Introduction to NETCONF and YANG

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Overview

Structure of the Tutorial

- Part 1: Motivation and Background (20 min)
- Part 2: NETCONF Protocol (30 min)
- Part 3: Practice NETCONF (50 min)
- Part 4: YANG Data Modeling Language (30 min)
- Part 5: Practice YANG (50 min)

Part: Motivation and Background

1. Configuration Management Approaches

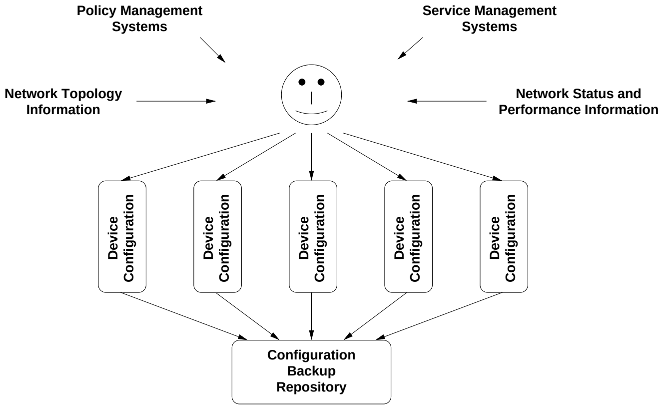
2. Configuration Management Requirements

3. Internet Management Framework

Part: Motivation and Background

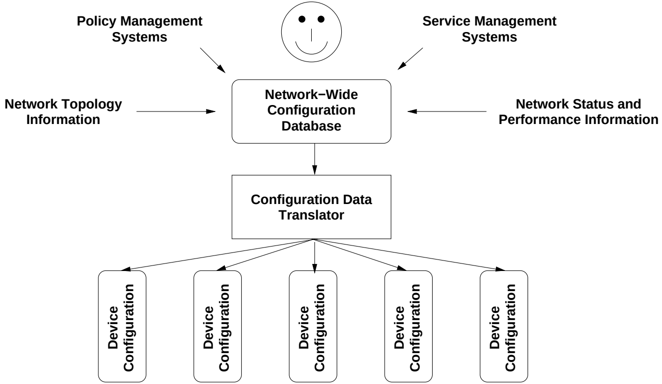
1. Configuration Management Approaches
2. Configuration Management Requirements
3. Internet Management Framework

"The Network is the Record" Approach



- Labor intensive, expensive, error prone, widely deployed

"Generate Everything" Approach



- All configuration changes are made (and validated) on the network-wide configuration database and devices are never touched manually

Part: Motivation and Background

Configuration Management Requirements (part 1)

R1: configuration state vs. operational state

A configuration management protocol must be able to distinguish between configuration state and operational state.

R2: concurrency support

A configuration management protocol must provide primitives to prevent errors due to concurrent configuration changes.

R3: configuration transactions

A configuration management protocol must provide primitives to apply configuration changes to a set of network elements in a robust and transaction-oriented way.

Configuration Management Requirements (part 2)

R4: distribution vs. activation

It is important to distinguish between the distribution of configurations and the activation of a certain configuration.

R5: distinguish multiple configurations

A configuration management protocol must be able to distinguish between several configurations and devices should be able to hold multiple configurations.

R6: persistence of configuration state

A configuration management protocol must be clear about the persistence of configuration changes.

Configuration Management Requirements (part 3)

R7: configuration change events

A configuration management protocol must be able to report configuration change events to help tracing back configuration changes.

R8: configuration dump and restore

A full configuration dump and a full configuration restore are primitive operations frequently used by operators and must be supported appropriately.

Configuration Management Requirements (part 4)

R9: support for standard tools

A configuration management protocol must represent configuration state and operational state in a form which allows operators to use existing comparison, conversion, and versioning tools.

R10: minimize impact of configuration changes

Configurations must be described such that devices can determine a set of operations to bring the devices from a given configuration state to the desired configuration state, minimizing the impact caused by the configuration change itself on networks and systems.

Part: Motivation and Background

Traditional IETF View: NM == SNMP

RFC 3410

The purpose of this document is to provide an overview of the third version of the Internet-Standard Management Framework, termed the SNMP version 3 Framework (SNMPv3).

Consequences

- WGs were forced to produce SNMP MIB modules
- Small group of people contributing to NM technologies
- Almost no operator involvement (they used CLIs, SYSLOG, SNMP, . . .)

