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Using off-path mechanisms for exposing Time-Variant Routing information
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Abstract

Time-Variant Routing (TVR) involves predictable, scheduled changes to network topology elements such as nodes, links, and adjacencies that impact routing behavior over time. All those changes can alter the connectivity in the network in a predictable manner, which is known as Time-Variant Routing (TVR). This document proposes mechanisms for exposing TVR information to both internal and external applications, focusing on off-path solutions that decouple the advertisement of scheduled changes from the routing control plane signaling.

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1. Introduction

Time-Variant Routing (TVR) refers to operational scenarios where network topology, including nodes, links, and adjacency attributes, changes in a predictable, scheduled manner.

There can be operational situations (e.g., maintenance windows, load balancing, energy-saving policies, or network upgrades) where changes in the network, such as modifications in either nodes, links or adjacencies, can introduce variations on the routing of that network. Use cases representative of such operational situations are documented in [RFC9657]. Those predictable changes can be scheduled either from a higher-level system (e.g., OSS) or from a Network Controller. Figure 1 sketches a potential architecture facilitating the exposure of changes introduced by TVR operation. There can be multiple variants of such architecture.

```
     Network             (programming       (impact
     Operator ---------+ of scheduled      estimation
                       | TVR changes)     of scheduled
                       V                  TVR changes)
                +-------------+       +--------------+
                |   Network   |       |   Network    |
                |  Controller |<----->| Digital Twin |
                +-------------+       +--------------+
                    A     |
(feeding impacts    |     |        (activation
of scheduled +------+     +------+ of scheduled
TVR changes) |                   | TVR changes)
             |                   |
             V                   V
     +-------------+          ,------._
     |Off-path Info|       ,-'         '-.
     |  Component  |      /               \
     +-------------+     (     Network     )
             A            \               /
             |             '-.         ,-'
  (exposure  |                '+------'
of scheduled |                     ^
TVR changes) |                     :
             |  (awareness         :
             | of scheduled        v
             | TVR changes) +-------------+
             +------------->| Application |
                            +-------------+
```

Figure 1. Potential architecture using a dedicated Off-path Information Component for advertising TVR scheduled changes

Since the expected changes can be predicted beforehand, then it is possible to anticipate the impacts of that changes in the routing of the network. , for instance by means of algorithms embedded in the Network Controller allowing to recalculate the resulting routing metrics, or through experimental observations e.g. in network digital twins [I-D.irtf-nmrg-network-digital-twin-arch].

Being feasible then to automatize the changes and to pre-calculate the impacts that those changes can introduce into the routing of the network, it is possible to expose in advance such changes in a way that applications (both internal and external) can become aware of those routing variations along time, allowing proactive service management and optimization ahead of the activation of those changes.

This document builds on TVR-related foundational work [RFC9657], [I-D.ietf-tvr-requirements] and [I-D.ietf-tvr-schedule-yang], but focussing on off-path exposure of TVR information, describing architectural considerations and mechanisms to present scheduled network changes to applications.

2. On-path vs Off-path Mechanisms for TVR

At the time of advertising and consuming TVR scheduled changes, two different mechanisms can be considered, namely on-path and off-path mechanisms.

2.1. On-path Mechanisms

On-path mechanisms disseminate scheduled topological changes directly through routing protocols such as OSPF, IS-IS, or BGP, augmented to carry time-scheduled advertisements [I-D.ietf-tvr-schedule-yang]. This approach embeds TVR information on the routing data plane.

One of the primary benefits of disseminating scheduled topological changes by routing protocols is the potential for timely, distributed updates. This tight coupling enables rapid propagation of scheduled changes across the network.

However, this approach also introduces several challenges:

* Cascading Updates: a single scheduled change (e.g., link metric adjustment or path re-optimization) may trigger a series of subsequent updates across the network. These cascading effects can lead to excess of processing in the network elements if not properly managed.

* Coordination and Conflict Resolution: in a distributed environment, multiple nodes may attempt to adjust routes or metrics concurrently. This increases the complexity of coordination and requires robust mechanisms to detect and resolve conflicts without introducing inconsistencies or loops.

2.2. Off-path Mechanisms

Off-path mechanisms expose TVR information via centralized or logically separate systems outside the routing protocol control plane, using specific protocols, data models or APIs for that purpose.

It can be advantageous for different reasons:

* Simplified conflict detection and resolution due to centralized control.

* Controlled and potentially filtered exposure of information to external or internal applications.

* Reduced impact on routing protocols and network stability.

Off-path solutions can ingest data from multiple sources, including controllers and augmented routing protocols, and provide aggregated, application-friendly views of scheduled network changes.

