ALTO Implementations and Use Cases: A Brief Survey

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v_2018-05-30

Outline

- Implementations
- ALTO in Literature/ Use Cases
- Ongoing and Future Use Cases

ALTO Implementation in OpenDaylight

Open Source Project in OpenDaylight

They have implemented 5 base ALTO services:

- Network Map
- Cost Map
- Filtered Map
- Endpoint Property Map
- Endpoint Cost Map

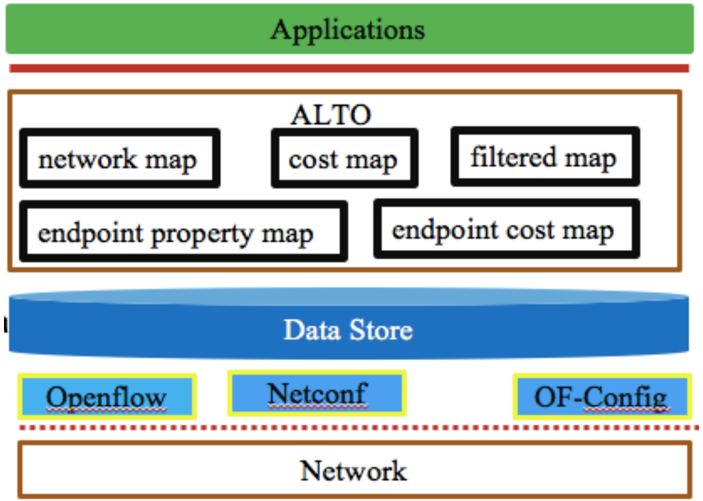
The implementation has participated the Interop at IETF 93

The implementation has been used for:

- Demo in Internet2 2016 Global Summit: provide network information for simple path computing engine
- Demo in Super Computing 2016 : For FDT-Scheduler and MonALISA

More information:

- OpenDaylight Wiki: https://wiki.opendaylight.org/view/ALTO:Main
- Documentation: http://docs.opendaylight.org/en/stable-oxygen/user-guide/alto-user-guide.html
- Source Code: https://git.opendaylight.org/gerrit/#/admin/projects/alto



ALTO in ODL

ALTO-based Broker-assisted Multi-domain Orchestration

By Danny Alex Lachos Perez, University of Campinas

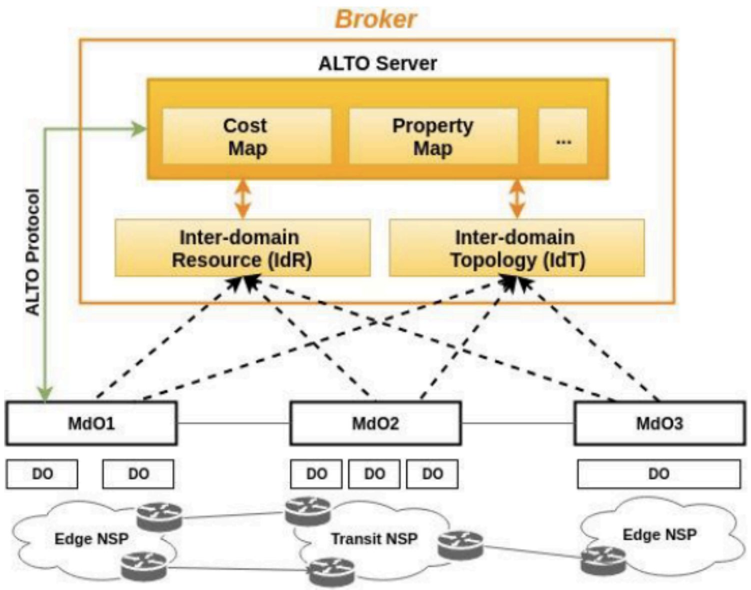
Objective: Discover resource and topology information from different administrative domains involved in the federation.

They have implemented:

- Network Map
- Cost Map
- Unified Property Map
- Path Vector

More information:

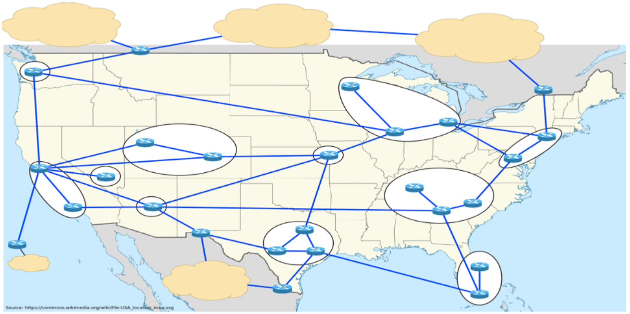
- Poster Presentation: WCNC 2018
- Short Paper: https://intrig.dca.fee.unicamp.br/wp-content/plugins/papercite/pdf/perez2018broker.pdf



