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Service Assurance for Intent-based Networking Architecture
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Abstract

This document describes an architecture for Service Assurance for Intent-based Networking (SAIN). This architecture aims at assuring that service instances are correctly running. As services rely on multiple sub-services by the underlying network devices, getting the assurance of a healthy service is only possible with a holistic view of network devices. This architecture not only helps to correlate the service degradation with the network root cause but also the impacted services when a network component fails or degrades.

Status of This Memo

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1. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP

14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

SAIN Agent: Component that communicates with a device, a set of devices, or another agent to build an expression graph from a received assurance graph and perform the corresponding computation.

Assurance Graph: DAG representing the assurance case for one or several service instances. The nodes (also known as vertices in the context of DAG) are the service instances themselves and the subservices, the edges indicate a dependency relations.

SAIN collector: Component that fetches or receives the computer-consumable output of the agent(s) and displays it in a user friendly form or process it locally.

DAG: Directed Acyclic Graph.

ECMP: Equal Cost Multiple Paths

Expression Graph: Generic term for a DAG representing a computation in SAIN. More specific terms are:

o Subservice Expressions: expression graph representing all the computations to execute for a subservice.

o Service Expressions: expression graph representing all the computations to execute for a service instance, i.e. including the computations for all dependent subservices.

o Global Computation Graph: expression graph representing all the computations to execute for all services instances (i.e. all computations performed).

Dependency: The directed relationship between subservice instances in the assurance graph.

Informational Dependency: Type of dependency whose score does not impact the score of its parent subservice or service instance(s) in the assurance graph. However, the symptoms should be taken into account in the parent service instance or subservice instance(s), for informational reasons.

Impacting Dependency: Type of dependency whose score impacts the score of its parent subservice or service instance(s) in the assurance graph. The symptoms are taken into account in the parent service instance or subservice instance(s), as the impacting reasons.

Metric: Information retrieved from a network device.

Metric Engine: Maps metrics to a list of candidate metric implementations depending on the target model.

Metric Implementation: Actual way of retrieving a metric from a device.

Network Service YANG Module: describes the characteristics of service, as agreed upon with consumers of that service [RFC8199].

Service Instance: A specific instance of a service.

Service configuration orchestrator: Quoting RFC8199, "Network Service YANG Modules describe the characteristics of a service, as agreed upon with consumers of that service. That is, a service module does not expose the detailed configuration parameters of all participating network elements and features but describes an abstract model that allows instances of the service to be decomposed into instance data according to the Network Element YANG Modules of the participating network elements. The service-to-element decomposition is a separate process; the details depend on how the network operator chooses to realize the service. For the purpose of this document, the term "orchestrator" is used to describe a system implementing such a process."

SAIN Orchestrator: Component of SAIN in charge of fetching the configuration specific to each service instance and converting it into an assurance graph.

Health status: Score and symptoms indicating whether a service instance or a subservice is healthy. A non-maximal score MUST always be explained by one or more symptoms.

Health score: Integer ranging from 0 to 100 indicating the health of a subservice. A score of 0 means that the subservice is broken, a score of 100 means that the subservice is perfectly operational.

Subservice: Part of an assurance graph that assures a specific feature or subpart of the network system.

Symptom: Reason explaining why a service instance or a subservice is not completely healthy.

2. Introduction

Network Service YANG Modules [RFC8199] describe the configuration, state data, operations, and notifications of abstract representations of services implemented on one or multiple network elements.

Quoting RFC8199: "Network Service YANG Modules describe the characteristics of a service, as agreed upon with consumers of that service. That is, a service module does not expose the detailed configuration parameters of all participating network elements and features but describes an abstract model that allows instances of the service to be decomposed into instance data according to the Network Element YANG Modules of the participating network elements. The service-to-element decomposition is a separate process; the details depend on how the network operator chooses to realize the service. For the purpose of this document, the term "orchestrator" is used to describe a system implementing such a process."