Overcoming the SNMP Dogma

Today's IETF view

NM = SNMP + SYSLOG + NETCONF + IPFIX + ...

Took years to change this view...

- COPS vs. SNMP debate (2000)
- IETF NM road show (2000-2001)
- IAB NM workshop in 2002
- Lots of (repeated) discussions

Reading Material

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Handbook of Network and System Administration, chapter Internet Management Protocols, pages 295–328.
Elsevier, November 2007.

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RFC 3139, Megisto, Cisco, JDS Consultant, June 2001.

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R. Mahajan, D. Wetherall, and T. Anderson.
Understanding BGP Misconfiguration.
In Proc. SIGCOMM 2002. ACM, August 2002.

D. Oppenheimer, A. Ganapathi, and D. A. Patterson.
Why do Internet services fail, and what can be done about it?
In Proc. 4th Usenix Symposium on Internet Technologies and Systems. Usenix, March 2003.

Part: NETCONF

4. Architectural Aspects

5. Capability Exchange and Remote Procedure Calls

6. Protocol Operations

7. Transport Mappings

NETCONF IETF Working Group

Milestones

- NETCONF WG chartered in May 2003, core specifications published in December 2006
- Heavily influenced by Juniper's JunoScript
- Core contributors from Juniper Networks and Cisco
- Some design decisions were difficult to take

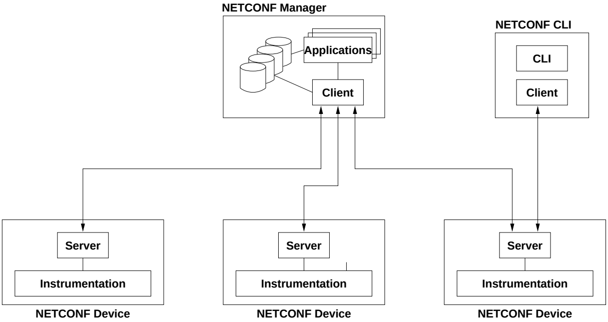
Status

The NETCONF WG is still active:

- notifications
- fine grained locking
- NETCONF monitoring
- TLS transport

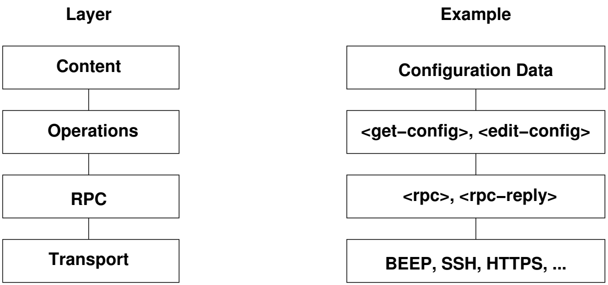
Part: NETCONF

Deployment Model



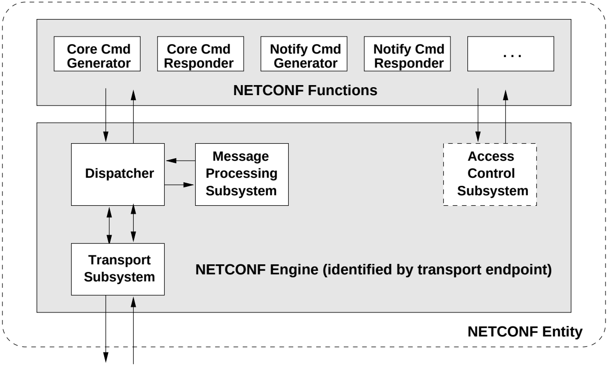
- NETCONF enabled devices include a NETCONF server
- Management applications include a NETCONF client
- Command Line Interfaces (CLIs) can be a wrapped around a NETCONF client

Layering Model (RFC4741)



- Security has to be provided by the transport layer.
- The operations layer provides the primitives to handle configurations.
- The set of operations is supposed to be extensible.

Architectural Model



- Does not exist formally (so take this with some care)
- Loosely based on SNMP architectural concepts

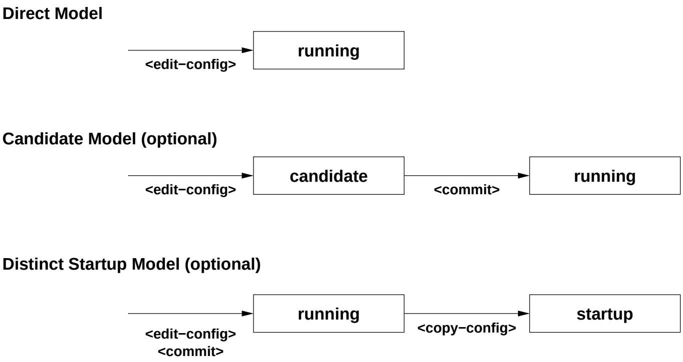
Configuration Datastores

Definition

A configuration datastore is the complete set of configuration information that is required to get a device from its initial default state into a desired operational state.

