

Workgroup: ALTO

Internet-Draft: draft-ietf-alto-path-vector-15

Published: 9 August 2021

Intended Status: Standards Track

Expires: 10 February 2022

Authors: K. Gao                      Y. Lee        S. Randriamasy  
         Sichuan University    Samsung    Nokia Bell Labs  
         Y.R. Yang                J. Zhang  
         Yale University    Tongji University

## **ALTO Extension: Path Vector**

### **Abstract**

This document is an extension to the base Application-Layer Traffic Optimization (ALTO) protocol. It extends the ALTO Cost Map service and ALTO Property Map service so that the application can decide which endpoint(s) to connect based on not only numerical/ordinal cost values but also details of the paths. This is useful for applications whose performance is impacted by specified components of a network on the end-to-end paths, e.g., they may infer that several paths share common links and prevent traffic bottlenecks by avoiding such paths. This extension introduces a new abstraction called Abstract Network Element (ANE) to represent these components and encodes a network path as a vector of ANEs. Thus, it provides a more complete but still abstract graph representation of the underlying network(s) for informed traffic optimization among endpoints.

### **Status of This Memo**

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at <https://datatracker.ietf.org/drafts/current/>.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on 10 February 2022.

### **Copyright Notice**

Copyright (c) 2021 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to BCP 78 and the IETF Trust's Legal Provisions Relating to IETF Documents (<https://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Simplified BSD License text as described in Section 4.e of the Trust Legal Provisions and are provided without warranty as described in the Simplified BSD License.

## Table of Contents

1. [Introduction](#)
2. [Requirements Languages](#)
3. [Terminology](#)
4. [Problem Statement](#)
  - 4.1. [Design Requirements](#)
  - 4.2. [Use Cases](#)
    - 4.2.1. [Large-scale Data Analytics](#)
    - 4.2.2. [Context-aware Data Transfer](#)
    - 4.2.3. [CDN and Service Edge](#)
5. [Path Vector Extension: Overview](#)
  - 5.1. [Abstract Network Element](#)
    - 5.1.1. [ANE Domain](#)
    - 5.1.2. [Ephemeral ANE and Persistent ANE](#)
    - 5.1.3. [Property Filtering](#)
  - 5.2. [Path Vector Cost Type](#)
  - 5.3. [Multipart Path Vector Response](#)
    - 5.3.1. [Identifying the Media Type of the Root Object](#)
    - 5.3.2. [References to Part Messages](#)
6. [Specification: Basic Data Types](#)
  - 6.1. [ANE Name](#)
  - 6.2. [ANE Domain](#)
    - 6.2.1. [Entity Domain Type](#)
    - 6.2.2. [Domain-Specific Entity Identifier](#)
    - 6.2.3. [Hierarchy and Inheritance](#)
    - 6.2.4. [Media Type of Defining Resource](#)
  - 6.3. [ANE Property Name](#)
  - 6.4. [Initial ANE Property Types](#)
    - 6.4.1. [New ANE Property Type: Maximum Reservable Bandwidth](#)
    - 6.4.2. [New ANE Property Type: Persistent Entity ID](#)
  - 6.5. [Path Vector Cost Type](#)
    - 6.5.1. [Cost Metric: ane-path](#)
    - 6.5.2. [Cost Mode: array](#)
  - 6.6. [Part Resource ID](#)
7. [Specification: Service Extensions](#)
  - 7.1. [Notations](#)
  - 7.2. [Multipart Filtered Cost Map for Path Vector](#)
    - 7.2.1. [Media Type](#)

7.2.2.	<a href="#">HTTP Method</a>
7.2.3.	<a href="#">Accept Input Parameters</a>
7.2.4.	<a href="#">Capabilities</a>
7.2.5.	<a href="#">Uses</a>
7.2.6.	<a href="#">Response</a>
7.3.	<a href="#">Multipart Endpoint Cost Service for Path Vector</a>
7.3.1.	<a href="#">Media Type</a>
7.3.2.	<a href="#">HTTP Method</a>
7.3.3.	<a href="#">Accept Input Parameters</a>
7.3.4.	<a href="#">Capabilities</a>
7.3.5.	<a href="#">Uses</a>
7.3.6.	<a href="#">Response</a>
8.	<a href="#">Examples</a>
8.1.	<a href="#">Example: Information Resource Directory</a>
8.2.	<a href="#">Example: Multipart Filtered Cost Map</a>
8.3.	<a href="#">Example: Multipart Endpoint Cost Service Resource</a>
8.4.	<a href="#">Example: Incremental Updates</a>
9.	<a href="#">Compatibility with Other ALTO Extensions</a>
9.1.	<a href="#">Compatibility with Legacy ALTO Clients/Servers</a>
9.2.	<a href="#">Compatibility with Multi-Cost Extension</a>
9.3.	<a href="#">Compatibility with Incremental Update</a>
9.4.	<a href="#">Compatibility with Cost Calendar</a>
10.	<a href="#">General Discussions</a>
10.1.	<a href="#">Constraint Tests for General Cost Types</a>
10.2.	<a href="#">General Multi-Resource Query</a>
11.	<a href="#">Security Considerations</a>
12.	<a href="#">IANA Considerations</a>
12.1.	<a href="#">ALTO Entity Domain Type Registry</a>
12.2.	<a href="#">ALTO Entity Property Type Registry</a>
13.	<a href="#">Acknowledgments</a>
14.	<a href="#">References</a>
14.1.	<a href="#">Normative References</a>
14.2.	<a href="#">Informative References</a>
Appendix A.	<a href="#">Revision Logs</a>
A.1.	<a href="#">Changes since -14</a>
A.2.	<a href="#">Changes since -13</a>
A.3.	<a href="#">Changes since -12</a>
A.4.	<a href="#">Changes since -11</a>
A.5.	<a href="#">Changes since -10</a>
A.6.	<a href="#">Changes since -09</a>
A.7.	<a href="#">Changes since -08</a>
A.8.	<a href="#">Changes Since Version -06</a>
<a href="#">Authors' Addresses</a>	

## **1. Introduction**

Network performance metrics are crucial to the Quality of Experience (QoE) of today's applications. The ALTO protocol allows Internet Service Providers (ISPs) to provide guidance, such as topological

distance between different end hosts, to overlay applications. Thus, the overlay applications can potentially improve the QoE by better orchestrating their traffic to utilize the resources in the underlying network infrastructure.

Existing ALTO Cost Map and Endpoint Cost Service provide only cost information on an end-to-end path defined by its <source, destination> endpoints: The base protocol [[RFC7285](#)] allows the services to expose the topological distances of end-to-end paths, while various extensions have been proposed to extend the capability of these services, e.g., to express other performance metrics [[I-D.ietf-alto-performance-metrics](#)], to query multiple costs simultaneously [[RFC8189](#)], and to obtain the time-varying values [[RFC8896](#)].

While the existing extensions are sufficient for many overlay applications, the QoE of some overlay applications depends not only on the cost information of end-to-end paths, but also on particular components of a network on the paths and their properties. For example, job completion time, which is an important QoE metric for a large-scale data analytics application, is impacted by shared bottleneck links inside the carrier network as link capacity may impact the rate of data input/output to the job. We refer to such components of a network as Abstract Network Elements (ANE).

Predicting such information can be very complex without the help of the ISP [[AAAI2019](#)]. With proper guidance from the ISP, an overlay application may be able to schedule its traffic for better QoE. In the meantime, it may be helpful as well for ISPs if applications could avoid using bottlenecks or challenging the network with poorly scheduled traffic.

Despite the benefits, ISPs are not likely to expose details on their network paths: first for the sake of confidentiality, second because it may increase volume and computation overhead, and last because it is difficult for ISPs to figure out what information and what details an application needs. Likewise, applications do not necessarily need all the network path details and are likely not able to understand them.

Therefore, it is beneficial for both parties if an ALTO server provides ALTO clients with an "abstract network state" that provides the necessary details to applications, while hiding the network complexity and confidential information. An "abstract network state" is a selected set of abstract representations of Abstract Network Elements traversed by the paths between <source, destination> pairs combined with properties of these Abstract Network Elements that are relevant to the overlay applications' QoE. Both an application via its ALTO client and the ISP via the ALTO server can achieve better

confidentiality and resource utilization by appropriately abstracting relevant Abstract Network Elements. Server scalability can also be improved by combining Abstract Network Elements and their properties in a single response.

This document extends [[RFC7285](#)] to allow an ALTO server to convey "abstract network state", for paths defined by their <source, destination> pairs. To this end, it introduces a new cost type called "Path Vector". A Path Vector is an array of identifiers that identifies an Abstract Network Element, which can be associated with various properties. The associations between ANEs and their properties are encoded in an ALTO information resource called Unified Property Map, which is specified in [[I-D.ietf-alto-unified-props-new](#)].

For better confidentiality, this document aims to minimize information exposure. In particular, this document enables and recommends that first ANEs are constructed on demand, and second an ANE is only associated with properties that are requested by an ALTO client. A Path Vector response involves two ALTO Maps: the Cost Map that contains the Path Vector results and the up-to-date Unified Property Map that contains the properties requested for these ANEs. To enforce consistency and improve server scalability, this document uses the multipart/related message defined in [[RFC2387](#)] to return the two maps in a single response.

The rest of the document is organized as follows. [Section 3](#) introduces the extra terminologies that are used in this document. [Section 4](#) uses an illustrative example to introduce the additional requirements of the ALTO framework, and discusses potential use cases. [Section 5](#) gives an overview of the protocol design. [Section 6](#) and [Section 7](#) specify the extension to the ALTO IRD and the information resources, with some concrete examples presented in [Section 8](#). [Section 9](#) discusses the backward compatibility with the base protocol and existing extensions. Security and IANA considerations are discussed in [Section 11](#) and [Section 12](#) respectively.

## 2. Requirements Languages

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.

When the words appear in lower case, they are to be interpreted with their natural language meanings.

### 3. Terminology

NOTE: This document depends on the Unified Property Map extension [[I-D.ietf-alto-unified-props-new](#)] and should be processed after the Unified Property Map document.

This document extends the ALTO base protocol [[RFC7285](#)] and the Unified Property Map extension [[I-D.ietf-alto-unified-props-new](#)]. In addition to the terms defined in these documents, this document also uses the following additional terms:

\*Abstract Network Element (ANE): An Abstract Network Element is an abstract representation for a component in a network that handles data packets and whose properties can potentially have an impact on the end-to-end performance of traffic. An ANE can be a physical device such as a router, a link or an interface, or an aggregation of devices such as a subnetwork, or a data center.

The definition of Abstract Network Element is similar to Network Element defined in [[RFC2216](#)] in the sense that they both provide an abstract representation of particular components of a network. However, they have different criteria on how these particular components are selected. Specifically, Network Element requires the components to be capable of exercising QoS control, while Abstract Network Element only requires the components to have an impact on the end-to-end performance.