In other words, service configuration orchestrators deploy Network Service YANG Modules through the configuration of Network Element YANG Modules. Network configuration is based on those YANG data models, with protocol/encoding such as NETCONF/XML [RFC6241] , RESTCONF/JSON [RFC8040], gNMI/gRPC/protobuf, etc. Knowing that a configuration is applied doesn't imply that the service is running correctly (for example the service might be degraded because of a failure in the network), the network operator must monitor the service operational data at the same time as the configuration. The industry has been standardizing on telemetry to push network element performance information.

A network administrator needs to monitor her network and services as a whole, independently of the use cases or the management protocols. With different protocols come different data models, and different ways to model the same type of information. When network administrators deal with multiple protocols, the network management must perform the difficult and time-consuming job of mapping data models: the model used for configuration with the model used for monitoring. This problem is compounded by a large, disparate set of data sources (MIB modules, YANG models [RFC7950], IPFIX information elements [RFC7011], syslog plain text [RFC3164], TACACS+ [I-D.ietf-opsawg-tacacs], RADIUS [RFC2865], etc.). In order to avoid this data model mapping, the industry converged on model-driven telemetry to stream the service operational data, reusing the YANG models used for configuration. Model-driven telemetry greatly facilitates the notion of closed-loop automation whereby events from the network drive remediation changes back into the network.

However, it proves difficult for network operators to correlate the service degradation with the network root cause. For example, why does my L3VPN fail to connect? Why is this specific service slow? The reverse, i.e. which services are impacted when a network component fails or degrades, is even more interesting for the operators. For example, which service(s) is(are) impacted when this specific optic dBM begins to degrade? Which application is impacted by this ECMP imbalance? Is that issue actually impacting any other customers?

Intent-based approaches are often declarative, starting from a statement of the "The service works correctly" and trying to enforce it. Such approaches are mainly suited for greenfield deployments.

Instead of approaching intent from a declarative way, this framework focuses on already defined services and tries to infer the meaning of "The service works correctly". To do so, the framework works from an assurance graph, deduced from the service definition and from the network configuration. This assurance graph is decomposed into components, which are then assured independently. The root of the assurance graph represents the service to assure, and its children represent components identified as its direct dependencies; each component can have dependencies as well. The SAIN architecture maintains the correct assurance graph when services are modified or when the network conditions change.

When a service is degraded, the framework will highlight where in the assurance service graph to look, as opposed to going hop by hop to troubleshoot the issue. Not only can this framework help to correlate service degradation with network root cause/symptoms, but it can deduce from the assurance graph the number and type of services impacted by a component degradation/failure. This added value informs the operational team where to focus its attention for maximum return.

This architecture provides the building blocks to assure both physical and virtual entities and is flexible with respect to services and subservices, of (distributed) graphs, and of components (Section 3.8).

3. Architecture

SAIN aims at assuring that service instances are correctly running. The goal of SAIN is to assure that service instances are operating correctly and if not, to pinpoint what is wrong. More precisely, SAIN computes a score for each service instance and outputs symptoms explaining that score, especially why the score is not maximal. The score augmented with the symptoms is called the health status.

The SAIN architecture is a generic architecture, applicable to multiple environments. Obviously wireline but also wireless, including 5G, virtual infrastructure manager (VIM), and even virtual functions. Thanks to the distributed graph design principle, graphs from different environments/orchestrator can be combined together.

As an example of a service, let us consider a point-to-point L2VPN connection (i.e. pseudowire). Such a service would take as parameters the two ends of the connection (device, interface or subinterface, and address of the other end) and configure both devices (and maybe more) so that a L2VPN connection is established between the two devices. Examples of symptoms might be "Interface has high error rate" or "Interface flapping", or "Device almost out of memory".

To compute the health status of such as service, the service is decomposed into an assurance graph formed by subservices linked through dependencies. Each subservice is then turned into an expression graph that details how to fetch metrics from the devices and compute the health status of the subservice. The subservice expressions are combined according to the dependencies between the subservices in order to obtain the expression graph which computes the health status of the service.

