lieter_
@lieter@mastodon.lieter.nl
pieterlexis

YANG and NETCONF

Model-based configuration management for networks

Pieter Lexis

cfgmgmtcamp 2020 Ghent, February 3

Config Management Camp

Lack of YAML

Mentions of XML

ASCII diagrams

DNS

Some bad memes

Agenda

- Introduction
- The solution
  - Configuring devices: NETCONF
  - Modeling data: YANG
  - YANG and NETCONF servers
- YANG and NETCONF on *NIX?
- Wrap up

Introduction

whoami

Pieter Lexis

- SysAdmin by training, developer by accident[1]
- Senior PowerDNS Engineer at PowerDNS
- Responsible for CI/CD, deployment automation, packaging & more

POWERDNS

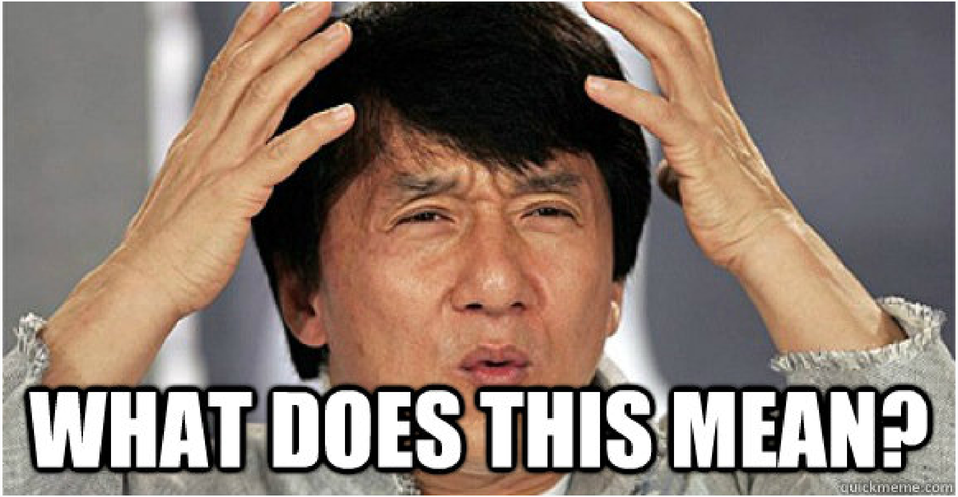
[1] Note the lack of "network engineer"

How did I get here?

“Please YANG-ify the PowerDNS Authoritative Server”

— $Customer’s research department

How did I get here?

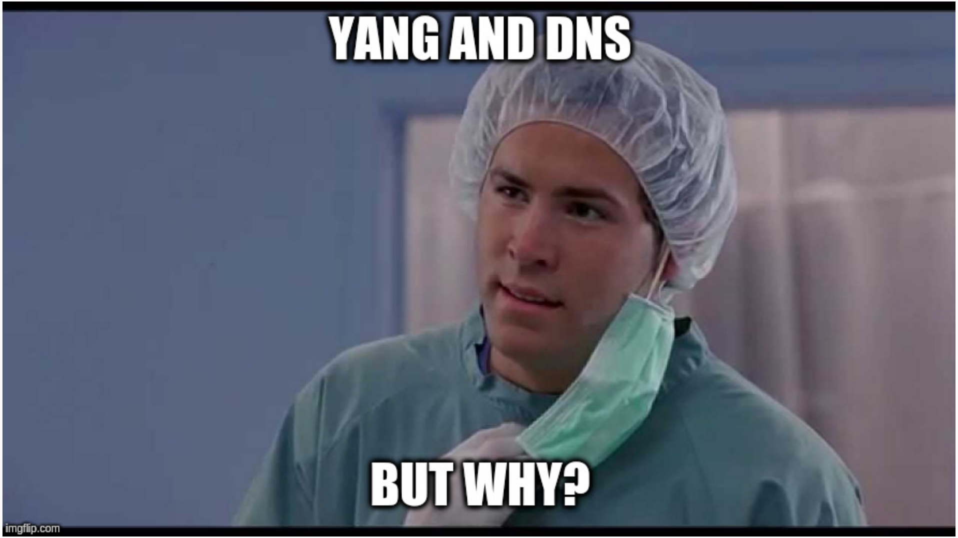


How did I get here?

“You model the server config, including the zone data”

— $Customer’s research department

How did I get here?



How did I get here?

“OK, hear me out...”

