The bridge to possible

Performance Monitoring of a 5G Hybrid Cloud Network

A Technical Deep Dive

September 2023

Contents

1 Network Monitoring Architecture

A networking monitoring solution is a proactive measure undertaken to anticipate potential network outages and address them ahead of time. This type of solution helps to maintain a seamless, congestion-free, and efficient network. A network monitoring solution reports the performance of a network, forecasts key performance indicators, and helps you make architectural decisions to enhance the network in capacity and efficiency. To be able to remotely visualize your network performance is not simply a wish anymore, it is a necessity.

1.1 The Dish Networks Architecture: Overview

Before we dig into the network monitoring strategy, let us briefly examine the architecture of Dish Networks. The network deployment of different flavors of hardware and software is a combination of on-premises (cell site, local and Provider Edge data centers) and Cloud (Breakout Edge, national and regional data centers) architecture, or simplistically called a **Hybrid Cloud Model**. This makes monitoring the network a greater challenge, wherein your strategy should seamlessly work for both on-premises and Cloud elements of the network. Further details of the Cloud architecture that is an Amazon Web Services (AWS) deployment is captured in this article.

1.2 Streaming Strategy

Telemetry (or Model-Driven Telemetry) is the recommended network monitoring strategy for Dish Networks. It is fast, reliable, easy to use, and deterministic. The device (itself) can stream the data of interest in a structured format for a collector/visualization engine to read and interpret. The format (or model) of data supported on a Cisco® router (and XRv or Cisco's Cloud router on AWS) are:

a) Open Config models

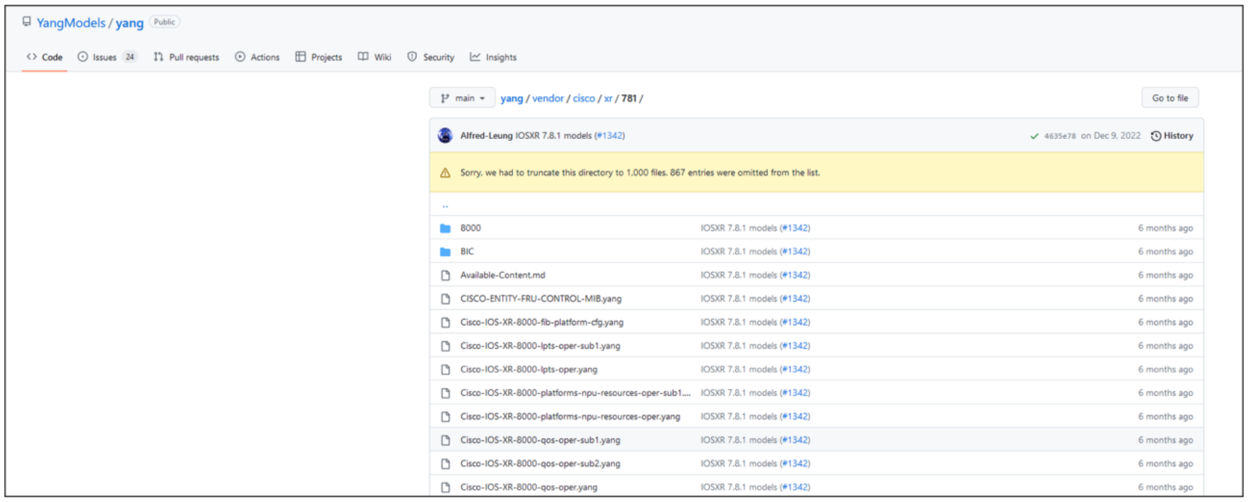
b) Internet Engineering Task Force (IETF) models

c) Native YANG models **

Cisco has recommended using the native Yet Another Next Generation (YANG) model (operational/configuration) to stream the data of interest out of the router to a network monitoring engine, based on the outstanding coverage and support we have with native YANG models compared to Open Config and IETF models.

** All Cisco Internetwork Operating System (Cisco IOS XR data models can be found at this link.

Here is a snapshot of Cisco IOS XR data models on GitHub.



yang / vendor / cisco / xr / 781 /

Alfred-Leung IOSXR 7.8.1 models (#1342) ✓ 4635e78 on Dec 9, 2022

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..		
8000	IOSXR 7.8.1 models (#1342)	6 months ago
BIC	IOSXR 7.8.1 models (#1342)	6 months ago
Available-Content.md	IOSXR 7.8.1 models (#1342)	6 months ago
CISCO-ENTITY-FRU-CONTROL-MIB.yang	IOSXR 7.8.1 models (#1342)	6 months ago
Cisco-IOS-XR-8000-fib-platform-cfg.yang	IOSXR 7.8.1 models (#1342)	6 months ago
Cisco-IOS-XR-8000-lpts-oper-sub1.yang	IOSXR 7.8.1 models (#1342)	6 months ago
Cisco-IOS-XR-8000-lpts-oper.yang	IOSXR 7.8.1 models (#1342)	6 months ago
Cisco-IOS-XR-8000-platforms-npu-resources-oper-sub1....	IOSXR 7.8.1 models (#1342)	6 months ago
Cisco-IOS-XR-8000-platforms-npu-resources-oper.yang	IOSXR 7.8.1 models (#1342)	6 months ago
Cisco-IOS-XR-8000-qos-oper-sub1.yang	IOSXR 7.8.1 models (#1342)	6 months ago
Cisco-IOS-XR-8000-qos-oper-sub2.yang	IOSXR 7.8.1 models (#1342)	6 months ago
Cisco-IOS-XR-8000-qos-oper.yang	IOSXR 7.8.1 models (#1342)	6 months ago

Figure 1.
IOS XR 7.8.1 Data Models

1.3 Streaming Layers

The data of interest that we want to stream out of our routers are divided into three layers:

a) **Data model layer** – The information (raw data) from the router's database is mapped into a data model (YANG definition) and is ready to be streamed out of a device using an assortment of transport mechanism.

b) **Producer layer** – There is a cadence definition (or time interval) required to stream your YANG-based data out of the router to a collector. If you don't specify a cadence (time interval = 0), you are initializing Event-Driven Telemetry. For MDT or Model-Driven Telemetry, we always specify a cadence based on the importance (criticality) of the data being monitored.

c) **Exporter Layer** – There is an encoding and transport mechanism defined to export this data out of your router to a centralized collector. The mechanism is defined based on several requirements like security, sizing, and granularity of the information.

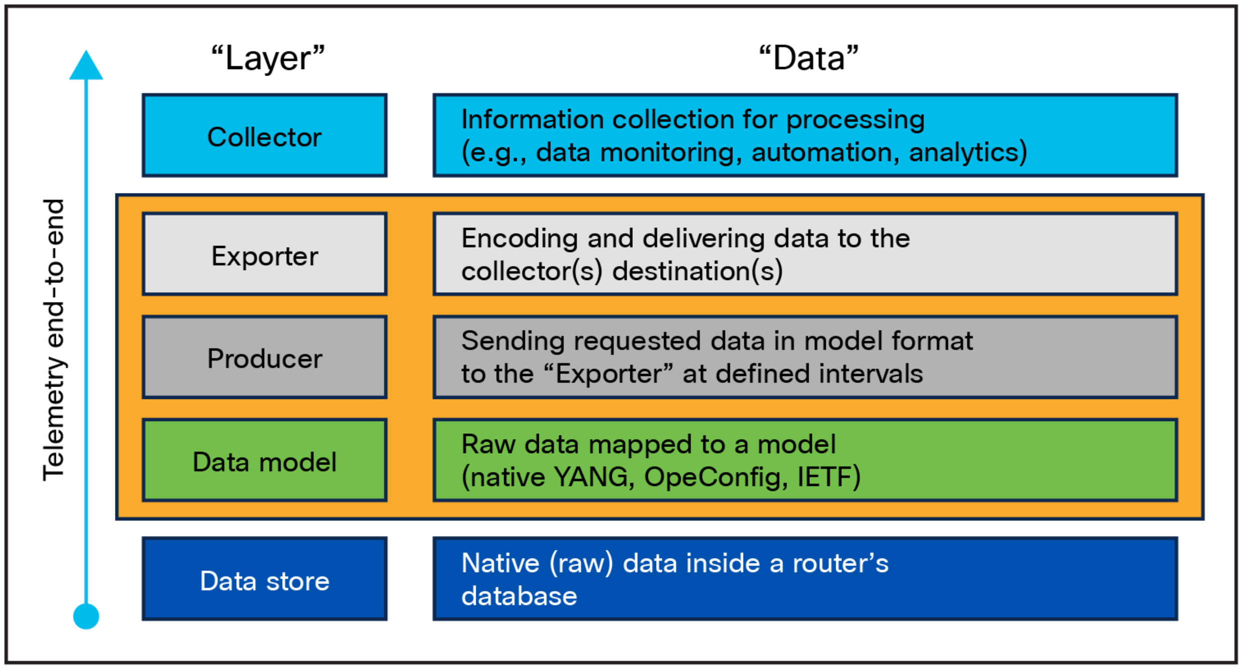

"Layer"
"Data"
Collector
Information collection for processing (e.g., data monitoring, automation, analytics)
Exporter
Encoding and delivering data to the collector(s) destination(s)
Producer
Sending requested data in model format to the "Exporter" at defined intervals
Data model
Raw data mapped to a model (native YANG, OpeConfig, IETF)
Data store
Native (raw) data inside a router's database
Telemetry end-to-end

Figure 2.
Telemetry Layers

All the three layers defined above are independent of each other; changing one won't impact the other.

What transport and encoding mechanism is Dish Networks using for their network monitoring?

gNMI (Google Network Management Interface) is the transport mechanism (dial in) used along with gRPC as the protocol (over HTTP/2) and JSON_IETF as the data format. This was defined by the OpenConfig forum (mostly lead by Google, based on the Google Remote Procedure Call [RPC] framework), and the specification is available here. There are other transport, protocol, and encoding mechanisms available as shown in Figure 3, but gNMI is the approach incorporated at Dish Networks.

What is the advantage of using dial-in over the dial-out approach?

Once we had modeled our network on software-defined networking, it was an easy choice to go for the dial-in approach (over dial-out). We wanted a single software-defined controller to manage configuration and monitoring of the entire network. Instead of **touching** close to 20,000 network elements with configuration, we would define it on the controller and implement the "pull" method to stream data from the network.

What is the advantage of using gNMI or OpenConfig RPC model over the Cisco IOS XR MDT RPC?

In a 5G Open Radio Access Network (oRAN), the ideal approach was to go for a vendor-neutral Model-Driven Telemetry to be in line with the ideology of the customer. Cisco IOS XR supports the Google network management interface framework in combination with the native YANG models supported on the routers. It greatly simplifies telemetry configuration by having to start only the gRPC server on the router.

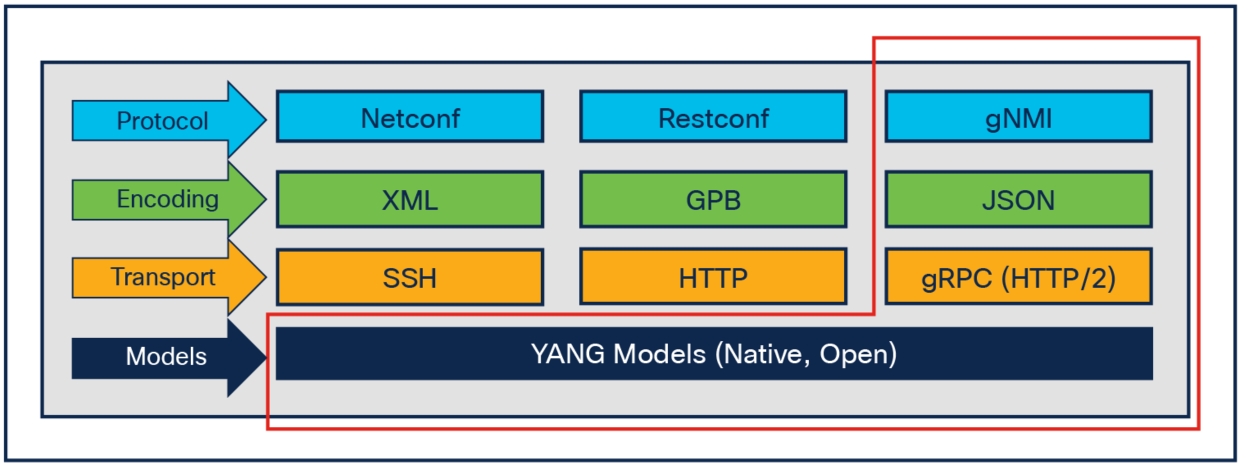


Figure 3.
Streaming Methodology - Dish Networks

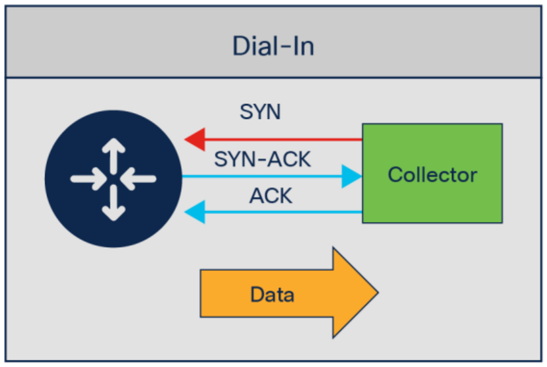


Figure 4.
Dial IN with gRPC.

2 Network Monitoring Workflow

2.1 Workflow Process

This section outlines the workflow process; every component of this workflow will be explained in subsequent sections of this white paper.

- Define Key Performance Indicators and telemetry sensors for transport network.
- Enable sensors in the form of a collection job on Cisco Crosswork Network Controller
- Collection jobs will contain gNMI subscribe requests of all sensors toward the transport network.
- Crosswork Data Gateway (CDG), an application of Cisco Crosswork Network Controller (CNC), triggers these Subscribe Requests (either per sensor or for all sensors) toward the transport network in the form of collection jobs.
- The transport devices respond back with “raw data” (gNMI response to the CDG)
- The raw data is then published into the Cisco Software-Defined Networking (SDN) Kafka Message Bus (to a specific topic)
- Matrix (Collector) pulls the raw data from Kafka via the topic.
- KPI and analytics logic are applied, and monitoring dashboards are created for end-user consumption.
- Processed KPIs and anomaly detection is pushed to Kafka for consumption of other applications (like Vitria which is our fault management application)

2.2 Software-Defined Networking – Controller

The essential functions of Cisco’s Software-Defined Networking Controller that play a major role in the performance monitoring function are:

1) **CNC** or Cisco Crosswork Network Controller – It is used to onboard transport elements with respect to topology mapping and inventory management and facilitate data collection in the form of telemetry, logs, and events.
2) **CDG** or Cisco Crosswork Data Gateway – It is a common collection platform for gathering network data from transport devices that support multiple data collection protocols including MDT, Simple Network Management Protocol (SNMP), Command-Line Interface (CLI), standards-based gNMI (dial-in), and syslog.
3) **Matrix** is a Cisco Performance Monitoring platform that can compute the health score of network elements, build KPI dashboards for network monitoring, detect threshold violation with the help of anomaly detection, and even assist in event generation (essentially the anomaly detection), which is sent to the fault management platform for further correlation (more details below).
4) **Kafka** Message Bus is an internal communication framework between the above applications. All data from various devices and applications is published into the Kafka Message Bus for further consumption and processing (more details below).

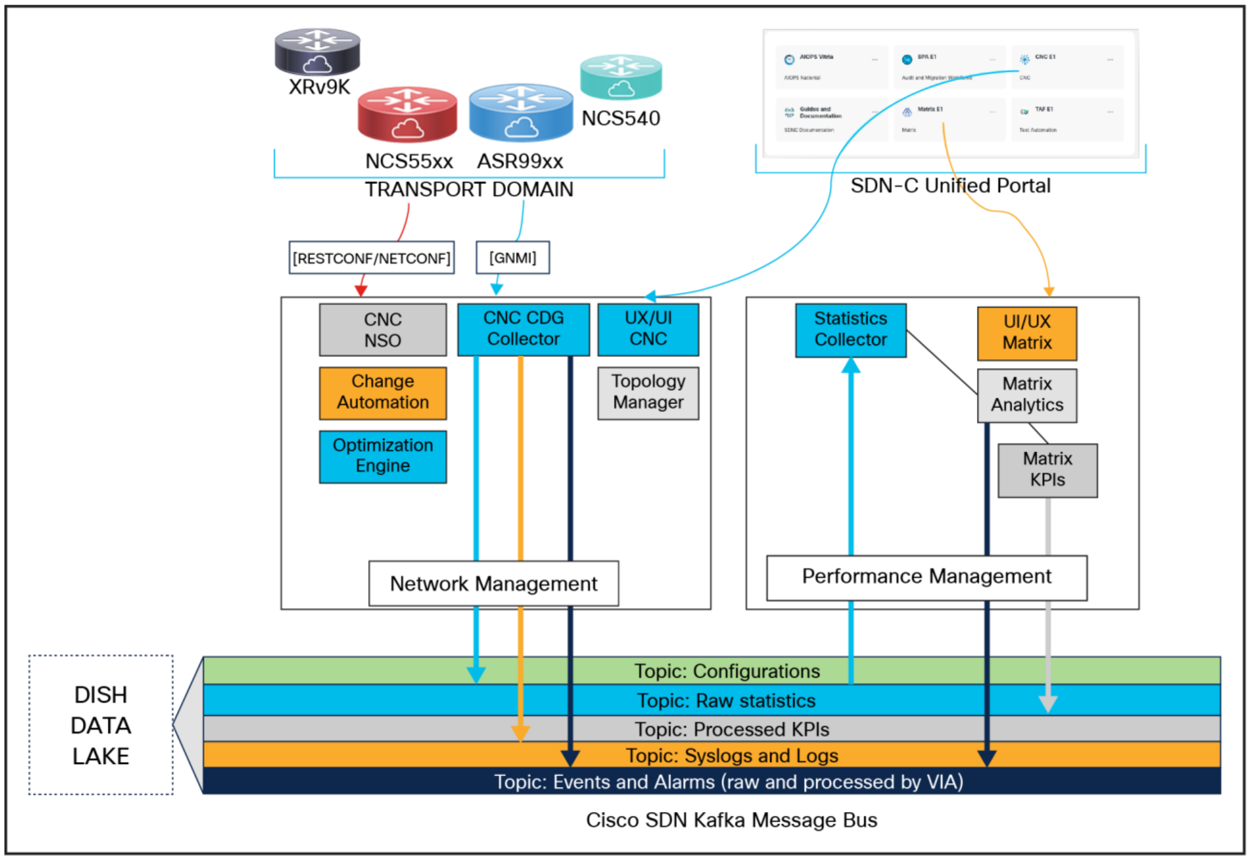


Figure 5.
SDN-C Components Workflow

2.3 Matrix – Performance Monitoring with AI/ML

Matrix is a multi-vendor analytics platform that performs anomaly detection, correlation, and forecasting based on infrastructure and application insights and subsequently triggers action with orchestrator tools.

As far as end-to-end network intelligence goes, Matrix can correlate data and logs gathered from numerous network elements and formulate easily consumable reports. Insights that we gain from such reports can be applied to problem solving and operational efficiency of the customer network.

Matrix also has capacity planning capability with the help of forecasting and historical trends developed using telemetry data streamed from network elements.

The tool provides advanced analytics including logic-based health scores and real-time performance view of network applications, and physical and virtual network infrastructure.

2.4 Kafka Message Bus

The Kafka Message Bus, which is an open-source application from Apache Kafka, is a consumer of telemetry data, alerts, metrics, and events from network elements including routers and monitoring tools. In a Message Bus, we support separate topics and partitions for different categorization of data. One or more producers can write, and one or more consumers can read from a Kafka Message Bus (specifically a topic) at the same time.

In the Figure 5, look at all the topics in the Message Bus and the corresponding consumers and producers of that topic (note the arrows).

3 Key performance indicators

3.1 Identification of KPIs

It is critical that we identify the Key Performance Indicators that will help us monitor the performance of a network. For the 5G Dish transport network, we have an assortment of network elements, both on physical environment and virtual (cloud) infrastructure. The **one size fits all** type of KPI definition might not work in such a diverse heterogenous network. There will be KPIs only applicable to cell site routers and not relevant to other edge routers (physical/cloud). There will be KPIs applicable to all physical routers but not relevant to cloud routers (like hardware KPIs). And then there will be KPIs applicable to all routers in the network.

The important KPIs (among many others) defined for dish networks are:

1) System
    a. CPU Utilization
    b. Network Processing Unit (NPU) Utilization
    c. Memory Utilization
2) Routing
    a. Intermediate System to Intermediate System (ISIS) Route Counts
    b. Border Gateway Protocol (BGP) Route Counts
    c. ISIS/BGP Neighbor States
3) Services
    a. Interface Bandwidth Utilization
    b. Generic Routing Encapsulation (GRE) Tunnel Bandwidth Utilization
    c. Interface Ingress/Egress Throughput
    d. GRE Tunnel Ingress/Egress Throughput
    e. Quality of Service (QoS) Packets Transmitted/Drops
    f. Interface State
    g. Interface Errors
    h. Path Latency
4) Hardware
    a. Environment Temperature
    b. Optics Health
    c. Chassis Status
    d. Media Storage Status

5) Timing

   a. PTP Interface State

   b. PTP Interface Status

   c. SyncE Status

   d. Grand Master (GM) Status

   e. Global Navigation Satellite System (GNSS) Status

3.2 YANG Capabilities

Identifying a KPI is the first step of the streaming puzzle, the second step is figuring out how to stream that data out of the device. To be able to stream a data we need a transport and a data modeling mechanism.