The overall architecture of our solution is presented in Figure 1. Based on the service configuration, the SAIN orchestrator deduces the assurance graph. It then sends to the SAIN agents the assurance graph along some other configuration options. The SAIN agents are responsible for building the expression graph and computing the health statuses in a distributed manner. The collector is in charge of collecting and displaying the current inferred health status of the service instances and subservices. Finally, the automation loop is closed by having the SAIN Collector providing feedback to the network orchestrator.

```
          +-----------------+
          | Service         |
          | Configuration   |<--------------------+
          | Orchestrator    |                     |
          +-----------------+                     |
             |            |                       |
             |            | Network               |
             |            | Service               | Feedback
             |            | Instance              | Loop
             |            | Configuration         |
             |            |                       |
             |            V                       |
             |        +-----------------+       +-------------------+
             |        | SAIN            |       | SAIN              |
             |        | Orchestrator    |       | Collector         |
             |        +-----------------+       +-------------------+
             |            |                        ^
             |            | Configuration          | Health Status
             |            | (assurance graph)      | (Score + Symptoms)
             |            V                        | Streamed
             |     +-------------------+           | via Telemetry
             |     |+-------------------+          |
             |     ||+-------------------+         |
             |     +|| SAIN              |---------+
             |      +| agent             |
             |       +-------------------+
             |               ^ ^ ^
             |               | | |
             |               | | |  Metric Collection
             V               V V V
         +-------------------------------------------------------------+
         | Monitored Entities                                          |
         |                                                             |
         +-------------------------------------------------------------+
```

Figure 1: SAIN Architecture

In order to produce the score assigned to a service instance, the architecture performs the following tasks:

o Analyze the configuration pushed to the network device(s) for configuring the service instance and decide: which information is needed from the device(s), such a piece of information being called a metric, which operations to apply to the metrics for computing the health status.

- Stream (via telemetry [RFC8641]) operational and config metric values when possible, else continuously poll.

- Continuously compute the health status of the service instances, based on the metric values.

3.1. Decomposing a Service Instance Configuration into an Assurance Graph

In order to structure the assurance of a service instance, the service instance is decomposed into so-called subservice instances. Each subservice instance focuses on a specific feature or subpart of the network system.

The decomposition into subservices is an important function of this architecture, for the following reasons.

- TThe result of this decomposition provides a relational picture of a service instance, that can be represented as a graph (called assurance graph) to the operator.

- Subservices provide a scope for particular expertise and thereby enable contribution from external experts. For instance, the subservice dealing with the optics health should be reviewed and extended by an expert in optical interfaces.

- Subservices that are common to several service instances are reused for reducing the amount of computation needed.

The assurance graph of a service instance is a DAG representing the structure of the assurance case for the service instance. The nodes of this graph are service instances or subservice instances. Each edge of this graph indicates a dependency between the two nodes at its extremities: the service or subservice at the source of the edge depends on the service or subservice at the destination of the edge.

Figure 2 depicts a simplistic example of the assurance graph for a tunnel service. The node at the top is the service instance, the nodes below are its dependencies. In the example, the tunnel service instance depends on the peer1 and peer2 tunnel interfaces, which in turn depend on the respective physical interfaces, which finally depend on the respective peer1 and peer2 devices. The tunnel service instance also depends on the IP connectivity that depends on the IS-IS routing protocol.

```
                             +------------------+
                             | Tunnel           |
                             | Service Instance |
                             +-----------------+
                                       |
                   +-------------------+-------------------+
                   |                   |                   |
            +-------------+     +-------------+     +--------------+
            | Peer1       |     | Peer2       |     | IP           |
            | Tunnel      |     | Tunnel      |     | Connectivity |
            | Interface   |     | Interface   |     |              |
            +-------------+     +-------------+     +--------------}
                   |                   |                  |
            +-------------+     +-------------+     +-------------+
            | Peer1       |     | Peer2       |     | IS-IS       |
            | Physical    |     | Physical    |     | Routing     |
            | Interface   |     | Interface   |     | Protocol    |
            +-------------+     +-------------+     +-------------+
                   |                   |
            +-------------+     +-------------+
            |             |     |             |
            | Peer1       |     | Peer2       |
            | Device      |     | Device      |
            +-------------+     +-------------+
```