Architecture Design

Benocs: ALTO Implementation in Telekom

By TU-Berlin and Telekom Innovation Laboratories, Now Benocs GmbH



network map by location

Objective: optimize CDN content delivery

Network Data Accumulation:

- IS-IS: topology, link weights
- BGP: prefixes, AS numbers, AS distances
- SNMP: latency, utilization, bandwidth

They have implemented:

- network map: grouping functions (routers and location) to generate PID
- cost map: cost functions (IGP properties, dynamic network properties)

to compute costs between PIDs

The implementation has participated the Interop at IETF 93

Real-Life Test of ALTO Maps Calculation

- Attached to large European ISP network
- 800 Routers
- ~3200 links
- ~700,000 prefixes

Source: Hans, S. (2015, July 21). ALTO map calculation from network data. Retrieve from https://datatracker.ietf.org/meeting/93/materials/slides-93-alto-9
https://www.benocs.com

ALTO in SDN Mobile Networks

A sub-project of Celtic-Plus SIGMONA
by Budapest University of Technology and Economics

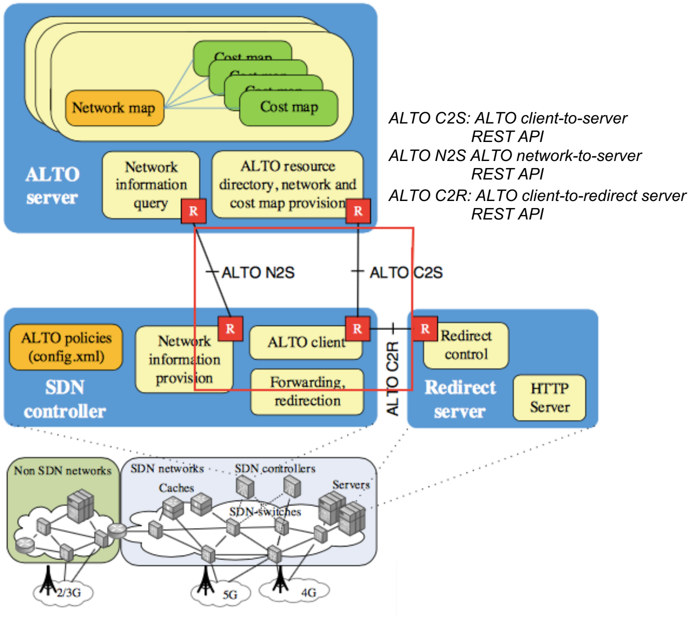
Objective: An orchestration of endpoint selection for distributed services

The have implemented:

- Network Map
- Cost Map

Achievements:

- Dynamically configurable ALTO policies
- ALTO client-to-server interface
- ALTO client-to-redirect server interface (new)
- ALTO network-to-server interface (new)



ALTO SDN building blocks

More information:

- Demo in Celtic-Plus Event 2015 https://mik.bme.hu/~zfaigl/ALTO-SDN/doc/
- Related paper: Faigl, Zoltan, Zsolt Szabo, and Robert Schulcz. "Application-layer traffic optimization in software-defined mobile networks: A proof-of-concept implementation." *Telecommunications Network Strategy and Planning Symposium* (*Networks*), *2014 16th International*. IEEE, 2014.

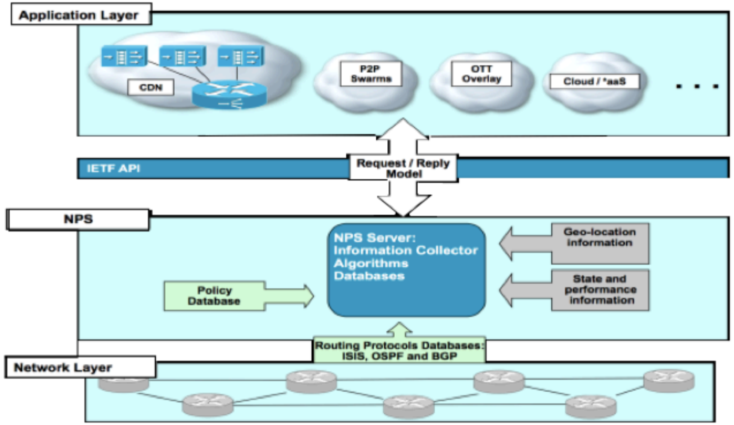
Network Positioning System

By Cisco

Objective: Optimze SP resources utilization while improving service delivered to CDNs, applicationas and OTT overlays. And improve user experiences.