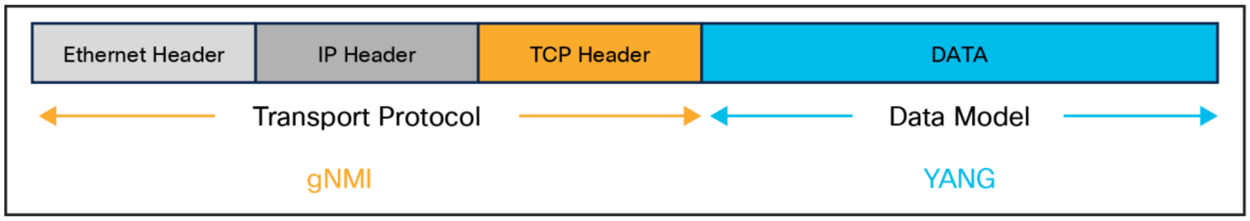


Figure 6.
gNMI (Transport) & YANG (Data Modeling)

Once you have identified the KPI, you need to verify if your device has a data model for the corresponding KPI. Let us look at a few examples.

CPU

```
<router>#show processes cpu thread location 0/rp0/CPU0
Thu Feb  2 16:30:05.504 UTC
---- node0_RP0_CPU0 ----
CPU utilization for one minute: 6%; five minutes: 5%; fifteen minutes: 6%
```

```
<router>#yang-describe operational show processes cpu thread location 0/rp0/CPU0
Thu Feb  2 16:31:14.362 UTC
YANG Paths:
  Cisco-IOS-XR-wdsysmon-fd-oper:system-monitoring/cpu-utilization
```

So, do we have the YANG capability (or the corresponding data model) to be able to stream this data out of the device?

```
<router>show netconf-yang capabilities | inc wdsysmon-fd-ope
Thu Feb  2 16:32:57.226 UTC
http://cisco.com/ns/yang/Cisco-IOS-XR-wdsysmon-fd-oper                                |2019-07-05|
```

Looks like we do. Let us look at another data.

Memory

```
<router>#show memory summary
Thu Feb  2 16:34:08.880 UTC

node:      node0_RP0_CPU0
------------------------------------------------------------------


 Physical Memory: 26292M total (26272M available)
 Application Memory : 26292M (26272M available)
 Image: 4M (bootram: 0M)
 Reserved: 0M, IOMem: 0M, flashfsys: 0M
 Total shared window: 969M

<router>#yang-describe operational show memory summary
Thu Feb  2 16:34:29.320 UTC
YANG Paths:
  Cisco-IOS-XR-nto-misc-oper:memory-summary/nodes/node/detail

<router>#show netconf-yang capabilities | inc nto-misc-oper
Thu Feb  2 16:35:16.422 UTC
http://cisco.com/ns/yang/Cisco-IOS-XR-nto-misc-oper                                   |2022-01-25|
```

If you want to look at the structure and content of the operational data model, this is how you do it on the device itself:

```
<router>#show yang operational nto-misc-oper:memory-summary JSON
Tue Jun 20 16:29:56.055 UTC
{
 "Cisco-IOS-XR-nto-misc-oper:memory-summary": {
  "nodes": {
   "node": [
    {
     "node-name": "0/RP0/CPU0",
     "summary": {
      "page-size": 4096,
      "ram-memory": "8061009920",
      "free-physical-memory": "2902458368",
      "system-ram-memory": "8061009920",
      "free-application-memory": "2902458368",
      "image-memory": "4194304",
      "boot-ram-size": "0",
      "reserved-memory": "0",
      "io-memory": "0",
      "flash-system": "0"
     },
     "detail": {
      "page-size": 4096,
      "ram-memory": "8061009920",
      "free-physical-memory": "2902458368",
      "private-physical-memory": "0",
      "system-ram-memory": "8061009920",
      "free-application-memory": "2902458368",
      "image-memory": "4194304",
      "boot-ram-size": "0",
      "reserved-memory": "0",
      "io-memory": "0",
      "flash-system": "0",
      "shared-window": [
       {
        "shared-window": "ptp",
        "window-size": "36904"
       },
       {
        "shared-window": "soasync-app-1",
        "window-size": "249168"
       },

…
…
…
…
// truncated from snippet //
…
…
…
      ],
      "total-shared-window": "536998660",
      "allocated-memory": "0",
      "program-text": "140721518205504",
      "program-data": "1",
      "program-stack": "0",
      "total-used": "5158551552"
     }
    }
   ]
  }
 }
}
```

3.3 Defining telemetry sensors

We have managed to take a sneak peek at two telemetry sensor definitions in the last section. So, how do we arrive at a telemetry sensor from the KPI definition? Thankfully, with Cisco's latest IOS XR releases, we have that option available readily at our fingertips using the "**yang-describe**" command. You can now fetch the YANG model (both operational and configuration) and the path for that specific command/CLI.

```
<router>#yang-describe ?
  configuration  Describe configuration commands(cisco-support)
  operational    Describe operational commands(cisco-support)
```

Here is an example of deriving Bidirectional Forwarding Detection (BFD) session sensor directly from the BFD session “show” CLI command.

```
<router>#yang-describe operational show bfd session
Thu Feb 16 04:17:15.867 UTC
YANG Paths:
  Cisco-IOS-XR-ip-bfd-oper:bfd/session-briefs/session-brief
```

Here is another example of deriving a sensor directly from the “show” CLI command.

```
<router>#yang-describe operational show memory summary
Thu Feb 16 04:21:11.361 UTC
YANG Paths:
  Cisco-IOS-XR-nto-misc-oper:memory-summary/nodes/node/detail
```

A few more examples of arriving at the exact sensor path for the corresponding command that you are running on the router.

```
<router>#yang-describe operational show interfaces HundredGigE 0/0/0/1
Tue Jun 20 16:41:18.805 UTC
YANG Paths:
  Cisco-IOS-XR-pfi-im-cmd-oper:interfaces/interface-xr/interface

<router>#yang-describe operational show cef summary
Tue Jun 20 16:41:27.680 UTC
YANG Paths:
  Cisco-IOS-XR-fib-common-oper:fib/nodes/node/protocols/protocol/fib-summaries/fib-summary
```

Now, deriving all telemetry sensors may not be this straightforward. There are scenarios in which you will have to pull data from the router by looking at a combination of data models; we call them augmented sensors. Here is an example of an augmented sensor: if you explore the Cisco-IOS-XR-NCS-BDplatforms-npu-resources-oper.yang data model, you will notice that to fetch specific data via this model, you will need to augment data from another data model, which is Cisco-IOS-XR-platforms-ofa-oper.yang.

```
<server># pyang -f tree Cisco-IOS-XR-NCS-BDplatforms-npu-resources-oper.yang --tree-depth 4

module: Cisco-IOS-XR-NCS-BDplatforms-npu-resources-oper
  augment /a1:ofa/a1:stats/a1:nodes/a1:node:
    +--ro hw-resources-datas
       +--ro hw-resources-data* [resource]
          +--ro resource
          +--ro resource-id?   uint32
          +--ro num-npus?      uint32
          +--ro cmd-invalid?   boolean
          +--ro asic-type?     uint32
          +--ro asic-name?     string
          +--ro npu-hwr* []
             +--ro npu-id?                        uint32
             +--ro red-oor-threshold-percent?     uint32
             +--ro yellow-oor-threshold-percent?  uint32
             +--ro num-bank?                      int32
             +--ro bank* []
                   ...

<server># pyang -f tree Cisco-IOS-XR-platforms-ofa-oper.yang --tree-depth 5
module: Cisco-IOS-XR-platforms-ofa-oper
  +--ro ofa
     +--ro stats
        +--ro nodes
           +--ro node* [node-name]
              +--ro node-name    xr:Node-id
```

After augmentation, the final sensor path to fetch hardware resources data for each NPU will look something like this:

```
Cisco-IOS-XR-platforms-ofa-oper:ofa/stats/nodes/node/Cisco-IOS-XR-NCS-BDplatforms-npu-
resources-oper:hw-resources-datas/hw-resources-data/npu-hwr/bank
```

For older IOS XR releases where you don't have support for the yang-describe command, we can look at the schema and arrive at the corresponding sensor (with a bit of digging and experience with platform-specific telemetry sensors).

```
<router>#schema-describe show processes cpu thread location 0/rp0/CPU0
Thu Feb  2 17:05:15.854 UTC
Action: get
Path:   RootOper.SystemMonitoring.CPUUtilization({'NodeName': '0/RP0/CPU0'})
```

As mentioned in Section 1.1, we have all the YANG models available publicly for specific Cisco releases, so you can look at it to arrive at a specific container/leaf of a YANG model.

```
<server># pyang -f tree Cisco-IOS-XR-wdsysmon-fd-oper.yang --tree-path system-
monitoring/cpu-utilization --tree-depth 3
module: Cisco-IOS-XR-wdsysmon-fd-oper
  +--ro system-monitoring
     +--ro cpu-utilization* [node-name]
        +--ro node-name                   xr:Node-id
        +--ro total-cpu-one-minute?       uint32
        +--ro total-cpu-five-minute?      uint32
        +--ro total-cpu-fifteen-minute?   uint32
        +--ro process-cpu* []
              ...
```

From the above YANG tree display, if your KPI is "total-cpu-five-minute," then the telemetry sensor will be:

```
Cisco-IOS-XR-wdsysmon-fd-oper:system-monitoring/cpu-utilization/total-cpu-five-minute
```

If you want to define the sensor for a specific location or node name, you can substitute the variable and define the telemetry sensor as below:

```
module: Cisco-IOS-XR-wdsysmon-fd-oper
  +--ro system-monitoring
     +--ro cpu-utilization* [node-name]
        +--ro node-name                  xr:Node-id
        +--ro total-cpu-one-minute?      uint32
        +--ro total-cpu-five-minute?     uint32
        +--ro total-cpu-fifteen-minute?  uint32
        +--ro process-cpu* []
              ...

Cisco-IOS-XR-wdsysmon-fd-oper:system-monitoring/cpu-utilization
[node-name=0/RP0/CPU0]/total-cpu-five-minute
```

You can also use regular expression instead of the variable name inside a sensor. Let us take an example of interface statistics. If you want to fetch the statistics for all interfaces from the router, you can use this sensor:

```
Cisco-IOS-XR-drivers-media-eth-oper:ethernet-interface/statistics/statistic
```

If you want to fetch the statistics for a specific interface from the device, refer to the data model, pick the variable-name, and use it to construct your sensor:

```
module: Cisco-IOS-XR-drivers-media-eth-oper
  +--ro ethernet-interface
     +--ro statistics
        +--ro statistic* [interface-name]
           +--ro interface-name                       xr:Interface-name
           +--ro received-total-bytes?                           uint64
           +--ro received-good-bytes?                            uint64
           +--ro received-total-frames?                          uint64
           +--ro received8021q-frames?                           uint64

Cisco-IOS-XR-drivers-media-eth-oper:ethernet-interface/statistics/statistic
[interface-name=HundredGigE0/0/0/26]
```

Now, if you want to fetch the statistics for all hundred gigabit interfaces, you can use the following sensor path with a regular expression:

```
Cisco-IOS-XR-drivers-media-eth-oper:ethernet-interface/statistics/statistic
[interface-name=HundredGigE*]
```

Also, note that there is a possibility of different sensors for different platforms for the same KPI. In the case of hardware-specific environment sensors, there will be different sensors for different platforms as the platforms are built differently.

The environmental sensor for a cell site router is defined below:

```
Cisco-IOS-XR-envmon-oper:environmental-monitoring/rack/nodes/node/sensor-types/sensor-
type/sensor-names/sensor-name
```

The environmental sensor for a NCS5504 (Provider Edge Router) is defined below:

```
Cisco-IOS-XR-sysadmin-fretta-envmon-
ui:environment/oper/temperatures/location/sensor_attributes
```

The environmental sensor for a ASR9903 (Provider Edge Router) is defined below:

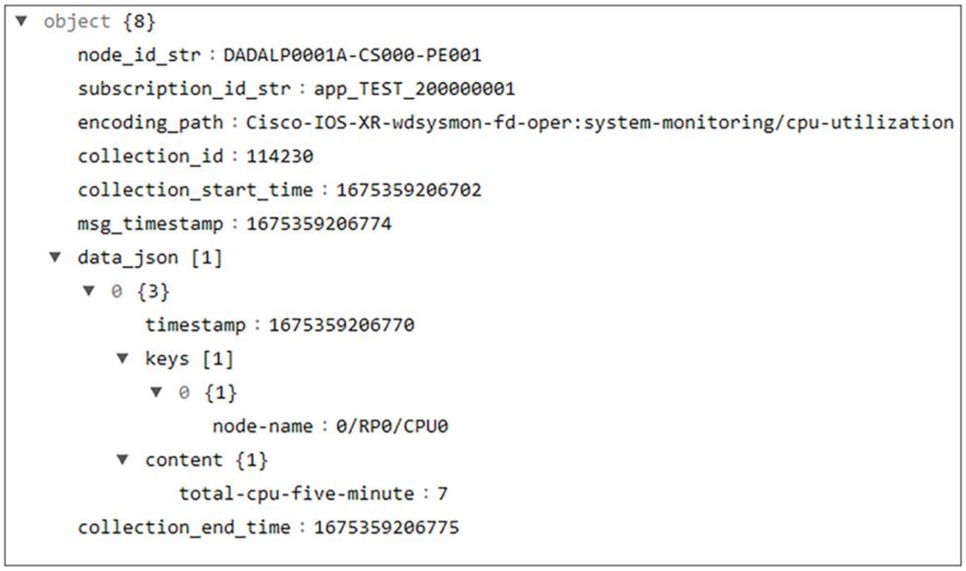
```
Cisco-IOS-XR-sysadmin-asr9k-envmon-
ui:environment/oper/temperatures/location/sensor_attributes
```

If you want to verify the JavaScript Object Notation (JSON) formatted data that will be streamed out of the router for a specific data model/container/leaf structure, the router has the capability to do it on the device itself.

```
<router>#show telemetry internal json Cisco-IOS-XR-nto-misc-oper:memory-
summary/nodes/node/summary
Tue Jun 20 16:26:55.005 UTC
{
  "encoding_path": "Cisco-IOS-XR-nto-misc-oper:memory-summary/nodes/node/summary",
  "subscription_id_str": "app_TEST_200000001",
  "collection_start_time": "1687278415456",
  "msg_timestamp": "1687278415465",
  "collection_end_time": "1687278415465",
  "node_id_str": "<router-hostname>",
  "data_json": [
    {
      "keys": [
        {
          "node-name": "0/RP0/CPU0"
        }
      ],
      "timestamp": "1687278415464",
      "content": {
        "page-size": 4096,
        "reserved-memory": "0",
        "boot-ram-size": "0",
        "flash-system": "0",
        "io-memory": "0",
        "free-physical-memory": "2994733056",
        "ram-memory": "8061009920",
        "system-ram-memory": "8061009920",
        "free-application-memory": "2994733056",
        "image-memory": "4194304"
      }
    }
  ],
  "collection_id": "437184"
},
```

You can also verify the data streamed out of the router in an external JSON Coding Viewer available on the internet. Here, we are using **mdt_exec** to look at a sample JSON being streamed out of the router and then verifying the data on an online JSON Coding Viewer.

```
<router>#run mdt_exec -s Cisco-IOS-XR-wdsysmon-fd-oper:system-monitoring/cpu-
utilization[node-name=0/RP0/CPU0]/total-cpu-five-minute -c 10000
Thu Feb  2 17:33:26.563 UTC
Enter any key to exit...
--------
{"node_id_str":"router","subscription_id_str":"app_TEST_200000001","encoding_path":"Cisco-
IOS-XR-wdsysmon-fd-oper:system-monitoring/cpu-
utilization","collection_id":"114230","collection_start_time":"1675359206702","msg_timestam
p":"1675359206774","data_json":[{"timestamp":"1675359206770","keys":[{"node-
name":"0/RP0/CPU0"}],"content":{"total-cpu-five-
minute":7}}],"collection_end_time":"1675359206775"}
--------
```



```
▼ object {8}
    node_id_str : DADALP0001A-CS000-PE001
    subscription_id_str : app_TEST_200000001
    encoding_path : Cisco-IOS-XR-wdsysmon-fd-oper:system-monitoring/cpu-utilization
    collection_id : 114230
    collection_start_time : 1675359206702
    msg_timestamp : 1675359206774
  ▼ data_json [1]
    ▼ 0 {3}
        timestamp : 1675359206770
      ▼ keys [1]
        ▼ 0 {1}
            node-name : 0/RP0/CPU0
      ▼ content {1}
          total-cpu-five-minute : 7
    collection_end_time : 1675359206775
```

Figure 7.
JSON streamed for your KPI

```
<router>#show processes cpu thread location 0/rp0/cpu0
Thu Feb  2 17:36:36.478 UTC
---- node0_RP0_CPU0 ----

CPU utilization for one minute: 6%; five minutes: 7%; fifteen minutes: 7%
```

Is that it? Is the device stream-ready already? Unfortunately, no, there is that one last step. We need to enable the gRPC port (Start the gRPC Server) on the router for it to listen to a gRPC request (gNMI Subscribe Request) and respond to that (gNMI Response).

```
<router>#show running-config grpc
Thu Feb  2 17:56:15.583 UTC
grpc
 dscp cs2
 port 57400
 no-tls
 address-family ipv4
!
```

To verify your device is streaming data (and/or is responding to the gRPC request for data), run the following command:

```
<router>#show grpc streams
Fri Feb  3 18:39:18.106 UTC

Streaming gRPCs: 10

10.226.140.133:53820
  User       : svc_WDNCiscoSDNCp
  Request-ID : 230
  Type       : gNMI
  Created    : 2023-01-23T17:15:06.771191Z
  Duration   : 955452s

10.226.140.133:53820
  User       : svc_WDNCiscoSDNCp
  Request-ID : 231
  Type       : gNMI
  Created    : 2023-01-23T17:15:06.778634Z
  Duration   : 955452s

10.226.140.133:53820
  User       : svc_WDNCiscoSDNCp
  Request-ID : 226
  Type       : gNMI
  Created    : 2023-01-23T17:15:06.77888Z
  Duration   : 955452s

10.226.140.133:53820
  User       : svc_WDNCiscoSDNCp
  Request-ID : 269
  Type       : gNMI
  Created    : 2023-01-24T16:26:13.939525Z
  Duration   : 871985s

10.226.140.133:53820
  User       : svc_WDNCiscoSDNCp
  Request-ID : 275
  Type       : gNMI
  Created    : 2023-01-24T16:26:14.159797Z
  Duration   : 871984s
```

```
10.226.140.133:53820
  User       : svc_WDNCiscoSDNCp
  Request-ID : 276
  Type       : gNMI
  Created    : 2023-01-24T16:26:18.59124Z
  Duration   : 871980s

10.226.140.133:53820
  User       : svc_WDNCiscoSDNCp
  Request-ID : 277
  Type       : gNMI
  Created    : 2023-01-24T16:26:18.594697Z
  Duration   : 871980s

10.226.140.133:53820
  User       : svc_WDNCiscoSDNCp
  Request-ID : 278
  Type       : gNMI
  Created    : 2023-01-24T16:26:18.599124Z
  Duration   : 871980s

10.226.140.133:53820
  User       : svc_WDNCiscoSDNCp
  Request-ID : 279
  Type       : gNMI
  Created    : 2023-01-24T16:26:18.602972Z
  Duration   : 871980s

10.226.140.133:53820
  User       : svc_WDNCiscoSDNCp
  Request-ID : 280
  Type       : gNMI
  Created    : 2023-01-24T16:26:18.606819Z
  Duration   : 871980s
```

3.5 Sensor Definition – Transport and Encoding

As discussed earlier, there is a transport method, protocol, encoding, and sample intervals defined for every telemetry sensor.