\*ANE Name: An ANE can be constructed either statically in advance or on demand based on the requested information. Thus, different ANEs may only be valid within a particular scope, either ephemeral or persistent. Within each scope, an ANE is uniquely identified by an ANE Name, as defined in [Section 6.1](#). Note that an ALTO client must not assume ANEs in different scopes but with the same ANE Name refer to the same component(s) of the network.

\*Path Vector: A Path Vector, or an ANE Path Vector, is a JSON array of ANE Names. It is a generalization of BGP path vector. While standard BGP path vector specifies a sequence of autonomous systems for a destination IP prefix, the Path Vector defined in this extension specifies a sequence of ANEs either for a source PID and a destination PID as in the CostMapData (11.2.3.6 in [[RFC7285](#)]), or for a source endpoint and a destination endpoint as in the EndpointCostMapData (11.5.1.6 in [[RFC7285](#)]).

\*Path Vector resource: A Path Vector resource refers to an ALTO resource which supports the extension defined in this document.

\*Path Vector cost type: The Path Vector cost type is a special cost type, which is specified in [Section 6.5](#). When this cost type is present in an IRD entry, it indicates that the information

resource is a Path Vector resource. When this cost type is present in a Filtered Cost Map request or an Endpoint Cost Service request, it indicates each cost value must be interpreted as a Path Vector.

\*Path Vector request: A Path Vector request refers to the POST message sent to an ALTO Path Vector resource.

\*Path Vector response: A Path Vector response refers to the multipart/related message returned by a Path Vector resource.

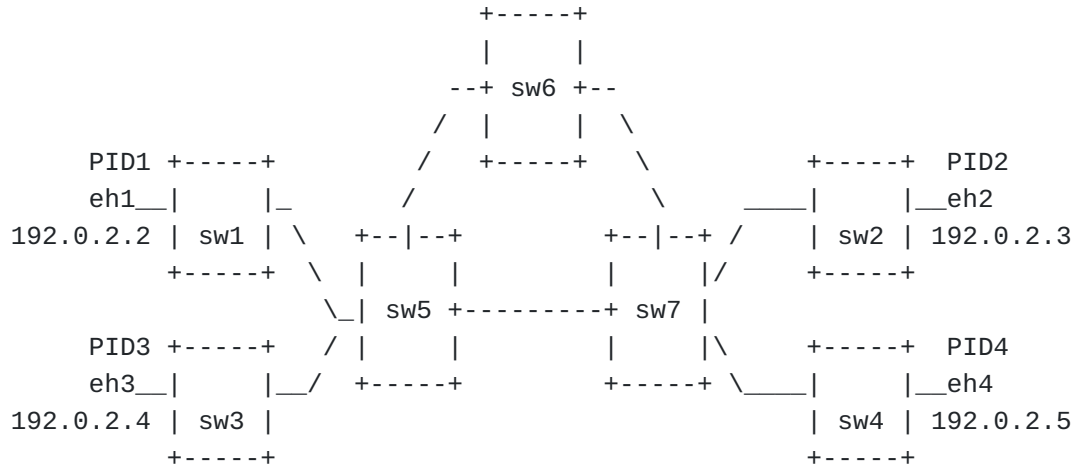
## **4. Problem Statement**

### **4.1. Design Requirements**

This section gives an illustrative example of how an overlay application can benefit from the extension defined in this document.

Assume that an application has control over a set of flows, which may go through shared links or switches and share bottlenecks. The application hopes to schedule the traffic among multiple flows to get better performance. The capacity region information for those flows will benefit the scheduling. However, existing cost maps can not reveal such information.

Specifically, consider a network as shown in [Figure 1](#). The network has 7 switches (sw1 to sw7) forming a dumb-bell topology. Switches sw1/sw3 provide access on one side, sw2/sw4 provide access on the other side, and sw5-sw7 form the backbone. End hosts eh1 to eh4 are connected to access switches sw1 to sw4 respectively. Assume that the bandwidth of link eh1 -> sw1 and link sw1 -> sw5 is 150 Mbps, and the bandwidth of the other links is 100 Mbps.



$\text{bw}(\text{eh1}--\text{sw1}) = \text{bw}(\text{sw1}--\text{sw5}) = 150 \text{ Mbps}$   
 $\text{bw}(\text{eh2}--\text{sw2}) = \text{bw}(\text{eh3}--\text{sw3}) = \text{bw}(\text{eh4}--\text{sw4}) = 100 \text{ Mbps}$   
 $\text{bw}(\text{sw1}--\text{sw5}) = \text{bw}(\text{sw3}--\text{sw5}) = \text{bw}(\text{sw2}--\text{sw7}) = \text{bw}(\text{sw4}--\text{sw7}) = 100 \text{ Mbps}$   
 $\text{bw}(\text{sw5}--\text{sw6}) = \text{bw}(\text{sw5}--\text{sw7}) = \text{bw}(\text{sw6}--\text{sw7}) = 100 \text{ Mbps}$

Figure 1: Raw Network Topology

The single-node ALTO topology abstraction of the network is shown in [Figure 2](#). Assume the cost map returns a hypothetical cost type representing the available bandwidth between a source and a destination.

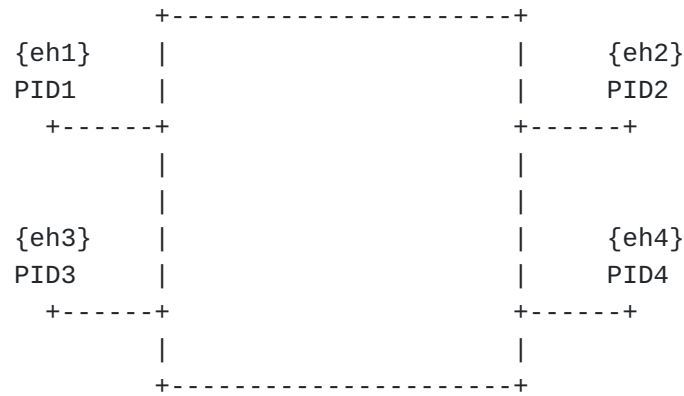


Figure 2: Base Single-Node Topology Abstraction

Now assume the application wants to maximize the total rate of the traffic among a set of  $\langle \text{source}, \text{destination} \rangle$  pairs, say  $\text{eh1} \rightarrow \text{eh2}$  and  $\text{eh1} \rightarrow \text{eh4}$ . Let  $x$  denote the transmission rate of  $\text{eh1} \rightarrow \text{eh2}$  and  $y$  denote the rate of  $\text{eh1} \rightarrow \text{eh4}$ . The objective function is

$$\max(x + y).$$



With the ALTO Cost Map, the cost between PID1 and PID2 and between PID1 and PID4 will be 100 Mbps. And the client can get a capacity region of

$$\begin{aligned}x &\leq 100 \text{ Mbps,} \\y &\leq 100 \text{ Mbps.}\end{aligned}$$

With this information, the client may mistakenly think it can achieve a maximum total rate of 200 Mbps. However, one can easily see that this rate is infeasible, as there are only two potential cases:

\*Case 1: eh1 -> eh2 and eh1 -> eh4 take different path segments from sw5 to sw7. For example, if eh1 -> eh2 uses path eh1 -> sw1 -> sw5 -> sw6 -> sw7 -> sw2 -> eh2 and eh1 -> eh4 uses path eh1 -> sw1 -> sw5 -> sw7 -> sw4 -> eh4, then the shared bottleneck links are eh1 -> sw1 and sw1 -> sw5. In this case, the capacity region is

$$\begin{aligned}x &\leq 100 \text{ Mbps} \\y &\leq 100 \text{ Mbps} \\x + y &\leq 150 \text{ Mbps}\end{aligned}$$

and the real optimal total rate is 150 Mbps.

\*Case 2: eh1 -> eh2 and eh1 -> eh4 take the same path segment from sw5 to sw7. For example, if eh1 -> eh2 uses path eh1 -> sw1 -> sw5 -> sw7 -> sw2 -> eh2 and eh1 -> eh4 also uses path eh1 -> sw1 -> sw5 -> sw7 -> sw4 -> eh4, then the shared bottleneck link is sw5 -> sw7. In this case, the capacity region is

$$\begin{aligned}x &\leq 100 \text{ Mbps} \\y &\leq 100 \text{ Mbps} \\x + y &\leq 100 \text{ Mbps}\end{aligned}$$

and the real optimal total rate is 100 Mbps.

Clearly, with more accurate and fine-grained information, the application can gain a better prediction of its traffic and may orchestrate its resources accordingly. However, to provide such information, the network needs to expose more details beyond the simple cost map abstraction. In particular:

\*The ALTO server must give more details about the network paths that are traversed by the traffic between a source and a destination beyond a simple numerical value, which allows the overlay application to distinguish between Case 1 and Case 2 and to compute the optimal total rate accordingly.

\*The ALTO server must allow the client to distinguish the common ANE shared by eh1 -> eh2 and eh1 -> eh4, e.g., eh1 - sw1 and sw1 - sw5 in Case 1.

\*The ALTO server must give details on the properties of the ANEs used by eh1 -> eh2 and eh1 -> eh4, e.g., the available bandwidth between eh1 - sw1, sw1 - sw5, sw5 - sw7, sw5 - sw6, sw6 - sw7, sw7 - sw2, sw7 - sw4, sw2 - eh2, sw4 - eh4 in Case 1.

In general, we can conclude that to support the multiple flow scheduling use case, the ALTO framework must be extended to satisfy the following additional requirements:

**AR1:** An ALTO server must provide essential information on ANEs on the path of a <source, destination> pair that are critical to the QoE of the overlay application.

**AR2:** An ALTO server must provide essential information on how the paths of different <source, destination> pairs share a common ANE.

**AR3:** An ALTO server must provide essential information on the properties associated with the ANEs.

The extension defined in this document proposes a solution to provide these details.

## **4.2. Use Cases**

While the multiple flow scheduling problem is used to help identify the additional requirements, the extension defined in this document can be applied to a wide range of applications. This section highlights some real use cases that are reported.

### **4.2.1. Large-scale Data Analytics**

One potential use case of the extension defined in this document is for large-scale data analytics such as [[SENSE](#)] and [[LHC](#)], where data of gigabytes, terabytes and even petabytes are transferred. For these applications, the QoE is usually measured as the job completion time, which is related to the completion time of all the data transfers belonging to the job. With the extension defined in this document, an ALTO client can identify bottlenecks inside the network. Therefore, the overlay application can make optimal traffic distribution or resource reservation (i.e., proportional to the size of the transferred data), leading to optimal job completion time and network resource utilization.

#### 4.2.2. Context-aware Data Transfer

It is important to know the capabilities of various ANEs between two end hosts, especially in the mobile environment. With the extension defined in this document, an ALTO client may query the "network context" information, i.e., whether the two hosts are connected to the access network through a wireless link or a wire, and the capabilities of the access network. Thus, the client may use different data transfer mechanisms, or even deploy different 5G User Plane Functions (UPF) [[I-D.ietf-dmm-5g-uplane-analysis](#)] to optimize the data transfer.

