="xsd:NMTOKEN"
            maxOccurs="unbounded" />
        </xsd:sequence>
      </xsd:complexType>
    </xsd:element>
    <xsd:element name="metadataProduced" minOccurs="0">
      <xsd:complexType>
        <xsd:choice maxOccurs="unbounded">
          <!-- ref must refer to a name of a defined
            metadata -->
          <xsd:element name="ref"
            type="metadataOutputRefType" />
          <xsd:element name="one-of"
```



```
        type="metadataOutputChoiceType" />
      </xsd:choice>
    </xsd:complexType>
  </xsd:element>
</xsd:sequence>
</xsd:complexType>
<xsd:complexType name="metadataOutputChoiceType">
  <xsd:choice minOccurs="2" maxOccurs="unbounded">
    <!-- ref must refer to a name of a defined metadata -->
    <xsd:element name="ref" type="xsd:NMTOKEN" />
    <xsd:element name="one-of" type="metadataOutputChoiceType" />
    <xsd:element name="metadataSet"
      type="metadataOutputSetType" />
  </xsd:choice>
</xsd:complexType>
<xsd:complexType name="metadataOutputSetType">
  <xsd:choice minOccurs="2" maxOccurs="unbounded">
    <!-- ref must refer to a name of a defined metadata -->
    <xsd:element name="ref" type="metadataOutputRefType" />
    <xsd:element name="one-of"
      type="metadataOutputChoiceType" />
  </xsd:choice>
</xsd:complexType>
<xsd:complexType name="metadataOutputRefType">
  <xsd:simpleContent>
    <xsd:extension base="xsd:NMTOKEN">
      <xsd:attribute name="availability" use="optional"
        default="unconditional">
        <xsd:simpleType>
          <xsd:restriction base="xsd:string">
            <xsd:enumeration value="unconditional" />
            <xsd:enumeration value="conditional" />
          </xsd:restriction>
        </xsd:simpleType>
      </xsd:attribute>
    </xsd:extension>
  </xsd:simpleContent>
</xsd:complexType>
<xsd:complexType name="LFBComponentsType">
  <xsd:sequence>
    <xsd:element name="component" maxOccurs="unbounded">
      <xsd:complexType>
        <xsd:sequence>
          <xsd:element name="name" type="xsd:NMTOKEN" />
          <xsd:element ref="synopsis" />
          <xsd:element ref="description"
            minOccurs="0" />
          <xsd:element name="optional" minOccurs="0" />
        </xsd:sequence>
      </xsd:complexType>
    </xsd:element>
  </xsd:sequence>
</xsd:complexType>
```



```
        <xsd:group ref="typeDeclarationGroup" />
        <xsd:element name="defaultValue" type="xsd:token"
            minOccurs="0" />
    </xsd:sequence>
    <xsd:attribute name="access" use="optional"
        default="read-write">
        <xsd:simpleType>
            <xsd:list itemType="accessModeType" />
        </xsd:simpleType>
    </xsd:attribute>
    <xsd:attribute name="componentID"
        type="xsd:unsignedInt" use="required" />
</xsd:complexType>
</xsd:element>
</xsd:sequence>
</xsd:complexType>
<xsd:simpleType name="accessModeType">
    <xsd:restriction base="xsd:NMTOKEN">
        <xsd:enumeration value="read-only" />
        <xsd:enumeration value="read-write" />
        <xsd:enumeration value="write-only" />
        <xsd:enumeration value="read-reset" />
        <xsd:enumeration value="trigger-only" />
    </xsd:restriction>
</xsd:simpleType>
<xsd:complexType name="LFBCapabilitiesType">
    <xsd:sequence>
        <xsd:element name="capability" maxOccurs="unbounded">
            <xsd:complexType>
                <xsd:sequence>
                    <xsd:element name="name" type="xsd:NMTOKEN" />
                    <xsd:element ref="synopsis" />
                    <xsd:element ref="description"
                        minOccurs="0" />
                    <xsd:element name="optional" minOccurs="0" />
                    <xsd:group ref="typeDeclarationGroup" />
                </xsd:sequence>
                <xsd:attribute name="componentID" type="xsd:integer"
                    use="required" />
            </xsd:complexType>
        </xsd:element>
    </xsd:sequence>
</xsd:complexType>
<xsd:complexType name="eventsType">
    <xsd:sequence>
        <xsd:element name="event" maxOccurs="unbounded">
            <xsd:complexType>
                <xsd:sequence>
```



```
<xsd:element name="name" type="xsd:NMTOKEN" />
<xsd:element ref="synopsis" />
<xsd:element name="eventTarget"
  type="eventPathType" />
<xsd:element ref="eventCondition" />
<xsd:element name="eventReports"
  type="eventReportsType" minOccurs="0" />
<xsd:element ref="description"
  minOccurs="0" />
</xsd:sequence>
<xsd:attribute name="eventID" type="xsd:integer"
  use="required" />
</xsd:complexType>
</xsd:element>
</xsd:sequence>
<xsd:attribute name="baseID" type="xsd:integer"
  use="optional" />
</xsd:complexType>
<!-- the substitution group for the event conditions -->
<xsd:element name="eventCondition" abstract="true" />
<xsd:element name="eventCreated"
  substitutionGroup="eventCondition" />
<xsd:element name="eventDeleted"
  substitutionGroup="eventCondition" />
<xsd:element name="eventChanged"
  substitutionGroup="eventCondition" />
<xsd:element name="eventGreaterThan"
  substitutionGroup="eventCondition" />
<xsd:element name="eventLessThan"
  substitutionGroup="eventCondition" />
<!-- Extension -->
  <xsd:element name="eventEqualTo"
    substitutionGroup="eventCondition"/>
<!-- /Extension -->
<xsd:complexType name="eventPathType">
  <xsd:sequence>
    <xsd:element ref="eventPathPart" maxOccurs="unbounded" />
  </xsd:sequence>
</xsd:complexType>
<!-- the substitution group for the event path parts -->
<xsd:element name="eventPathPart" type="xsd:string"
  abstract="true" />
<xsd:element name="eventField" type="xsd:string"
  substitutionGroup="eventPathPart" />
<xsd:element name="eventSubscript" type="xsd:string"
  substitutionGroup="eventPathPart" />
<xsd:complexType name="eventReportsType">
  <xsd:sequence>
```



```
        <xsd:element name="eventReport" type="eventPathType"
          maxOccurs="unbounded" />
      </xsd:sequence>
</xsd:complexType>
<xsd:simpleType name="booleanType">
  <xsd:restriction base="xsd:string">
    <xsd:enumeration value="0" />
    <xsd:enumeration value="1" />
  </xsd:restriction>
</xsd:simpleType>
</xsd:schema>
```

OpenFlow XML Library

6. Acknowledgements

TBD

7. IANA Considerations

This memo includes no request to IANA.

8. Security Considerations

TBD

9. References

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