- $CUSTOMER has a fully Software Defined Network
- DNS is a *network function*
  - A functional building block with well-defined interfaces
  - Defined by ETSI in the Network Functions Virtualisation (NFV) standard
- DNS authoritative is currently a non-modeled function

The problem

- CLI differs between vendors
- Vendors have different configuration APIs
- SNMP is unreliable
- MIBs don’t distinguish between “state” and “configuration”
- Little standardized MIBs, no “common” MIBs

RFC 3535, §3 “Operator Requirements”

The problem — In short

- Heterogeneous environments are painful to configure
- Need for standardized configuration
- Need for data *and* configuration

The problem

Thanks to programmability, new features are validated, new services are deployed, and routers are upgraded in no time. This requires consistent and complete instrumentation application programming interfaces (APIs) in network devices with the end goal that everything that can be automated in networking vendors is automated. As a consequence, operators reduce the service deployment time and offer differentiated services compared to the competition. Adapting the management software is typically faster than waiting for the traditional development lifecycle for equipment vendors.

CLI Is No Longer the Norm (If a Feature Cannot Be Automated, It Does Not Exist)

While it may be enjoyable the first couple of times to configure networks manually for learning and testing, the CLI is not a scalable way to introduce new features in production networks. There have been countless "network down" situations due to manual misconfiguration, sometimes called "fat-finger typing." A typical example is with access list management: Some, if not most, network engineers have inadvertently locked themselves out from the router configuration while updating an access list at least once in their career. It is so easy to mistype an IP address. (You are probably smiling right now, remembering some similar experience in the past.)

The CLI is an interface for configuring and monitoring network elements, designed for consumption by users who will think through an extra space or an added comma, or even a submenu. Although the CLI is not an API, you unfortunately had to treat it as one because that is all you had for so long. However, using the CLI for automation is neither reliable nor cost-effective.

First off, many service-related configuration changes involve more than one device, such as the point-to-point L3VPN example, which requires the configuration of four different devices, or a fully meshed

Figure 1: From "Network Programming with YANG", by Claise, Clarke, and Lindblad

The solution

The solution — NETCONF and YANG documents

RFC 4741 – “NETCONF Configuration Protocol”, December 2006
RFC 6020 – “YANG - A Data Modeling Language for the Network Configuration Protocol (NETCONF)”, October 2010
RFC 6241 – “Network Configuration Protocol (NETCONF)”, June 2011
RFC 6244 – “An Architecture for Network Management Using NETCONF and YANG”, June 2011
RFC 7950 – “The YANG 1.1 Data Modeling Language”, August 2016
RFC 7951 – “JSON Encoding of Data Modeled with YANG”, August 2016
RFC 8040 – “RESTCONF Protocol”, January 2017
RFC 8342 – “Network Management Datastore Architecture (NMDA)”, March 2018

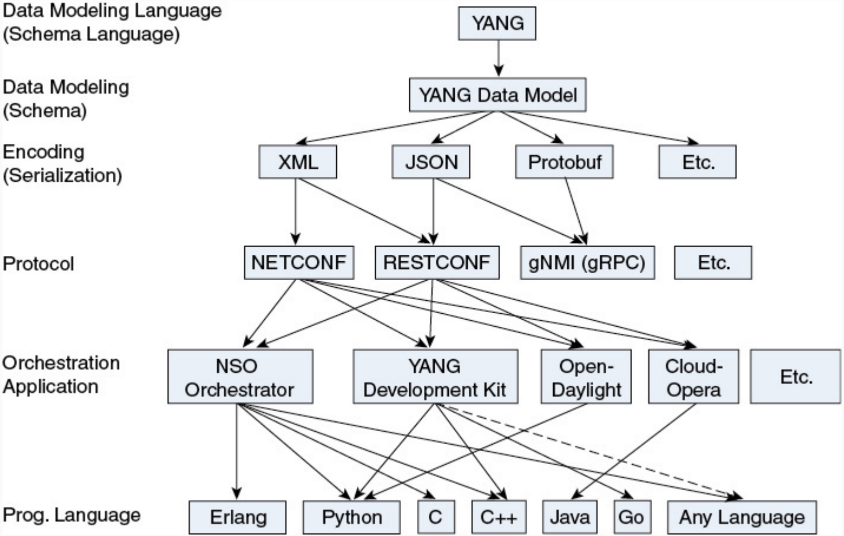
The solution

Configuring devices: NETCONF

NETCONF architecture

```
             Layer                 Example
        +-------------+      +-----------------+      +----------------+
    (4) |   Content   |      |  Configuration  |      |  Notification  |
        |             |      |      data       |      |      data      |
        +-------------+      +-----------------+      +----------------+
               |                       |                      |
        +-------------+      +-----------------+              |
    (3) | Operations  |      |  <edit-config>  |              |
        |             |      |                 |              |
        +-------------+      +-----------------+              |
               |                       |                      |
        +-------------+      +-----------------+      +----------------+
    (2) |  Messages   |      |     <rpc>,      |      | <notification> |
        |             |      |   <rpc-reply>   |      |                |
        +-------------+      +-----------------+      +----------------+
               |                       |                      |
        +-------------+      +-----------------------------------------+
    (1) |   Secure    |      |  SSH, TLS, BEEP/TLS, SOAP/HTTP/TLS, ... |
        |  Transport  |      |                                         |
        +-------------+      +-----------------------------------------+
```