- The `<running>` configuration datastore represents the currently active configuration of a device and is always present.
- The `<startup>` configuration datastore represents the configuration that will be used during the next startup.
- The `<candidate>` configuration datastore represents a configuration that may become a `<running>` configuration through an explicit commit.

Transaction Models



- Some operations (`edit-config`) may support different error behaviours, including rollback behaviour.

Part: NETCONF

Capability Exchange

Hello

After estabilishing a (secure) transport, both NETCONF protocol engines send a `hello` message to announce their capabilities and the session identifier.

```
A: <hello>
A:   <capabilities>
A:     <capability>
A:       urn:ietf:params:xml:ns:netconf:base:1.0
A:     </capability>
A:     <capability>
A:       urn:ietf:params:xml:ns:netconf:base:1.0#startup
A:     </capability>
A:   </capabilities>
A:   <session-id>4<session-id>
A: </hello>
```

Remote Procedure Calls

RPC protocol

The Remote Procedure Call (RPC) protocol consists of a <rpc/> message followed by an <rpc-reply/> message.

```
M: <rpc message-id="101"
M:      xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
M:   <get-config>
M:     <source>
M:       <running/>
M:     </source>
M:   </get-config>
M: </rpc>
A: <rpc-reply message-id="101"
A:      xmlns="urn:ietf:params:xml:ns:netconf:base:1.0"
A:   <data><!-- ...contents here... --></data>
A: </rpc-reply>
```

Remote Procedure Calls (cont.)

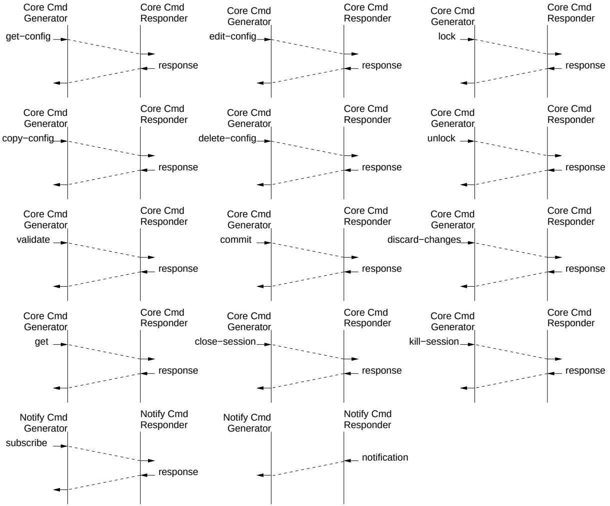
RPC protocol

RPC failures are indicated by one or more <rpc-error/> elements in the <rpc-reply/> element.

```
M: <rpc xmlns=''urn:ietf:params:xml:ns:netconf:base:1.0''>
M:   <get-config><source><running/></source></get-config>
M: </rpc>
A: <rpc-reply xmlns=urn:ietf:params:xml:ns:netconf:base:1.0>
A:   <rpc-error>
A:     <error-type>rpc</error-type>
A:     <error-tag>missing-attribute</error-tag>
A:     <error-severity>error</error-severity>
A:     <error-info>
A:      <bad-attribute>message-id</bad-attribute>
A:      <bad-element>rpc</bad-element>
A:     </error-info>
A:   </rpc-error>
A: </rpc-reply>
```

Part: NETCONF

NETCONF Operations Overview



NETCONF Operations

- `get-config(source, filter)`
  Retrieve a (filtered subset of a) configuration from the configuration datastore `source`.
- `edit-config(target, default-operation, test-option, error-option, config)`
  Edit the `target` configuration datastore by merging, replacing, creating, or deleting new config elements.
- `copy-config(target, source)`
  Copy the content of the configuration datastore `source` to the configuration datastore `target`.
- `delete-config(target)`
  Delete the named configuration datastore `target`.

NETCONF Operations (cont.)