Network Data Accumulation:

- Topology: Routing Database (IGP/BGP)
- Additional informaation sources: NMS, Geolocation, BGP LG,…
- Policy: Prefix Groups / BGP Communities
  Cost/weight between group of prefixes (conmunnities)



Cisco Network Positioning System
Architecture-Layer Separation

The have implemented:

- Network Map
- Cost Map

More information:

- Slides: http://ripe61.ripe.net/presentations/355-NPS-sprevidi-201011-RIPE61-v1.pdf
  https://meetings.apnic.net/31/pdf/NPS-sprevidi-201102-APRICOT.pdf

Unicorn: Multi-Domain, Multi-Controller Resource Orchestration

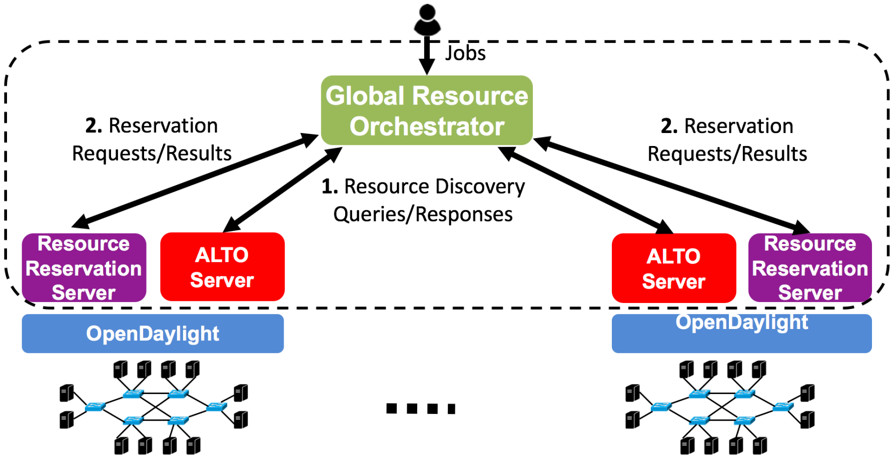
A joint work of Tongji University, Yale University and California Institute of Technology

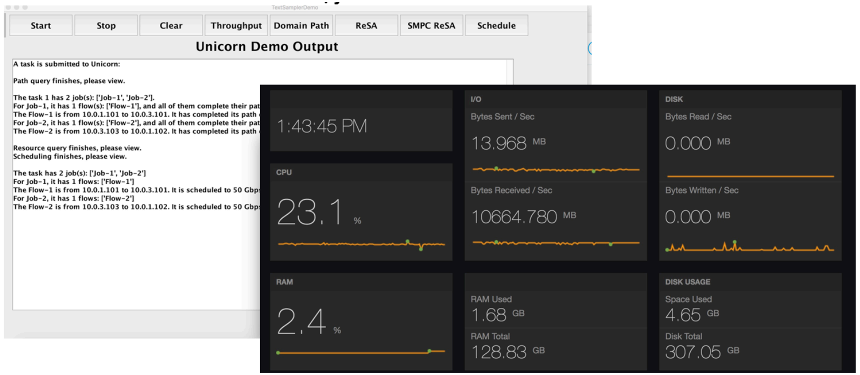
Design Requirements:

- Multi-controller coordination
- Consistent operation paradigm
- Autonomy and privacy of resource providers

They have implemented:

- Orchestrator: ~2700 LoC Python code
- ALTO Server: ~3500 LoC Java Code
- Resource Reservation Server:
  - Fast Data Transfer (FDT), FireQoS, OpenvSwitch, etc.
- Network Controller Based on OpenDaylight
- User GUI to show resource/job information





Outline

- Implementations
- ALTO in Literature/ Use Cases
- Ongoing and Future Use Cases

ALTO Use Case: ALTO as a SDN Northbound Interface

- Xia, Wenfeng, et al. "A survey on software-defined networking." *IEEE Communications Surveys & Tutorials* 17.1 (2015): 27-51.
- https://ieeexplore.ieee.org/abstract/document/6834762/

V. APPLICATION LAYER

As illustrated in Fig. 1, the application layer resides above the control layer. Through the control layer, SDN applications can conveniently access a global network view with instantaneous status through a northbound interface of controllers, for example, the Application Layer Traffic Optimization (ALTO) protocol [168], [169] and the eXtensible Session Protocol (XSP) [170]. Equipped with this information, SDN applications can programmatically implement strategies to manipulate the underlying physical networks using a high level language provided by the control layer. In this aspect, SDN offers "Platform as a Service" model for networking [171]. In the section, we describe several SDN applications built on this platform.