2.3. Hybrid Approaches

Hybrid approaches may combine on-path and off-path methods, e.g., using routing protocol advertisements for internal synchronization and off-path systems for external exposure.

3. Ways of retrieving scheduled topological changes

According to the two strategies commented in the Introduction, it can be considered two different ways in which off-path solutions retrieve the information about scheduled topological changes. In one case, the changes can be notified directly by a network controller, while in the second case the changes are collected from advertisements in augmented routing protocols.

In both cases, the data model for representing the scheduled changes can be the same, describing the changing topological events in a similar way. A data model for representing TVR information is proposed in [I-D.ietf-tvr-schedule-yang], which can be used in any of the options describe next.

3.1. Interaction with a network controller

The architecture in Figure 1 assumes the intervention of a Network Controller in order to schedule and activate the changes in the network in a predictable manner. The network controller can pass the information about the planned changes to a separate component dedicated to advertise the TVR changes off-path, or it could even incorporate such capability as part of the functional capabilities of the controller. Thus, depending on the capabilities of the controller, it may either provide raw scheduled changes or precomputed future topologies reflecting those changes.

3.2. Interaction with routing protocols augmented to support TVR advertisements

As an alternative solution, it could be the case that existing routing protocols become augmented in order to natively support the advertisement of network changes along the time (for instance, an example of schedules for OSPF costs is provided in [I-D.ietf-tvr-schedule-yang]). If that is the case, the off-path solution can participate of the signaling of the network routing information by listening to IGPs and/or peering with BGP speakers, as described in [RFC7971]. This enables the off-path system to build time-aware topological views based on routing advertisements.

3.3. Applicability

Uniform representation of scheduled changes facilitates ingestion and processing. The YANG data model draft [I-D.ietf-tvr-schedule-yang] provides a framework to represent schedules for nodes, interfaces, and attributes, including timing, periodicity, and availability.

For instance, an engineer in the Network Operation Center (NOC) represented in Figure 1 can program some changes in the network in a planned, anticipated way so that the impacts of such changes can be estimated in advance. For instance, the engineer can enter the following data, according to [I-D.ietf-tvr-schedule-yang]:

```
module: ietf-tvr-node
  +--rw node-schedule
     +--rw node-id? "192.168.10.17"
     ...
     +--rw interface-schedule
        +--rw interfaces*
           +--rw name "GigabitEthernet0"
           ...
           +--rw attribute-schedule
              +--rw schedules*
                 +--rw schedule-id "0123456789"
                 +--rw (schedule-type)?
                    +--:(period)
                      ...
                       +--rw period-start "2024-07-08T10:30:00"
                       +--rw time-zone-identifier? "Africa/Dakar"
                       +--rw (period-type)?
                          ...
                          +--:(duration)
                             +--rw duration? "3600"
                                  ...
                                  +--rw attr-value
                     +--rw available? "false"
```

This order represents the action of tearing down interface GigabitEthernet0 of the node with loopback IP address 192.168.10.17 for one hour, at 10:30 local time of Dakar, due for instance to a maintenance action in the network. With this information, the network systems can analyse the impact of such action (the way in which that impacts are evaluated are out of scope of this document). According to the estimated impacts, the engineer can decide to continue or to replan the action.

4. Mechanisms for Exposing TVR Information

Exposing TVR information requires mechanisms able to represent time-varying network states, including topology and associated metrics, with appropriate granularity and temporal precision.

4.1. ALTO Protocol

The Application-Layer Traffic Optimization (ALTO) protocol [RFC7285] has been designed to expose network topological and cost information to applications. In consequence, ALTO can an act as an off-path mechanism for the purpose of exposing the impacts due to changes in the routing of a network. In that case, the Off-path Information Component in Figure 1 is realized by means of an ALTO Server.

ALTO [RFC7285] provides topological-related information in the form of both network and cost maps. The network map basically summarizes the IP address ranges aggregated in each Provider-defined Identifier (PID). Such IP addresses define either customers or service functions attached to each network node. The cost map details the topological relationship among PIDs in terms of a certain metric. The basic metric provided is the routing cost among PIDs, but other metrics can be also provided such as performance-related metrics [RFC9439].

For the purpose of exposing future changes on the reachability between PIDs in the network, ALTO defines in [RFC8896] a calendared cost map (named ALTO cost calendar) which allows to signal future changes on the cost metric. Thus, for a metric related to routing, the cost calendar can expose scheduled modifications in the connectivity between PIDs in a natural manner.