#### 4.2.3. CDN and Service Edge

A growing trend in today's applications is to bring storage and computation closer to the end users for better QoE, such as Content Delivery Network (CDN), AR/VR, and cloud gaming, as reported in various documents ([[I-D.contreras-alto-service-edge](#)], [[I-D.huang-alto-mowie-for-network-aware-app](#)], and [[I-D.yang-alto-deliver-functions-over-networks](#)]).

With the extension defined in this document, an ALTO server can selectively reveal the CDNs and service edges that reside along the paths between different end hosts, together with their properties such as capabilities (e.g., storage, GPU) and available Service Level Agreement (SLA) plans. Thus, an ALTO client may leverage the information to better conduct CDN request routing or offload functionalities from the user equipment to the service edge, with considerations on different resource constraints.

### 5. Path Vector Extension: Overview

This section gives a non-normative overview of the extension defined in this document. It is assumed that readers are familiar with both the base protocol [[RFC7285](#)] and the Unified Property Map extension [[I-D.ietf-alto-unified-props-new](#)].

To satisfy the additional requirements, this extension:

1. introduces Abstract Network Element (ANE) as the abstraction of components in a network whose properties may have an impact on the end-to-end performance of the traffic handled by those component,
2. extends the Cost Map and Endpoint Cost Service to convey the ANEs traversed by the path of a <source, destination> pair as Path Vectors,
3. uses the Unified Property Map to convey the association between the ANEs and their properties.

Thus, an ALTO client can learn about the ANEs that are critical to the QoE of a <source, destination> pair by investigating the corresponding Path Vector value (AR1), identify common ANEs if an ANE appears in the Path Vectors of multiple <source, destination> pairs (AR2), and retrieve the properties of the ANEs by searching the Unified Property Map (AR3).

### 5.1. Abstract Network Element

This extension introduces Abstract Network Element (ANE) as an indirect and network-agnostic way to specify a component or an aggregation of components of a network whose properties have an impact on the end-to-end performance for traffic between a source and a destination.

When an ANE is defined by the ALTO server, it is assigned an identifier, i.e., a string of type ANENAME as specified in [Section 6.1](#), and a set of associated properties.

#### 5.1.1. ANE Domain

In this extension, the associations between ANE and the properties are conveyed in a Unified Property Map. Thus, ANEs must constitute an entity domain (Section 5.1 of [[I-D.ietf-alto-unified-props-new](#)]), and each ANE property must be an entity property (Section 5.2 of [[I-D.ietf-alto-unified-props-new](#)]).

Specifically, this document defines a new entity domain called ane as specified in [Section 6.2](#) and defines two initial properties for the ane domain.

#### 5.1.2. Ephemeral ANE and Persistent ANE

By design, ANEs are ephemeral and not to be used in further requests. More precisely, the corresponding ANE names are no longer valid beyond the scope of the Path Vector response or the incremental update stream for a Path Vector request. This has several benefits including better privacy of the ISPs and more flexible ANE computation.

For example, an ALTO server may define an ANE for each aggregated bottleneck link between the sources and destinations specified in the request. For requests with different sources and destinations, the bottlenecks may be different but can safely reuse the same ANE names. The client can still adjust its traffic based on the information but is difficult to infer the underlying topology with multiple queries.

However, sometimes an ISP may intend to selectively reveal some "persistent" network components which, opposite to being ephemeral,

have a longer life cycle. For example, an ALTO server may define an ANE for each service edge cluster. Once a client chooses to use a service edge, e.g., by deploying some user-defined functions, it may want to stick to the service edge to avoid the complexity of state transition or synchronization, and continuously query the properties of the edge cluster.

This document provides a mechanism to expose such network components as persistent ANEs. A persistent ANE has a persistent ID that is registered in a Property Map, together with their properties. See [Section 6.2.4](#) and [Section 6.4.2](#) for more detailed instructions on how to identify ephemeral ANEs and persistent ANEs.

### 5.1.3. Property Filtering

Resource-constrained ALTO clients may benefit from the filtering of Path Vector query results at the ALTO server, as an ALTO client may only require a subset of the available properties.

Specifically, the available properties for a given resource are announced in the Information Resource Directory as a new capability called `ane-property-names`. The selected properties are specified in a filter called `ane-property-names` in the request body, and the response includes and only includes the selected properties for the ANEs in the response.

The `ane-property-names` capability for Cost Map and for Endpoint Cost Service is specified in [Section 7.2.4](#) and [Section 7.3.4](#) respectively. The `ane-property-names` filter for Cost Map and Endpoint Cost Service is specified in [Section 7.2.3](#) and [Section 7.3.3](#) accordingly.

## 5.2. Path Vector Cost Type

For an ALTO client to correctly interpret the Path Vector, this extension specifies a new cost type called the Path Vector cost type.

The Path Vector cost type must convey both the interpretation and semantics in the `"cost-mode"` and `"cost-metric"` respectively. Unfortunately, a single `"cost-mode"` value cannot fully specify the interpretation of a Path Vector, which is a compound data type. For example, in programming languages such as C++, a Path Vector will have the type of `JSONArray<ANENAME>`.

Instead of extending the "type system" of ALTO, this document takes a simple and backward compatible approach. Specifically, the `"cost-mode"` of the Path Vector cost type is `"array"`, which indicates the value is a JSON array. Then, an ALTO client must check the value of

the "cost-metric". If the value is "ane-path", it means that the JSON array should be further interpreted as a path of ANENames.

The Path Vector cost type is specified in [Section 6.5](#).

### 5.3. Multipart Path Vector Response

For a basic ALTO information resource, a response contains only one type of ALTO resources, e.g., Network Map, Cost Map, or Property Map. Thus, only one round of communication is required: An ALTO client sends a request to an ALTO server, and the ALTO server returns a response, as shown in [Figure 3](#).

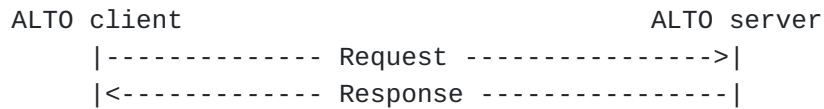


Figure 3: A Typical ALTO Request and Response

The extension defined in this document, on the other hand, involves two types of information resources: Path Vectors conveyed in an `InfoResourceCostMap` (defined in Section 11.2.3.6 of [\[RFC7285\]](#)) or an `InfoResourceEndpointCostMap` (defined in Section 11.5.1.6 of [\[RFC7285\]](#)), and ANE properties conveyed in an `InfoResourceProperties` (defined in Section 7.6 of [\[I-D.ietf-alto-unified-props-new\]](#)).

Instead of two consecutive message exchanges, the extension defined in this document enforces one round of communication. Specifically, the ALTO client must include the source and destination pairs and the requested ANE properties in a single request, and the ALTO server must return a single response containing both the Path Vectors and properties associated with the ANEs in the Path Vectors, as shown in [Figure 4](#). Since the two parts are bundled together in one response message, their orders are interchangeable. See [Section 7.2.6](#) and [Section 7.3.6](#) for details.

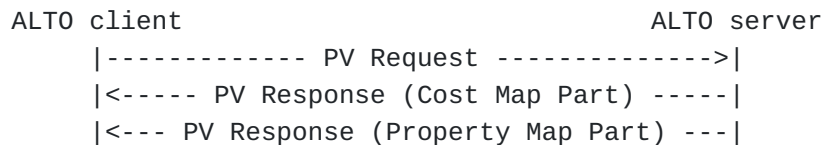


Figure 4: The Path Vector Extension Request and Response

This design is based on the following considerations:

1. Since ANEs may be constructed on demand, and potentially based on the requested properties (See [Section 5.1](#) for more details). If sources and destinations are not in the same request as the

properties, an ALTO server either cannot construct ANEs on-demand, or must wait until both requests are received.

2. As ANEs may be constructed on demand, mappings of each ANE to its underlying network devices and resources can be specific to the request. In order to respond to the Property Map request correctly, an ALTO server must store the mapping of each Path Vector request until the client fully retrieves the property information. The "stateful" behavior may substantially harm the server scalability and potentially lead to Denial-of-Service attacks.

One approach to realize the one-round communication is to define a new media type to contain both objects, but this violates modular design. This document follows the standard-conforming usage of multipart/related media type defined in [[RFC2387](#)] to elegantly combine the objects. Path Vectors are encoded in an InfoResourceCostMap or an InfoResourceEndpointCostMap, and the Property Map is encoded in an InfoResourceProperties. They are encapsulated as parts of a multipart message. The modular composition allows ALTO servers and clients to reuse the data models of the existing information resources. Specifically, this document addresses the following practical issues using multipart/related.

#### **5.3.1. Identifying the Media Type of the Root Object**

ALTO uses media type to indicate the type of an entry in the Information Resource Directory (IRD) (e.g., application/alto-costmap+json for Cost Map and application/alto-endpointcost+json for Endpoint Cost Service). Simply putting multipart/related as the media type, however, makes it impossible for an ALTO client to identify the type of service provided by related entries.

To address this issue, this document uses the type parameter to indicate the root object of a multipart/related message. For a Cost Map resource, the media-type in the IRD entry is multipart/related with the parameter type=application/alto-costmap+json; for an Endpoint Cost Service, the parameter is type=application/alto-endpointcost+json.

#### **5.3.2. References to Part Messages**

As the response of a Path Vector resource is a multipart message with two different parts, it is important that each part can be uniquely identified. Following the designs of [[RFC8895](#)], this extension requires that an ALTO server assigns a unique identifier to each part of the multipart/related response message. This identifier, referred to as a Part Resource ID (See [Section 6.6](#) for details), is present in the part message's Content-ID header. By

concatenating the Part Resource ID to the identifier of the Path Vector request, an ALTO server/client can uniquely identify the Path Vector Part or the Property Map part.

## **6. Specification: Basic Data Types**

### **6.1. ANE Name**

An ANE Name is encoded as a JSON string with the same format as that of the type PIDName (Section 10.1 of [[RFC7285](#)]).

The type ANENAME is used in this document to indicate a string of this format.

### **6.2. ANE Domain**

The ANE domain associates property values with the Abstract Network Elements in a Property Map. Accordingly, the ANE domain always depends on a Property Map.

#### **6.2.1. Entity Domain Type**

ane

#### **6.2.2. Domain-Specific Entity Identifier**

The entity identifiers are the ANE Names in the associated Property Map.

#### **6.2.3. Hierarchy and Inheritance**

There is no hierarchy or inheritance for properties associated with ANEs.

#### **6.2.4. Media Type of Defining Resource**

When resource specific domains are defined with entities of domain type ane, the defining resource for entity domain type pid MUST be a Property Map. The media type of defining resources for the ane domain is:

application/alto-propmap+json

Specifically, for ephemeral ANEs that appear in a Path Vector response, their entity domain names MUST be exactly ".ane" and the defining resource of these ANEs is the Property Map part of the multipart response. Meanwhile, for persistent ANEs whose entity domain name has the format of "PROPMAP.ane" where PROPMAP is the name of a Property Map resource, PROPMAP is the defining resource of these ANEs. Persistent entities are persistent because standalone



queries can be made by an ALTO client to their defining resources when the connection to the Path Vector service is closed.