NETCONF architecture



NETCONF Protocol Features

- CRUD operations for configuration
- Configuration is *fully* declarative
- Configuration and operational state
- Network-wide transactions, with full ACID properties
- Rollback support
- One protocol to implement in orchestrators and controllers

Who uses NETCONF

- Routers and Switches of the big vendors
- Orchestration frameworks
- Network Management Systems (NMS)
- Several *nix applications

The solution

Modeling data: YANG

Yet Another Next Generation

- The *schema* defines the data
- The NETCONF server has the *instantiated data*
- Schema describes a tree

YANG models — Example i

my-example-model.yang

```
grouping endpoint {
  description
    "An IP endpoint, including the port";
  leaf ip-address {
    type inet:ip-address-no-zone;
    mandatory true;
  }
  leaf port {
    type inet:port-number;
  }
}

container listen-addresses {
  list listen-address {
    key "name";
    leaf name {
      type string;
    }
    unique "ip-address port";
    uses endpoint {
```

YANG models — Example ii

```
        refine port {
          default 25;
        }
      }
    }
  }

  container counters {
    config false;
    leaf connection-count {
      type uint32;
    }
  }
}
```

YANG model as a tree

```
module: my-example-model
  +--rw listen-addresses
  |  +--rw listen-address* [name]
  |     +--rw name          string
  |     +--rw ip-address    inet:ip-address
  |     +--rw port?         inet:port-number
  +--ro counters
     +--ro connection-count?   uint32
```

The end-nodes are called *leafs*.

YANG Models — Tree elements

- *Grouping* — Set of nodes for re-use
- *Container* — A set of related nodes
- *List* — A keyed set of nodes
- *Leaf-list* — List of a single item

YANG Models — Built-in types

- (u)int8, (u)int16, (u)int32, (u)int64
- decimal64
- string
- bits
- boolean
- enumeration
- union

YANG Models — Other modeling tools

- Import: Enables re-use of models
- Augment: Add new nodes to previously defined nodes
- Grouping: Set of nodes for re-use
- Container: Group of related nodes
- Feature: Allows marking part of the tree as optional

Types — Derived types: Constraints

ietf-inet-types@2013-07-15.yang

```
  typedef port-number {
    type uint16 {
      range "0..65535";
    }
    description
     "The port-number type represents a 16-bit port number of an
      Internet transport-layer protocol such as UDP, TCP, DCCP, or
      SCTP.  Port numbers are assigned by IANA.  A current list of
      all assignments is available from <http://www.iana.org/>.

      Note that the port number value zero is reserved by IANA.  In
      situations where the value zero does not make sense, it can
      be excluded by subtyping the port-number type.
      In the value set and its semantics, this type is equivalent
      to the InetPortNumber textual convention of the SMIv2.";
```

Types — Derived types: Deriving further

ietf-inet-types@2013-07-15.yang

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

ietf-inet-types@2013-07-15.yang

```
typedef ipv4-address-no-zone {
  type inet:ipv4-address {
    pattern '[0-9\.]*';
  }
```

Types — Union

ietf-inet-types@2013-07-15.yang

```
typedef ip-address-no-zone {
  type union {
    type inet:ipv4-address-no-zone;
    type inet:ipv6-address-no-zone;
  }
  description
   "The ip-address-no-zone type represents an IP address and is
    IP version neutral.  The format of the textual representation
    implies the IP version.  This type does not support scoped
    addresses since it does not allow zone identifiers in the
    address format.";
  reference
   "RFC 4007: IPv6 Scoped Address Architecture";
}
```

Types — Grouping

my-example-model.yang

```
grouping endpoint {
  description
    "An IP endpoint, including the port";
  leaf ip-address {
    type inet:ip-address-no-zone;
    mandatory true;
  }
  leaf port {
    type inet:port-number;
  }
}
```

Types — Using groupings

my-example-model.yang

```
container listen-addresses {
  list listen-address {
    key "name";
    leaf name {
      type string;
    }
    unique "ip-address port";
    uses endpoint {
      refine port {
        default 25;
      }
    }
  }
}
```

Types — Non-config

my-example-model.yang

```
  container counters {
    config false;
    leaf connection-count {
      type uint32;
    }
  }
```

