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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.

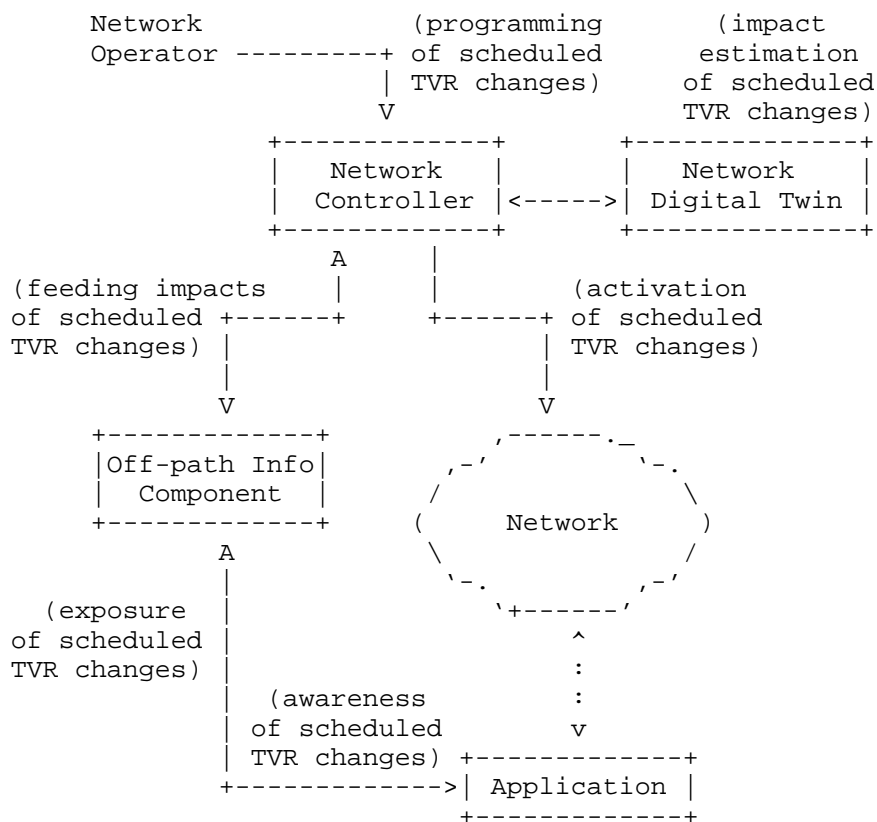


Figure 1. Potential architecture using a dedicated Off-path Information Component for advertising TVR scheduled changes

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 control 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 TVR YANG data model [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 Off-Path Exposure of 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 information and associated costs to applications. In consequence, ALTO can 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 scheduled changes, two possible strategies can be in place.

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 they 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 into 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.

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