Let us try to understand a few subscriptions and clarify the above information:

a) Encoding for all the streams is JSON (specifically JSON_IETF)

b) Transport method is “dial in” from the Network Controller

c) TLS or Transport Layer Certificate for data encryption is “FALSE” or not enabled.

d) State is “Active,” which means the subscription is actively sending data for the specified sample interval.

e) The sample intervals (we will discuss this in detail in the next section) will vary based on the subscriptions; the example below shows 5 minutes, 60 minutes, 5 minutes, and 60 minutes for the four data streams respectively.

```
<router>#show telemetry model-driven subscription
Tue Apr 18 17:41:36.712 UTC
Subscription:  GNMI__7083707911975322971  State: ACTIVE
-------------
  Sensor groups:
  Id                                Interval(ms)               State
  GNMI__7083707911975322971_0      300000                     Resolved

  Destination Groups:
  Id                 Encoding          Transport   State   Port    Vrf      IP
  GNMI_1001          gnmi-json         dialin      Active  48828         10.226.140.133
    TLS :             False

Subscription:  GNMI__12328441295892632155  State: ACTIVE
-------------
  Sensor groups:
  Id                                Interval(ms)               State
  GNMI__12328441295892632155_0     3600000                    Resolved

  Destination Groups:
  Id                 Encoding            Transport   State   Port    Vrf       IP
  GNMI_1002          gnmi-json           dialin      Active  48828            10.226.140.133
    TLS :             False

Subscription:  GNMI__864269735462518853  State: ACTIVE
-------------
  Sensor groups:
```

```
  Id                                Interval(ms)               State
  GNMI__864269735462518853_0       300000                     Resolved

  Destination Groups:
  Id                 Encoding            Transport   State   Port    Vrf    IP
  GNMI_1003          gnmi-json           dialin      Active  48828      10.226.140.133
    TLS :             False

Subscription:  GNMI__1575747990938550928  State: ACTIVE
-------------
  Sensor groups:
  Id                                Interval(ms)               State
  GNMI__1575747990938550928_0      3600000                    Resolved

  Destination Groups:
  Id                 Encoding            Transport   State   Port    Vrf       IP
  GNMI_1004          gnmi-json           dialin      Active  48828        10.226.140.133
    TLS :             False
```

If you want to explore the properties of a specific gNMI subscription, you can run this command:

```
<router>#show telemetry model-driven subscription GNMI__17743548769788099304
Tue Jun 20 16:45:18.706 UTC
Subscription:  GNMI__17743548769788099304
-------------
  State:       ACTIVE
  Sensor groups:
  Id: GNMI__17743548769788099304_0
    Sample Interval:      3600000 ms
    Heartbeat Interval:   NA
    Sensor Path:          Cisco-IOS-XR-ip-bfd-oper:bfd/summary
    Sensor Path State:    Resolved

  Destination Groups:
  Group Id: GNMI_1196
    Destination IP:       10.226.140.133
    Destination Port:     59026
    DSCP/Qos setting:     CS2
    Compression:          gzip
    Encoding:             gnmi-json
    Transport:            dialin
    State:                Active
    TLS :                 False
    Total bytes sent:     450
    Total packets sent:   4
    Last Sent time:       2023-06-20 15:45:38.2331421186 +0000

  Collection Groups:
  ------------------
    Id: 195
    Sample Interval:      3600000 ms
    Heartbeat Interval:   NA
    Heartbeat always:     False
    Encoding:             gnmi-json
    Num of collection:    3
    Incremental updates:  0
    Collection time:      Min:     2 ms Max:     2 ms
    Total time:           Min:     2 ms Avg:     2 ms Max:     3 ms
    Total Deferred:       0
    Total Send Errors:    0
    Total Send Drops:     0
    Total Other Errors:   0
    No data Instances:    0
    Last Collection Start:2023-06-20 15:45:38.2331419186 +0000
    Last Collection End:  2023-06-20 15:45:38.2331421186 +0000
    Sensor Path:          Cisco-IOS-XR-ip-bfd-oper:bfd/summary
```

3.6 Sensor Definition – Sample Intervals

We have the capability of defining different **sample intervals** for different telemetry sensors. A sample interval is the interval at which the device streams data responding to the gNMI requests defined in the Network Controller. The basic difference between Model-Driven (MDT) and Event-Driven Telemetry (EDT) is the definition of this sample interval. In EDT, we don't define any sample interval; the device sends data when an event is triggered (for example, interface goes down). Contrastingly for MDT, we periodically stream data based on the defined interval. The interval definition is based on the importance and magnitude of the data. For example, for critical components like CPU or timing, we have defined stringent sample intervals like 300 seconds while for non-critical components like environment temperature we have defined the interval at 1800 seconds.

Let us try to understand a few subscriptions (as seen on the router below):

a) There are two gNMI requests below, both using JSON as the encoding for the response.

b) The subscriptions are for NPU resources and interfaces data.

c) The defined sample interval (at CNC) is 60 minutes for NPU resources and 5 minutes for interfaces data.

d) The destination of this data is 10.226.140.133 which is a Crosswork Data Gateway, and supports collection protocols including gNMI, MDT, SNMP, CLI, Syslog, and Network Configuration Protocol (NETCONF).

e) List, Datalist, and Finddata are different access methods to get statistics from internal database. You can see the method used here is "DATALIST."

```
<router>#show telemetry model-driven internal subscription


Subscription:  GNMI__8703499362854295784
-------------
  State:       ACTIVE
  Sensor groups:
  Id: GNMI__8703499362854295784_0
    Sample Interval:      3600000 ms
    Heartbeat Interval:   NA
    Sensor Path:          Cisco-IOS-XR-platforms-ofa-oper:ofa/stats/nodes/node/Cisco-IOS-
XR-NCS-BDplatforms-npu-resources-oper:hw-resources-datas
    Sensor Path State:    Resolved


  Destination Groups:
  Group Id: GNMI_1232
    Destination IP:       10.226.140.133
    Destination Port:     58036
    DSCP/Qos setting:     CS2
    Compression:          gzip
    Encoding:             gnmi-json
    Transport:            dialin
    State:              Active
    TLS :               False
    Total bytes sent:   5327398
    Total packets sent: 1612
    Last Sent time:     2023-04-18 16:43:33.34335699 +0000

  Collection Groups:
  ------------------
    Id: 226
    Sample Interval:    3600000 ms
    Heartbeat Interval: NA
    Heartbeat always:   False
    Encoding:           gnmi-json
    Num of collection:  179
    Collection time:    Min:    10 ms Max:   141 ms
    Total time:         Min:    12 ms Avg:    14 ms Max:   143 ms
    Total Deferred:     0
    Total Send Errors:  0
    Total Send Drops:   0
    Total Other Errors: 0
    No data Instances:  0
    Last Collection Start:2023-04-18 16:43:32.34320996 +0000
    Last Collection End:  2023-04-18 16:43:33.34335738 +0000
    Sensor Path:        Cisco-IOS-XR-platforms-ofa-oper:ofa/stats/nodes/node/Cisco-IOS-
XR-NCS-BDplatforms-npu-resources-oper:hw-resources-datas/hw-resources-data


      Sysdb Path:     /oper/ofa/stats/node/*/hw_resources/*
      Count:          179 Method: DATALIST Min: 10 ms Avg: 12 ms Max: 141 ms
      Item Count:     1611 Status: Active
      Missed Collections:0  send bytes: 5327398 packets: 1611 dropped bytes: 0
      Missed Heartbeats:0
                      success         errors          deferred/drops
      Gets            0               0
      List            179             0
      Datalist        179             0
      Finddata        179             0
      GetBulk         0               0
      Encode                          0               0
      Send                            0               0

Subscription:  GNMI__864269735462518853
-------------
```

```
  State:       ACTIVE
  Sensor groups:
  Id: GNMI__864269735462518853_0
    Sample Interval:      300000 ms
    Heartbeat Interval:   NA
    Sensor Path:          Cisco-IOS-XR-ifmgr-oper:interface-properties/data-nodes/data-
node/system-view/interfaces/interface
    Sensor Path State:    Resolved

  Destination Groups:
  Group Id: GNMI_1233
    Destination IP:       10.226.140.133
    Destination Port:     58036
    DSCP/Qos setting:     CS2
    Compression:          gzip
    Encoding:             gnmi-json
    Transport:            dialin
    State:                Active
    TLS :                 False
    Total bytes sent:     126051260
    Total packets sent:   220730
    Last Sent time:       2023-04-18 17:13:33.1834844422 +0000

  Collection Groups:
  ------------------
    Id: 227
    Sample Interval:      300000 ms
    Heartbeat Interval:   NA
    Heartbeat always:     False
    Encoding:             gnmi-json
    Num of collection:    2143
    Collection time:      Min:    12 ms Max:    44 ms
    Total time:           Min:    19 ms Avg:    21 ms Max:    51 ms
    Total Deferred:       0
    Total Send Errors:    0
    Total Send Drops:     0
    Total Other Errors:   0
    No data Instances:    0
    Last Collection Start:2023-04-18 17:13:33.1834820318 +0000
    Last Collection End:  2023-04-18 17:13:33.1834844502 +0000
    Sensor Path:          Cisco-IOS-XR-ifmgr-oper:interface-properties/data-nodes/data-
node/system-view/interfaces/interface
```

```
Sysdb Path:     /oper/im/3pg/node/*/sys/all/*
Count:          2143 Method: DATALIST Min: 12 ms Avg: 14 ms Max: 44 ms
Item Count:     220729 Status: Active
Missed Collections:0  send bytes: 126051260 packets: 220729 dropped bytes: 0
Missed Heartbeats:0
                success         errors          deferred/drops
Gets            0               0
List            2143            0
Datalist        2143            0
Finddata        2143            0
GetBulk         0               0
Encode                          0               0
Send
```

3.7 Defining GNMI Collection on Crosswork Network Controller

Before defining the gNMI Subscribe Requests on Crosswork Network Controller (CNC), let us look at the expectations/format of the request and response (some of which might not be applicable as per latest protocol/controller version).

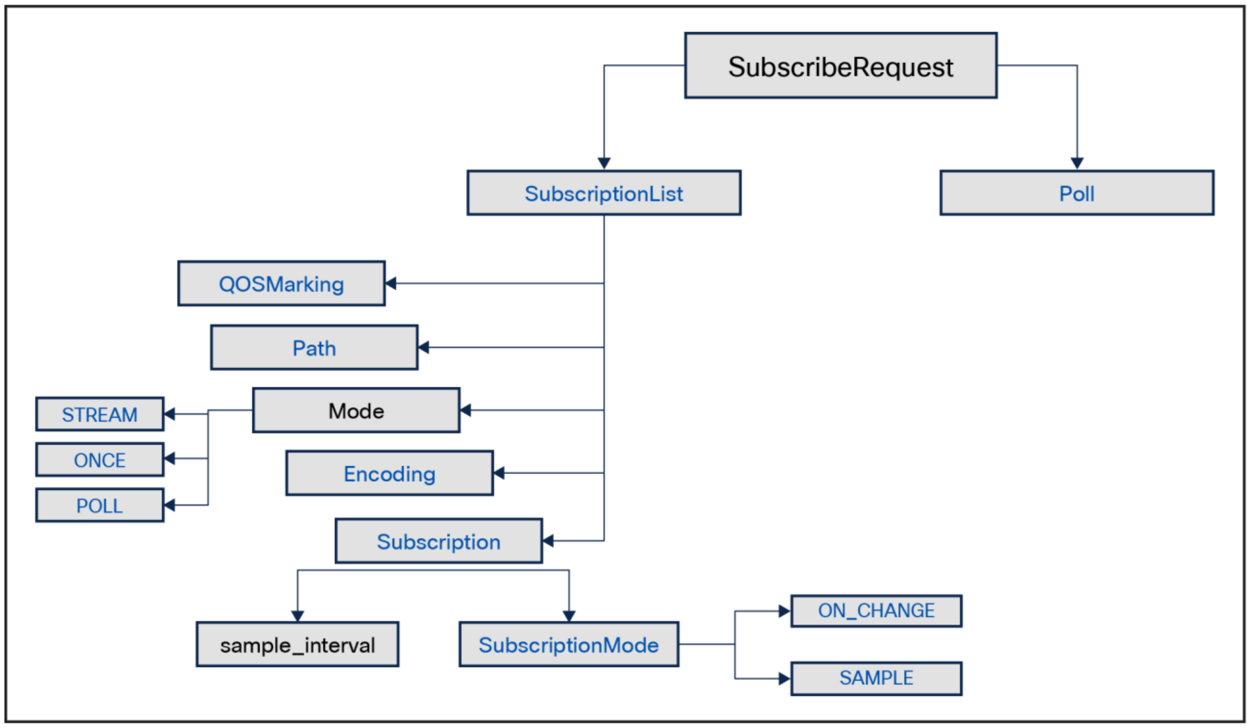


Figure 8.
gNMI Subscribe Request Message

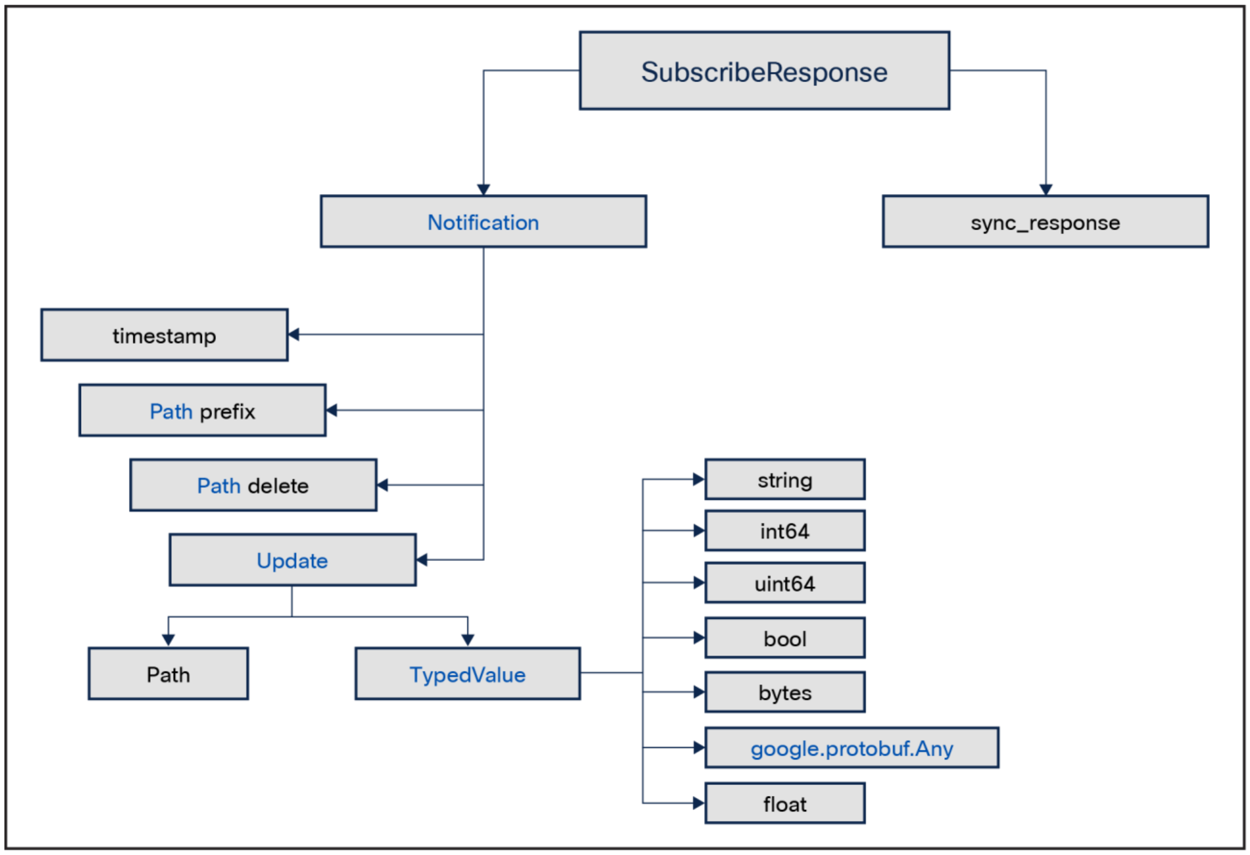
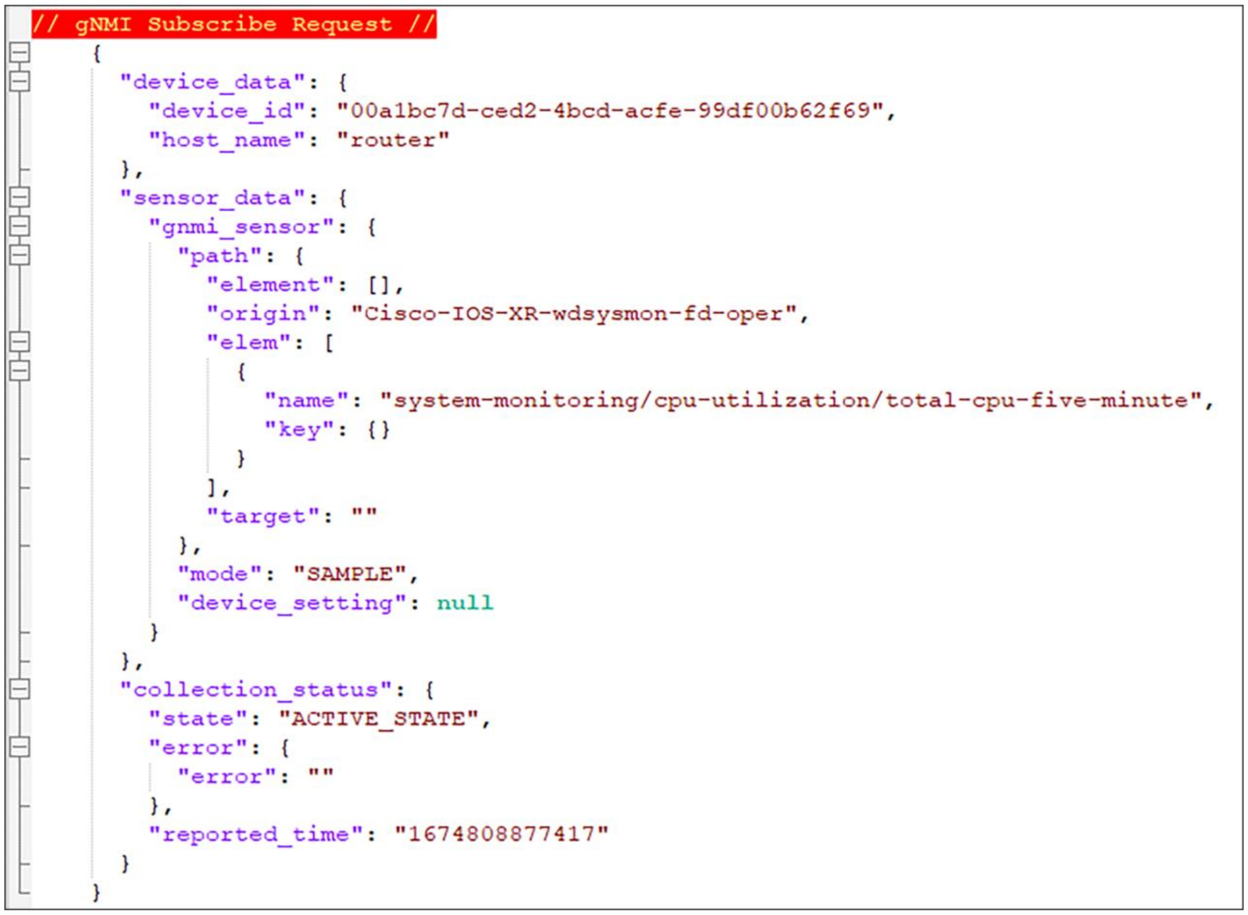


Figure 9.
gNMI Subscribe Response Message

Once you are aware of the message format, you need to define the collection job (a collection of subscriptions) with the telemetry sensors and router name/s (that you want to respond to the gNMI request). You also need to define the cadence or time interval for each subscription. If you have defined a cadence of 300 seconds, the device will respond with the requested data every 5 minutes.