The ALTO cost calendar presents the information (i.e., metrics between PIDs) in the form of JSON arrays, where each listed value corresponds to a certain time interval. The ALTO cost calendar also includes attributes to describe the time scope of the calendar. The calendar provided by ALTO has the following attributes defined in [RFC8896]:

* "Calendar-start-time", which indicates the date at which the first value of the calendar applies.

* "Time-interval-size", that defines the duration of an ALTO Calendar time interval in a unit of seconds.

* "Number-of-intervals", that indicates the number of values of the cost calendar array.

* "Repeated", which is an optional attribute that indicates how many iterations of the calendar value array have the same values.

In order to know about cheduled changes, two possibles strategies can be in placed.

One strategy is to relay on centralized network control elements populating scheduled changes to the ALTO server sufficiently in advance as to calculate and expose the intended changes before them are effectively activated in the network by the controllers. That is, the introduction of changes is governed by the network controller configuring dynamically the network elements (i.e., nodes, links) following a planned set of actions. Such planned actions are the ones fed to ALTO so that ALTO can create and expose updated topological views for the scheduled modifications.

A second strategy is to disseminate the scheduled changes by means of the routing protocols in the network, so that the routing protocols distribute the planned topological changes at link or node level. It is worthy to note that a change distributed in this manner just by a single node can motivate a cascade of some other scheduled changes in different other nodes, thus representing potential stability issues that should be addressed with care. Anyway, in certain environments it can be suitable for signaling scheduled changes so that can serve as basis for deriving from it the topological views to be exposed by ALTO.

4.2. Other Off-path Mechanisms

While ALTO is a mature example, other off-path mechanisms may include custom APIs exposing scheduled network data. Such APIs could be supported by;

* Network Controllers, in case such controller is able to compute and maintain the changes.

* Managing device, in charge of generating and maintaining the schedules, or Schedule Database as defined in [I-D.zdm-tvr-applicability].

5. Security and operational considerations

Same security and operational considerations as described in [RFC8896] apply also in this document.

Apart from that, [I-D.ietf-tvr-requirements] describes relevant security considerations for TVR solutions.

The off-path approach prevents some of those security issues, as the ones requiring direct access to the source of information in risk, like the time synchronization signals. However, some other threats are of applicability, like the ones referring to the access to the information, activity identification and privacy.

In order to mitigate such security risks, the off-path solution should implement the necessary mechanisms for authentication, secure data transfer and privacy preservation.

6. References

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Appendix A. Assessment of ALTO as off-path solution against TVR requirements

(Note: to be updated with [I-D.ietf-tvr-requirements] version -05 or higher)

The Time Variant Routing requirements are being documented in [I-D.ietf-tvr-requirements]. Despite that is yet a work in progress, it is convenient to start an assessment of the off-path solution provided by ALTO against the requirements expected to be supported by any TVR-capable solution.

The following Table summarizes the assessment exercise. The requirements are listed including the section (in brackets) of [I-D.ietf-tvr-requirements] where they are defined.

Requirement	Compliance
(2.1) Resource scheduling	Feasible to reflect scheduled changes in a topology by means of a sequence of network and cost maps along the time
(2.2.1) Scope of Time-Variability	Combines both time-invariant and time-variant entities. Allows representation of global and individual changes
(2.2.2) Time Horizon	Specified by means of "time-interval-size" attribute expressed in seconds
(2.2.3) Time Precision and Accuracy	Determined in units of seconds
(2.2.4) Validity in a Schedule	Permits to accommodate multiple subsequent schedules
(2.2.5) Periodicity in a Schedule	Repetitive states specified by means of the attribute "repeated"
(2.2.6) Continuity in a Schedule	Governed by the "time-interval-size" attribute expressed in seconds
(2.2.7) Time-Overlap and Priority	Not supported. It would require extension of RFC8896
(2.2.8) Property Value Interpolation	Zero-order hold mode. Other modes could be potentially supported
(2.2.9) Changes to Model State	Support of fine-grained changes
(2.3) Topologies	Schedules applicable to nodes and links. Support of potential future node or link connectivity
(2.4) Routing	Allows computation of TVR-enabled paths. Reported

	constrains can be considered
(2.5) Integrity Considerations	Security considerations in both [RFC7285] and [RFC7971] apply in this case

Appendix B. Assessment of the archietcture proposed in [I-D.wqb-tvr-applicability]

(Note: to reconsider this section since [I-D.wqb-tvr-applicability] already expired, and new version of the document in [I-D.zdm-tvr-applicability] does not consider the same architecture)

[I-D.wqb-tvr-applicability] introduces an architecture for the control scheduling of network resources, with two functional components, namely the Scheduled Service Requester, in charge of soliciting a resource schedule change, and the Scheduled Service Responder, in charge of handling the scheduling orders. Such architecture assumes the existence of funcitonal interfaces between both comoponents.