- Zhou, Wei, et al. "REST API design patterns for SDN northbound API." *Advanced Information Networking and Applications Workshops (WAINA), 2014 28th International Conference on*. IEEE, 2014.
- https://ieeexplore.ieee.org/document/6844664/#full-text-section

Floodlight [10], a popular open-source SDN controller, provides a built-in virtual-network module, which exposes a REST API to the application of OpenStack Quantum [13]. Meridian, implemented as a module inside Floodlight, also provides a REST API for managing virtual networks [16]. However, different from the Floodlight module for Quantum, Meridian provides a virtual-network model from the perspective of application operators. Another example of REST-based northbound API is the Application Layer Traffic Optimization (ALTO) protocol [14], which aims to provide the right network abstraction for applications with heavy east-west traffics.

ALTO Use Case: ALTO as Network Abstraction Provider in SDN

- Reference: Gurbani, Vijay K., et al. "Abstracting network state in Software Defined Networks (SDN) for rendezvous services." *Communications (ICC), 2012 IEEE International Conference on*. IEEE, 2012.
- https://ieeexplore.ieee.org/document/6364858/

TABLE I
OVERVIEW OF SDN FUNCTIONS OFFERED BY ALTO

SDN primitive	**ALTO equivalent**
Abstraction	Aggregation into PIDs Generic cost types and ranking
Get network topology	Map service, providing both network maps and cost maps
Get network resources	Cost maps, optionally extended by multi-cost maps* and historical statistics*
Get device capabilities	Endpoint property service
Event notifications	Publish-subscribe service*

Legend: * Currently not part of the core ALTO protocol

to-peer services and various other widely-used distributed applications. We further argue that the network abstractions made possible by the Application Layer Traffic Optimization (ALTO) protocol are very much in the spirit of the network state abstractions envisaged for SDNs, i.e, ALTO hides unnecessary detail of the underlying networks without unnecessarily constraining applications. The ALTO protocol is a well-defined and mature solution that provides the required information for the rendezvous-class of services in a SDN.

The rest of this paper is structured as follows: we provide further motivation of the rendezvous application class driven from real-life example services (Section II). We then look at the ALTO protocol in detail (Section III). Section IV shows where ALTO fits in the SDN continuum and Section V outlines how the ALTO abstraction in SDNs can be used in the rendezvous problem for a wide variety of applications. We conclude in Section VI.

This paper makes a case that network abstraction is an essential component in an SDN framework and that the ALTO protocol is a suitable tool for this purpose. The fundamental

ALTO Use Case: ALTO as Network Abstraction Provider in SDN

- Alvizu, Rodolfo, et al. "Comprehensive survey on T-SDN: Software-defined networking for transport networks." *IEEE Communications Surveys & Tutorials* 19.4 (2017): 2232-2283.
- https://ieeexplore.ieee.org/document/7947156/#full-text-section

The ABNO framework includes the Interface to the Routing System (I2RS), that is a work in progress described in draft [191].

The Application-Layer Traffic Optimization (ALTO) server can be also part of the ABNO framework, it provides abstract representations of the network to applications on top of ABNO. The abstractions are computed from the information stored in the TED, LSP-DB, policies and paths computation from the PCE, to simplify the route selection for the application layer traffic. The ALTO protocol is described in RFC 7285 [119].

ALTO Use Case: ALTO as Network Abstraction Provider in SDN

- Mendiola, Alaitz, et al. "A survey on the contributions of software-defined networking to traffic engineering." *IEEE Communications Surveys & Tutorials* 19.2 (2016): 918-953.
- https://ieeexplore.ieee.org/abstract/document/7762818/

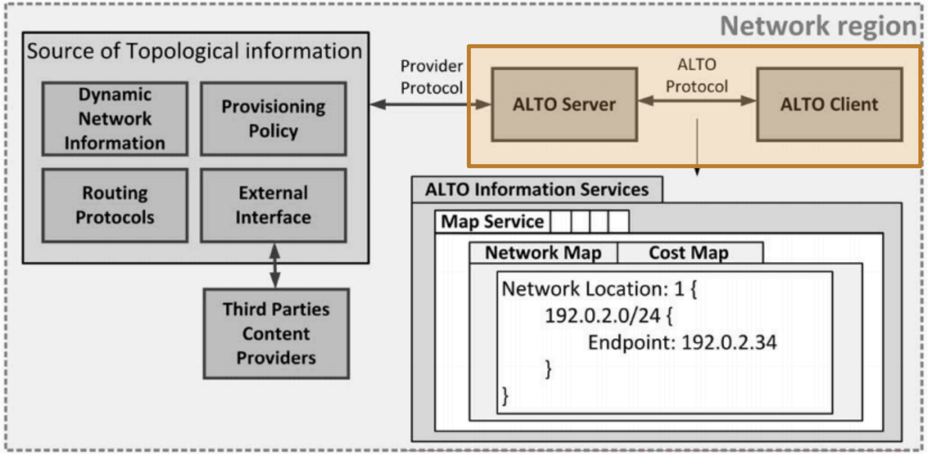
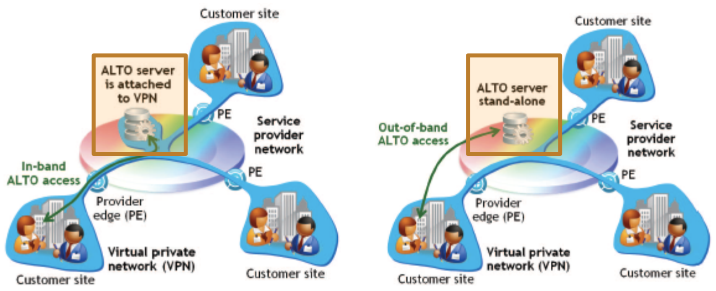