For example, the defining resource of an ephemeral ANE whose entity identifier is ".ane:NET1" is the Property Map part that contains this identifier. The defining resource of a persistent ANE whose entity identifier is "dc-props.ane:DC1" is the Property Map with the resource ID "dc-props".

### 6.3. ANE Property Name

An ANE Property Name is encoded as a JSON string with the same format as that of Entity Property Name (Section 5.2.2 of [[I-D.ietf-alto-unified-props-new](#)]).

#### 6.4. Initial ANE Property Types

In this document, two initial ANE property types are specified, max-reservable-bandwidth and persistent-entity-id.

Note that the two property types defined in this document do not depend on any information resource, so their ResourceID part must be empty.

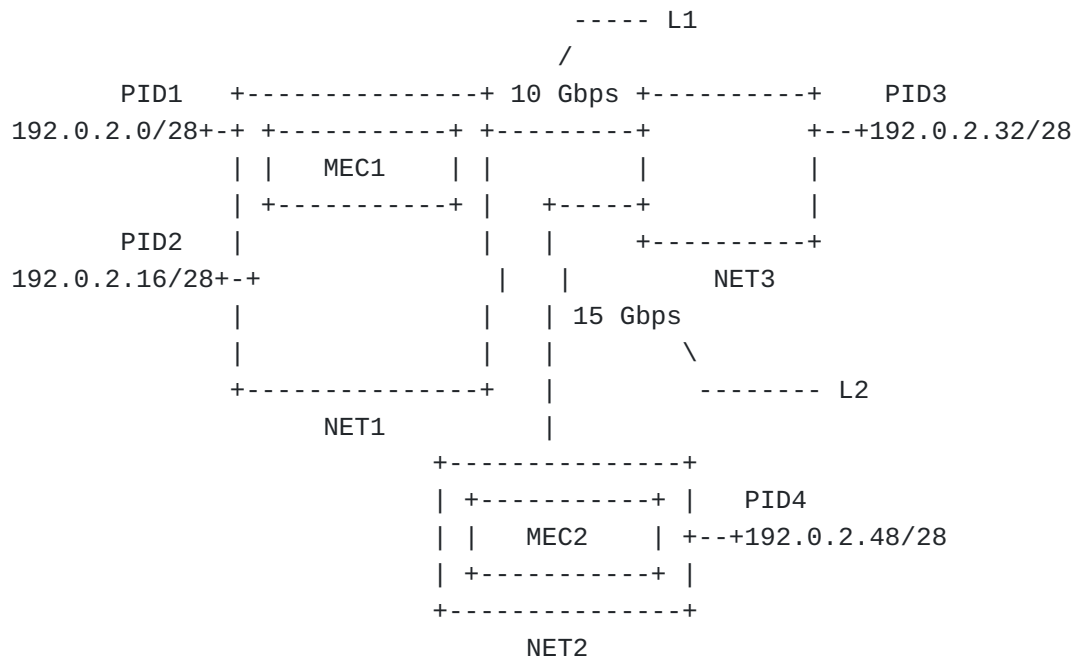


Figure 5: Examples of ANE Properties

In this document, [Figure 5](#) is used to illustrate the use of the two initial ANE property types. There are 3 sub-networks (NET1, NET2 and NET3) and two interconnection links (L1 and L2). It is assumed that each sub-network has sufficiently large bandwidth to be reserved.

#### 6.4.1. New ANE Property Type: Maximum Reservable Bandwidth

**Identifier:** max-reservable-bandwidth

**Intended Semantics:** The maximum reservable bandwidth property stands for the maximum bandwidth that can be reserved for all the traffic that traverses an ANE. The value MUST be encoded as a non-negative numerical cost value as defined in Section 6.1.2.1 of [\[RFC7285\]](#) and the unit is bit per second. If this property is requested but not present in an ANE, it MUST be interpreted as that the ANE does not support bandwidth reservation.

**Security Considerations:** ALTO entity properties expose information to ALTO clients. ALTO service providers should be made aware of the security ramifications related to the exposure of an entity property.

To illustrate the use of max-reservable-bandwidth, consider the network in [Figure 5](#). An ALTO server can create an ANE for each interconnection link, where the initial value for max-reservable-bandwidth is the link capacity.

#### 6.4.2. New ANE Property Type: Persistent Entity ID

**Identifier:** persistent-entity-id

**Intended Semantics:** The persistent entity ID property is the entity identifier of the persistent ANE which an ephemeral ANE presents (See [Section 5.1.2](#) for details). The value of this property is encoded with the format defined in Section 5.1.3 of [\[I-D.ietf-alto-unified-props-new\]](#).

In this format, the entity ID combines:

- \*a defining information resource for the ANE on which a "persistent-entity-id" is queried, which is the Property Map resource defining the ANE as a persistent entity, together with the properties

- \*the persistent name of the ANE in that Property Map

With this format, the client has all the needed information for further standalone query properties on the persistent ANE.

**Security Considerations:** ALTO entity properties expose information to ALTO clients. ALTO service providers should be made aware of the security ramifications related to the exposure of an entity property.

To illustrate the use of persistent-entity-id, consider the network in [Figure 5](#). Assume the ALTO server has a Property Map resource called "mec-props" that defines persistent ANEs "MEC1" and "MEC2" that represent the corresponding mobile edge computing (MEC) clusters. Since MEC1 is associated with NET1, the persistent-entity-id of the ephemeral ANE .ane:NET1 is the persistent entity id mec-props.ane:MEC1.

## **6.5. Path Vector Cost Type**

This document defines a new cost type, which is referred to as the Path Vector cost type. An ALTO server **MUST** offer this cost type if it supports the extension defined in this document.

### **6.5.1. Cost Metric: ane-path**

The cost metric "ane-path" indicates the value of such a cost type conveys an array of ANE names, where each ANE name uniquely represents an ANE traversed by traffic from a source to a destination.

An ALTO client **MUST** interpret the Path Vector as if the traffic between a source and a destination logically traverses the ANEs in the same order as they appear in the Path Vector.

### **6.5.2. Cost Mode: array**

The cost mode "array" indicates that every cost value in the response body of a (Filtered) Cost Map or an Endpoint Cost Service **MUST** be interpreted as a JSON array object.

Note that this cost mode only requires the cost value to be a JSON array of JSONValue. However, an ALTO server that enables this extension **MUST** return a JSON array of ANENAME ([Section 6.1](#)) when the cost metric is "ane-path".

## **6.6. Part Resource ID**

A Part Resource ID is encoded as a JSON string with the same format as that of the type ResourceID (Section 10.2 of [[RFC7285](#)]).

Even though the client-id assigned to a Path Vector request and the Part Resource ID **MAY** contain up to 64 characters by their own definition, their concatenation (see [Section 5.3.2](#)) **MUST** also conform to the same length constraint. The same requirement applies to the resource ID of the Path Vector resource, too. Thus, it is **RECOMMENDED** to limit the length of resource ID and client ID related to a Path Vector resource to 31 characters.

## 7. Specification: Service Extensions

### 7.1. Notations

This document uses the same syntax and notations as introduced in Section 8.2 of RFC 7285 [[RFC7285](#)] to specify the extensions to existing ALTO resources and services.

### 7.2. Multipart Filtered Cost Map for Path Vector

This document introduces a new ALTO resource called multipart Filtered Cost Map resource, which allows an ALTO server to provide other ALTO resources associated with the Cost Map resource in the same response.

#### 7.2.1. Media Type

The media type of the multipart Filtered Cost Map resource is multipart/related;type=application/alto-costmap+json.

#### 7.2.2. HTTP Method

The multipart Filtered Cost Map is requested using the HTTP POST method.

#### 7.2.3. Accept Input Parameters

The input parameters of the multipart Filtered Cost Map are supplied in the body of an HTTP POST request. This document extends the input parameters to a Filtered Cost Map, which is defined as a JSON object of type ReqFilteredCostMap in Section 11.3.2.3 of RFC 7285 [[RFC7285](#)], with a data format indicated by the media type application/alto-costmapfilter+json, which is a JSON object of type PVReqFilteredCostMap:

```
object {  
  [EntityPropertyName ane-property-names<0..*>;]  
} PVReqFilteredCostMap : ReqFilteredCostMap;
```

with fields:

**ane-property-names:** A list of selected ANE properties to be included in the response. Each property in this list MUST match one of the supported ANE properties indicated in the resource's ane-property-names capability (See [Section 7.2.4](#)). If the field is NOT present, it MUST be interpreted as an empty list.

Example: Consider the network in [Figure 1](#). If an ALTO client wants to query the max-reservable-bandwidth between PID1 and PID2, it can submit the following request.

```
POST /costmap/pv HTTP/1.1
Host: alto.example.com
Accept: multipart/related;type=application/alto-costmap+json,
       application/alto-error+json
Content-Length: 201
Content-Type: application/alto-costmapfilter+json
```

```
{
  "cost-type": {
    "cost-mode": "array",
    "cost-metric": "ane-path"
  },
  "pids": {
    "srcs": [ "PID1" ],
    "dsts": [ "PID2" ]
  },
  "ane-property-names": [ "max-reservable-bandwidth" ]
}
```

#### 7.2.4. Capabilities

The multipart Filtered Cost Map resource extends the capabilities defined in Section 11.3.2.4 of [[RFC7285](#)]. The capabilities are defined by a JSON object of type PVFilteredCostMapCapabilities:

```
object {
  [EntityPropertyName ane-property-names<0..*>;]
} PVFilteredCostMapCapabilities : FilteredCostMapCapabilities;
```

with fields:

**cost-type-names:** The cost-type-names field MUST only include the Path Vector cost type, unless explicitly documented by a future extension. This also implies that the Path Vector cost type MUST be defined in the cost-types of the Information Resource Directory's meta field.

**cost-constraints:** If the cost-type-names field includes the Path Vector cost type, cost-constraints field MUST be false or not present unless specifically instructed by a future document.

**testable-cost-type-names:** If the cost-type-names field includes the Path Vector cost type, the Path Vector cost type MUST NOT be included in the testable-cost-type-names field unless specifically instructed by a future document.

**ane-property-names:** Defines a list of ANE properties that can be returned. If the field is NOT present, it MUST be interpreted as an empty list, indicating the ALTO server cannot provide any ANE property.

#### 7.2.5. Uses

This member MUST include the resource ID of the network map based on which the PIDs are defined. If this resource supports persistent-entity-id, it MUST also include the defining resources of persistent ANEs that may appear in the response.

#### 7.2.6. Response

The response MUST indicate an error, using ALTO protocol error handling, as defined in Section 8.5 of [\[RFC7285\]](#), if the request is invalid.

The "Content-Type" header of the response MUST be multipart/related as defined by [\[RFC2387\]](#) with the following parameters:

**type:** The type parameter MUST be "application/alto-costmap+json". Note that [\[RFC2387\]](#) permits both parameters with and without the double quotes.

**start:** The start parameter is as defined in [\[RFC2387\]](#). If present, it MUST have the same value as the Content-ID header of the Path Vector part.