Comparing such architecture with the one depicted in Figure 1, the following mapping is possible, as represented in Figure 2.

```
          Network Operator         (programming       (impact
         [ScheduleRequester]-----+ of scheduled      estimation
                                 | TVR changes)     of scheduled
        ......................   V  ............... TVR changes) ...
        : [Schedule       +-------------+       +--------------+   :
        :  Service        |   Network   |       |   Network    |   :
        : Responder]      |  Controller |<----->| Digital Twin |   :
        :                 +-------------+       +--------------+   :
        :                     A ... | .............................:
        : (feeding impacts    | :   |        (activation
        : of scheduled +-------+ :   +------+ of scheduled
        : TVR changes) |        :          | TVR changes)
        :              |        :          |
        :              V        :          V
        :      +-------------+  :       ,------._
        :      |Off-path Info|  :    ,-'         '-.
        :      |  Component  |  :   /               \
        :      +-------------+  :  (      Network    )
        :              A        :   \               /
        :............. | .......:    '-.         ,-'
            (exposure  |                '+------'
          of scheduled |                     ^
          TVR changes) |                     :
                       |  (awareness         :
                       | of scheduled        v
                       | TVR changes) +-------------+
                       +------------->| Application |
                                      +-------------+
                                    [Schedule Consumer]
```

Figure 2. Schedule Requester, Responder and Consumer in the off-path solution

From this assessment, it can be concluded that the roles of Schedule Requester and Schedule Responder have its correspondance in the off-path solution here described. However, the intended architecture in [I-D.wqb-tvr-applicability] lacks of the role of Schedule Consumer here described (or at least assumes that the Requester will be also the Consumer, which cannot be necessarily the case).

Appendix C. Implementation status

The scenario proposed in Figure 1 has been implemented for the validation of the off-path TVR approach using ALTO as off-path mechanism. The use case to exercise the off-path solution considers operational tasks in the network such as hardware and/or software maintenance and upgrades. Such actions imply temporal topological changes that can be anticipated since they are planned interventions in teh network. By leveraging on TVR, applications consuming the network can be timnely informed of those changes in advanced, permitting re-configurations and re-optimizations on the application side minimizing negative impacts due to the foreseen changes.

A video demonstrating the scenario can be found in [OPTIMAIX_video]. The modules implementing the functionality have been released as open source and are available at [OPTIMAIX_repo].

* Network Operation Center (NOC), developed by E-lighthouse. This component is represented as the "Network Operator" in Figure 1. It is in charge of requesting scheduled changes in the network.

* Net2plan_NDT, developed by E-lighthouse. This component is part of the "Network Digital Twin" module in Figure 1. It is in charge of performing advanced network simulations and reporting Key Performance Indicator (KPI) evaluation consequence of the topological changes.

* Change_Scheduler, devoloped by Telef坦nica. This component is part of the "Network Controller" module in Figure 1. It is in charge of receiving the topological changes requests, including the intended execution time for the scheduled changes. It passess / receive topological information and KPIs to / from Net2plan_NDT. It is also in charge of triggering the execution of the network chages at due time.

* ALTO_CostCalendar, developed by Telef坦nica. This component is part of the "ALTO Server" module in Figure 1. It is in charge of processing the predicted KPIs on the topology with the proposed changes, and exposing those changes to external applications as an example of off-path mechanism.

Appendix D. Identified gaps on TVR specifications

The work carried out for implementing the architecture in Figure 1 reveals some gaps.

* [I-D.ietf-tvr-schedule-yang] only provides granularity for schedule changes at node and link level. However, operational scenarios as the one described here can require further granularity, as cards. A current workaround could be to count all the interfaces of the same card, which can be onerous in some cases (e.g., cards of 48 GigaEthernet ports).

* Advertisements of scheduled changes in distributed manner (that is, on-path, directly using augmented routing protocols) can raise conflicts. While conflicts are easy to be handled by centralized

(i.e., off-path) solutions, it can require the definition of arbitration mechanisms for the case of distributed (i.e., on-path) ones.

* When distributed advertisements are in place, there are no means defined for reverting planned changes other than reconfiguring and launch new advertisements. Centralized approach simplifies the evaluation of impacts, and then, facilitates the indetification of potential problems that a planned change can cause. Distributed means of distributed scheduled changes can require ways of easily reverting proposed changes.

* When using distributed advertisement, the exposure of planned changes to external parties or applications can be a security problem, because the potential accessibility to internal information beyond the topological changes. Secure ways of accessing to that information can be needed to allow such use cases.

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