“Mode” is an important parameter of the subscribe request; the example below shows SAMPLE as the value, which means data is streamed every sample interval. Further explanation of the different modes is mentioned below:

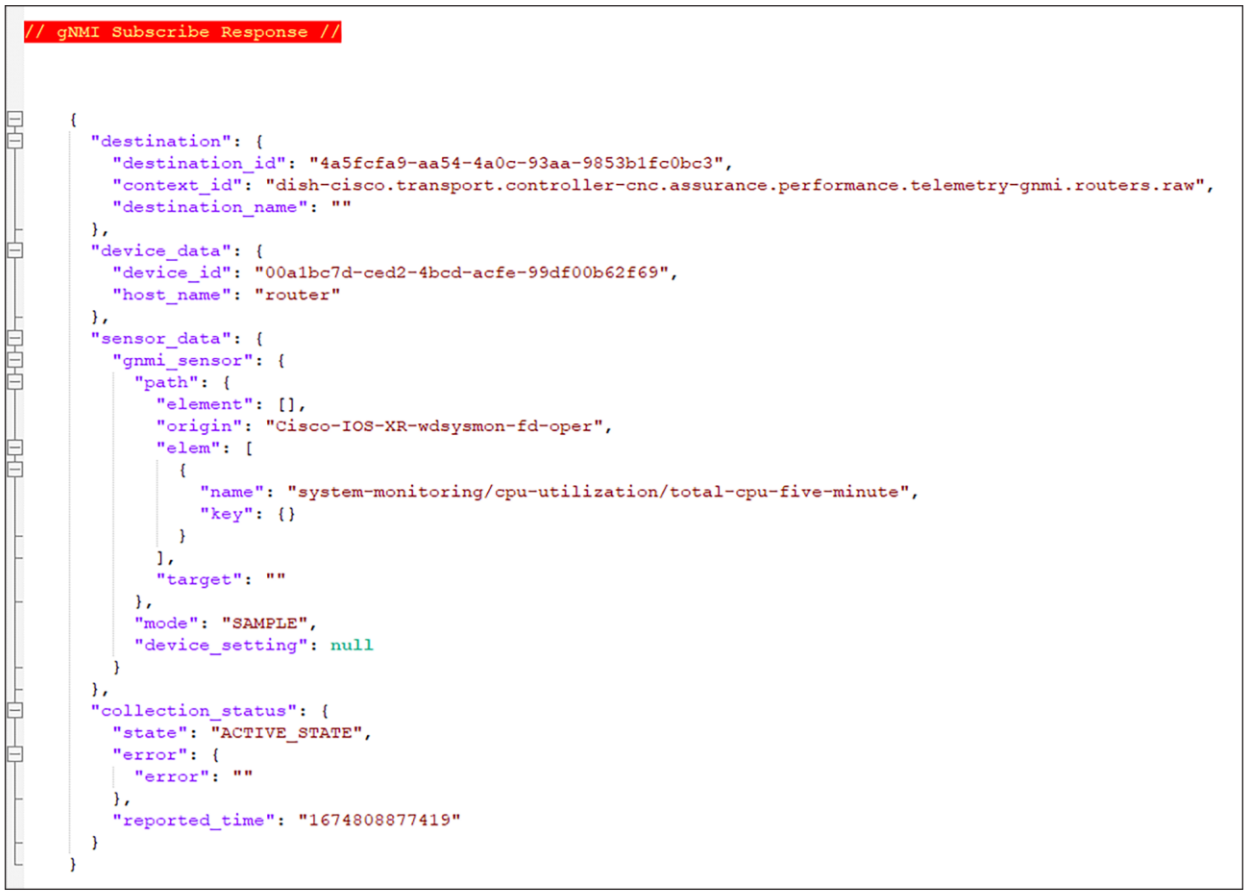
- **ONCE** – The data is streamed only once and never repeated over sample intervals.
- **POLL** – The data is streamed only when subscribed with the current values for all specified paths.
- **STREAM** – As mentioned earlier, this can be “SAMPLE” where data is streamed **every sample interval** or “ON_CHANGE” where data is streamed **if there is a change in value**. The ON_CHANGE option can be explored if you don’t want to stream continuous data to the consumer without any need of action (or remediation). The downside of that is, of course, you will lose the trending and forecasting capability of a KPI if you decide to switch to ON_CHANGE.



```
// gNMI Subscribe Request //
    {
      "device_data": {
        "device_id": "00a1bc7d-ced2-4bcd-acfe-99df00b62f69",
        "host_name": "router"
      },
      "sensor_data": {
        "gnmi_sensor": {
          "path": {
            "element": [],
            "origin": "Cisco-IOS-XR-wdsysmon-fd-oper",
            "elem": [
              {
                "name": "system-monitoring/cpu-utilization/total-cpu-five-minute",
                "key": {}
              }
            ],
            "target": ""
          },
          "mode": "SAMPLE",
          "device_setting": null
        }
      },
      "collection_status": {
        "state": "ACTIVE_STATE",
        "error": {
          "error": ""
        },
        "reported_time": "1674808877417"
      }
    }
```

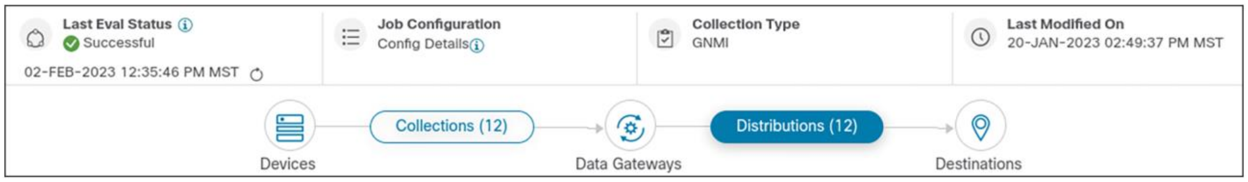
Figure 10.
gNMI Subscribe Request for CPU KPI

If the collection is a success, you get a response in the form of “Distribution,” which is destined to the Kafka Message Bus (mentioned in Section 2.4). The response contains the data in raw format that can be read from the Message Bus.



```
// gNMI Subscribe Response //


{
  "destination": {
    "destination_id": "4a5fcfa9-aa54-4a0c-93aa-9853b1fc0bc3",
    "context_id": "dish-cisco.transport.controller-cnc.assurance.performance.telemetry-gnmi.routers.raw",
    "destination_name": ""
  },
  "device_data": {
    "device_id": "00a1bc7d-ced2-4bcd-acfe-99df00b62f69",
    "host_name": "router"
  },
  "sensor_data": {
    "gnmi_sensor": {
      "path": {
        "element": [],
        "origin": "Cisco-IOS-XR-wdsysmon-fd-oper",
        "elem": [
          {
            "name": "system-monitoring/cpu-utilization/total-cpu-five-minute",
            "key": {}
          }
        ],
        "target": ""
      },
      "mode": "SAMPLE",
      "device_setting": null
    }
  },
  "collection_status": {
    "state": "ACTIVE_STATE",
    "error": {
      "error": ""
    },
    "reported_time": "1674808877419"
  }
}
```

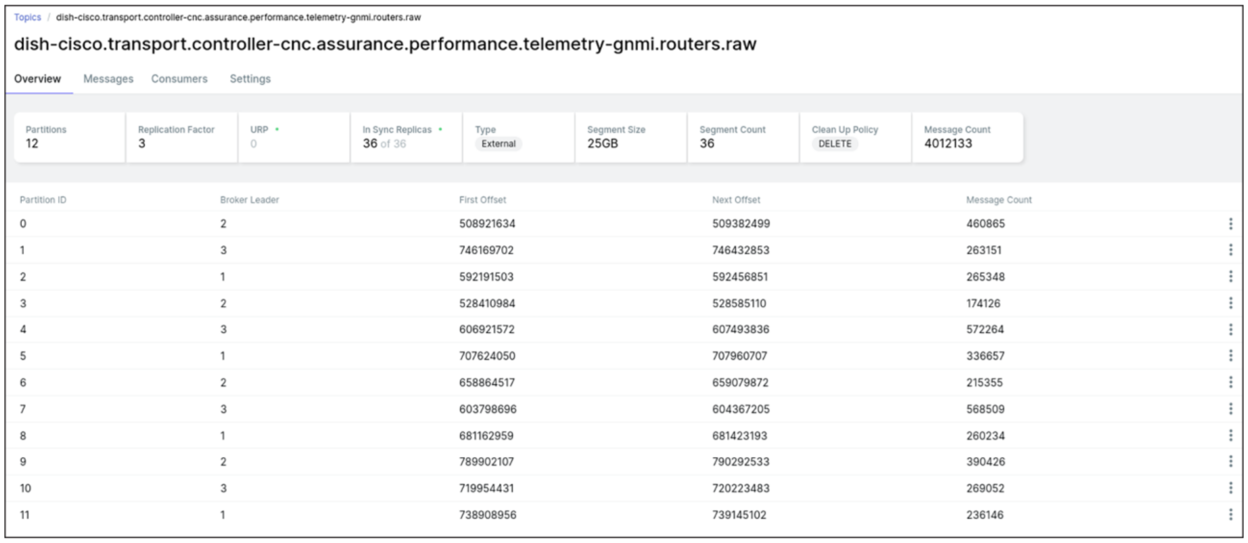
Figure 11.
gNMI Subscribe Response for CPU KPI



Last Eval Status	Job Configuration	Collection Type	Last Modified On
Successful	Config Details	GNMI	20-JAN-2023 02:49:37 PM MST
02-FEB-2023 12:35:46 PM MST			

Figure 12.
Data streamed toward CDG

3.8 Reading GNMI Response on Kafka Bus



Topics / dish-cisco.transport.controller-cnc.assurance.performance.telemetry-gnmi.routers.raw

dish-cisco.transport.controller-cnc.assurance.performance.telemetry-gnmi.routers.raw

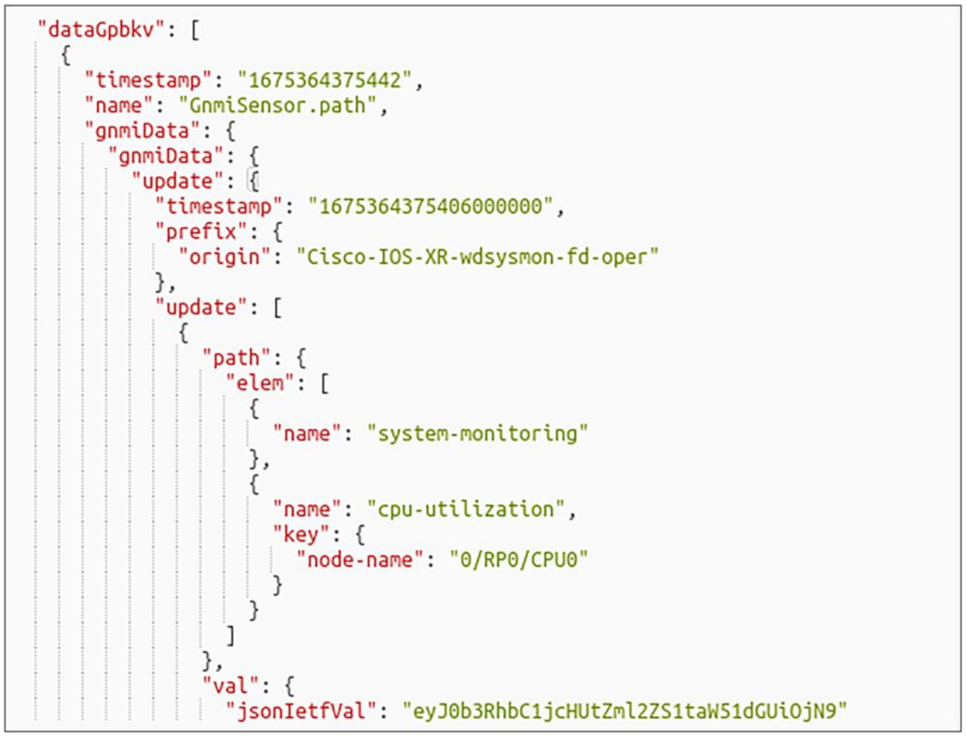
Overview | Messages | Consumers | Settings

Partitions	Replication Factor	URP	In Sync Replicas	Type	Segment Size	Segment Count	Clean Up Policy	Message Count
12	3	0	36 of 36	External	25GB	36	DELETE	4012133

Partition ID	Broker Leader	First Offset	Next Offset	Message Count
0	2	508921634	509382499	460865
1	3	746169702	746432853	263151
2	1	592191503	592456851	265348
3	2	528410984	528585110	174126
4	3	606921572	607493836	572264
5	1	707624050	707960707	336657
6	2	658864517	659079872	215355
7	3	603798696	604367205	568509
8	1	681162959	681423193	260234
9	2	789902107	790292533	390426
10	3	719954431	720223483	269052
11	1	738908956	739145102	236146

Figure 13.
Topic on Kafka Message Bus

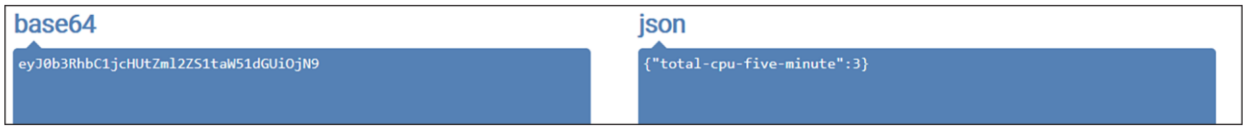
Now that you have plugged onto the same topic as mentioned in the gNMI Distribution in CNC, you will be able to parse the raw data from the Kafka Message Bus. Let us try to read that data in the Message Bus and then decode it.



```
"dataGpbkv": [
  {
    "timestamp": "1675364375442",
    "name": "GnmiSensor.path",
    "gnmiData": {
      "gnmiData": {
        "update": {
          "timestamp": "1675364375406000000",
          "prefix": {
            "origin": "Cisco-IOS-XR-wdsysmon-fd-oper"
          },
          "update": [
            {
              "path": {
                "elem": [
                  {
                    "name": "system-monitoring"
                  },
                  {
                    "name": "cpu-utilization",
                    "key": {
                      "node-name": "0/RP0/CPU0"
                    }
                  }
                ]
              },
              "val": {
                "jsonIetfVal": "eyJ0b3RhbC1jcHUtZml2ZS1taW51dGUiOjN9"
```

Figure 14.
Raw Data of CPU KPI on Message Bus

Let us use a Base64 Decoder to decode this JSON_IETF value.



```
eyJ0b3RhbC1jcHUtZml2ZS1taW51dGUiOjN9
```

```
{"total-cpu-five-minute":3}
```

Figure 15.
JSON decoded from BASE64 Value

Now that we have got our data that needs to be printed in Matrix, we can process this data and build Matrix Panels based on customized logic. As JSON data is a (key, value) pair, you can process the data based on certain keys. For example, in the case of CPU utilization of a fixed chassis physical router like ASR9902, there will be three key values in the form of "node-name":

1) 0/RP0/CPU0
2) 0/RP1/CPU0
3) 0/0/CPU0

You can use any of these keys to fetch the data (cpu-utilization) specific to that node-name. For a cell site router, you will have just one key (node-name = 0/RP0/CPU0), and it is not mandatory for you to specify a key to fetch the value (content) of that KPI.

To verify the gNMI-based subscriptions on your router (that is defined in the collection job on CNC), you need to run the following command:

```
<router>#show telemetry model-driven sensor-group
Fri Feb  3 18:41:59.772 UTC
  Sensor Group Id:GNMI__8703499362854295784_0
    Sensor Path:        Cisco-IOS-XR-platforms-ofa-oper:ofa/stats/nodes/node/Cisco-IOS-XR-
NCS-BDplatforms-npu-resources-oper:hw-resources-datas
    Sensor Path State:  Resolved

  Sensor Group Id:GNMI__147082646091452568_0
    Sensor Path:        Cisco-IOS-XR-qos-ma-oper:qos/interface-
table/interface/output/service-policy-names/service-policy-instance/statistics
    Sensor Path State:  Resolved

  Sensor Group Id:GNMI__2203298433605397407_0
    Sensor Path:        Cisco-IOS-XR-mediasvr-linux-oper:media-svr/nodes/node/partition
    Sensor Path State:  Resolved

  Sensor Group Id:GNMI__7083707911975322971_0
    Sensor Path:        Cisco-IOS-XR-fib-common-oper:fib-statistics/nodes/node/drops
    Sensor Path State:  Resolved

  Sensor Group Id:GNMI__10442864159394791983_0
    Sensor Path:        Cisco-IOS-XR-drivers-media-eth-oper:ethernet-
```

```
interface/statistics/statistic
    Sensor Path State:  Resolved


  Sensor Group Id:GNMI__864269735462518853_0
    Sensor Path:        Cisco-IOS-XR-ifmgr-oper:interface-properties/data-nodes/data-
node/system-view/interfaces/interface
    Sensor Path State:  Resolved


  Sensor Group Id:GNMI__9422764881658769044_0
    Sensor Path:        Cisco-IOS-XR-infra-statsd-oper:infra-
statistics/interfaces/interface/latest/data-rate
    Sensor Path State:  Resolved


  Sensor Group Id:GNMI__5396827438168630175_0
    Sensor Path:        Cisco-IOS-XR-nto-misc-oper:memory-summary/nodes/node/summary
    Sensor Path State:  Resolved


  Sensor Group Id:GNMI__18328265757967605119_0
    Sensor Path:        Cisco-IOS-XR-pfi-im-cmd-oper:interfaces/interface-xr/interface
    Sensor Path State:  Resolved


  Sensor Group Id:GNMI__12761477014645305428_0
    Sensor Path:        Cisco-IOS-XR-wdsysmon-fd-oper:system-monitoring/cpu-
utilization/total-cpu-five-minute
    Sensor Path State:  Resolved
```

It is important to verify this output to make sure your sensor definition is correct in the collector. If the sensor doesn't get resolved on the router, you will get an error response. There are multiple reasons for a sensor to not get resolved.

1) The sensor hasn't been defined yet.
2) The sensor definition is incorrect.
3) The sensor is not applicable to the platform.

Here is an example of that last point (3), where the sensor was not applicable to this platform:

```
Sensor Group Id:GNMI__2772047299061468887_0
Sensor Path: Cisco-IOS-XR-envmon-oper:environmental-monitoring/rack/nodes/node/sensor-
types/sensor-type[type='temperature']/sensor-names/sensor-name[name='MB-Inlet Temp Sensor']
Sensor Path State: Not Resolved
Status: Module 'Cisco-IOS-XR-envmon-oper' not recognized or supported for the specified
operation
```

Here is an example of (2), where the sensor was defined incorrectly.

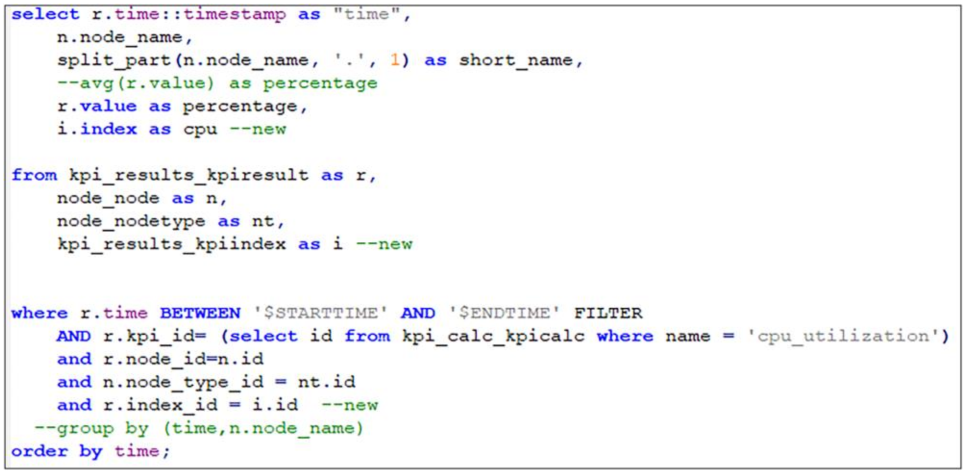
```
<<router>>#show telemetry model-driven sensor-group


    Sensor Group Id:GNMI__5957134147446068896_0
    Sensor Path:        Cisco-IOS-XR-pfi-im-cmd-oper:interfaces/interface-xr/interface/
    Sensor Path State:  Not Resolved
      Status:           Invalid sensor path

  Sensor Group Id:GNMI__16416561783471716548_0
    Sensor Path:        Cisco-IOS-XR-ip-bfd-oper:bfd/summary
    Sensor Path State:  Resolved

  Sensor Group Id:GNMI__16950133171544085696_0
    Sensor Path:        Cisco-IOS-XR-nto-misc-oper:memory-summary/nodes/node/summary/
    Sensor Path State:  Not Resolved
      Status:           Invalid sensor path
```

3.9 Defining Matrix Panels Based on Query Logic (SQL)

The final piece (and the most important) of the monitoring puzzle is building the panel for the KPI defined at the beginning of this process. Let us summarize what we have done so far (Reference Section 2.1).

1) Enabled plumbing on the routers to get ready to stream data (gRPC configuration)
2) Defined the Key Performance Indicators for all routers.
3) Defined the corresponding Telemetry Sensor on CNC with proper cadence.
4) Enabled subscription toward the routers in the form of collection jobs from CNC
5) Enabled the mechanism of gNMI response to a Kafka Message Bus (Topic/Partition)
6) Read and parsed that message from the Message Bus and verified its accuracy.

Now, we need to build our query logic to showcase the KPI in the form of a Matrix Panel. You may have your customized logic to display the data. Instead of displaying it as a number, you may display it as percentage and thereby modify the KPI value as streamed from the device. Here is a sample SQL code for CPU Utilization KPI.



```
select r.time::timestamp as "time",
    n.node_name,
    split_part(n.node_name, '.', 1) as short_name,
    --avg(r.value) as percentage
    r.value as percentage,
    i.index as cpu --new

from kpi_results_kpiresult as r,
    node_node as n,
    node_nodetype as nt,
    kpi_results_kpiindex as i --new


where r.time BETWEEN '$STARTTIME' AND '$ENDTIME' FILTER
    AND r.kpi_id= (select id from kpi_calc_kpicalc where name = 'cpu_utilization')
    and r.node_id=n.id
    and n.node_type_id = nt.id
    and r.index_id = i.id  --new
  --group by (time,n.node_name)
order by time;
```

Figure 16.
SQL for CPU Utilization

4 Monitoring KPIs on Matrix

4.1 System KPIs

Here we are reporting CPU utilization of all cell site routers in a specific region of the network for the last 12 hours of the day.

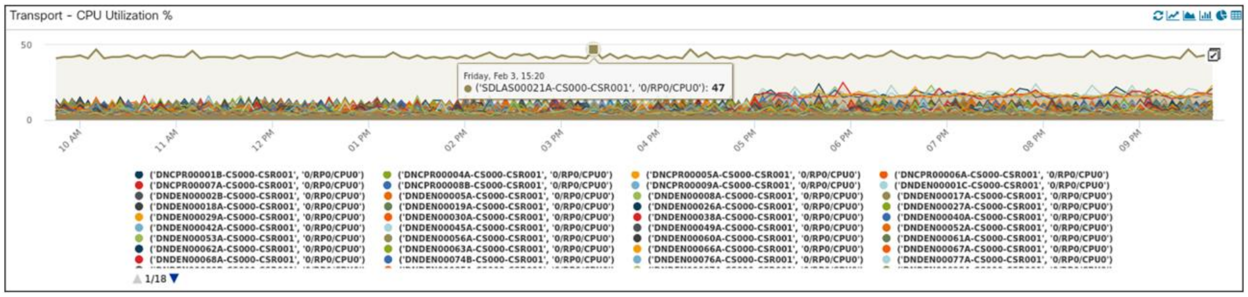


Figure 17.
CPU Utilization of CSRs

Here we are reporting NPU utilization of a specific NPU Bank (FEC) for all Provider Edge Data Center edge routers in a specific region of the network for the last two hours of the day.