- `lock(target)`
  Lock the configuration datastore `target`.
- `unlock(target)`
  Unlock the configuration datastore `target`.
- `get(filter)`
  Retrieve (a filtered subset of a) the running configuration and device state information.
- `close-session()`
  Gracefully close the current session.
- kill-session(session)
  Force the termination of the session `session`.

NETCONF Operations (cont.)

- `commit()`
  Commit candidate configuration datastore to the running configuration (#candidate capability).
- `discard-changes()`
  Revert the candidate configuration datastore to the running configuration (#candidate capability).
- `validate(source)`
  Validate the contents of the configuration datastore `source` (#validate capability).
- `create-subscription(stream, filter, start, stop)`
  Subscribe to a notification `stream` with a given `filter` and the `start` and `stop` times.

Editing Configuration

merge

The configuration data is merged with the configuration at the corresponding level in the configuration datastore.

replace

The configuration data replaces any related configuration in the configuration datastore identified by the target parameter.

create

The configuration data is added to the configuration if and only if the configuration data does not already exist.

delete

The configuration data identified by the element containing this attribute is deleted in the configuration datastore.

Editing Configuration Example

```
M:  <rpc message-id="101"
M:       xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
M:    <edit-config>
M:      <target>
M:        <running/>
M:      </target>
M:      <config xmlns:xc="urn:ietf:params:xml:ns:netconf:base:1.0">
M:        <top xmlns="http://example.com/schema/1.2/config">
M:          <interface xc:operation="replace">
M:            <name>Ethernet0/0</name>
M:            <mtu>1500</mtu>
M:            <address>
M:              <name>192.0.2.4</name>
M:              <prefix-length>24</prefix-length>
M:            </address>
M:          </interface>
M:        </top>
M:      </config>
M:    </edit-config>
M:  </rpc>
```

Subtree Filtering

Subtree Filter Expressions

Subtree filter expressions select particular XML subtrees to include in `get` and `get-config` responses.

Namespace Selection

If the 'xmlns' attribute is present, then the filter output will only include elements from the specified namespace.

Attribute Match Expressions

The set of (unqualified or qualified) XML attributes present in any type of filter node form an "attribute match expression" The selected data must have matching values for every attribute of an attribute match expression.

Subtree Filtering (cont.)

Containment Nodes

For each containment node specified in a subtree filter, all data model instances must exactly match the specified namespaces, element hierarchy, and any attribute match expressions.

Selection Nodes

An empty leaf node within a filter is called a "selection node" and it selects the specified subtree(s) and it suppresses the automatic selection of the entire set of sibling nodes in the underlying data model.

Content Match Nodes

A leaf node that contains simple content is called a "content match node" and it selects some or all of its sibling nodes. It represents an exact-match filter on the leaf node element content.

Subtree Filtering Example

```
<filter type="subtree">

   <!-- namespace selection and containment node selection -->
   <t:top xmlns:t="http://example.com/schema/1.2/config">

      <!-- containment node selection -->
      <t:interfaces>

         <!-- containment node selection and attribute match expression -->
         <t:interface t:ifName="eth0">

            <!-- selection node -->
            <t:ifSpeed/>

            <!-- content match node -->
            <t:ifType>Ethernet</t:if-type>

         </t:interface>
      </t:interfaces>
   </t:top>
</filter>
```

Part: NETCONF

SSH Protocol

- SSH is a protocol for secure remote login and other secure network services over an insecure network.
- The SSH protocol consists of three major components:
  1. The *Transport Layer Protocol* provides server authentication, confidentiality, and integrity with perfect forward secrecy.
  2. The *User Authentication Protocol* authenticates the client-side user to the server.
  3. The *Connection Protocol* multiplexes the encrypted tunnel into several logical channels. It runs over the user authentication protocol.
- SSH is widely deployed on network devices as a secure protocol to access the command line interface.

NETCONF over SSH

- Motivation: Use an already deployed security protocol, thereby reducing the operational costs associated with key management.
- SSH supports multiple logical channels over one transport layer association.
- For framing purposes, the special end of message marker `]]>]]>` has been introduced.
- NETCONF over SSH has been selected as the mandatory to implement transport for NETCONF.