Fig. 8. Main components of the ALTO architecture and details about how the network topology is presented to the ALTO Client by the ALTO Server.

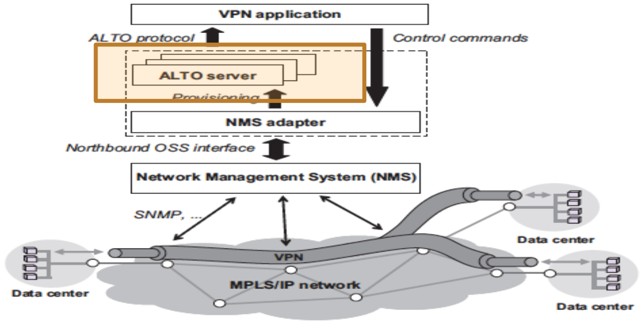
- *A-CPI protocols:* protocols that are used to communicate the controller plane with the application plane. The protocols in this category can provide an abstraction of the network resources to the applications, or user-friendly and standardised mechanisms to program the network elements.
- *MI protocols:* the ONF's SDN architecture includes management technologies to operate over the three planes. However, given that currently there are not standardised technologies to manage the controller plane or the application plane, this survey focuses on management technologies that operate over the data plane. Therefore, the MIs surveyed in this paper are used to manage the network elements, and are in charge of tasks such as policy provisioning, port, queues or LSPs configuration and in some cases, even of failure detection. They operate on much slower timescale when compared with the D-CPI protocols, within minutes or hours.

According to this taxonomy, the SDN protocols that are analysed in this paper are classified as depicted in Figure 3. On the one hand, OpenFlow, ForCES, I2RS and BGP-LS/PCEP are D-CPI technologies. On the other hand, NETCONF, OVSDB Management Protocol and OF-CONFIG are MIs. Finally, ALTO is the only protocol identified as an A-CPI protocol.

ALTO Use Case: ALTO as a Topology Abstraction for VPN Scale-out Decisions



In-band and Out-band use of ALTO



Architecture of an ALTO based network manager

standardized protocol that could bridge this gap. There exist two different usage patterns in how applications access and consume information provided by ALTO.

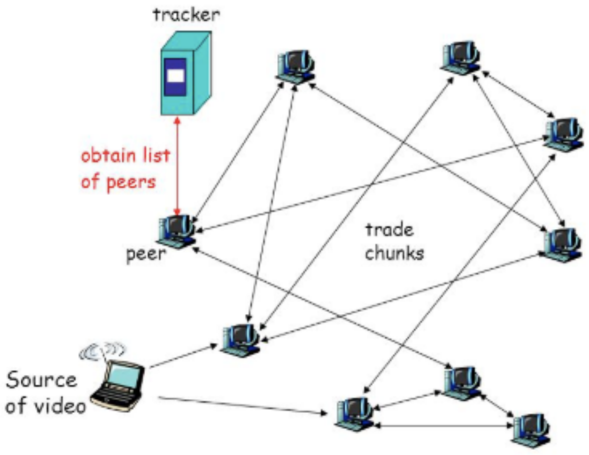
User application. This use case considers discrete application instances that are hosted at various sites and are interconnected through a VPN. ALTO can be used to optimize the application-level routing or resource consumption among those application instances inside the VPN.

Management applications. A second class represents management applications that typically operate at *meta* level to the VPN itself. This type of application is able to modify the network topology by using interfaces offered by the NSP.

As discussed in [11], there are several use cases for user and management application guidance in L3VPNs and L2VPNs. The first use case is *ranking of endpoints* connected by the VPN according to measurable (delay, bandwidth, etc.) or non-measurable network characteristics (redundancy, CE multi-homing, etc.). Second, ALTO can be used for *extending the VPN*, i.e., ALTO guidance is used to decide how to grow the VPN to include new sites optimally matching the requirements. A third usage example is *shrinking the VPN* dynamically if resources in the VPN are underutilized.