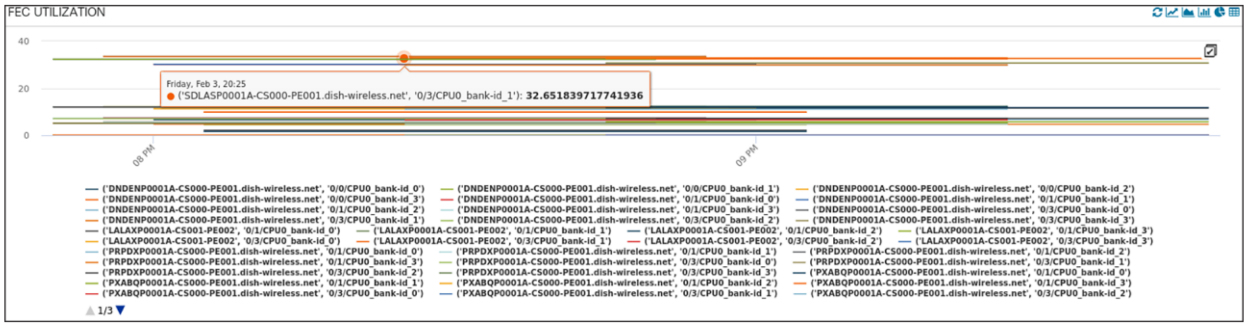


Figure 18.
NPU Utilization of PEDC PEs

Here we are reporting memory utilization of a specific Local Data Center Edge Router. We are looking at trends over a period of 24 hours for two KPIs: one being the memory utilization of all processes specific to 0/RP0/CPU0, the other being the Memory Utilization of all processes specific to 0/0/CPU0.

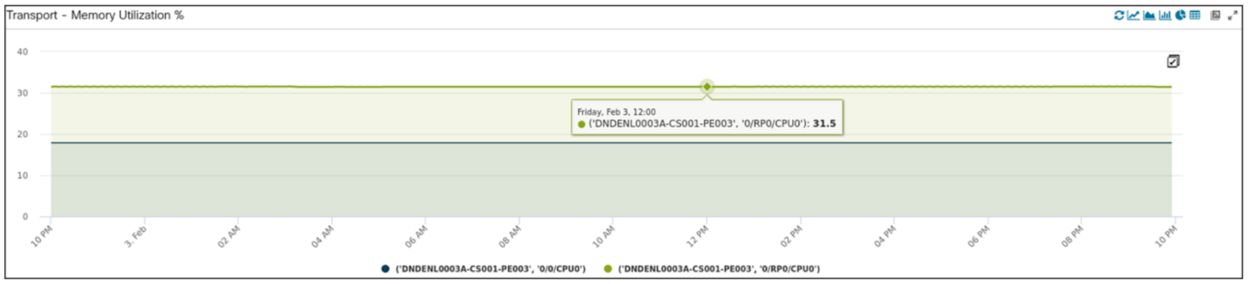
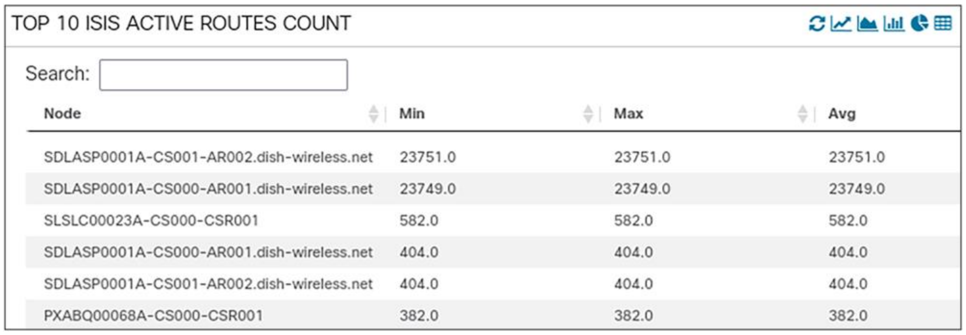


Figure 19.
Memory Utilization of one LDC PE

4.2 Routing KPIs

Here we are looking at a non-graphical panel of the "top N" routers of a specific region in a network with the highest number of ISIS routes

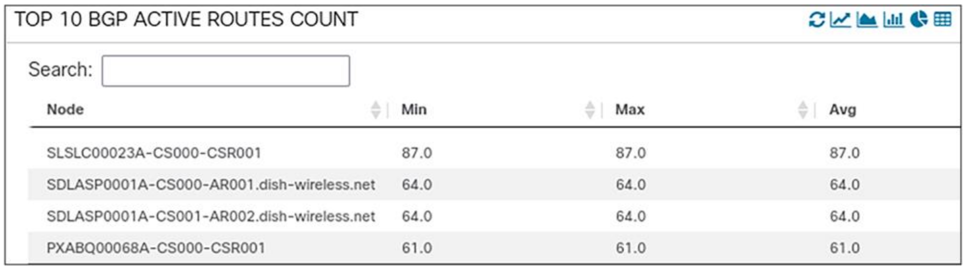

TOP 10 ISIS ACTIVE ROUTES COUNT

Search:

Node	Min	Max	Avg
SDLASP0001A-CS001-AR002.dish-wireless.net	23751.0	23751.0	23751.0
SDLASP0001A-CS000-AR001.dish-wireless.net	23749.0	23749.0	23749.0
SLSLC00023A-CS000-CSR001	582.0	582.0	582.0
SDLASP0001A-CS000-AR001.dish-wireless.net	404.0	404.0	404.0
SDLASP0001A-CS001-AR002.dish-wireless.net	404.0	404.0	404.0
PXABQ00068A-CS000-CSR001	382.0	382.0	382.0

Figure 20.
Top N ISIS Routes

Here we are looking at a non-graphical panel of the “top N” routers of a specific region in a network with the highest number of BGP routes.



TOP 10 BGP ACTIVE ROUTES COUNT

Search:

Node	Min	Max	Avg
SLSLC00023A-CS000-CSR001	87.0	87.0	87.0
SDLASP0001A-CS000-AR001.dish-wireless.net	64.0	64.0	64.0
SDLASP0001A-CS001-AR002.dish-wireless.net	64.0	64.0	64.0
PXABQ00068A-CS000-CSR001	61.0	61.0	61.0

Figure 21.
Top N BGP Routes

Here we are looking at BGP Neighbors on all PEDCs over the last two hours. Different Area of Interest (AOIs) will have different scale, and that is why you are seeing different numbers in the graph below. The important takeaway is that the neighbors scale is not changing over time.

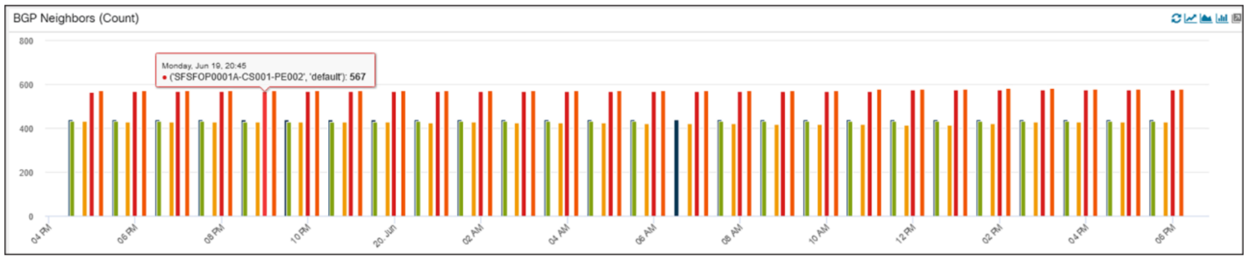


Figure 22.
BGP neighbor Count for PEDCs

Another KPI Panel is snapped below; it is showing ISIS neighbors across all routers in the network over the last two hours.

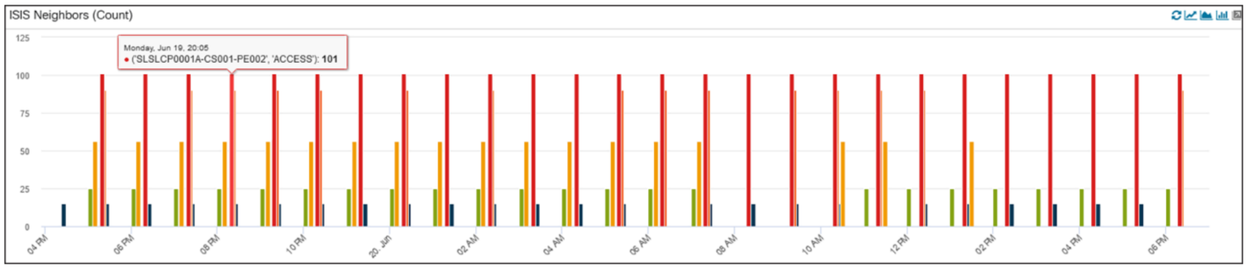


Figure 23.
ISIS Neighbor Count

4.3 Services KPIs

Here we are looking at Interface Bandwidth Utilization (for both Ingress and Egress) for all XRv routers in a specific region of the network. Bandwidth Utilization trends greatly helps with capacity planning of networks once it goes live.

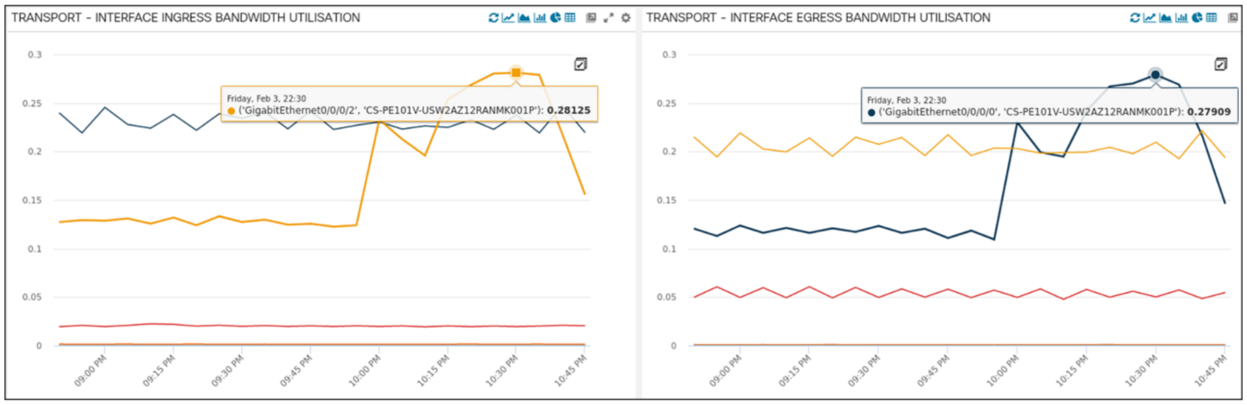


Figure 24.
Interface Bandwidth Utilization for all XRv

Here we are looking at GRE Tunnel Bandwidth Utilization (for both Ingress and Egress) for all XRv routers in a specific region of the network. These are Cisco GRE tunnels running on top of a cloud underlay in the network.

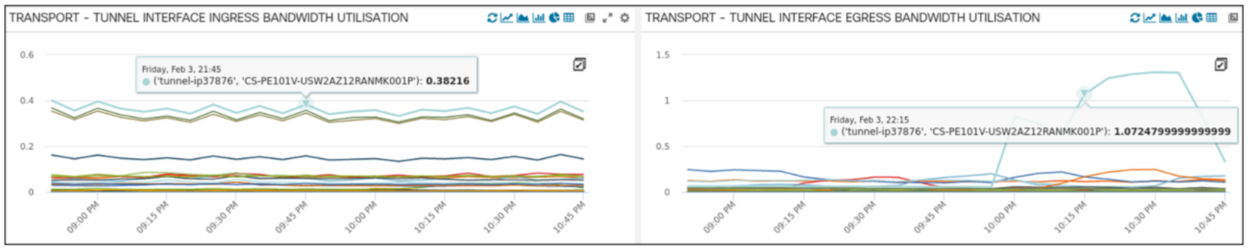


Figure 25.
Tunnel Bandwidth Utilization for all XRv

Here we are looking at Interface Throughput (Ingress/Egress) for one specific XRv in a region of the network. We are measuring it in Gbps, and it shows us a trend of the last two hours.

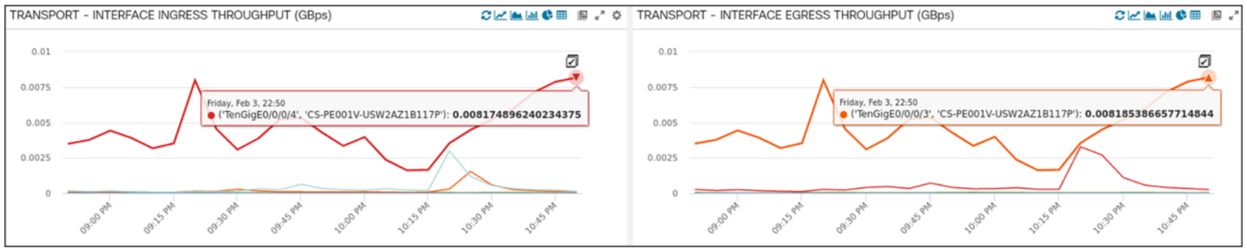
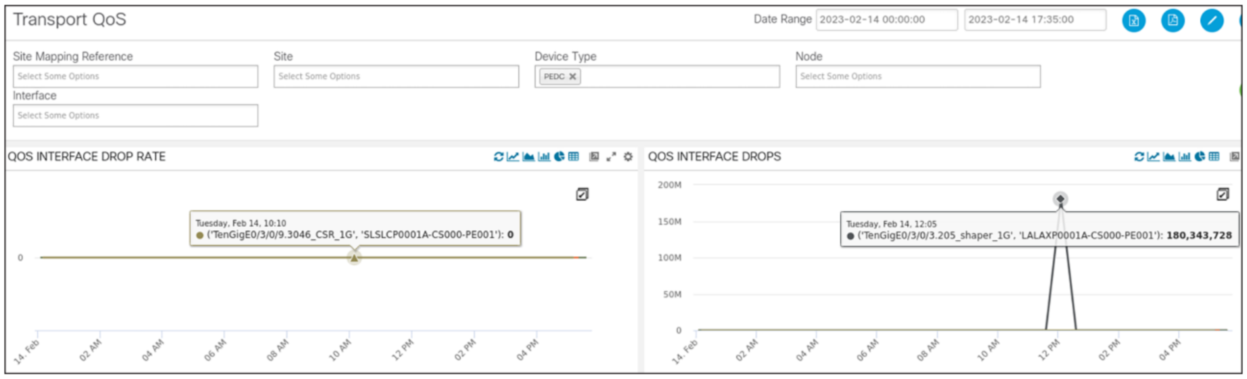


Figure 26.
Interface Throughput on one XRv

This is Transport QoS Drops (and Rate of Drops) for all Provider Edge Routers (NCS55xx) in a region of the network. This is a trend for the present day. We did see a spike in QoS Interface Drops, but it went back to normalcy very soon.



Date Range 2023-02-14 00:00:00 2023-02-14 17:35:00

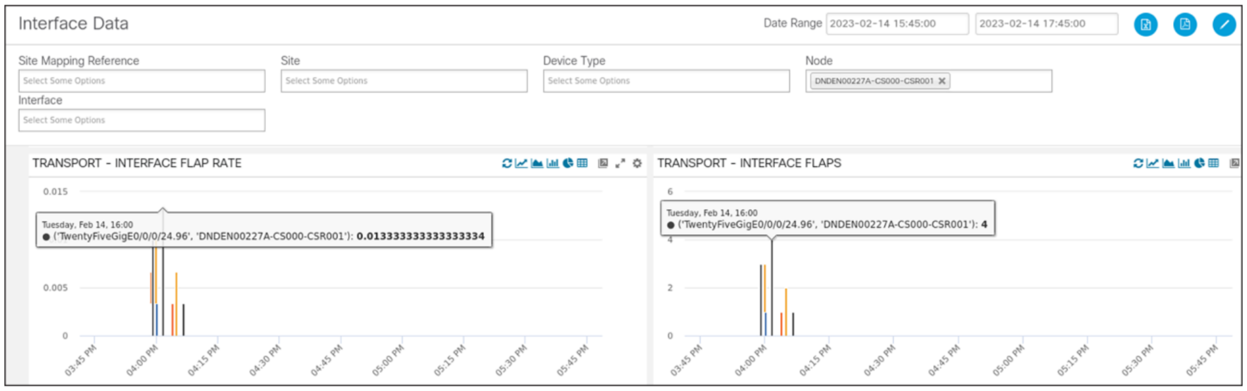
Device Type PEDC

Tuesday, Feb 14, 10:10
● ('TenGigE0/3/0/9.3046_CSR_1G', 'SLSLCP0001A-CS000-PE001'): 0

Tuesday, Feb 14, 12:05
● ('TenGigE0/3/0/3.205_shaper_1G', 'LALAXP0001A-CS000-PE001'): 180,343,728

Figure 27.
Interface QoS Drops | Drop Rate

We are monitoring Interface Flaps and Interface Flap Rate by looking at the Carrier Transitions KPI for every interface. The Carrier Transition of an interface is essentially the change in Operational Status of an interface caused by flaps or micro-flaps. The following table is looking at a “suspected” cell site router over the last two hours. We can see there is a specific interface that is flapping on the router and the operations team needs to troubleshoot this.



Date Range 2023-02-14 15:45:00 2023-02-14 17:45:00

Node DNDEN00227A-CS000-CSR001

Tuesday, Feb 14, 16:00
● ('TwentyFiveGigE0/0/0/24.96', 'DNDEN00227A-CS000-CSR001'): 0.013333333333333334

Tuesday, Feb 14, 16:00
● ('TwentyFiveGigE0/0/0/24.96', 'DNDEN00227A-CS000-CSR001'): 4

Figure 28.
Interface Flaps | Flap Rate

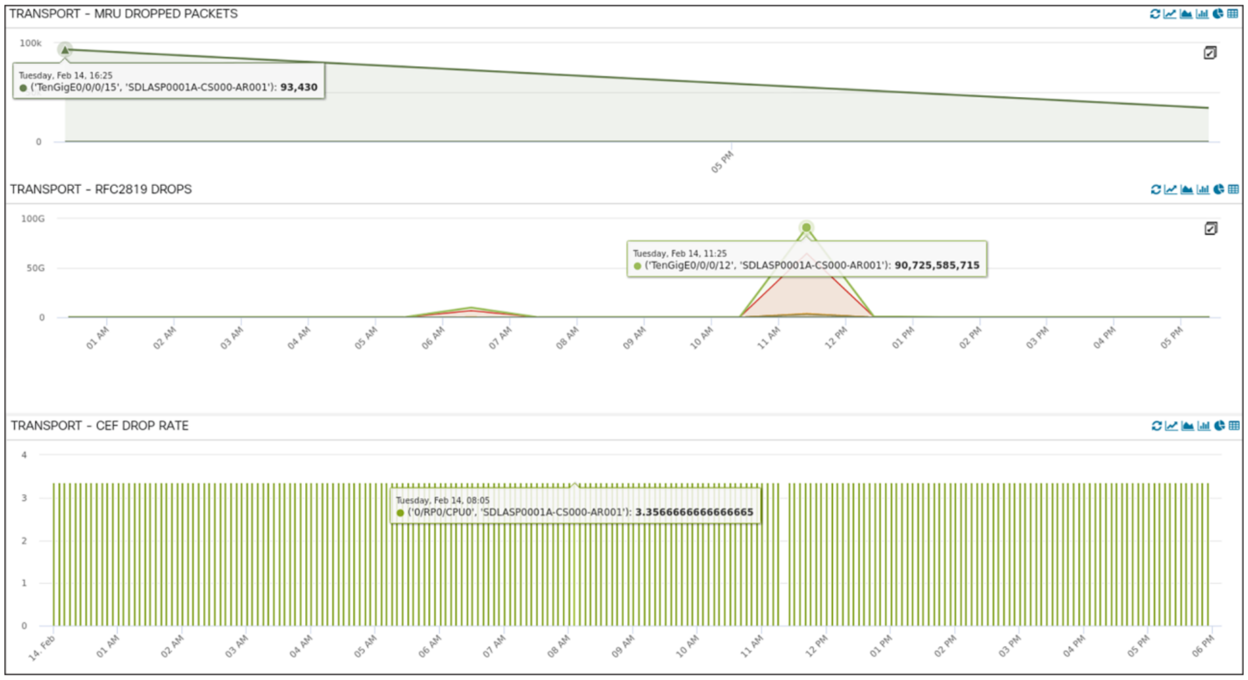


Figure 29.
Interface | CEF Errors

Latency is another important KPI we are monitoring at Dish Networks. The three panels listed below show us the latency incurred on the odd path, even path, and between the Cell Site Router (CSR) and the BEDC XRv router (Midhaul: DU to CU). We can see an average latency of 4 milliseconds (ms) on both the odd and even paths here. The Midhaul latency has a lot of spikes, but it averages around 5 ms over time.