NETCONF over SSH Example

```
A: <?xml version="1.0" encoding="UTF-8"?>
A: <hello>
A:   <capabilities>
A:     <capability>
A:       urn:ietf:params:xml:ns:netconf:base:1.0
A:     </capability>
A:     <capability>
A:       urn:ietf:params:xml:ns:netconf:base:1.0#startup
A:     </capability>
A:   </capabilities>
A:   <session-id>4<session-id>
A: </hello>
A: ]]>]]>
```

NETCONF over SSH Example

```
M: <?xml version="1.0" encoding="UTF-8"?>
M: <hello>
M:   <capabilities>
M:     <capability>
M:       urn:ietf:params:xml:ns:netconf:base:1.0
M:     </capability>
M:   </capabilities>
M: </hello>
M: ]]>]]>
```

NETCONF over SSH Example

```
M: <?xml version="1.0" encoding="UTF-8"?>
M: <rpc message-id="105" xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
M:   <get-config>
M:     <source>
M:       <running/>
M:     </source>
M:     <fitler type="subtree">
M:       <config xmlns="http://example.com/schema/1.2/config">
M:         <users/>
M:       </config>
M:     </filter>
M:   </get-config>
M: </rpc>
M: ]]>]]>
```

NETCONF over SSH Example

```
A: <?xml version="1.0" encoding="UTF-8"?>
A: <rpc-reply message-id="105" xmlns="urn:ietf:params:xml:ns:netconf:base:1
A:   <data>
A:     <config xmlns="http://example.com/schema/1.2/config">
A:       <users>
A:         <user><name>root</name><type>superuser</type></user>
A:         <user><name>fred</name><type>admin</type></user>
A:         <user><name>barney</name><type>admin</type></user>
A:       </users>
A:     </config>
A:   </data>
A: </rpc-reply>
A: ]]>]]>
```

BEEP Protocol (RFC 3080)

- BEEP is a generic application protocol kernel for connection-oriented, asynchronous interactions.
- BEEP supports multiple channels, application layer framing and fragmentation.
- BEEP exchange styles:
  - `MSG/RPY`
  - `MSG/ERR`
  - `MSG/ANS`
- Integrates into SASL (RFC 2222) and TLS (RFC 2246) for security.
- Connections can be initiated by both participating peers (no strict client/server roles).

NETCONF over BEEP

- BEEP supports multiple logical channels.
- Every peer can be the initiator of a connection.
- SASL allows to map to existing security infrastructures.
- Framing and fragmentation services provided by BEEP.
- BEEP is currently not widely deployed and there is a lack of operational experience with BEEP in the operator community.
- BEEP is an optional NETCONF transport.

NETCONF over BEEP Example

```
M: MSG 0 1 . 10 48 101
M: Content-Type: application/beep+xml
M: <start number=''1''>
M:   <profile uri=''http://iana.org/beep/netconf'' />
M: </start>
M: END
A: RPY 0 1 . 38 87
A: Content-Type: application/beep+xml
A:
A: <profile uri=''http://iana.org/beep/netconf'' />
A: END
```

NETCONF over BEEP Example

```
A: MSG 1 0 . 0 436
A: Content-Type: application/beep+xml
A:
A: <hello xmlns=''urn:ietf:params:xml:ns:netconf:base:1.0''>
A:   <capabilities>
A:     <capability>
A:       urn:ietf:params:xml:ns:netconf:base:1.0
A:     </capability>
A:     <capability>
A:       urn:ietf:params:xml:ns:netconf:base:1.0#startup
A:     </capability>
A:   </capabilities>
A:   <session-id>4</session-id>
A: </hello>
A: END
M: RPY 1 0 . 0 0
M: END
```

NETCONF over BEEP Example

```
M: MSG 1 42 . 24 344
M: Content-Type: text/xml; charset=utf-8
M:
M: <rpc message-id="105" xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
M:   <get-config>
M:     <source>
M:       <running/>
M:     </source>
M:     <filter type="subtree">
M:       <config xmlns="http://example.com/schema/1.2/config">
M:         <users/>
M:       </config>
M:     </filter>
M:   </get-config>
M: </rpc>
M: END
```

NETCONF over BEEP Example

```
A: RPY 1 42 . 24 542
A: Content-Type: text/xml; charset=utf-8
A:
A: <rpc-reply message-id="105" xmlns="urn:ietf:params:xml:ns:netconf:base:1
A:   <data>
A:     <config xmlns="http://example.com/schema/1.2/config">
A:       <users>
A:         <user><name>root</name><type>superuser</type></user>
A:         <user><name>fred</name><type>admin</type></user>
A:         <user><name>barney</name><type>admin</type></user>
A:       </users>
A:     </config>
A:   </data>
A: </rpc-reply>
A: END
```

NETCONF over SOAP/HTTP[S]

- Instead of inventing a special purpose RPC protocol, use existing Web Services standards.
- Pros:
  - more developers / tools available
  - better integration with IT infrastructure
- Cons:
  - base technology not under control of the IETF
  - unneeded complexity
  - interoperability problems (immature technology)
  - HTTP is a bad generic application protocol kernel
- Note: Transport mapping does not map NETCONF operations to SOAP operations!