Figure 2: Assurance Graph Example

Depicting the assurance graph helps the operator to understand (and assert) the decomposition. The assurance graph shall be maintained during normal operation with addition, modification and removal of service instances. A change in the network configuration or topology shall be reflected in the assurance graph. As a first example, a change of routing protocol from IS-IS to OSPF would change the assurance graph accordingly. As a second example, assuming that ECMP is in place for the source router for that specific tunnel; in that case, multiple interfaces must now be monitored, on top of the monitoring the ECMP health itself.

3.2. **Intent and Assurance Graph**

The SAIN orchestrator analyzes the configuration of a service instance to:

- o Try to capture the intent of the service instance, i.e. what is the service instance trying to achieve,

- o Decompose the service instance into subservices representing the network features on which the service instance relies.

The SAIN orchestrator must be able to analyze configuration from various devices and produce the assurance graph.

To schematize what a SAIN orchestrator does, assume that the configuration for a service instance touches 2 devices and configure on each device a virtual tunnel interface. Then:

- o Capturing the intent would start by detecting that the service instance is actually a tunnel between the two devices, and stating that this tunnel must be functional. This is the current state of SAIN, however it does not completely capture the intent which might additionally include, for instance, on the latency and bandwidth requirements of this tunnel.

- o Decomposing the service instance into subservices would result in the assurance graph depicted in Figure 2, for instance.

In order for SAIN to be applied, the configuration necessary for each service instance should be identifiable and thus should come from a "service-aware" source. While the Figure 1 makes a distinction between the SAIN orchestrator and a different component providing the service instance configuration, in practice those two components are mostly likely combined. The internals of the orchestrator are currently out of scope of this document.

3.3. Subservices

A subservice corresponds to subpart or a feature of the network system that is needed for a service instance to function properly. In the context of SAIN, subservice is actually a shortcut for subservice assurance, that is the method for assuring that a subservice behaves correctly.

Subservices, just as with services, have high-level parameters that specify the type and specific instance to be assured. For example, assuring a device requires the specific deviceId as parameter. For example, assuring an interface requires the specific combination of deviceId and interfaceId.

A subservice is also characterized by a list of metrics to fetch and a list of computations to apply to these metrics in order to infer a health status.

3.4. Building the Expression Graph from the Assurance Graph

From the assurance graph is derived a so-called global computation graph. First, each subservice instance is transformed into a set of subservice expressions that take metrics and constants as input (i.e.

sources of the DAG) and produce the status of the subservice, based on some heuristics. Then for each service instance, the service expressions are constructed by combining the subservice expressions of its dependencies. The way service expressions are combined depends on the dependency types (impacting or informational). Finally, the global computation graph is built by combining the service expressions. In other words, the global computation graph encodes all the operations needed to produce health statuses from the collected metrics.

Subservices shall be device independent. To justify this, let's consider the interface operational status. Depending on the device capabilities, this status can be collected by an industry-accepted YANG module (IETF, Openconfig), by a vendor-specific YANG module, or even by a MIB module. If the subservice was dependent on the mechanism to collect the operational status, then we would need multiple subservice definitions in order to support all different mechanisms. This also implies that, while waiting for all the metrics to be available via standard YANG modules, SAIN agents might have to retrieve metric values via non-standard YANG models, via MIB modules, Command Line Interface (CLI), etc., effectively implementing a normalization layer between data models and information models.