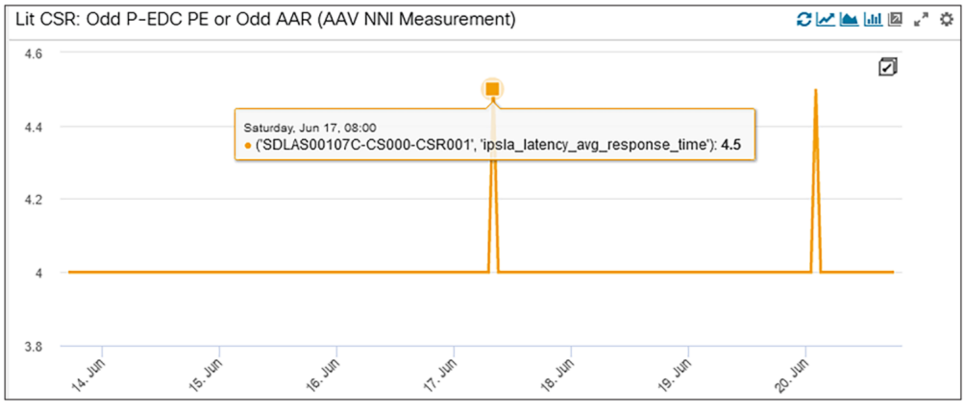


Figure 30.
LIT CSR Odd Path Latency

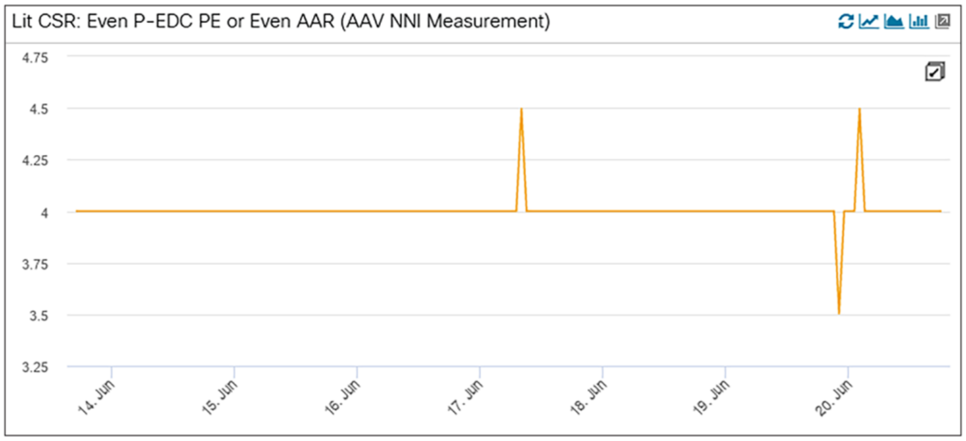


Figure 31.
LIT CSR Even Path Latency

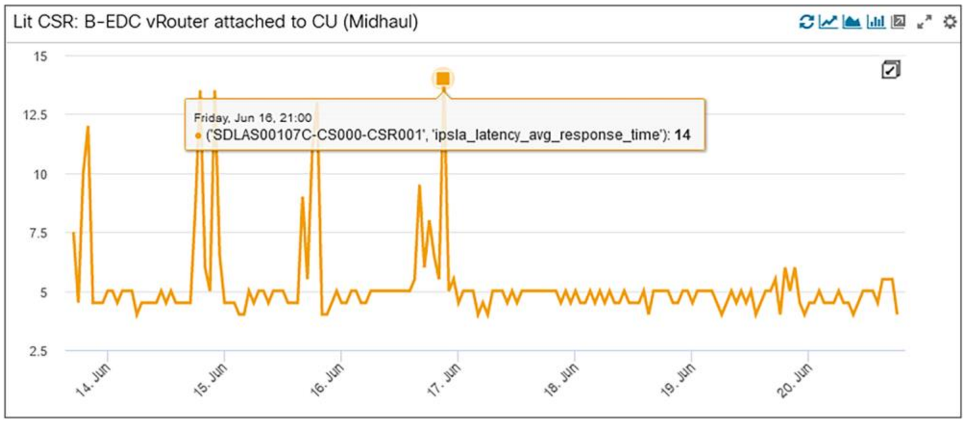


Figure 32.
CSR to BEDC Midhaul Latency

4.4 Hardware KPIs

Inlet temperature for CSRs is an important environmental KPI as these devices are deployed outdoor at a cell site (albeit inside a cabinet). Here are two CSRs with inlet temperature KPI implemented, we can see the trending values over a period of 24 hours.

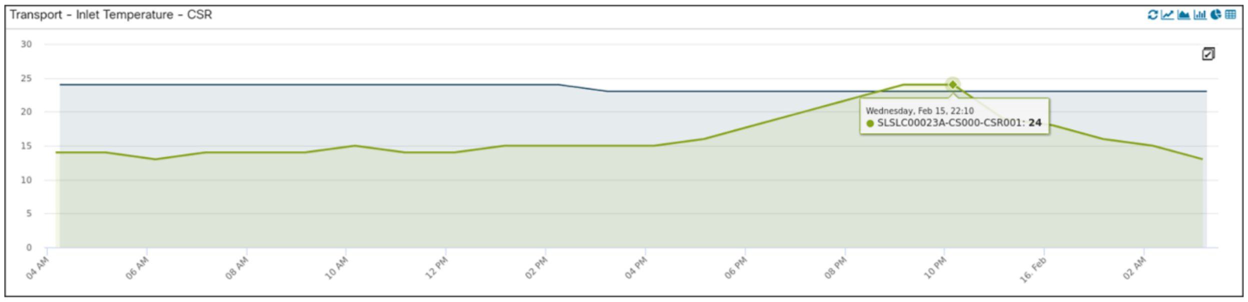


Figure 33.
Inlet Temperature of 2 CSRs

Another environmental KPI is CPU temperature, which is being monitored in this panel below. You can see the sharp spike of a CPU temperature on a CSR increasing possibly because of a power/environmental event at that cell site.

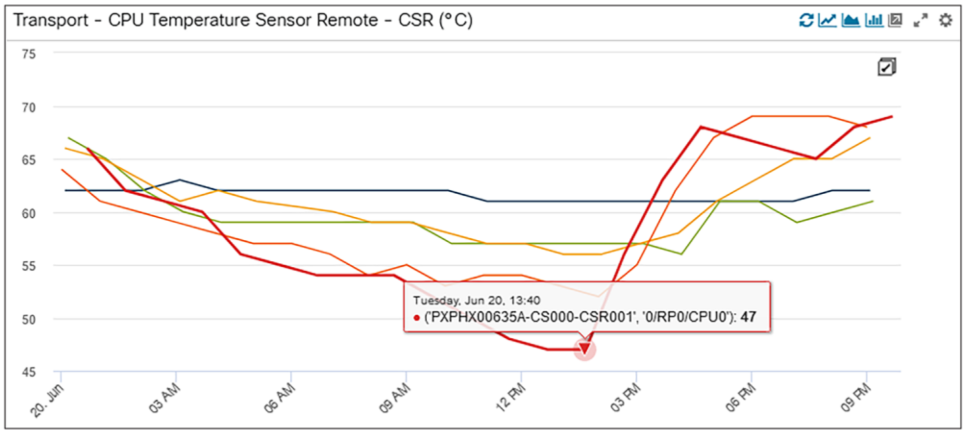


Figure 34.
CPU Temperature of 5 CSRs

Another important hardware KPI is the Transmit (Tx) and Receive (Rx) power drawn by the optical transceiver connected to the routers. The power value shown here is in dBm (decibel-milliwatts). These indicate the "light" on the wire. If the power levels are very low, it means there is no light/traffic on the wire.

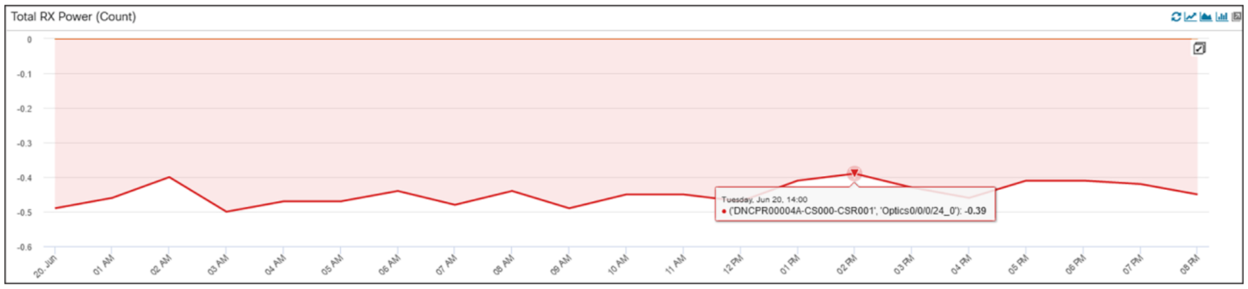


Figure 35.
Total Rx Power

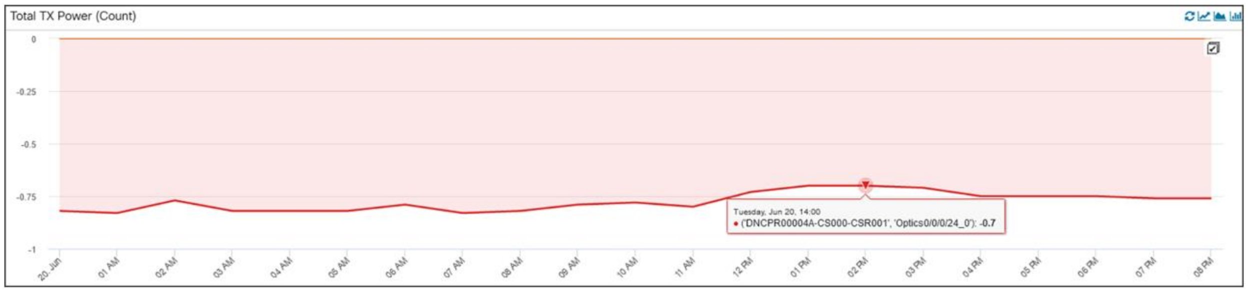


Figure 36.
Total Tx Power

The final hardware KPI captured here is media storage utilization. There are different flavors of media types based on the device types in the network. It is important to monitor media storage, as the lack of storage space can lead to low memory which can impact certain processes running in the router.

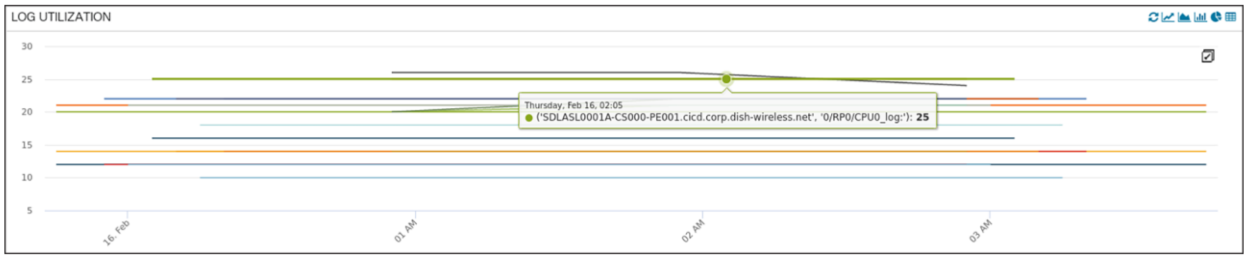


Figure 37.
Media Storage (Log) Utilization of LDCs

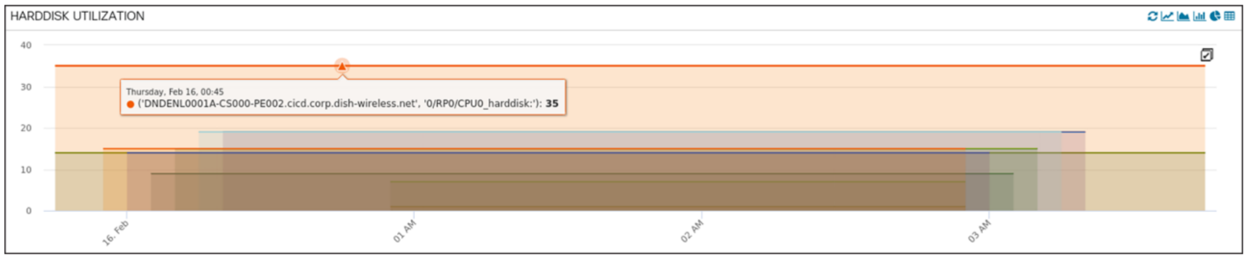


Figure 38.
Media Storage (Hard disk) Utilization of LDCs

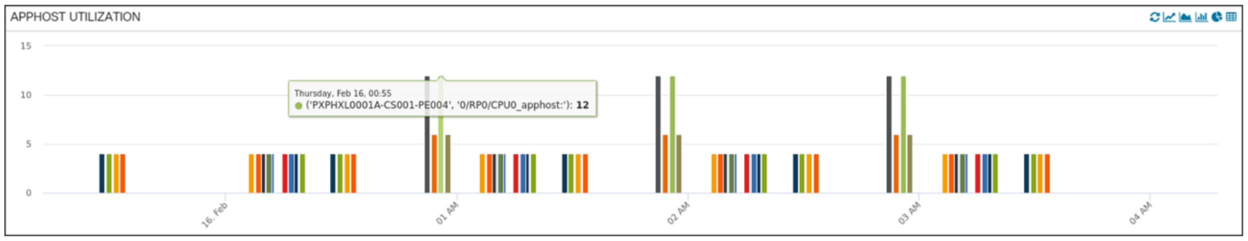
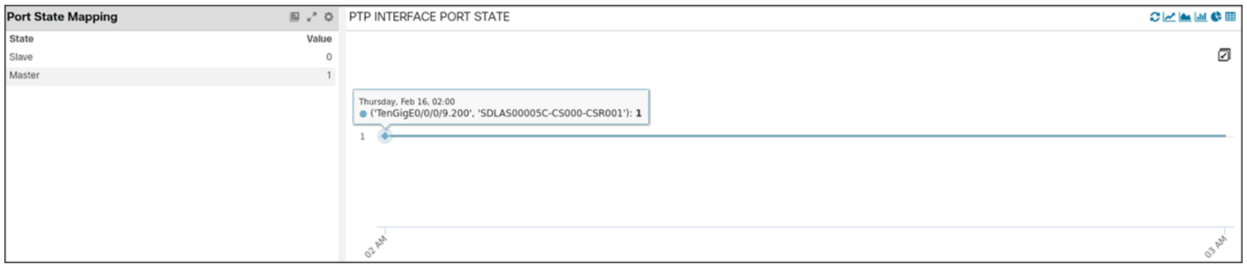


Figure 39.
Media Storage (Apphost) Utilization of LDCs

4.5 Timing KPIs

Another extremely important KPI at a cell site is timing (a combination of phase, frequency, and time of day) and it helps to synchronize data between end systems. If all devices (RU, CSR, LDC PE, and DU) are synchronized (in phase/frequency/time of day) to each other with respect to a single clocking source like the GNSS (Global Navigation Satellite System), our Mobile Fronthaul timing solution is working fine. (also means there is no **out-of-sync communication** in the mobile fronthaul network). We need to monitor these KPIs and report an anomaly if there is any.

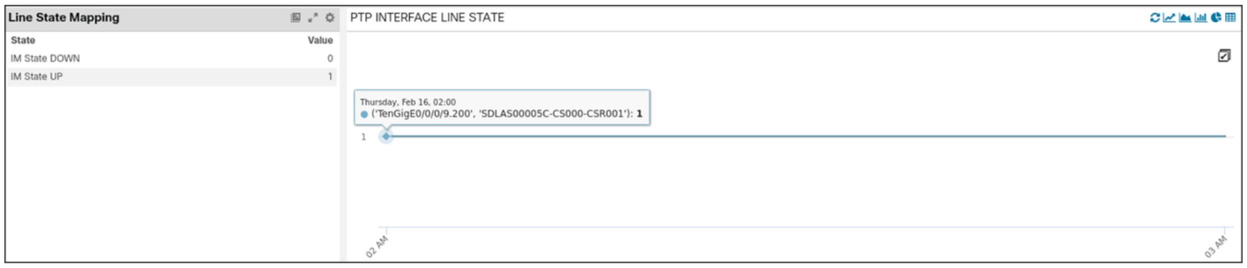
Below you can see PTP Port and Line State being monitored for the interfaces distributing clock from the CSR to the slave nodes (for ex: RU & DU are slave nodes while CSR is a master node with respect to distributing and receiving clock in the network). If these interface flaps or encounter errors, these KPIs might get impacted.



Port State Mapping

State	Value
Slave	0
Master	1

Figure 40.
PTP Port State of One CSR

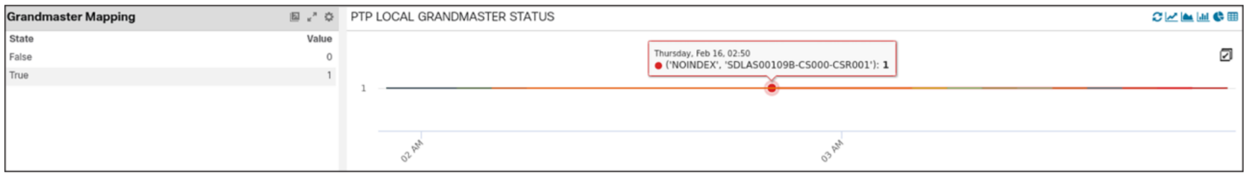


Line State Mapping

State	Value
IM State DOWN	0
IM State UP	1

Figure 41.
PTP Line State of One CSR

Similarly, we are looking at the Grandmaster State of all CSRs, this should ideally be true as all CSRs are acting as T-GMs in the network (Telecom-Grandmaster)



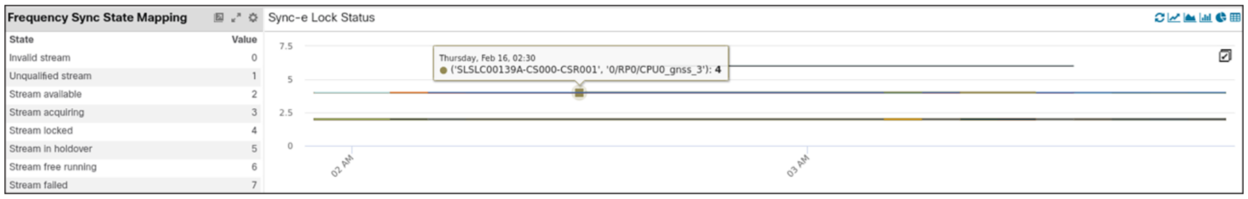
Grandmaster Mapping

State	Value
False	0
True	1

PTP LOCAL GRANDMASTER STATUS
Thursday, Feb 16, 02:50
● ('NOINDEX', 'SDLAS00109B-CS000-CSR001'): 1
1
02 AM
03 AM

Figure 42.
GNSS Grandmaster State of All CSRs

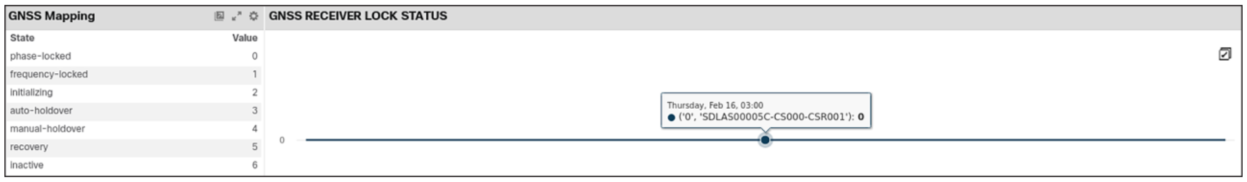
For frequency, time of day, and phase, we are monitoring these two KPIs – SyncE Frequency Status and GNSS Receiver Status. If we are synchronized to the centralized clocking source or GNSS, the KPIs will show as “locked”; if we are disconnected or **drifting**, we will show different states of these KPIs like “holdover,” and “free running.” Some of the state mapping is captured in the snapshots below as per definition of the corresponding YANG models (and data being streamed from the network).