NETCONF over SOAP/HTTP Example

```
M: POST /netconf HTTP/1.1
M: Host: netconfdevice
M: Content-Type: text/xml; charset=utf-8
M: Accept: application/soap+xml, text/*
M: Cache-Control: no-cache
M: Pragma: no-cache
M: Content-Length: 490
M:
M: <?xml version="1.0" encoding="UTF-8"?>
M: <soapenv:Envelope
M:   xmlns:soapenv="http://www.w3.org/2003/05/soap-envelope">
M:   <soapenv:Body>
M:     <rpc message-id="101"
M:          xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
M:       <get-config>
M:         <source><running/></source>
M:         <filter type="subtree">
M:           <top xmlns="http://example.com/schema/1.2/config">
M:             <users/>
M:           </top>
M:         </filter>
M:       </get-config>
M:     </rpc>
M:   </soapenv:Body>
M: </soapenv:Envelope>
```

NETCONF over SOAP/HTTP Example

```
A: HTTP/1.1 200 OK
A: Content-Type: application/soap+xml; charset=utf-8
A: Content-Length: 668
A:
A: <?xml version="1.0" encoding="UTF-8"?>
A: <soapenv:Envelope
A:   xmlns:soapenv="http://www.w3.org/2003/05/soap-envelope">
A:   <soapenv:Body>
A:     <rpc-reply message-id="101"
A:                xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">
A:       <data>
A:         <top xmlns="http://example.com/schema/1.2/config">
A:           <users>
A:             <user>
A:               <name>root</name>
A:               <type>superuser</type>
A:               <full-name>Charlie Root</full-name>
A:                 <dept>1</dept>
A:                 <id>1</id>
A:               </company-info>
A:             </user>
A:           </users>
A:         </top>
A:       </data>
A:     </rpc-reply>
A:   </soapenv:Body>
A: </soapenv:Envelope>
```

Reading Material

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NETCONF Configuration Protocol.
RFC 4741, Juniper Networks, December 2006.

M. Wasserman and T. Goddard.
Using the NETCONF Configuration Protocol over Secure SHell (SSH).
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Using the NETCONF Protocol over the Blocks Extensible Exchange Protocol (BEEP).
RFC 4744, Cisco Systems, December 2006.

S. Chisholm and H. Trevino.
NETCONF Event Notifications.
Internet Draft (work in progress) <draft-ietf-netconf-notification-13.txt>, Nortel, Cisco, May 2008.

Part: YANG

8. Overview
9. Modules
10. Built-in types and derived types
11. Leafs, Leaf-lists, Container, Lists
12. Tools

Part: YANG

8 Overview

9 Modules

10 Built-in types and derived types

11 Leafs, Leaf-lists, Container, Lists

12 Tools

YANG, YIN, XSD, RELAX NG

YANG's purpose

YANG is an extensible NETCONF data modeling language able to model configuration data, state data, operations, and notifications. YANG definitions directly map to XML content.

YANG vs. YIN

YANG uses a compact SMIng like syntax since readability is highest priority. YIN is an XML version of YANG (lossless roundtrip conversion).

YANG vs. XSD or RELAX NG

YANG can be translated to XML Schema (XSD) and RELAX NG so that existing tools can be utilized.

YANG and IETF NETMOD WG History

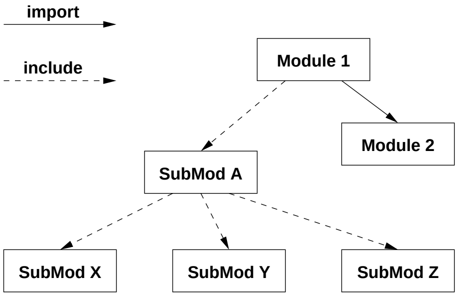
YANG Milestones (pre IETF)

- YANG design team created in Spring 2007
- Three design team meetings (USA, London, Stockholm)
- YANG discussions at the 71st IETF (Vancouver)
- YANG discussions at the 72nd IETF (Philadelphia)

NETMOD Milestones

- Apr. 2008: NETMOD WG chartered
- Aug. 2008: initial YANG, YIN, DSDL, . . . documents
- Mar. 2009: submit architecture document to the IESG
- Sep. 2009: submit YANG, YIN, DSDL, . . . to the IESG

Modules and submodules



Module

A self-contained collection of YANG definitions.