**boundary:** The boundary parameter is as defined in [\[RFC2387\]](#).

The body of the response MUST consist of two parts:

\*The Path Vector part MUST include Content-ID and Content-Type in its header. The value of Content-ID MUST have the format of a Part Resource ID. The Content-Type MUST be application/alto-costmap+json.

The body of the Path Vector part MUST be a JSON object with the same format as defined in Section 11.2.3.6 of [\[RFC7285\]](#). The JSON object MUST include the vtag field in the meta field, which provides the version tag of the returned CostMapData. The resource ID of the version tag MUST follow the format of

resource-id '.' part-resource-id

where resource-id is the resource Id of the Path Vector resource, and part-resource-id has the same value as the Content-ID of the Path Vector part. The meta field MUST also include the dependent-vtags field, whose value is a single-element array to indicate the version tag of the network map used, where the network map is specified in the uses attribute of the multipart Filtered Cost Map resource in IRD.

\*The Unified Property Map part MUST also include Content-ID and Content-Type in its header. The value of Content-ID has the format of a Part Resource ID. The Content-Type MUST be application/alto-propmap+json.

The body of the Unified Property Map part is a JSON object with the same format as defined in Section 4.6 of [[I-D.ietf-alto-unified-props-new](#)]. The JSON object MUST include the dependent-vtags field in the meta field. The value of the dependent-vtags field MUST be an array of VersionTag objects as defined by Section 10.3 of [[RFC7285](#)]. The vtag of the Path Vector part MUST be included in the dependent-vtags. If persistent-entity-id is requested, the version tags of the dependent resources that MAY expose the entities in the response MUST also be included.

The PropertyMapData has one member for each ANENAME that appears in the Path Vector part, which is an entity identifier belonging to the self-defined entity domain as defined in Section 5.1.2.3 of [[I-D.ietf-alto-unified-props-new](#)]. The EntityProps for each ANE has one member for each property that is both 1) associated with the ANE, and 2) specified in the ane-property-names in the request.

A complete and valid response MUST include both the Path Vector part and the Property Map part in the multipart message. If any part is NOT present, the client MUST discard the received information and send another request if necessary.

According to [[RFC2387](#)], the Path Vector part, whose media type is the same as the type parameter of the multipart response message, is the root object. Thus, it is the element the application processes first. Even though the start parameter allows it to be placed anywhere in the part sequence, it is RECOMMENDED that the parts arrive in the same order as they are processed, i.e., the Path Vector part is always put as the first part, followed by the Property Map part. When doing so, an ALTO server MAY choose to NOT set the start parameter, which implies the first part is the root object.

Example: Consider the network in [Figure 1](#). The response of the example request in [Section 7.2.3](#) is as follows, where ANE1 represents the aggregation of all the switches in the network.

HTTP/1.1 200 OK  
Content-Length: 821  
Content-Type: multipart/related; boundary=example-1;  
type=application/alto-costmap+json

--example-1

Content-ID: costmap  
Content-Type: application/alto-costmap+json

```
{
  "meta": {
    "vtag": {
      "resource-id": "filtered-cost-map-pv.costmap",
      "tag": "d827f484cb66ce6df6b5077cb8562b0a"
    },
    "dependent-vtags": [
      {
        "resource-id": "my-default-networkmap",
        "tag": "75ed013b3cb58f896e839582504f6228"
      }
    ],
    "cost-type": { "cost-mode": "array", "cost-metric": "ane-path" },
    "cost-map": {
      "PID1": { "PID2": ["ANE1"] }
    }
  }
}
```

--example-1

Content-ID: propmap  
Content-Type: application/alto-propmap+json

```
{
  "meta": {
    "dependent-vtags": [
      {
        "resource-id": "filtered-cost-map-pv.costmap",
        "tag": "d827f484cb66ce6df6b5077cb8562b0a"
      }
    ]
  },
  "property-map": {
    ".ane:ANE1": { "max-reservable-bandwidth": 1000000000 }
  }
}
```

### 7.3. Multipart Endpoint Cost Service for Path Vector

This document introduces a new ALTO resource called multipart Endpoint Cost Service, which allows an ALTO server to provide other



ALTO resources associated with the Endpoint Cost Service resource in the same response.

#### 7.3.1. Media Type

The media type of the multipart Endpoint Cost Service resource is multipart/related;type=application/alto-endpointcost+json.

#### 7.3.2. HTTP Method

The multipart Endpoint Cost Service resource is requested using the HTTP POST method.

#### 7.3.3. Accept Input Parameters

The input parameters of the multipart Endpoint Cost Service resource are supplied in the body of an HTTP POST request. This document extends the input parameters to an Endpoint Cost Service, which is defined as a JSON object of type ReqEndpointCost in Section 11.5.1.3 in RFC 7285 [[RFC7285](#)], with a data format indicated by the media type application/alto-endpointcostparams+json, which is a JSON object of type PVReqEndpointCost:

```
object {  
  [EntityPropertyName ane-property-names<0..*>;]  
} PVReqEndpointcost : ReqEndpointcost;
```

with fields:

**ane-property-names:** This document defines the ane-property-names in PVReqEndpointcost as the same as in PVReqFilteredCostMap. See [Section 7.2.3](#).

Example: Consider the network in [Figure 1](#). If an ALTO client wants to query the max-reservable-bandwidth between eh1 and eh2, it can submit the following request.

```
POST /ecs/pv HTTP/1.1
Host: alto.example.com
Accept: multipart/related;type=application/alto-endpointcost+json,
       application/alto-error+json
Content-Length: 222
Content-Type: application/alto-endpointcostparams+json
```

```
{
  "cost-type": {
    "cost-mode": "array",
    "cost-metric": "ane-path"
  },
  "endpoints": {
    "srcs": [ "ipv4:192.0.2.2" ],
    "dsts": [ "ipv4:192.0.2.18" ]
  },
  "ane-property-names": [ "max-reservable-bandwidth" ]
}
```

#### 7.3.4. Capabilities

The capabilities of the multipart Endpoint Cost Service resource are defined by a JSON object of type `PVEndpointCostCapabilities`, which is defined as the same as `PVFilteredCostMapCapabilities`. See [Section 7.2.4](#).

#### 7.3.5. Uses

If this resource supports `persistent-entity-id`, it MUST also include the defining resources of persistent ANEs that may appear in the response.

#### 7.3.6. Response

The response MUST indicate an error, using ALTO protocol error handling, as defined in Section 8.5 of [\[RFC7285\]](#), if the request is invalid.

The "Content-Type" header of the response MUST be `multipart/related` as defined by [\[RFC7285\]](#) with the following parameters:

**type:** The type parameter MUST be `"application/alto-endpointcost+json"`.

**start:** The start parameter is as defined in [Section 7.2.6](#).

**boundary:** The boundary parameter is as defined in [\[RFC2387\]](#).

The body MUST consist of two parts:

\*The Path Vector part MUST include Content-ID and Content-Type in its header. The value of Content-ID MUST have the format of a Part Resource ID. The Content-Type MUST be application/alto-endpointcost+json.

The body of the Path Vector part MUST be a JSON object with the same format as defined in Section 11.5.1.6 of [\[RFC7285\]](#). The JSON object MUST include the vtag field in the meta field, which provides the version tag of the returned EndpointCostMapData. The resource ID of the version tag MUST follow the format of

resource-id '.' part-resource-id

where resource-id is the resource ID of the Path Vector resource, and part-resource-id has the same value as the Content-ID of the Path Vector part.

\*The Unified Property Map part MUST also include Content-ID and Content-Type in its header. The value of Content-ID MUST have the format of a Part Resource ID. The Content-Type MUST be application/alto-propmap+json.

The body of the Unified Property Map part MUST be a JSON object with the same format as defined in Section 4.6 of [\[I-D.ietf-alto-unified-props-new\]](#). The JSON object MUST include the dependent-vtags field in the meta field. The value of the dependent-vtags field MUST be an array of VersionTag objects as defined by Section 10.3 of [\[RFC7285\]](#). The vtag of the Path Vector part MUST be included in the dependent-vtags. If persistent-entity-id is requested, the version tags of the dependent resources that MAY expose the entities in the response MUST also be included.

The PropertyMapData has one member for each ANENAME that appears in the Path Vector part, which is an entity identifier belonging to the self-defined entity domain as defined in Section 5.1.2.3 of [\[I-D.ietf-alto-unified-props-new\]](#). The EntityProps for each ANE has one member for each property that is both 1) associated with the ANE, and 2) specified in the ane-property-names in the request.

A complete and valid response MUST include both the Path Vector part and the Property Map part in the multipart message. If any part is NOT present, the client MUST discard the received information and send another request if necessary.

According to [\[RFC2387\]](#), the Path Vector part, whose media type is the same as the type parameter of the multipart response message, is the root object. Thus, it is the element the application processes

first. Even though the start parameter allows it to be placed anywhere in the part sequence, it is RECOMMENDED that the parts arrive in the same order as they are processed, i.e., the Path Vector part is always put as the first part, followed by the Property Map part. When doing so, an ALTO server MAY choose to NOT set the start parameter, which implies the first part is the root object.

Example: Consider the network in [Figure 1](#). The response of the example request in [Section 7.3.3](#) is as follows.

HTTP/1.1 200 OK  
Content-Length: 810  
Content-Type: multipart/related; boundary=example-1;  
type=application/alto-endpointcost+json

--example-1

Content-ID: ecs

Content-Type: application/alto-endpointcost+json

```
{
  "meta": {
    "vtag": {
      "resource-id": "ecs-pv.costmap",
      "tag": "d827f484cb66ce6df6b5077cb8562b0a"
    },
    "dependent-vtags": [
      {
        "resource-id": "my-default-networkmap",
        "tag": "75ed013b3cb58f896e839582504f6228"
      }
    ],
    "cost-type": { "cost-mode": "array", "cost-metric": "ane-path" },
    "cost-map": {
      "ipv4:192.0.2.2": { "ipv4:192.0.2.18": ["ANE1"] }
    }
  }
}
```

--example-1

Content-ID: propmap

Content-Type: application/alto-propmap+json

```
{
  "meta": {
    "dependent-vtags": [
      {
        "resource-id": "ecs-pv.costmap",
        "tag": "d827f484cb66ce6df6b5077cb8562b0a"
      }
    ]
  },
  "property-map": {
    ".ane:ANE1": { "max-reservable-bandwidth": 100000000 }
  }
}
```

## 8. Examples

This section lists some examples of Path Vector queries and the corresponding responses. Some long lines are truncated for better readability.

### 8.1. Example: Information Resource Directory

To give a comprehensive example of the extension defined in this document, we consider the network in [Figure 5](#). Assume that the ALTO server provides the following information resources:

\*my-default-networkmap: A Network Map resource which contains the PIDs in the network.

\*filtered-cost-map-pv: A Multipart Filtered Cost Map resource for Path Vector, which exposes the max-reservable-bandwidth property for the PIDs in my-default-networkmap.

\*ane-props: A filtered Unified Property resource that exposes the information for persistent ANEs in the network.