In order to keep subservices independent from metric collection method, or, expressed differently, to support multiple combinations of platforms, OSes, and even vendors, the framework introduces the concept of "metric engine". The metric engine maps each device-independent metric used in the subservices to a list of device-specific metric implementations that precisely define how to fetch values for that metric. The mapping is parameterized by the characteristics (model, OS version, etc.) of the device from which the metrics are fetched.

3.5. Building the Expression from a Subservice

Additionally, to the list of metrics, each subservice defines a list of expressions to apply on the metrics in order to compute the health status of the subservice. The definition or the standardization of those expressions (also known as heuristic) is currently out of scope of this standardization.

3.6. Open Interfaces with YANG Modules

The interfaces between the architecture components are open thanks to the YANG modules specified in YANG Modules for Service Assurance [I-D.claise-opsawg-service-assurance-yang]; they specify objects for assuring network services based on their decomposition into so-called subservices, according to the SAIN architecture.

This module is intended for the following use cases:

- o Assurance graph configuration:

   * Subservices: configure a set of subservices to assure, by specifying their types and parameters.

   * Dependencies: configure the dependencies between the subservices, along with their types.

- o Assurance telemetry: export the health status of the subservices, along with the observed symptoms.

3.7. Handling Maintenance Windows

Whenever network components are under maintenance, the operator want to inhibit the emission of symptoms from those components. A typical use case is device maintenance, during which the device is not supposed to be operational. As such, symptoms related to the device health should be ignored, as well as symptoms related to the device-specific subservices, such as the interfaces, as their state changes is probably the consequence of the maintenance.

To configure network components as "under maintenance" in the SAIN architecture, the ietf-service-assurance model proposed in [I-D.claise-opsawg-service-assurance-yang] specifies an "under-maintenance" flag per service or subservice instance. When this flag is set and only when this flag is set, the companion field "maintenance-contact" must be set to a string that identifies the person or process who requested the maintenance. Any symptom produced by a service or subservice under maintenance, or by one of its dependencies MUST NOT be be reported. A service or subservice under maintenance MAY propagate a symptom "Under Maintenance" towards services or subservices that depend on it.

We illustrate this mechanism on three independent examples based on the assurance graph depicted in Figure 2:

- o Device maintenance, for instance upgrading the device OS. The operator sets the "under-maintenance" flag for the subservice "Peer1" device. This inhibits the emission of symptoms from "Peer1 Physical Interface", "Peer1 Tunnel Interface" and "Tunnel Service Instance". All other subservices are unaffected.

- o Interface maintenance, for instance replacing a broken optic. The operator sets the "under-maintenance" flag for the subservice "Peer1 Physical Interface". This inhibits the emission of

symptoms from "Peer 1 Tunnel Interface" and "Tunnel Service Instance". All other subservices are unaffected.

- Routing protocol maintenance, for instance modifying parameters or redistribution. The operator sets the "under-maintenance" flag for the subservice "IS-IS Routing Protocol". This inhibits the emission of symptoms from "IP connectivity" and "Tunnel Service Instance". All other subservices are unaffected.

3.8. Flexible Architecture

The SAIN architecture is flexible in terms of components. While the SAIN architecture in Figure 1 makes a distinction between two components, the SAIN configuration orchestrator and the SAIN orchestrator, in practice those two components are mostly likely combined. Similarly, the SAIN agents are displayed in Figure 1 as being separate components. Practically, the SAIN agents could be either independent components or directly integrated in monitored entities. A practical example is an agent in a router.

The SAIN architecture is also flexible in terms of services and subservices. Most examples in this document deal with the notion of Network Service YANG modules, with well known service such as L2VPN or tunnels. However, the concepts of services is general enough to cross into different domains. One of them is the domain of service management on network elements, with also requires its own assurance. Examples includes a DHCP server on a linux server, a data plane, an IPFIX export, etc. The notion of "service" is generic in this architecture. Indeed, a configured service can itself be a service for someone else. Exactly like an DHCP server/ data plane/IPFIX export can be considered as services for a device, exactly like an routing instance can be considered as a service for a L3VPN, exactly like a tunnel can considered as a service for an application in the cloud. The assurance graph is created to be flexible and open, regardless of the subservice types, locations, or domains.