- Scharf, Michael, et al. "Dynamic VPN optimization by ALTO guidance." *Software Defined Networks (EWSDN), 2013 Second European Workshop on*. IEEE, 2013.
- Scharf, Michael, et al. “The Virtual Private Network (VPN) Service in ALTO: Use Cases, Requirements and Extensions.” Expired draft

ALTO Use Case: ALTO as a Peer Ranking Service for P2P Streaming



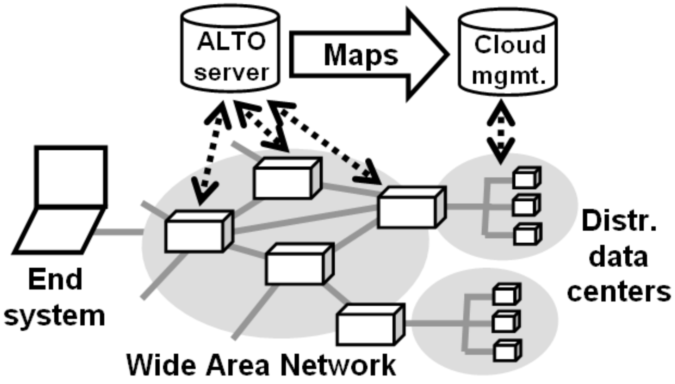
P2P Network with Tracker

P2P video streaming applications such as CoolStreaming [1], PPlive [2], SopCast [3] helps users to enjoy playing video while collaborating for the dissemination of the video data to each other. In such systems, since video streaming is based on sending video data between peers, nodes in the system helps to reduce server(s) load. Since most of the these applications are not network-aware at necessary level [4], users in such systems exchange data from a random user and this causes an extra burden in the internet traffic.

Based on the previous studies [5-7], IETF ALTO WG have been working on a protocol which provides network topology related information for P2P video streaming application users. Users can reduce the Internet traffic by using this information such as location, hop count, upload bandwith, since it is possible to implement more feasible peer selection when having the knowledge of network topology. ALTO protocol [8] aims to help nodes to select better-than random partner selection, to improve the performance of P2P video streaming applications and to reduce the burden of Internet traffic.

- Teket, Kemal Deniz, and Müge Sayit. "P2P video streaming with ALTO protocol: a simulation study." *Broadband Multimedia Systems and Broadcasting (BMSB), 2013 IEEE International Symposium on*. IEEE, 2013.
- Wydrych, Piotr, and Piotr Chołda. "Locality-and quality-awareness for P2PTV systems based on Scalable Video Coding (SVC)." *Communications (ICC), 2015 IEEE International Conference on*. IEEE, 2015.
- Poderys, Justas, and Jose Soler. "Evaluating Application-Layer Traffic Optimization Cost Metrics for P2P Multimedia Streaming." *25th Telecommunications forum*. 2017.

ALTO Use Case: ALTO as Information Exposure for Intelligent VM Placement



Network-awareness by ALTO for cloud management

> Figure 2 illustrates how ALTO integrates into a networked cloud. The cloud management system gets information about the internal network topology from the ALTO server, and it uses that information to manage the resources. Most notably, the cloud management system can select the best data center to serve a given customer, taking into account both Quality-of-Service (QoS) constraints (e.g., delay) as well as network status (e.g., internal routing and load information). ALTO can thus be a simple, standardized interface to support the management of a network-aware cloud [8].

- Scharf, Michael, et al. "Monitoring and abstraction for networked clouds." *Intelligence in Next Generation Networks (ICIN), 2012 16th International Conference on*. IEEE, 2012.