\*endpoint-cost-pv: A Multipart Endpoint Cost Service for Path Vector, which exposes the max-reservable-bandwidth and the persistent-entity-id properties.

\*update-pv: An Update Stream service, which provides the incremental update service for the endpoint-cost-pv service.

Below is the Information Resource Directory of the example ALTO server. To enable the extension defined in this document, the path-vector cost type ([Section 6.5](#)) is defined in the cost-types of the meta field, and is included in the cost-type-names of resources filtered-cost-map-pv and endpoint-cost-pv.

```

{
  "meta": {
    "cost-types": {
      "path-vector": {
        "cost-mode": "array",
        "cost-metric": "ane-path"
      }
    }
  },
  "resources": {
    "my-default-networkmap": {
      "uri" : "https://alto.example.com/networkmap",
      "media-type" : "application/alto-networkmap+json"
    },
    "filtered-cost-map-pv": {
      "uri": "https://alto.example.com/costmap/pv",
      "media-type": "multipart/related;
                    type=application/alto-costmap+json",
      "accepts": "application/alto-costmapfilter+json",
      "capabilities": {
        "cost-type-names": [ "path-vector" ],
        "ane-property-names": [ "max-reservable-bandwidth" ]
      },
      "uses": [ "my-default-networkmap" ]
    },
    "ane-props": {
      "uri": "https://alto.example.com/ane-props",
      "media-type": "application/alto-propmap+json",
      "accepts": "application/alto-propmapparams+json",
      "capabilities": {
        "mappings": {
          ".ane": [ "cpu" ]
        }
      }
    },
    "endpoint-cost-pv": {
      "uri": "https://alto.exmaple.com/endpointcost/pv",
      "media-type": "multipart/related;
                    type=application/alto-endpointcost+json",
      "accepts": "application/alto-endpointcostparams+json",
      "capabilities": {
        "cost-type-names": [ "path-vector" ],
        "ane-property-names": [
          "max-reservable-bandwidth", "persistent-entity-id"
        ]
      },
      "uses": [ "ane-props" ]
    },
    "update-pv": {

```

```
    "uri": "https://alto.example.com/updates/pv",
    "media-type": "text/event-stream",
    "uses": [ "endpoint-cost-pv" ],
    "accepts": "application/alto-updatestreamparams+json",
    "capabilities": {
      "support-stream-control": true
    }
  }
}
```



## 8.2. Example: Multipart Filtered Cost Map

The following examples demonstrate the request to the filtered-cost-map-pv resource and the corresponding response.

The request uses the "path-vector" cost type in the cost-type field. The ane-property-names field is missing, indicating that the client only requests for the Path Vector but not the ANE properties.

The response consists of two parts. The first part returns the array of ANEName for each source and destination pair. There are two ANEs, where L1 represents the interconnection link L1, and L2 represents the interconnection link L2.

The second part returns an empty Property Map. Note that the ANE entries are omitted since they have no properties (See Section 3.1 of [\[I-D.ietf-alto-unified-props-new\]](#)).

```
POST /costmap/pv HTTP/1.1
Host: alto.example.com
Accept: multipart/related;type=application/alto-costmap+json,
       application/alto-error+json
Content-Length: 153
Content-Type: application/alto-costmapfilter+json
```

```
{
  "cost-type": {
    "cost-mode": "array",
    "cost-metric": "ane-path"
  },
  "pids": {
    "srcs": [ "PID1" ],
    "dsts": [ "PID3", "PID4" ]
  }
}
```

HTTP/1.1 200 OK  
Content-Length: 818  
Content-Type: multipart/related; boundary=example-1;  
type=application/alto-costmap+json

--example-1

Content-ID: costmap

Content-Type: application/alto-costmap+json

```
{
  "meta": {
    "vtag": {
      "resource-id": "filtered-cost-map-pv.costmap",
      "tag": "d827f484cb66ce6df6b5077cb8562b0a"
    },
    "dependent-vtags": [
      {
        "resource-id": "my-default-networkmap",
        "tag": "75ed013b3cb58f896e839582504f6228"
      }
    ],
    "cost-type": {
      "cost-mode": "array",
      "cost-metric": "ane-path"
    }
  },
  "cost-map": {
    "PID1": {
      "PID3": [ "L1" ],
      "PID4": [ "L1", "L2" ]
    }
  }
}
```

--example-1

Content-ID: propmap

Content-Type: application/alto-propmap+json

```
{
  "meta": {
    "dependent-vtags": [
      {
        "resource-id": "filtered-cost-map-pv.costmap",
        "tag": "d827f484cb66ce6df6b5077cb8562b0a"
      }
    ]
  },
  "property-map": {
  }
}
```

### 8.3. Example: Multipart Endpoint Cost Service Resource

The following examples demonstrate the request to the endpoint-cost-pv resource and the corresponding response.

The request uses the Path Vector cost type in the cost-type field, and queries the Maximum Reservable Bandwidth ANE property and the Persistent Entity property for two source and destination pairs: 192.0.2.34 -> 192.0.2.2 and 192.0.2.34 -> 192.0.2.50.

The response consists of two parts. The first part returns the array of ANENAME for each valid source and destination pair. As one can see in [Figure 5](#), flow 192.0.2.34 -> 192.0.2.2 traverses NET2, L1 and NET1, and flow 192.0.2.34 -> 192.0.2.50 traverses NET2, L2 and NET3.

The second part returns the requested properties of ANEs. Assume NET1, NET2 and NET3 has sufficient bandwidth and their max-reservable-bandwidth values are set to a sufficiently large number (50 Gbps in this case). On the other hand, assume there are no prior reservation on L1 and L2, and their max-reservable-bandwidth values are the corresponding link capacity (10 Gbps for L1 and 15 Gbps for L2).

Both NET1 and NET2 have a mobile edge deployed, i.e., MEC1 in NET1 and MEC2 in NET2. Assume the ANENAME for MEC1 and MEC2 are MEC1 and MEC2 and their properties can be retrieved from the Property Map ane-props. Thus, the persistent-entity-id property of NET1 and NET3 are ane-props.ane:MEC1 and ane-props.ane:MEC2 respectively.

```
POST /endpointcost/pv HTTP/1.1
Host: alto.example.com
Accept: multipart/related;
      type=application/alto-endpointcost+json,
      application/alto-error+json
Content-Length: 278
Content-Type: application/alto-endpointcostparams+json
```

```
{
  "cost-type": {
    "cost-mode": "array",
    "cost-metric": "ane-path"
  },
  "endpoints": {
    "srcs": [ "ipv4:192.0.2.34" ],
    "dsts": [ "ipv4:192.0.2.2", "ipv4:192.0.2.50" ]
  },
  "ane-property-names": [
    "max-reservable-bandwidth",
    "persistent-entity-id"
  ]
}
```

HTTP/1.1 200 OK  
Content-Length: 1305  
Content-Type: multipart/related; boundary=example-2;  
type=application/alto-endpointcost+json

--example-2

Content-ID: ecs

Content-Type: application/alto-endpointcost+json

```
{
  "meta": {
    "vtags": {
      "resource-id": "endpoint-cost-pv.ecs",
      "tag": "bb6bb72eafe8f9bdc4f335c7ed3b10822a391cef"
    },
    "cost-type": {
      "cost-mode": "array",
      "cost-metric": "ane-path"
    }
  },
  "endpoint-cost-map": {
    "ipv4:192.0.2.34": {
      "ipv4:192.0.2.2": [ "NET3", "L1", "NET1" ],
      "ipv4:192.0.2.50": [ "NET3", "L2", "NET2" ]
    }
  }
}
```

--example-2

Content-ID: propmap

Content-Type: application/alto-propmap+json

```
{
  "meta": {
    "dependent-vtags": [
      {
        "resource-id": "endpoint-cost-pv.ecs",
        "tag": "bb6bb72eafe8f9bdc4f335c7ed3b10822a391cef"
      },
      {
        "resource-id": "ane-props",
        "tag": "bf3c8c1819d2421c9a95a9d02af557a3"
      }
    ]
  },
  "property-map": {
    ".ane:NET1": {
      "max-reservable-bandwidth": 50000000000,
      "persistent-entity-id": "ane-props.ane:MEC1"
    }
  },
}
```

```
    ".ane:NET2": {  
      "max-reservable-bandwidth": 50000000000,  
      "persistent-entity-id": "ane-props.ane:MEC2"  
    },  
    ".ane:NET3": {  
      "max-reservable-bandwidth": 50000000000  
    },  
    ".ane:L1": {  
      "max-reservable-bandwidth": 10000000000  
    },  
    ".ane:L2": {  
      "max-reservable-bandwidth": 15000000000  
    }  
  }  
}
```

As mentioned in [Section 6.5.1](#), an advanced ALTO server may obfuscate the response in order to preserve its own privacy or conform to its own policies. For example, an ALTO server may choose to aggregate NET1 and L1 as a new ANE with ANE name AGGR1, and aggregate NET2 and L2 as a new ANE with ANE name AGGR2. The max-reservable-bandwidth of AGGR1 takes the value of L1, which is smaller than that of NET1, and the persistent-entity-id of AGGR1 takes the value of NET1. The properties of AGGR2 are computed in a similar way and the obfuscated response is as shown below. Note that the obfuscation of Path Vector responses is implementation-specific and is out of the scope of this document, and developers may refer to [Section 11](#) for further references.

HTTP/1.1 200 OK  
Content-Length: 1157  
Content-Type: multipart/related; boundary=example-2;  
type=application/alto-endpointcost+json

--example-2

Content-ID: ecs

Content-Type: application/alto-endpointcost+json

```
{
  "meta": {
    "vtags": {
      "resource-id": "endpoint-cost-pv.ecs",
      "tag": "bb6bb72eafe8f9bdc4f335c7ed3b10822a391cef"
    },
    "cost-type": {
      "cost-mode": "array",
      "cost-metric": "ane-path"
    }
  },
  "endpoint-cost-map": {
    "ipv4:192.0.2.34": {
      "ipv4:192.0.2.2": [ "NET3", "AGGR1" ],
      "ipv4:192.0.2.50": [ "NET3", "AGGR2" ]
    }
  }
}
```

--example-2

Content-ID: propmap

Content-Type: application/alto-propmap+json

```
{
  "meta": {
    "dependent-vtags": [
      {
        "resource-id": "endpoint-cost-pv.ecs",
        "tag": "bb6bb72eafe8f9bdc4f335c7ed3b10822a391cef"
      },
      {
        "resource-id": "ane-props",
        "tag": "bf3c8c1819d2421c9a95a9d02af557a3"
      }
    ]
  },
  "property-map": {
    ".ane:AGGR1": {
      "max-reservable-bandwidth": 10000000000,
      "persistent-entity-id": "ane-props.ane:MEC1"
    }
  },
}
```



```
    ".ane:AGGR2": {  
      "max-reservable-bandwidth": 15000000000,  
      "persistent-entity-id": "ane-props.ane:MEC2"  
    },  
    ".ane:NET3": {  
      "max-reservable-bandwidth": 50000000000  
    }  
  }  
}
```

#### 8.4. Example: Incremental Updates

In this example, an ALTO client subscribes to the incremental update for the multipart Endpoint Cost Service resource endpoint-cost-pv.

```
POST /updates/pv HTTP/1.1
Host: alto.example.com
Accept: text/event-stream
Content-Type: application/alto-updatestreamparams+json
Content-Length: 112
```

```
{
  "add": {
    "ecspvsub1": {
      "resource-id": "endpoint-cost-pv",
      "input": <ecs-input>
    }
  }
}
```

Based on the server-side process defined in [\[RFC8895\]](#), the ALTO server will send the control-uri first using Server-Sent Event (SSE), followed by the full response of the multipart message.