Frequency Sync State Mapping

State	Value
Invalid stream	0
Unqualified stream	1
Stream available	2
Stream acquiring	3
Stream locked	4
Stream in holdover	5
Stream free running	6
Stream failed	7

Figure 43.
SyncE Frequency Status of all CSRs



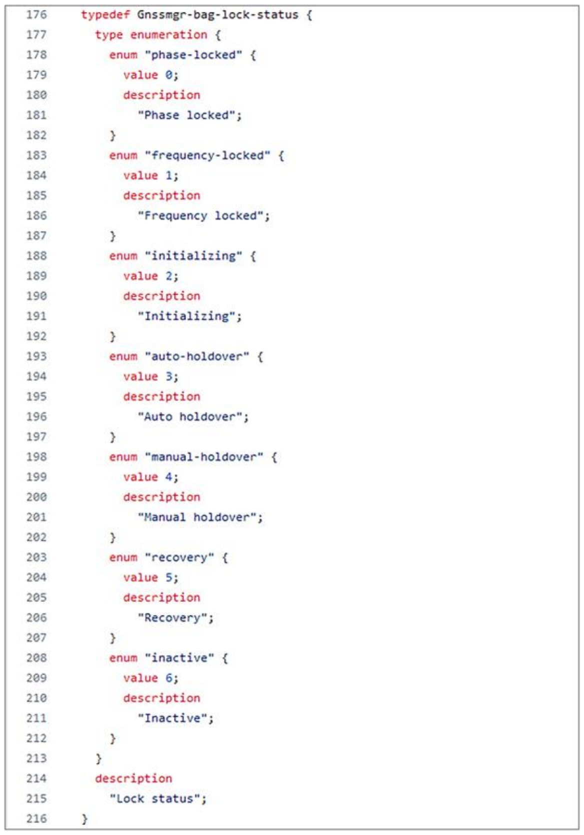
GNSS Mapping

State	Value
phase-locked	0
frequency-locked	1
initializing	2
auto-holdover	3
manual-holdover	4
recovery	5
inactive	6

GNSS RECEIVER LOCK STATUS

Thursday, Feb 16, 03:00
● ('0', 'SDLAS00005C-CS000-CSR001'): **0**

Figure 44.
GNSS Receiver Lock Status of all CSRs



```
typedef Gnssmgr-bag-lock-status {
  type enumeration {
    enum "phase-locked" {
      value 0;
      description
        "Phase locked";
    }
    enum "frequency-locked" {
      value 1;
      description
        "Frequency locked";
    }
    enum "initializing" {
      value 2;
      description
        "Initializing";
    }
    enum "auto-holdover" {
      value 3;
      description
        "Auto holdover";
    }
    enum "manual-holdover" {
      value 4;
      description
        "Manual holdover";
    }
    enum "recovery" {
      value 5;
      description
        "Recovery";
    }
    enum "inactive" {
      value 6;
      description
        "Inactive";
    }
  }
  description
    "Lock status";
}
```

Figure 45.
YANG Definition of GNSS Lock Status

4.6 Composite KPIs

There are Composite KPIs in the network that are either a combination of two or more KPIs or a mathematic derivative of a single KPI. Let us look at the composite KPIs deployed at Dish Network:

1) GRE Tunnel Bundle Interface Ingress Bandwidth Utilization / GRE Tunnel Bundle Interface Egress Bandwidth Utilization

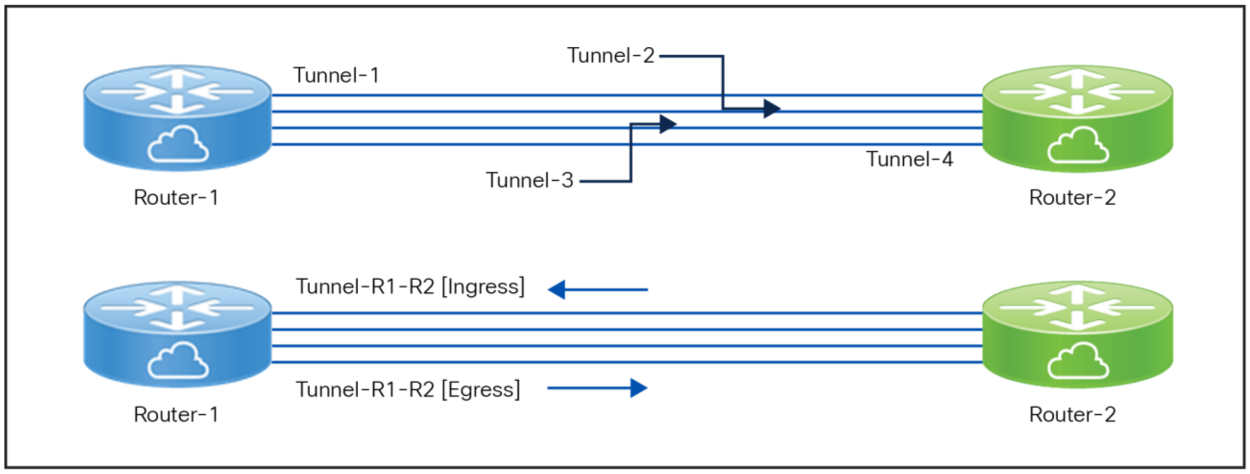
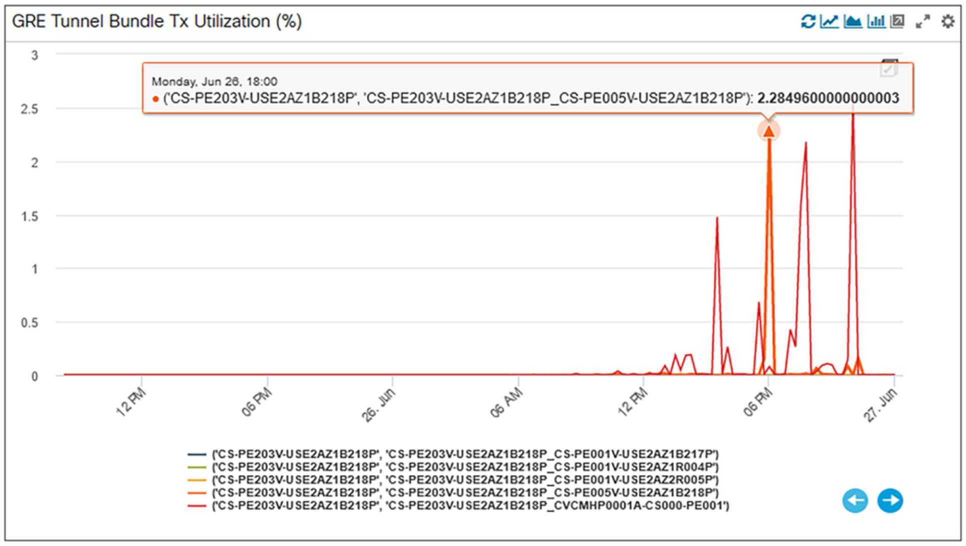


Figure 46.
Tunnel Bundle Interface BW Utilization

As we had a tunnel bandwidth defined between a pair of XRv Cloud Routers, it made more sense to create and monitor a bundled Tunnel Bandwidth Interface Utilization. So, as you can see in the snapshot above, we are monitoring **Tunnel-R1-R2** Interface Bandwidth Utilization for both ingress and egress directions instead of individual tunnels (like Tunnel-1, Tunnel-2 etc.). The Tunnel Bundle Interface Bandwidth Utilization is a logical composite KPI created as a mathematic derivative of the tunnels between two routers (which can be between two and eight in number). The below panel is GRE Tunnel Bundle Egress Utilization for all Tunnel Bundles from a cloud router.


GRE Tunnel Bundle Tx Utilization (%)

Monday, Jun 26, 18:00
● ('CS-PE203V-USE2AZ1B218P', 'CS-PE203V-USE2AZ1B218P_CS-PE005V-USE2AZ1B218P'): **2.2849600000000003**

— ('CS-PE203V-USE2AZ1B218P', 'CS-PE203V-USE2AZ1B218P_CS-PE001V-USE2AZ1B217P')
— ('CS-PE203V-USE2AZ1B218P', 'CS-PE203V-USE2AZ1B218P_CS-PE001V-USE2AZ1R004P')
— ('CS-PE203V-USE2AZ1B218P', 'CS-PE203V-USE2AZ1B218P_CS-PE001V-USE2AZ2R005P')
— ('CS-PE203V-USE2AZ1B218P', 'CS-PE203V-USE2AZ1B218P_CS-PE005V-USE2AZ1B218P')
— ('CS-PE203V-USE2AZ1B218P', 'CS-PE203V-USE2AZ1B218P_CVCMHP0001A-CS000-PE001')

Figure 47.
Tunnel Bundle Egress Utilization

2) Total Interface Error Count is a total of all ingress and egress interface errors and interface packet drops. There can be drops because of MTUs, CRCs, underruns, overruns etc. We are looking at the composite of all those KPIs to derive the health of the Interface Errors on the router.
3) Interface Flaps is another composite KPI defined from the carrier transition data streamed from the router. We subtract the value of the last **carrier transition** KPI data from the present carrier transition KPI data to arrive at the Interface Flaps Composite KPI.

Interface Flaps = Present Carrier Transition Data Value (streamed at time T) – Previous Carrier Transition Data Value (streamed at time [T – 5] mins).

5 Anomaly Detection – Closed Loop Automation

The detection of an anomaly in the network and taking a suitable action is the most critical piece of the entire monitoring puzzle. To be able to detect an anomaly in the network, we need to define thresholds for all the Key Performance Indicators. We can either reuse the thresholds defined in IOS XR code for every KPI, or manually define thresholds based on network objective (role of that KPI in the network) and experience (based on similar KPIs deployed at other service provider networks), or **machine learn** the thresholds and implement it in our anomaly detection process.

5.1 Threshold Defined in IOS XR Code

This snippet is from a cell site router where we look at thresholds of environmental temperature KPIs defined in IOS XR code. For example, we are using MB-Inlet Temp Sensor as one of our KPIs at Dish Network. We can define (in Matrix) four values of threshold for Major Low, Critical Low, Major High, and Critical High. If the data streamed from the router cross this threshold defined in Matrix, we generate alerts (Warning, Critical). An alert is cleared when the KPI values drop down/move up from these thresholds.

```
<router>#show environment temperature
Tue Jun 20 22:51:06.338 UTC

Location    TEMPERATURE                 Value    Crit    Major   Minor     Major         Crit
            Sensor                     (deg C)   (Lo)     (Lo)    (Lo)     (Lo)    (Hi)    (Hi)
0/RP0/CPU0

            X86_PACKAGE_TEMP_SENSOR       33      -40      -25     -10      85      89      91

            X86_CORE_0_TEMP_SENSOR        31      -40      -25     -10      85      89      91

            X86_CORE_1_TEMP_SENSOR        33      -40      -25     -10      85      89      91

            X86_CORE_2_TEMP_SENSOR        31      -40      -25     -10      85      89      91

            X86_CORE_3_TEMP_SENSOR        30      -40      -25     -10      85      89      91

            X86_CORE_4_TEMP_SENSOR        29      -40      -25     -10      85      89      91

            X86_CORE_5_TEMP_SENSOR        29      -40      -25     -10      85      89      91

            X86_CORE_6_TEMP_SENSOR        31      -40      -25     -10      85      89      91

            X86_CORE_7_TEMP_SENSOR        31      -40      -25     -10      85      89      91
```

```
    MB-Inlet Temp Sensor          26       -40      -25      -10      65       70       75
    P1V15_CPU_CORE_TEMP1          29       -40      -25      -10      85       89       91
    P1V0_CPU_UNCORE_TEMP1         32       -40      -25      -10      85       89       91
    P1V15_CPU_VCCRAM_TEMP1        31       -40      -25      -10      85       89       91
    P1V2A_CPUDDR_TEMP1            30       -40      -25      -10      85       89       91
    VP1P0_TEMP1                   33       -40      -25      -10      85       89       91
    P1V05_CPU_SRDS_TEMP1          34       -40      -25      -10      85       89       91
    P3_3V_TEMP1                   39       -40      -25      -10      85       89       91
    P1V0B_QAX_TEMP1               41       -40      -25      -10      97       103      108
    P1V0_QAX_CORE_TEMP1           38       -40      -25      -10      97       103      108
    P1V2B_QAX_TEMP1               34       -40      -25      -10      97       103      108
    MB-Outlet Temp Sensor         28       -40      -25      -10      68       73       78
    MB-CPU Temp Sensor Local      34       -40      -25      -10      85       89       91
    MB-CPU Temp Sensor Remote     33       -40      -25      -10      85       89       91
    MB-QAX Temp Sensor Local      37       -40      -25      -10      97       103      108
    MB-QAX Temp Sensor Remote     44       -40      -25      -10      97       103      108
    MB-QAX In-Die Temp Sensor     41       -40      -25      -10      97       103      108
```

Another example of a KPI threshold defined in IOS XR code is NPU resources. This snapshot is from a cell site router for the NPU Resource FEC (Forwarding Equivalence Class) KPI. The “warning” (80%) and “critical” (95%) thresholds are defined in code. The “OOR” (Out of Resource) flag turns YELLOW or RED based on the type of threshold alert. It is GREEN in this snapshot. We re-use the same thresholds and define our anomalies in Matrix. If our NPU Resource Utilization cross these thresholds, we trigger an alert.

```
RP/0/RP0/CPU0:DADAL00241A-CS000-CSR001#show controllers npu resources fec location
0/RP0/CPU0
Wed Jun 21 16:34:32.478 UTC
HW Resource Information
    Name                            : fec
    Asic Type                       : QAX

NPU-0
OOR Summary
        Estimated Max Entries       : 61440
        Red Threshold               : 95 %
        Yellow Threshold            : 80 %
        OOR State                    : Green
        Bank Info                    : FEC



OFA Table Information
(May not match HW usage)
        ipnhgroup                    : 1414
        ip6nhgroup                   : 50
        edpl                         : 0
        limd                         : 0
        punt                         : 19
        iptunneldecap                : 0
        ipmcroute                    : 1
        ip6mcroute                   : 0
        ipnh                         : 0
        ip6nh                        : 0
        mplsmdtbud                   : 0
        ipvrf                        : 6
        ippbr                        : 0
        redirectvrf                  : 0
        l2protect                    : 0
        l2bridgeport                 : 25

Current Hardware Usage
    Name: fec
        Estimated Max Entries        : 61440
        Total In-Use                 : 1515     (2 %)
        OOR State                    : Green
        Bank Info                    : FEC



       Name: hier_0
           Estimated Max Entries        : 61440
           Total In-Use                 : 1515     (2 %)
           OOR State                    : Green
           Bank Info                    : FEC
```

5.2 Manual Threshold Definition

We have manually defined thresholds for several KPIs based on the overall impact of the KPI on the network (when the values hit threshold). These are defined in Matrix – Our Network Performance Management System. Some examples are mentioned below:

1) CPU Utilization (Critical: 90%, Warning: 75%)

2) Memory Utilization (Critical: 90%, Warning: 75%)
3) Interface Operational Status (NOT Up)
4) Interface Admin Status (NOT Up)
5) Interface Transmit Link Utilization (Critical: 90%, Warning: 75%)
6) Interface Receive Link Utilization (Critical: 90%, Warning: 75%)
7) PTP Interface Line State (NOT Up)
8) PTP Interface Port State (NOT Master)

5.3 AI/ML-Based Threshold Definition

Inbuilt Machine Learning (ML) framework of Matrix with integrated ML algorithms enables you to build Machine Learning capabilities for anomaly detection, predictive analytics, forecasting, and pattern mining. Now why do we need machine learning when we can manually define thresholds? Unfortunately, there are certain KPIs for which we can't define manual thresholds. The thresholds differ between devices and services within the network.

For example, the ISIS routes count is a KPI for all routers in the network. We can't define manual thresholds as the count differ per ISIS process and per router type (CSR/PEs). The only way around this problem is to **machine learn** the routes over a period for a process for a router type and **machine define** the thresholds or outliers using the most suitable algorithm.

Another example is **average latency**. We are using the Internet Protocol Service Level Agreement User Datagram Protocol IP SLA UDP Jitter application to measure average latency from source to destination and vice-versa. We can only define the end-to-end midhaul latency based on the oRAN latency budget and/or latency budget agreed upon with the RAN vendor. What about the latency between the CSR and the PEDC Provider Edge router? For such scenarios, we need to rely on machine learning algorithms to give us the following information:

1) Mean of average latency incurred between CSR and PEDC PE over a period.
2) Outlier or threshold (critical and warning) values for average latency over the same period

5.3.1 ML-Based Use Cases: IP SLA

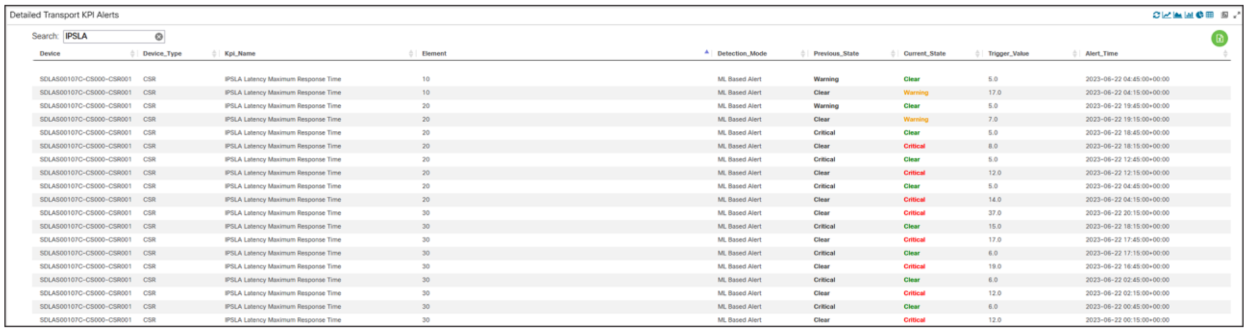
We have implemented the second use case in Matrix. The algorithms available to us to implement this KPI were:

1) K-Means,
2) K-Means 24
3) DBScan
4) OneClass
5) Percentage Change
6) Standard Deviation

We initially started with K-Means, which is an unsupervised clustering algorithm that would divide the data values into clusters of similar values and arrive at a **centroid** from all clusters (in a simplistic world, it is an educated "mean"). The algorithm also sets thresholds (warning, critical) based on intelligent learning of spikes and troughs on the entire data set used for training.

But, upon days of **training our data**, we realized there aren't enough clusters to create effective centroids/means for IP SLA average latency. We eventually switched our algorithm to standard deviation, which seemed like a more realistic match based on the data that was being streamed.

Here is a snapshot of the IPSLA maximum latency detailed KPI alerts (we haven't hit any alerts for average latency). The threshold for the alert's detection were set by the K-Means algorithm. For different elements (10, 20, 30 – which are essentially different links in the network between the CSR and PEs, captured in figs. 47, 48, and 49) you can see alerts getting triggered (critical, warning) and cleared when values go below the **machine-defined** thresholds.



Detailed Transport KPI Alerts

Search: IPSLA

Device	Device_Type	Kpi_Name	Element	Detection_Mode	Previous_State	Current_State	Trigger_Value	Alert_Time
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	10	ML Based Alert	Warning	Clear	5.0	2023-06-22 04:45:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	10	ML Based Alert	Clear	Warning	17.0	2023-06-22 04:15:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	20	ML Based Alert	Warning	Clear	5.0	2023-06-22 19:45:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	20	ML Based Alert	Clear	Warning	7.0	2023-06-22 19:15:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	20	ML Based Alert	Critical	Clear	5.0	2023-06-22 18:45:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	20	ML Based Alert	Clear	Critical	8.0	2023-06-22 18:15:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	20	ML Based Alert	Critical	Clear	5.0	2023-06-22 12:45:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	20	ML Based Alert	Clear	Critical	12.0	2023-06-22 12:15:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	20	ML Based Alert	Critical	Clear	5.0	2023-06-22 04:45:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	20	ML Based Alert	Clear	Critical	14.0	2023-06-22 04:15:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	30	ML Based Alert	Clear	Critical	37.0	2023-06-22 20:15:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	30	ML Based Alert	Critical	Clear	15.0	2023-06-22 18:15:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	30	ML Based Alert	Clear	Critical	17.0	2023-06-22 17:45:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	30	ML Based Alert	Critical	Clear	6.0	2023-06-22 17:15:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	30	ML Based Alert	Clear	Critical	19.0	2023-06-22 16:45:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	30	ML Based Alert	Critical	Clear	6.0	2023-06-22 02:45:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	30	ML Based Alert	Clear	Critical	12.0	2023-06-22 02:15:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	30	ML Based Alert	Critical	Clear	6.0	2023-06-22 00:45:00+00:00
SDLAS00107C-CS000-CSR001	CSR	IPSLA Latency Maximum Response Time	30	ML Based Alert	Clear	Critical	12.0	2023-06-22 00:15:00+00:00