ALTO Use Case: ALTO as Information Source for Path Selection in MPTS-AR

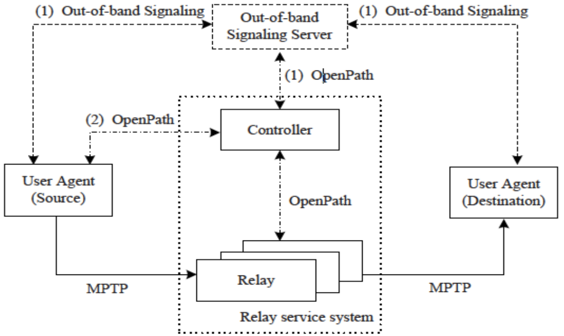


Fig1: Structure of MPTS-AR framework

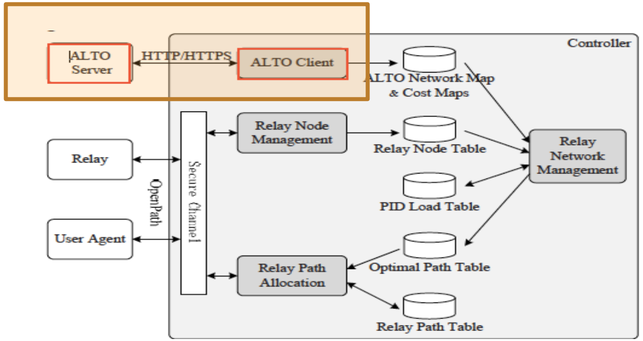


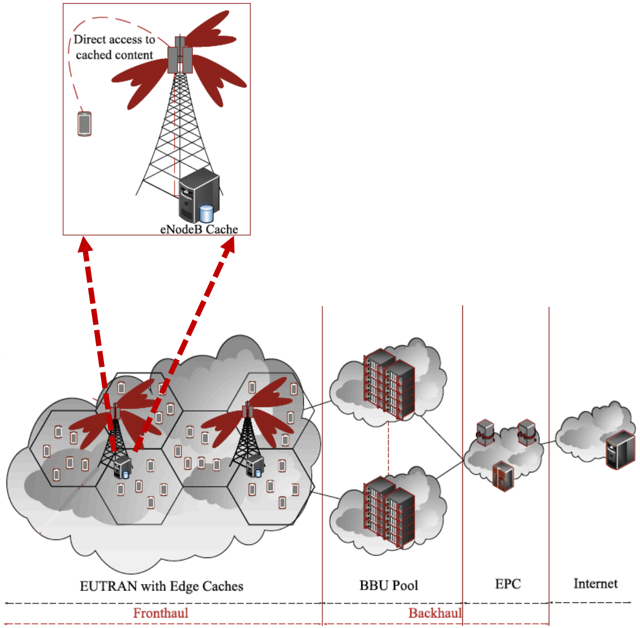
Fig2: Functional architecture of the controller in the relay system

the default IP path. Consequently, selecting superior relay path is critical. In this section, our work focuses on the behaviour of controller, and more specifically on how ALTO can improve relay path selection. As shown in Figure 3, a controller includes four functional modules: ALTO client, relay node management, relay network management and relay path allocation.

ALTO server uses so-called maps to convey information to applications. An ALTO *network map* contains a set of Network Location groupings [22]. These groupings are defined in the form of so-called *Provider-defined Identifiers* (PIDs). A PID is an identifier to group network location endpoints, e.g. IP-addresses in the form of prefixes and may denote a subnet, a set of subnets, a metropolitan area, an autonomous system, or a set of autonomous systems. ALTO introduces PIDs to provide an indirect and network-

- Zhang, Wei, et al. "Multipath transport based on application-level relay service and traffic optimization." (2014): 1-009.
- Zhang, Wei, et al. “A Framework of Multipath Transport System Based on Application-Level Relay (MPTS-AR).” Available at https://datatracker.ietf.org/doc/draft-leiwm-tsvwg-mpts-ar/

ALTO Use Case: ALTO as Information Source to Locate Content in Mobile Edge Cache

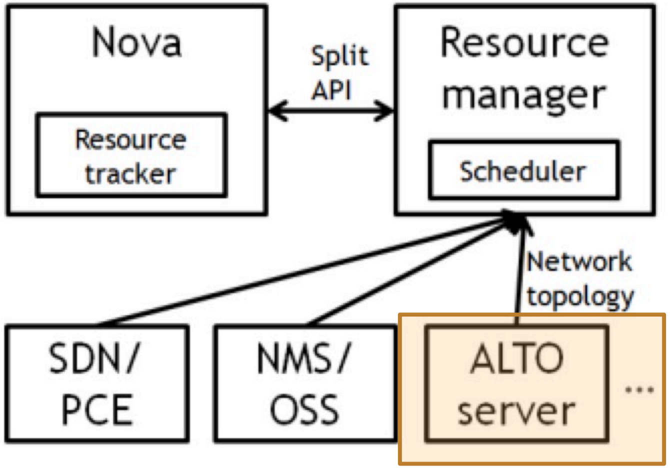


Content Cache Co-located with Base Station

To leverage ALTO for NDO IP address discovery, the ALTO server assigns a unique Provider-defined Identifier (PID) to each NDO. A PID is an alphanumeric identifier created by the operator to identify a network location. In this context a network location is one or more IP addresses used by the cache servers containing the requested NDO. Upon receiving an ALTO protocol request to locate the PID, an ALTO server would perform the same two tasks as a DNS server described previously. The results are then returned to the UE in the form of an ALTO *Network Map*. The returned network map contains a list of PIDs, each with an IP address of a cache server. Using the ALTO-provided network map to discover NDO IP addresses has several advantages. First, it allows the operator to inform the UE about all cache servers that contain the required NDO in single operation. Second, the UE can use additional ALTO protocol features (such as cost-maps) to inquire which cache-server is preferred in terms of data routing costs (i.e., available bandwidth, network load and others).