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Type: text/event-stream
```

```
event: application/alto-updatestreamcontrol+json
data: {"control-uri": "https://alto.example.com/updates/streams/123"}
```

```
event: multipart/related;boundary=example-3;
      type=application/alto-endpointcost+json,ecspvsub1
data: --example-3
data: Content-ID: ecsmap
data: Content-Type: application/alto-endpointcost+json
data:
data: <endpoint-cost-map-entry>
data: --example-3
data: Content-ID: propmap
data: Content-Type: application/alto-propmap+json
data:
data: <property-map-entry>
data: --example-3--
```

When the contents change, the ALTO server will publish the updates for each node in this tree separately.

event: application/merge-patch+json, ecspvsub1.ecsmap  
data: <Merge patch for endpoint-cost-map-update>

event: application/merge-patch+json, ecspvsub1.propmap  
data: <Merge patch for property-map-update>

## **9. Compatibility with Other ALTO Extensions**

### **9.1. Compatibility with Legacy ALTO Clients/Servers**

The multipart Filtered Cost Map resource and the multipart Endpoint Cost Service resource has no backward compatibility issue with legacy ALTO clients and servers. Although these two types of resources reuse the media types defined in the base ALTO protocol for the accept input parameters, they have different media types for responses. If the ALTO server provides these two types of resources, but the ALTO client does not support them, the ALTO client will ignore the resources without incurring any incompatibility problem.

### **9.2. Compatibility with Multi-Cost Extension**

The extension defined in this document is NOT compatible with the multi-cost extension [[RFC8189](#)]. The reason is that if a resource supports both the extension defined in this document and the multi-cost extension, the media type of this resource depends on the selection of cost types: if the Path Vector cost type is selected, the media type of the response is either multipart/related; type=application/alto-costmap+json or multipart/related; type=application/alto-endpointcost+json; if the Path Vector cost type is not selected, the media type of the response is either application/alto-costmap+json or application/alto-endpointcost+json. Thus, there can be multiple media types associated with the information resource, which is not compatible with [[RFC7285](#)] (Section 9.1.2).

Note that this problem may happen when an ALTO information resource supports multiple cost types, even if it does not enable the multi-cost extension. Thus, [Section 7.2.4](#) has specified that if an ALTO information resource enables the extension defined in this document, the Path Vector cost type MUST be the only cost type in the cost-type-names capability of this resource.

### **9.3. Compatibility with Incremental Update**

ALTO clients and servers MUST follow the specifications given in Section 5.2 of [[RFC8895](#)] to support incremental updates for a Path Vector resource.

## 9.4. Compatibility with Cost Calendar

The extension specified in this document is compatible with the Cost Calendar extension [[RFC8896](#)]. When used together with the Cost Calendar extension, the cost value between a source and a destination is an array of Path Vectors, where the k-th Path Vector refers to the abstract network paths traversed in the k-th time interval by traffic from the source to the destination.

When used with time-varying properties, e.g., maximum reservable bandwidth (maxresbw), a property of a single ANE may also have different values in different time intervals. In this case, if such an ANE has different property values in two time intervals, it MUST be treated as two different ANEs, i.e., with different entity identifiers. However, if it has the same property values in two time intervals, it MAY use the same identifier.

This rule allows the Path Vector extension to represent both changes of ANEs and changes of the ANEs' properties in a uniform way. The Path Vector part is calendared in a compatible way, and the Property Map part is not affected by the calendar extension.

The two extensions combined together can provide the historical network correlation information for a set of source and destination pairs. A network broker or client may use this information to derive other resource requirements such as Time-Block-Maximum Bandwidth, Bandwidth-Sliding-Window, and Time-Bandwidth-Product (TBP) (See [[SENSE](#)] for details).

## 10. General Discussions

### 10.1. Constraint Tests for General Cost Types

The constraint test is a simple approach to query the data. It allows users to filter the query result by specifying some boolean tests. This approach is already used in the ALTO protocol. [[RFC7285](#)] and [[RFC8189](#)] allow ALTO clients to specify the constraints and or-constraints tests to better filter the result.

However, the current syntax can only be used to test scalar cost types, and cannot easily express constraints on complex cost types, e.g., the Path Vector cost type defined in this document.

In practice, developing a bespoke language for general-purpose boolean tests can be a complex undertaking, and it is conceivable that there are some existing implementations already (the authors have not done an exhaustive search to determine whether there are such implementations). One avenue to develop such a language may be to explore extending current query languages like XQuery [[XQuery](#)] or JSONiq [[JSONiq](#)] and integrating these with ALTO.

Filtering the Path Vector results or developing a more sophisticated filtering mechanism is beyond the scope of this document.

## **10.2. General Multi-Resource Query**

Querying multiple ALTO information resources continuously is a general requirement. Enabling such a capability, however, must address general issues like efficiency and consistency. The incremental update extension [[RFC8895](#)] supports submitting multiple queries in a single request, and allows flexible control over the queries. However, it does not cover the case introduced in this document where multiple resources are needed for a single request.

This extension gives an example of using a multipart message to encode the responses from two specific ALTO information resources: a Filtered Cost Map or an Endpoint Cost Service, and a Property Map. By packing multiple resources in a single response, the implication is that servers may proactively push related information resources to clients.

Thus, it is worth looking into the direction of extending the SSE mechanism as used in the incremental update extension [[RFC8895](#)], or upgrading to HTTP/2 [[RFC7540](#)] and HTTP/3 [[I-D.ietf-quic-http](#)], which provides the ability to multiplex queries and to allow servers proactively send related information resources.

Defining a general multi-resource query mechanism is out of the scope of this document.

## **11. Security Considerations**

This document is an extension of the base ALTO protocol, so the Security Considerations [[RFC7285](#)] of the base ALTO protocol fully apply when this extension is provided by an ALTO server.

The Path Vector extension requires additional scrutiny on three security considerations discussed in the base protocol: confidentiality of ALTO information (Section 15.3 of [[RFC7285](#)]), potential undesirable guidance from authenticated ALTO information (Section 15.2 of [[RFC7285](#)]), and availability of ALTO service (Section 15.5 of [[RFC7285](#)]).

For confidentiality of ALTO information, a network operator should be aware of that this extension may introduce a new risk: the Path Vector information may make network attacks easier. For example, as the Path Vector information may reveal more fine-grained internal network structures than the base protocol, an ALTO client may detect the bottleneck link and start a distributed denial-of-service (DDoS) attack involving minimal flows to conduct the in-network congestion.

To mitigate this risk, the ALTO server should consider protection mechanisms to reduce information exposure or obfuscate the real information, in particular, in settings where the network and the application do not belong to the same trust domain. For example, in the multi-flow bandwidth reservation use case as introduced in [Section 4](#), only the available bandwidth of the shared bottleneck link is crucial, and the ALTO server may only preserve the critical bottlenecks and can change the order of links appearing in the Path Vector response.

However, arbitrary reduction and obfuscation of information exposure may potentially introduce a risk on the integrity of the ALTO information, leading to infeasible or suboptimal decisions of ALTO clients,

To mitigate this risk, if an ALTO client finds that the traffic distribution based on the Path Vector information is not feasible (e.g., causing constant congestion) or not better than a distribution which does not fully conform to the information (e.g., by randomly choosing the source/destination for certain flows), it can follow the protection strategies for potential undesirable guidance from authenticated ALTO information, specified in Section 15.2.2 of RFC 7285 [[RFC7285](#)]. While repeatedly sending the same query can potentially detect the integrity problem for certain obfuscation methods (e.g., those based on time or randomness) under certain network conditions (e.g., where the routing and ANE properties are stable), an ALTO client must be aware that this behavior may be considered as a denial-of-service attack on the server and may lead to the rejection of further requests from the client.

On the other hand, this risk can also be mitigated from the server side. While the implementation of an ALTO server is beyond the scope of this document, implementations of ALTO servers involving reduction or obfuscation of the Path Vector information should consider reduction/obfuscation mechanisms that can preserve the integrity of ALTO information, for example, by using minimal feasible region compression algorithms [[TON2019](#)] or obfuscation protocols [[SC2018](#)][[JSAC2019](#)].

For availability of ALTO service, an ALTO server should be cognizant that using Path Vector extension might have a new risk: frequent requesting for Path Vectors might consume intolerable amounts of the server-side computation and storage, which can break the ALTO server. For example, if an ALTO server implementation dynamically computes the Path Vectors for each request, the service providing Path Vectors may become an entry point for denial-of-service attacks on the availability of an ALTO server.

To mitigate this risk, an ALTO server may consider using optimizations such as precomputation-and-projection mechanisms [JSAC2019] to reduce the overhead for processing each query. Also, an ALTO server may also protect itself from malicious clients by monitoring the behaviors of clients and stopping serving clients with suspicious behaviors (e.g., sending requests at a high frequency).