Reuse of modules

- YANG models can `import` other models
- Large collection of “ground work” modules
  - Interface types
  - IP addresses
  - TLS server and client (including X509)
  - SSH server and client
- Used by vendors to model devices
- Published e.g. on YangModels/yang

Addressing

- Individual leafs can be addressed using XPath
- XPaths can contain one or more expressions
- Expressions can also do arithmetic

```
/my-example-model:listen-addresses/listen-address[name='localhost']/ip-
↪ address
/my-example-model:listen-addresses/listen-address[name='localhost']/port
```

```
/ietf-interfaces:interfaces/interface[name='iface1']/ietf-ip:ipv4/ietf-
↪ ip:address[ietf-ip:ip='10.0.0.1']
```

```
/ietf-interfaces:interfaces/interface[position() =
↪ last()]/ietf-ip:ipv4/*
```

The solution

YANG and NETCONF servers

Server Architecture

```
                   +-----------------------------+
                   |Server (device)              |
                   |    +--------------------+   |
                   |    |      configuration |   |
         +----+    |    |     ---------------|   |
         |YANG|+   |    | m d  state data    |   |
         |mods||+  |    | e a ---------------|   |
         +----+|| -----> | t t  notifications |   |
          +----+|  |    | a a ---------------|   |
           +----+  |    |      operations    |   |
                   |    +--------------------+   |
                   |           ^                 |
                   |           |                 |
                   |           v                 |
+------+           |     +-------------+         |
|      | -------------> |             |         |
|Client| <rpc>     |     |  NETCONF    |         |
| (app)|           |     |   engine    |         |
|      | <------------   |             |         |
+------+ <rpc-reply>     +-------------+         |
                   |       /        \            |
                   |      /          \           |
                   |     /            \          |
                   | +--------+   +---------+    |
                   | | config |   |system   |+   |
                   | |  data- |   |software ||+  |
                   | |   base |   |component|||  |
                   | +--------+   +---------+||  |
                   |               +---------+|  |
                   |                +---------+  |
                   +-----------------------------+
```

Datastores

- Startup — Config to use upon boot
- Running — Current configuration
- Candidate — Used for staging config changes
- Operational – Contains the config and state of the system

Datastores

```
+-------------+              +-----------+
| <candidate> |              | <startup> |
|  (ct, rw)   |<---+    +--->| (ct, rw)  |
+-------------+    |    |    +-----------+
       |           |    |           |
       |         +-----------+      |
       +-------->| <running> |<-----+
                 | (ct, rw)  |
                 +-----------+
                       |
                       |        // configuration transformations,
                       |        // e.g., removal of nodes marked as
                       |        // "inactive", expansion of
                       |        // templates
                       v
                 +------------+
                 | <intended> | // subject to validation
                 | (ct, ro)   |
                 +------------+
                       |        // changes applied, subject to
                       |        // local factors, e.g., missing
                       |        // resources, delays
                       |
  dynamic              |   +-------- learned configuration
  configuration        |   +-------- system configuration
  datastores -----+    |   +-------- default configuration
                  |    |   |
                  v    v   v
               +---------------+
               | <operational> | <-- system state
               | (ct + cf, ro) |
               +---------------+

ct = config true; cf = config false
rw = read-write; ro = read-only
boxes denote named datastores
```

YANG and NETCONF on *NIX?

Why should I care?

- Many applications could be “network functions”
- With the right orchestrator, have “versioned infra”
- Even without NETCONF, YANG is a powerful config language
  - Typed and constrained configuration items
  - Dhall (for Haskell) is similar, sans the tree
- Integrates into telco environments

Software Support

- `libyang` – YANG parser and toolkit
- `sysrepo` – YANG Datastore
- `Netopeer2` – NETCONF server and client
- `pyang` – Python YANG validator, transformer and code generator
- YDK – YANG Development Kit by Cisco

`pdns-sysrepo`

- Uses `libyang` and `sysrepo`
- Configures PowerDNS Authoritative Server
- Stores zone-data in sysrepo
- Exposes a Remote Backend endpoint for PowerDNS
- PowerDNS/pdns-sysrepo

Wrap up

In conclusion

- The networking world is not so different
- YANG and NETCONF are the industry standard
- It is a viable technology for *nix service configuration

Thank you!

Any questions?

References and further reading

- `http://www.netconfcentral.org/modulelist`
- `https://www.fir3net.com/Networking/Protocols/an-introduction-to-netconf-yang.html`
- `https://www.sysrepo.org/static/doc/html/`
- `https://www.slideshare.net/Cisco/software-defined-networking-and-network-programmability`
- “Network Programming with YANG”, Claise, Clarke, and Lindblad6