Figure 48.
Detailed IPSLA KPI Alerts

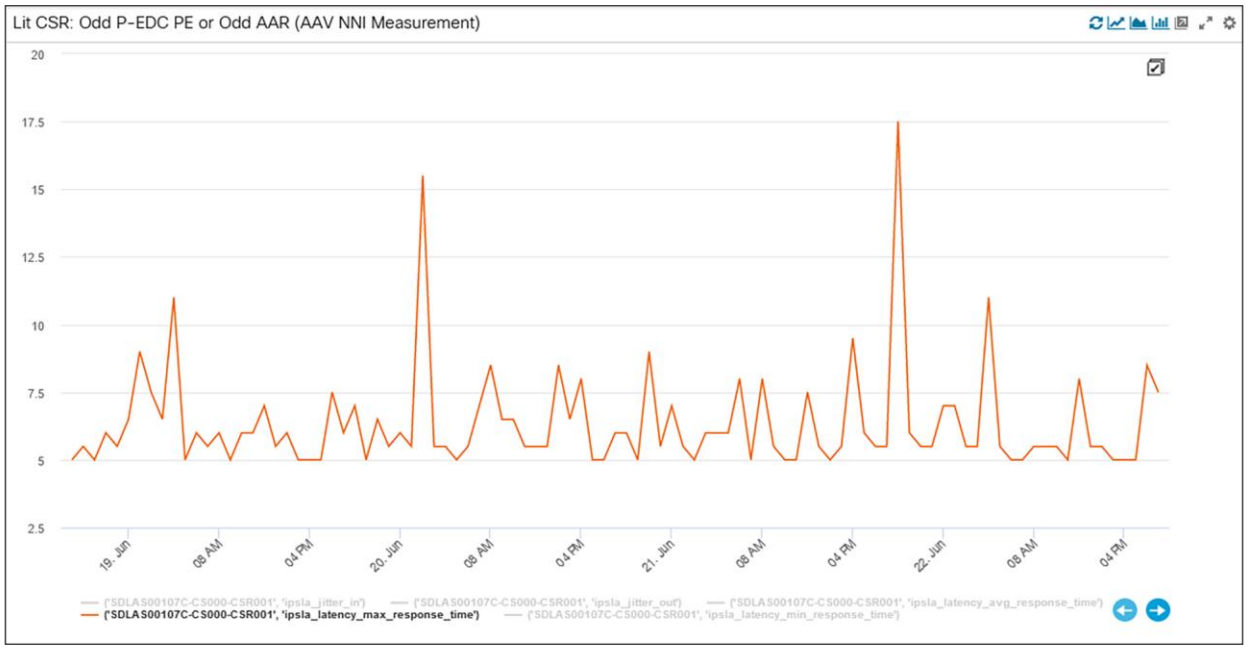


Figure 49.
Element 10 Max Latency

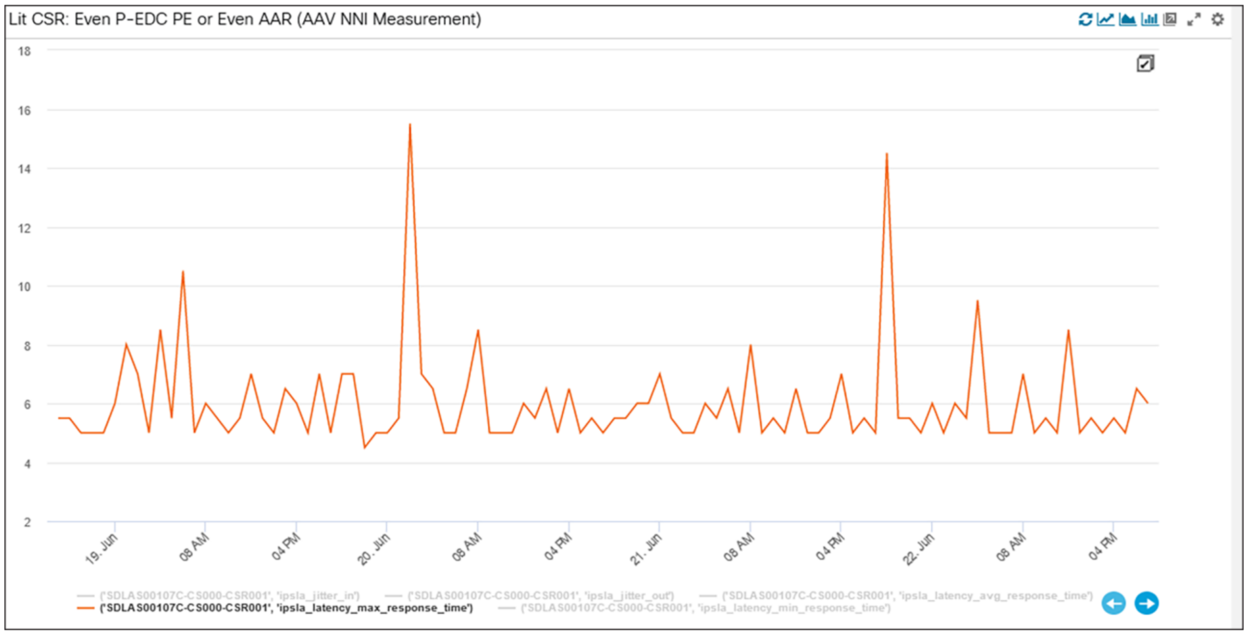


Figure 50.
Element 20 Max Latency

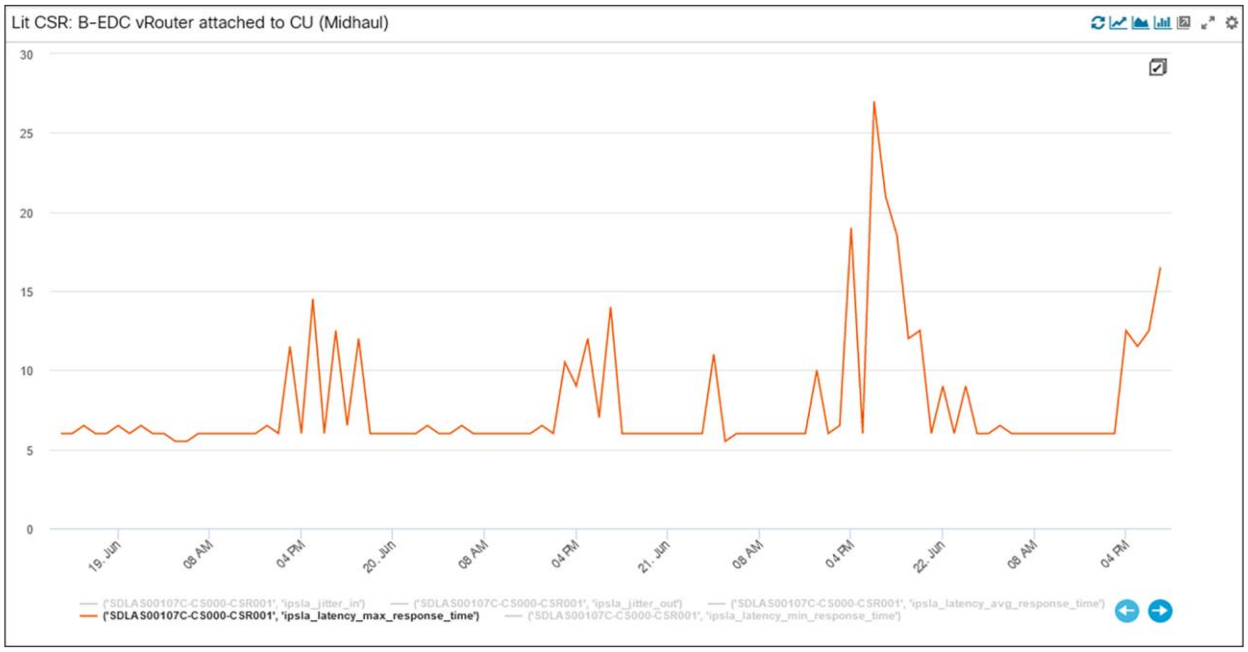


Figure 51.
Element 30 Max Latency

We have a KPI Alert Workbench in Matrix where you can track alerts and data over time. Here is a snapshot with the KPI trending along with machine learned warning, critical, and "good" values using the K-Means clustering algorithm.

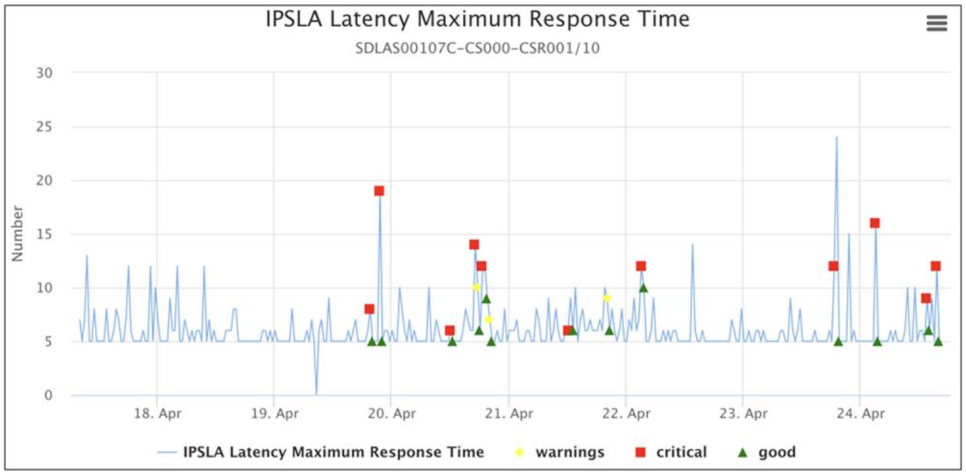
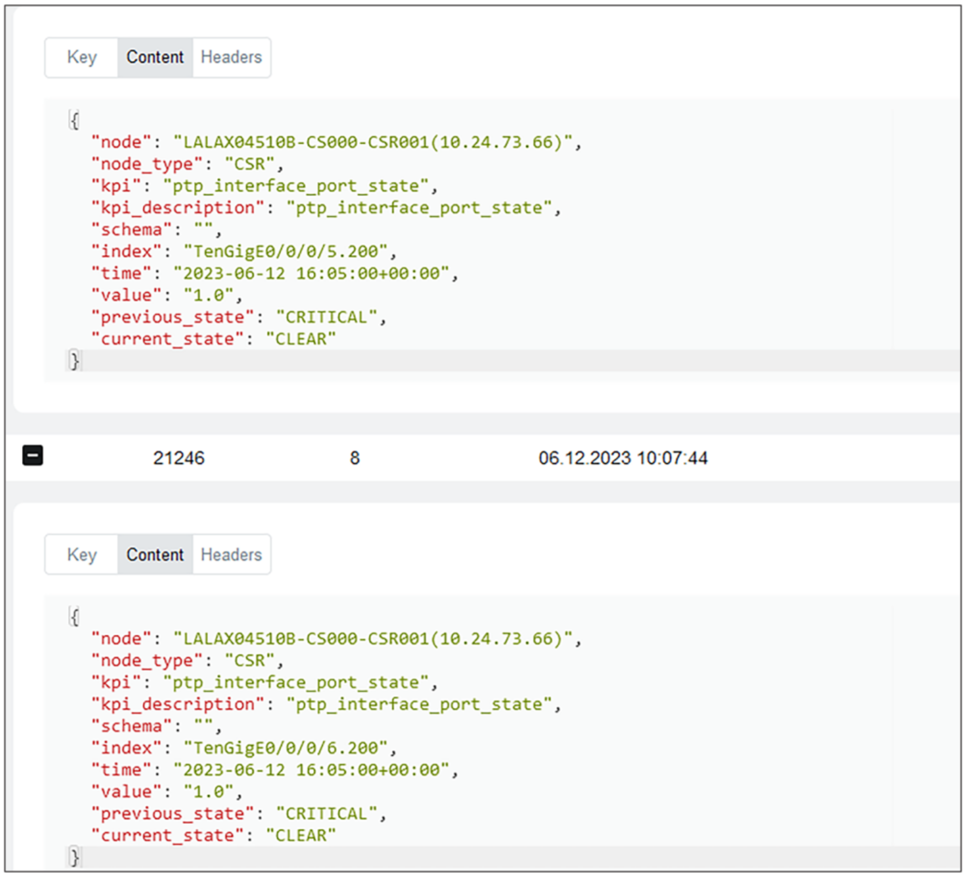


Figure 52.
KPI Alert Workbench for IP SLA

5.4 Exporting Anomaly Detection to Fault Management Application

We have incorporated **fault management** with the VIA-AIOPS platform. Detecting faults or anomalies is not the end of the monitoring solution; we need to alert stakeholders who will act on such faults in the network.

These alerts or anomaly detection is published back to the Kafka Message Bus for VIA to ingest them. The below shows the alerts in the Message Bus for consumers to ingest.



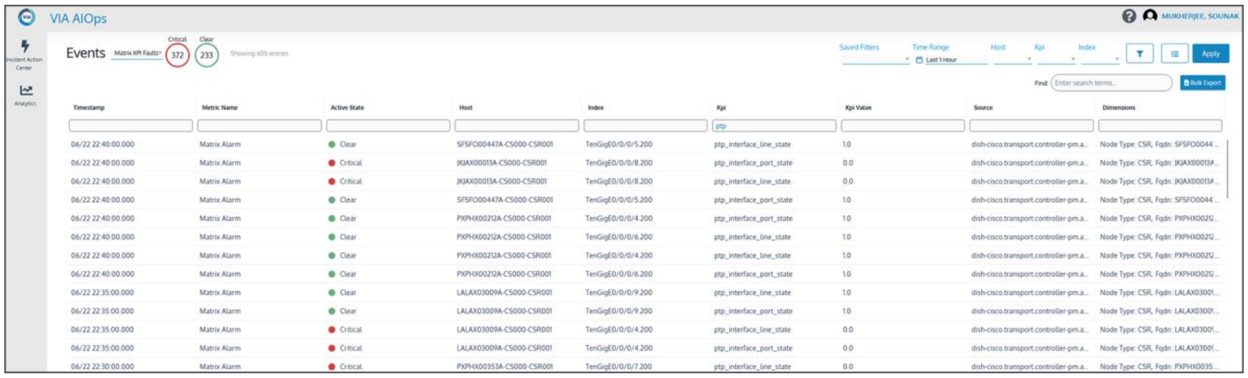
```
{
  "node": "LALAX04510B-CS000-CSR001(10.24.73.66)",
  "node_type": "CSR",
  "kpi": "ptp_interface_port_state",
  "kpi_description": "ptp_interface_port_state",
  "schema": "",
  "index": "TenGigE0/0/0/5.200",
  "time": "2023-06-12 16:05:00+00:00",
  "value": "1.0",
  "previous_state": "CRITICAL",
  "current_state": "CLEAR"
}
```

21246 8 06.12.2023 10:07:44

```
{
  "node": "LALAX04510B-CS000-CSR001(10.24.73.66)",
  "node_type": "CSR",
  "kpi": "ptp_interface_port_state",
  "kpi_description": "ptp_interface_port_state",
  "schema": "",
  "index": "TenGigE0/0/0/6.200",
  "time": "2023-06-12 16:05:00+00:00",
  "value": "1.0",
  "previous_state": "CRITICAL",
  "current_state": "CLEAR"
}
```

Figure 53.
PTP Alerts in Kafka Message Bus

Once the alerts are processed and correlated in VIA (with other similar alerts from the same router), **incidents** can be created and assigned to a Network Operations Engineer for the purpose of remediation. Figure 54 shows the above PTP Alerts ingested by VIA from the Message Bus.



Timestamp	Metric Name	Active State	Host	Index	Kpi	Kpi Value	Source	Dimensions
					ptp			
06/22 22:40:00.000	Matrix Alarm	● Clear	SFSFO00447A-CS000-CSR001	TenGigE0/0/0/5.200	ptp_interface_line_state	1.0	dish-cisco.transport.controller-pm.a...	Node Type: CSR, Fqdn: SFSFO0044 ...
06/22 22:40:00.000	Matrix Alarm	● Critical	JKJAX00013A-CS000-CSR001	TenGigE0/0/0/8.200	ptp_interface_port_state	0.0	dish-cisco.transport.controller-pm.a...	Node Type: CSR, Fqdn: JKJAX00013A...
06/22 22:40:00.000	Matrix Alarm	● Critical	JKJAX00013A-CS000-CSR001	TenGigE0/0/0/8.200	ptp_interface_line_state	0.0	dish-cisco.transport.controller-pm.a...	Node Type: CSR, Fqdn: JKJAX00013A...
06/22 22:40:00.000	Matrix Alarm	● Clear	SFSFO00447A-CS000-CSR001	TenGigE0/0/0/5.200	ptp_interface_port_state	1.0	dish-cisco.transport.controller-pm.a...	Node Type: CSR, Fqdn: SFSFO0044 ...
06/22 22:40:00.000	Matrix Alarm	● Clear	PXPHX00212A-CS000-CSR001	TenGigE0/0/0/4.200	ptp_interface_port_state	1.0	dish-cisco.transport.controller-pm.a...	Node Type: CSR, Fqdn: PXPHX00212...
06/22 22:40:00.000	Matrix Alarm	● Clear	PXPHX00212A-CS000-CSR001	TenGigE0/0/0/6.200	ptp_interface_line_state	1.0	dish-cisco.transport.controller-pm.a...	Node Type: CSR, Fqdn: PXPHX00212...
06/22 22:40:00.000	Matrix Alarm	● Clear	PXPHX00212A-CS000-CSR001	TenGigE0/0/0/4.200	ptp_interface_line_state	1.0	dish-cisco.transport.controller-pm.a...	Node Type: CSR, Fqdn: PXPHX00212...
06/22 22:40:00.000	Matrix Alarm	● Clear	PXPHX00212A-CS000-CSR001	TenGigE0/0/0/6.200	ptp_interface_port_state	1.0	dish-cisco.transport.controller-pm.a...	Node Type: CSR, Fqdn: PXPHX00212...
06/22 22:35:00.000	Matrix Alarm	● Clear	LALAX03009A-CS000-CSR001	TenGigE0/0/0/9.200	ptp_interface_line_state	1.0	dish-cisco.transport.controller-pm.a...	Node Type: CSR, Fqdn: LALAX03001...
06/22 22:35:00.000	Matrix Alarm	● Clear	LALAX03009A-CS000-CSR001	TenGigE0/0/0/9.200	ptp_interface_port_state	1.0	dish-cisco.transport.controller-pm.a...	Node Type: CSR, Fqdn: LALAX03001...
06/22 22:35:00.000	Matrix Alarm	● Critical	LALAX03009A-CS000-CSR001	TenGigE0/0/0/4.200	ptp_interface_line_state	0.0	dish-cisco.transport.controller-pm.a...	Node Type: CSR, Fqdn: LALAX03001...
06/22 22:35:00.000	Matrix Alarm	● Critical	LALAX03009A-CS000-CSR001	TenGigE0/0/0/4.200	ptp_interface_port_state	0.0	dish-cisco.transport.controller-pm.a...	Node Type: CSR, Fqdn: LALAX03001...
06/22 22:30:00.000	Matrix Alarm	● Critical	PXPHX00353A-CS000-CSR001	TenGigE0/0/0/7.200	ptp_interface_line_state	0.0	dish-cisco.transport.controller-pm.a...	Node Type: CSR, Fqdn: PXPHX0035...

Figure 54.
KPI Alerts Events in VIA

5.5 Remediation Using Closed Loop Automation

Finally, here we are, at the last stop, the final piece of the monitoring puzzle. We are creating alerts for any critical deviation from the expected values for a KPI, but we are not (yet) remediating the problem through automation. We are publishing that information to network operations and waiting for them to take manual action. Now, to **close the loop** through automation, we need to take this solution a step further, and take automated remediation actions.

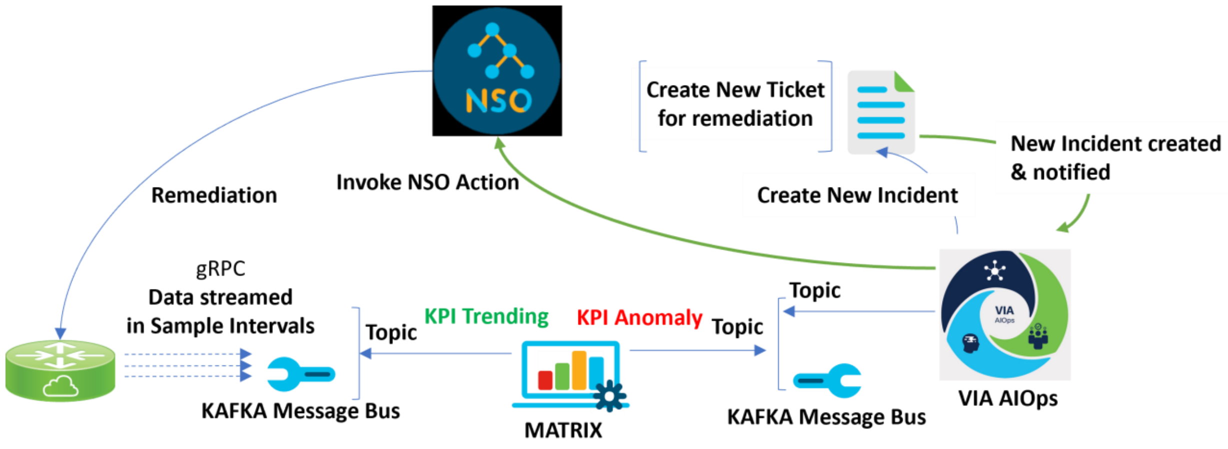


Figure 55.
Closed Loop Automation Life Cycle

Let us consider an example to understand the closed loop automaton life cycle demonstrated above:

1) The router is streaming data for Timing KPI to the Message Bus (via CDG).
2) Matrix is pulling that data from the concerned topic and **observing/trending** it.
3) Matrix has also defined alerts for this KPI (Warning/Critical) based on manually defined thresholds.
4) Once the KPI value crosses a threshold (for example: GNSS KPI Alert is triggered because of an anomaly), it creates an alert in Matrix.
5) The alert is published into a Kafka Topic, which gets pulled by VIA to create an incident.
6) The incident results in a ticket for the purpose of remediation.
7) It also triggers a Closed Loop Automation workflow wherein it invokes an NSO action to remediate the problem on the router.
8) NSO (for this example) restarts the GNSS Survey on the cell site router (or reboots the router) by running specific commands on the router.
9) Once the problem is remediated, the new data (at the defined sample interval) streamed towards Matrix shows that the KPI Value has come back to the **“expected”** one.
10) The associated applications now close the alert and the corresponding incident.

6 Conclusion – What is the future of observability on a Hybrid Cloud?

The goal of every network operator is to build a **utopic** network which is low touch, seamlessly running, self-detecting (problems), and self-healing. Have we arrived there yet? I don’t think so, we have a mountain to climb but we have embarked on that journey already.

If we can build the intelligence to run a closed loop automated network that can self-detect and self-remediate for at least half the problems, we have done a fairly good job. But is that the end goal? Which KPIs do we need to define for our network? What data do we need to stream for specific device types? Do we stream data all the time or only when there is a significant change? Who defines that change (thresholds)?

Maybe we don’t have the answers to every question there, but **AI-Driven Telemetry** being deployed on Cisco routers is a great starting point. ADT (as it is called) leverages Machine Learning and Artificial Intelligence to detect and describe important state changes on the router, and export only the relevant data using telemetry. You can find more information in this article.

Your AI journey starts today.

Glossary

KPI – Key Performance Indicator

CSR – Cell Site Router

LIT CSR – LIT CSRs use fiber optics that are already in use by other fiber vendors.

Dark CSR – Dark CSRs use fiber optics that were currently not in use.

LDC – Local Data Center

BEDC – Breakout Edge Data Center

PEDC – Provider Edge Data Center

AI - Artificial Intelligence

NPU – Network Processing Unit

CPU – Central Processing Unit

BGP – Border Gateway Protocol

AWS - Amazon Web Services

IEFT - Internet Engineering Task Force

MDT - Model-Driven Telemetry

RPC - Remote Procedure Call

RAN - Radio Access Network

oRAN - Open RAN

CLI – Command-Line Interface

SDN – Software-Defined Networking

SNMP - Simple Network Management Protocol

ISIS - Intermediate System to Intermediate System

GRE - Generic Routing Encapsulation

QoS - Quality of Service

PTP - Precision Timing Protocol

SyncE - Synchronous Ethernet

GM / T-GM - Telecom Grand Master

GNSS - Global Navigation Satellite System

BFD - Bidirectional Forwarding Detection

RU - gNB Radio Unit

CU - gNB Control Unit

DU - gNB Distributed Unit

IP SLA - Internet Protocol Service Level Agreement

UDP - User Datagram Protocol

References

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- ADT, as implemented on ASR9K
- VIA Platform for Cisco Network Automation
- DISH Networks Deployment Architecture on AWS Cloud
- IOS XR YANG Models
- Apache Kafka Application

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