## 12. IANA Considerations

### 12.1. ALTO Entity Domain Type Registry

This document registers a new entry to the ALTO Domain Entity Type Registry, as instructed by Section 12.2 of [I-D.ietf-alto-unified-props-new]. The new entry is as shown below in Table 1.

Identifier	Entity Address Encoding	Hierarchy & Inheritance
ane	See <a href="#">Section 6.2.2</a>	None

Table 1: ALTO Entity Domain Type Registry

**Identifier:** See [Section 6.2.1](#).

**Entity Identifier Encoding:** See [Section 6.2.2](#).

**Hierarchy:** None

**Inheritance:** None

**Media Type of Defining Resource:** See [Section 6.2.4](#).

**Security Considerations:** In some usage scenarios, ANE addresses carried in ALTO Protocol messages may reveal information about an ALTO client or an ALTO service provider. Applications and ALTO service providers using addresses of ANEs will be made aware of how (or if) the addressing scheme relates to private information and network proximity, in further iterations of this document.

### 12.2. ALTO Entity Property Type Registry

Two initial entries are registered to the ALTO Domain ane in the ALTO Entity Property Type Registry, as instructed by Section 12.3 of [I-D.ietf-alto-unified-props-new]. The two new entries are shown below in Table 2.

Identifier	Intended Semantics
max-reservable-bandwidth	See <a href="#">Section 6.4.1</a>
persistent-entity-id	See <a href="#">Section 6.4.2</a>

Table 2: Initial Entries for ane Domain in the  
ALTO Entity Property Types Registry

### 13. Acknowledgments

The authors would like to thank discussions with Andreas Voellmy, Erran Li, Haibin Song, Haizhou Du, Jiayuan Hu, Qiao Xiang, Tianyuan Liu, Xiao Shi, Xin Wang, and Yan Luo. The authors thank Greg Bernstein (Grotto Networks), Dawn Chen (Tongji University), Wendy Roome, and Michael Scharf for their contributions to earlier drafts.

### 14. References

#### 14.1. Normative References

- [I-D.ietf-alto-unified-props-new] Roome, W., Randriamasy, S., Yang, Y. R., Zhang, J. J., and K. Gao, "ALTO Extension: Entity Property Maps", Work in Progress, Internet-Draft, draft-ietf-alto-unified-props-new-17, 16 April 2021, <<https://datatracker.ietf.org/doc/html/draft-ietf-alto-unified-props-new-17>>.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<https://www.rfc-editor.org/rfc/rfc2119>>.
- [RFC2387] Levinson, E., "The MIME Multipart/Related Content-type", RFC 2387, DOI 10.17487/RFC2387, August 1998, <<https://www.rfc-editor.org/rfc/rfc2387>>.
- [RFC7285] Alimi, R., Ed., Penno, R., Ed., Yang, Y., Ed., Kiesel, S., Previdi, S., Roome, W., Shalunov, S., and R. Woundy, "Application-Layer Traffic Optimization (ALTO) Protocol", RFC 7285, DOI 10.17487/RFC7285, September 2014, <<https://www.rfc-editor.org/rfc/rfc7285>>.
- [RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <<https://www.rfc-editor.org/rfc/rfc8174>>.
- [RFC8189] Randriamasy, S., Roome, W., and N. Schwan, "Multi-Cost Application-Layer Traffic Optimization (ALTO)", RFC 8189, DOI 10.17487/RFC8189, October 2017, <<https://www.rfc-editor.org/rfc/rfc8189>>.
- [RFC8895] Roome, W. and Y. Yang, "Application-Layer Traffic Optimization (ALTO) Incremental Updates Using Server-Sent Events (SSE)", RFC 8895, DOI 10.17487/RFC8895, November 2020, <<https://www.rfc-editor.org/rfc/rfc8895>>.



**[RFC8896]**

Randriamasy, S., Yang, R., Wu, Q., Deng, L., and N. Schwan, "Application-Layer Traffic Optimization (ALTO) Cost Calendar", RFC 8896, DOI 10.17487/RFC8896, November 2020, <<https://www.rfc-editor.org/rfc/rfc8896>>.

**14.2. Informative References**

**[AAAI2019]** Xiang, Q., Yu, H., Aspnes, J., Le, F., Kong, L., and Y.R. Yang, "Optimizing in the dark: Learning an optimal solution through a simple request interface", Proceedings of the AAAI Conference on Artificial Intelligence 33, 1674-1681, 2019.

**[I-D.contreras-alto-service-edge]** Contreras, L. M., Lachos, D. A., Rothenberg, C. E., and S. Randriamasy, "Use of ALTO for Determining Service Edge", Work in Progress, Internet-Draft, draft-contreras-alto-service-edge-03, 12 July 2021, <<https://datatracker.ietf.org/doc/html/draft-contreras-alto-service-edge-03>>.

**[I-D.huang-alto-mowie-for-network-aware-app]** Xiong, C., Zhang, Y., Yang, Y. R., Li, G., Lei, Y., and Y. Han, "MoWIE for Network Aware Application", Work in Progress, Internet-Draft, draft-huang-alto-mowie-for-network-aware-app-03, 12 July 2021, <<https://datatracker.ietf.org/doc/html/draft-huang-alto-mowie-for-network-aware-app-03>>.

**[I-D.ietf-alto-performance-metrics]**

Wu, Q., Yang, Y. R., Lee, Y., Dhody, D., Randriamasy, S., and L. M. C. Murillo, "ALTO Performance Cost Metrics", Work in Progress, Internet-Draft, draft-ietf-alto-performance-metrics-17, 27 July 2021, <<https://datatracker.ietf.org/doc/html/draft-ietf-alto-performance-metrics-17>>.

**[I-D.ietf-dmm-5g-uplane-analysis]** Homma, S., Miyasaka, T., Matsushima, S., and D. Voyer, "User Plane Protocol and Architectural Analysis on 3GPP 5G System", Work in Progress, Internet-Draft, draft-ietf-dmm-5g-uplane-analysis-04, 2 November 2020, <<https://datatracker.ietf.org/doc/html/draft-ietf-dmm-5g-uplane-analysis-04>>.

**[I-D.ietf-quic-http]** Bishop, M., "Hypertext Transfer Protocol Version 3 (HTTP/3)", Work in Progress, Internet-Draft, draft-ietf-quic-http-34, 2 February 2021, <<https://datatracker.ietf.org/doc/html/draft-ietf-quic-http-34>>.

**[I-D.yang-alto-deliver-functions-over-networks]**

Yang, S., Cui, L., Xu, M., Yang, Y., and R. Huang,  
"Delivering Functions over Networks: Traffic and  
Performance Optimization for Edge Computing using ALTO",  
Work in Progress, Internet-Draft, draft-yang-alto-  
deliver-functions-over-networks-01, 13 July 2020,  
<<https://datatracker.ietf.org/doc/html/draft-yang-alto-deliver-functions-over-networks-01>>.

**[JSAC2019]** Xiang, Q., Zhang, J., Wang, X., Liu, Y., Guok, C., Le, F., MacAuley, J., Newman, H., and Y.R. Yang, "Toward Fine-Grained, Privacy-Preserving, Efficient Multi-Domain Network Resource Discovery", IEEE/ACM IEEE Journal on Selected Areas of Communication 37(8): 1924-1940, 2019.

**[JSONiq]** "The JSON Query language", 2020, <<https://www.jsoniq.org/>>.

**[LHC]** "CERN - LHC", 2019, <<https://atlas.cern/tags/lhc>>.

**[RFC2216]** Shenker, S. and J. Wroclawski, "Network Element Service Specification Template", RFC 2216, DOI 10.17487/RFC2216, September 1997, <<https://www.rfc-editor.org/rfc/rfc2216>>.

**[RFC7540]** Belshé, M., Peon, R., and M. Thomson, Ed., "Hypertext Transfer Protocol Version 2 (HTTP/2)", RFC 7540, DOI 10.17487/RFC7540, May 2015, <<https://www.rfc-editor.org/rfc/rfc7540>>.

**[SC2018]** Xiang, Q., Zhang, J., Wang, X., Liu, Y., Guok, C., Le, F., MacAuley, J., Newman, H., and Y.R. Yang, "Fine-grained, multi-domain network resource abstraction as a fundamental primitive to enable high-performance, collaborative data sciences", Proceedings of the Super Computing 2018, 5:1-5:13 , 2019.

**[SENSE]** "Services - SENSE", 2019, <<http://sense.es.net/services>>.

**[TON2019]** Gao, K., Xiang, Q., Wang, X., Yang, Y.R., and J. Bi, "An objective-driven on-demand network abstraction for adaptive applications", IEEE/ACM Transactions on Networking (TON) Vol 27, no. 2 (2019): 805-818., 2019.

**[XQuery]** "XQuery 3.1: An XML Query Language", 2017, <<https://www.w3.org/TR/xquery-31/>>.

## **Appendix A. Revision Logs**

### **A.1. Changes since -14**

Revision -15

- \*fixes the IDNits warnings,
- \*fixes grammar issues,
- \*addresses the comments in the AD review.

### **A.2. Changes since -13**

Revision -14

- \*addresses the comments in the chair review,
- \*fixes most issues raised by IDNits.

### **A.3. Changes since -12**

Revision -13

- \*changes the abstract based on the chairs' reviews
- \*integrates Richard's responds to WGLC reviews

### **A.4. Changes since -11**

Revision -12

- \*clarifies the definition of ANEs in a similar way as how Network Elements is defined in [[RFC2216](#)]
- \*restructures several paragraphs that are not clear (Sec 3, Path Vector bullet, Sec 4.2, Sec 5.1.3, Sec 6.2.4, Sec 6.4.2, Sec 9.3)
- \*uses ALTO Entity Domain Type Registry

### **A.5. Changes since -10**

Revision -11

- \*replaces "part" with "components" in the abstract;
- \*identifies additional requirements (AR) derived from the flow scheduling example, and introduces how the extension addresses the additional requirements

- \*fixes the inconsistent use of "start" parameter in multipart responses;
- \*specifies explicitly how to handle "cost-constraints";
- \*uses the latest IANA registration mechanism defined in [[I-D.ietf-alto-unified-props-new](#)];
- \*renames persistent-entities to persistent-entity-id;
- \*makes application/alto-propmap+json as the media type of defining resources for the ane domain;
- \*updates the examples;
- \*adds the discussion on ephemeral and persistent ANEs.

#### **A.6. Changes since -09**

Revision -10

- \*revises the introduction which
  - extends the scope where the PV extension can be applied beyond the "path correlation" information
- \*brings back the capacity region use case to better illustrate the problem
- \*revises the overview to explain and defend the concepts and decision choices
- \*fixes inconsistent terms, typos

#### **A.7. Changes since -08**

This revision

- \*fixes a few spelling errors
- \*emphasizes that abstract network elements can be generated on demand in both introduction and motivating use cases

#### **A.8. Changes Since Version -06**

- \*We emphasize the importance of the path vector extension in two aspects:
  1. It expands the problem space that can be solved by ALTO, from preferences of network paths to correlations of network paths.

2. It is motivated by new usage scenarios from both application's and network's perspectives.

\*More use cases are included, in addition to the original capacity region use case.

\*We add more discussions to fully explore the design space of the path vector extension and justify our design decisions, including the concept of abstract network element, cost type (reverted to -05), newer capabilities and the multipart message.

\*Fix the incremental update process to be compatible with SSE -16 draft, which uses client-id instead of resource-id to demultiplex updates.

\*Register an additional ANE property (i.e., persistent-entities) to cover all use cases mentioned in the draft.

#### **Authors' Addresses**

Kai Gao  
Sichuan University  
No.24 South Section 1, Yihuan Road  
Chengdu  
610000  
China

Email: [kaigao@scu.edu.cn](mailto:kaigao@scu.edu.cn)

Young Lee  
Samsung  
South Korea

Email: [younglee.tx@gmail.com](mailto:younglee.tx@gmail.com)

Sabine Randriamasy  
Nokia Bell Labs  
Route de Villejust  
91460 Nozay  
France

Email: [sabine.randriamasy@nokia-bell-labs.com](mailto:sabine.randriamasy@nokia-bell-labs.com)

Yang Richard Yang  
Yale University  
51 Prospect Street  
New Haven, CT  
United States of America

Email: [yry@cs.yale.edu](mailto:yry@cs.yale.edu)

Jingxuan Jensen Zhang  
Tongji University  
4800 Caoan Road  
Shanghai  
201804  
China

Email: [jingxuan.n.zhang@gmail.com](mailto:jingxuan.n.zhang@gmail.com)