Submodule

A partial module definition which contributes derived types, groupings, data nodes, RPCs, and notifications to a module.

Module Example

```
module acme-module {
    namespace "http://acme.example.com/module";
    prefix "acme";

    import "yang-types" {
        prefix "yang";
    }
    include "acme-system";

    organization "ACME Inc.";
    contact      "support@acme.example.com";
    description
        "The module for entities implementing the ACME products";

    revision "2007-06-09" {
        description "Initial revision.";
    }
}
```

Part: YANG

Built-in Data Types

Category	Types	Restrictions
Integral	{u,}int{8,16,32,64}	range
Floats	float{32,64}	range
String	string	length, pattern
Enumeration	enumeration	enum
Bool and Bits	boolean, bits	
Binary	binary	length
References	keyref	
References	instance-identifier	
Other	empty	

Type system

The data type system is mostly an extension of the SMIng type system, accommodating XML and XSD requirements.

Example: typedef

```
module inet-types {

    namespace "urn:ietf:params:xml:ns:yang:inet-types";
    prefix "inet";

    typedef ipv4-address {
        type string {
            pattern '(([0-1]?[0-9]?[0-9]|2[0-4][0-9]|25[0-5])\.){3}'
                  + '([0-1]?[0-9]?[0-9]|2[0-4][0-9]|25[0-5])'
                  + '(%[\p{N}\p{L}]+)?';
        }
    }

    // ...

    typedef ip-address {
        type union {
            type inet:ipv4-address;
            type inet:ipv6-address;
        }
        description "Represents a version neutral IP address.";
    }
}
```

Leafs, Leaf-lists, Container, Lists

leaf

A `leaf` has one value, no children, one instance.

leaf-list

A `leaf-list` has one value, no children, multiple instances.

container

A `container` has no value, holds related children, has one instance.

list

A `list` has no value, holds related children, has multiple instances, has a key property.

Example: leaf and leaf-list

```
leaf domain {
    type inet:domain-name; // values are typed (type imported)
    mandatory true;        // must exist in a valid configuration
    config true;           // part of the set of configuration objects
    description
        "The host name of this system.";
}

// XML: <domain>example.com</domain>

leaf-list search {
    type inet:domain-name; // imported from the module with prefix inet
    ordered-by user;       // maintain the order given by the user
    description
        "List of domain names to search.";
}

// XML: <search>eng.example.com</search>
// XML: <search>example.com</search>
```

Example: container

```
container system {
    config true;
    leaf hostname {
        type inet:domain-name;
    }
    container resolver {
       leaf domain { /* see above */ }
       leaf-list search { /* see above */ }
       description
            "The configuration of the resolver library.";
    }
}

// XML: <system>
// XML:   <hostname>server.example.com<hostname>
// XML:   <resolver>
// XML:     <domain>example.com</domain>
// XML:     <search>eng.example.com</search>
// XML:     <search>example.com</search>
// XML:   </resolver>
// XML: </system>
```

Example: list

```
list nameserver {
    key address;
    leaf address {
        type inet:ip-address;
    }
    leaf status {
        type enumeration {
            enum enabled; enum disabled; enum failed;
        }
    }
}

// XML:   <nameserver>
// XML:     <address>192.0.2.1</address>
// XML:     <status>enabled</status>
// XML:   </nameserver>
// XML:   <nameserver>
// XML:     <address>192.0.2.2</address>
// XML:     <status>failed</status>
// XML:   </nameserver>
```

Augment, Must, When

augment

The `augment` statement can be used to place nodes into an existing hierarchy using the current module's namespace.

must

The `must` statement can be used to express constraints (in the form of XPATH expressions) that must be satisfied by a valid configuration.

when

The `when` statement can be used to define sparse augmentations where nodes are only added when a condition (expressed in the form of an XPATH expression) is true.