The SAIN architecture is also flexible in terms of distributed graphs. As shown in Figure 1, our architecture comprises several agents. Each agent is responsible for handling a subgraph of the assurance graph. The collector is responsible for fetching the subgraphs from the different agents and gluing them together. As an example, in the graph from Figure 2, the subservices relative to Peer 1 might be handled by a different agent than the subservices relative to Peer 2 and the Connectivity and IS-IS subservices might be handled by yet another agent. The agents will export their partial graph and the collector will stitch them together as dependencies of the service instance.

And finally, the SAIN architecture is flexible in terms of what it monitors. Most, if not all examples, in this document refer to physical components but this is not a constrain. Indeed, the assurance of virtual components would follow the same principles and an assurance graph composed of virtualized components (or a mix of virtualized and physical ones) is well possible within this architecture.

3.9. Timing

The SAIN architecture requires the Network Time Protocol (NTP) [RFC5905] between all elements: monitored entities, SAIN agents, Service Configuration Orchesttrator, the SAIN Collector, as well as the SAIN Orchestrator. This garantees the correlations of all symptoms in the system, correlated with the right assurance graph version.

The SAIN agent might have to remove some symptoms for specific subservice symptoms, because there are outdated and not relevant any longer, or simply because the SAIN agent needs to free up some space. Regardless of the reason, it's important for a SAIN collector (re-)connecting to a SAIN agent to understand the effect of this garbage collection. Therefore, the SAIN agent contains a YANG object specifying the date and time at which the symptoms history starts for the subservice instances.

3.10. New Assurance Graph Generation

The assurance graph will change along the time, because services and subservices come and go (changing the dependencies between subservices), or simply because a subservice is now under maintenance. Therefore an assurance graph version must be maintained, along with the date and time of its last generation. The date and time of a particular subservice instance (again dependencies or under maintenane) might be kept. From a client point of view, an assurance graph change is triggered by the value of the assurance-graph-version and assurance-graph-last-change YANG leaves. At that point in time, the client (collector) follows the following process:

- o Keep the previous assurance-graph-last-change value (let's call it time T)

- o Run through all subservice instance and process the subservice instances for which the last-change is newer that the time T

- o Keep the new assurance-graph-last-change as the new referenced date and time

4. Security Considerations

The SAIN architecture helps operators to reduce the mean time to detect and mean time to repair. As such, it should not cause any security threats. However, the SAIN agents must be secure: a compromised SAIN agents could be sending wrong root causes or symptoms to the management systems.

Except for the configuration of telemetry, the agents do not need "write access" to the devices they monitor. This configuration is applied with a YANG module, whose protection is covered by Secure Shell (SSH) [RFC6242] for NETCONF or TLS [RFC8446] for RESTCONF.

The data collected by SAIN could potentially be compromising to the network or provide more insight into how the network is designed. Considering the data that SAIN requires (including CLI access in some cases), one should weigh data access concerns with the impact that reduced visibility will have on being able to rapidly identify root causes.

If a closed loop system relies on this architecture then the well known issue of those system also applies, i.e., a lying device or compromised agent could trigger partial reconfiguration of the service or network. The SAIN architecture neither augments or reduces this risk.

5. IANA Considerations

This document includes no request to IANA.

6. Contributors

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7. Open Issues

Refer to the Intent-based Networking NMRG documents

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Appendix A. Changes between revisions

v02 - v03

- Timing Concepts
- New Assurance Graph Generation

v01 - v02

- Handling maintenance windows
- Flexible architecture better explained
- Improved the terminology
- Notion of mapping information model to data model, while waiting for YANG to be everywhere
- Started a security considerations section

v00 - v01

- Terminology clarifications
- Figure 1 improved

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