Example: augment and presence

```
augment system/resolver {
    container debug {
        presence "enables debugging";
        description
           "This container enables debugging.";
        leaf level {
            type enumeration {
                enum low;
                enum medium;
                enum full;
            }
            default "medium";
            mandatory false;
            description
               "The debugging level; default is medium debug information.";
        }
    }
}

// XML: <system><resolver>
// XML:    <debug/>
// XML: </resolver></system>
```

Example: augment and must

```
augment system/resolver {
    leaf access-timeout {
        type uint32;
        unit "seconds";
        mandatory true;
        description "Maximum time without server response.";
    }
    leaf retry-timer {
        type uint32;
        units "seconds";
        description "Period after which to retry an operation";
        must "$this < ../access-timeout" {
            error-app-tag "retry-timer-invalid";
            error-message "The retry timer must be less "
                        + "than the access timeout";
        }
    }
}
```

Example: augment and when

```
augment system/resolver/nameserver {
    when "status = enabled";
    leaf tx {
        type yang:counter32;
        config false;
    }
    leaf rx {
        type yang:counter32;
        config false;
    }
}

// XML:   <nameserver>
// XML:     <address>192.0.2.1</address>
// XML:     <status>enabled</status>
// XML:     <tx>2345</tx>
// XML:     <rx>1234</rx>
// XML:   </nameserver>
// XML:   <nameserver>
// XML:     <address>192.0.2.2</address>
// XML:     <status>failed</status>
// XML:   </nameserver>
```

Grouping and Choice

grouping

A `grouping` is a reusable collection of nodes. The `grouping` mechanism can be used to emulate structured data types or objects. A `grouping` can be refined when it is used.

choice

A `choice` allows one alternative of the choice to exist. The `choice` mechanism can be used to provide extensibility hooks that can be exploited using `augments`.

- Should a `grouping` be considered a template mechanism or a structured data type mechanism?

Example: grouping

```
grouping target {
    leaf address {
        type inet:ip-address;
        description "Target IP address.";
    }
    leaf port {
        type inet:ip-port;
        description "Target port number.";
    }
}

list nameserver {
    key "address port";
    uses target;
}

// XML: <nameserver>
// XML:   <address>192.0.2.1</address>
// XML:   <port>53</port>
// XML: </nameserver>
```

Example: choice

```
container transfer {
    choice how {
        default interval;
        case interval {
            leaf interval {
                type uint16; default 30; units minutes;
            }
        }
        case daily {
            leaf daily {
                type empty;
            }
            leaf time-of-day {
                type string; units 24-hour-clock; default 1am;
            }
        }
        case manual {
            leaf manual {
                type empty;
            }
        }
    }
}
```

Notification and RPC

notification

The `notification` statement can be used to define the contents of notifications.

rpc

The `rpc` statement can be used to define operations together with their input and output parameters carried over the RPC protocol.

- Should the `rpc` statement be called `operation` since it is used to define operations?
- Should all NETCONF operations be formally defined in YANG?

Example: notification

```
notification nameserver-failure {
    description
       "A failure of a nameserver has been detected and
        the server has been disabled."
    leaf address {
        type keyref {
            path "/system/resolver/nameserver/address";
        }
    }
}

// PROT: <notification>
// PROT:   <eventTime>2008-06-03T18:34:50+02:00</eventTime>
// PROT:   <nameserver-failure>
// PROT:     <address>192.0.2.2</address>
// PROT:   </nameserver-failure>
// PROT: </notification>
```

Example: rpc

```
rpc activate-software-image {
    input {
        leaf image name {
            type string;
        }
    }
    output {
        leaf status {
            type string;
        }
    }
}

// RPC: <rpc xmlns="urn:mumble" message-id="42">
// RPC:   <activate-software-image>
// RPC:     <image-name>image.tgz</image-name>
// RPC:   </activate-software-image>
// RPC: </rpc>
```

Part: YANG

8. Overview
9. Modules
10. Built-in types and derived types
11. Leafs, Leaf-lists, Container, Lists
12. Tools

Available Tools

pyang

Open source YANG validator and translator written in Python.

yangdump

Closed source YANG validator and translator written in C.

smidump

Open source SMI to YANG translator written in C.

emacs

Open source YANG editing mode for the emacs editor.

Reading Material

M. Bjorklund.
YANG - A data modeling language for NETCONF.
Internet Draft (work in progress) <draft-ietf-netmod-yang-00.txt>, Tail-f Systems, May 2008.

J. Schönwälder.
Common YANG Data Types.
Internet Draft (work in progress) <draft-schoenw-netmod-yang-types-00.txt>, Jacobs University, May 2008.

J. Schönwälder.
Protocol Independent Network Management Data Modeling Languages - Lessons Learned from the SMIng Project.
IEEE Communications Magazine, 46(5):148–153, May 2008.