- Poderys, Justas, et al. "Caching at the Mobile Edge: A Practical Implementation." *Ieee Access* 6 (2018): 8630-8637.

ALTO Use Case: ALTO as an Information Source for Virtualized Service Function Chain Placement

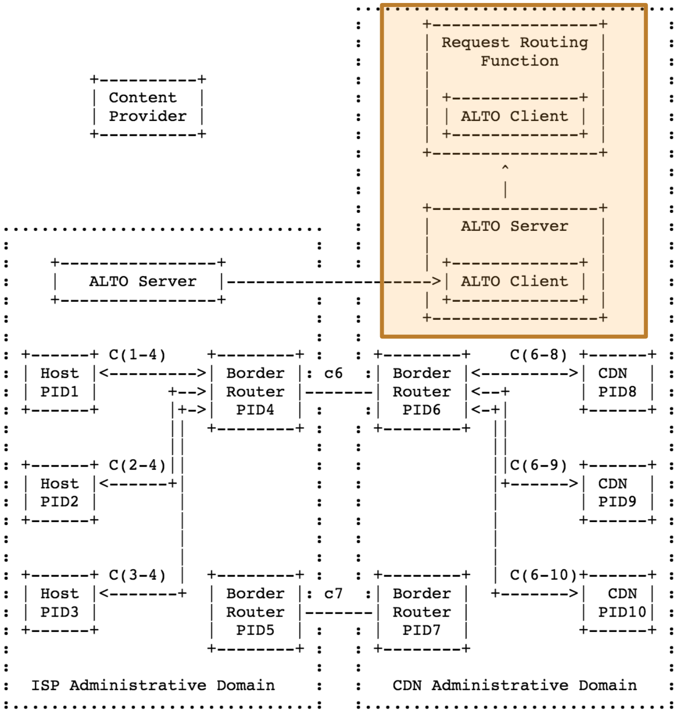


Potential scheduler design with topology awareness

minimal communication delay. Hence, the service chain is ideally deployed on compute resources of a single OpenStack zone. In contrast, a protected vNFC constitutes a set of replicas that provide the same functionality and mutually protect each other. Several types of protection have been proposed before, e.g., active-active protection or $n+k$ protection. If one instance fails the remaining replicas seamlessly take over continuously providing service. The deployment rules for protected vNFC is more complicated: the vNFC should not be deployed to the same fault domain, i.e., OpenStack availability zone, but to keep the replicas synchronized the communication distance should not exceed a certain threshold. Thus, we designed the TIMS in a way to take available communication resources between two VMs into account during deployment. We will show below, how we utilize ALTO to find suitable compute resources with sufficient communication resources between them. Before that, we introduce a use case and the information model to describe this network service.

- Scholler, Marcus, et al. "Resilient deployment of virtual network functions." *Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT), 2013 5th International Congress on*. IEEE, 2013.
- Stein, Manuel, Michael Scharf, and Volker Hilt. "SDN policy-driven service chain placement in OpenStack." *Integrated Network and Service Management (IM),* 2017 IFIP/IEEE Symposium on. IEEE, 2017.
- Scharf, Michael, et al. "Network-aware instance scheduling in OpenStack." Computer Communication and Networks (ICCCN), 2015 24th International Conference on. IEEE, 2015.

ALTO Use Case: ALTO as a Service to Select CDN Surrogate



Map advertising between ISP and CDN domains

3. CDN & ALTO Use Cases

The primary use case for ALTO in a CDN context is to improve the selection of a CDN Surrogate or Origin. The CDN makes use of an ALTO server to choose a better CDN Surrogate or Origin than would otherwise be the case. In its simplest form an ALTO server would provide an NSP with the capability to offer a service to a CDN which provides network map and cost information that the CDN can use to enhance its surrogate and/or Origin selection.

Although it is possible to obtain raw network map and cost information in other ways, for example passively listening to the NSP's routing protocols, the use of an ALTO service to expose that information may provide additional control to the NSP over how their network map/cost is exposed. Additionally it may enable the NSP to maintain a functional separation between their routing plane and network map computation functions. This may be attractive for a number of reasons, for example:

o The ALTO service could provide a filtered view of the network and/or cost map that relates to CDN locations and their proximity to end users, for example to allow the NSP to control the level of topology detail they are willing to share with the CDN.

o The ALTO service could apply additional policies to the network map and cost information to provide a CDN-specific view of the network map/cost, for example to allow the NSP to encourage the CDN to use network links that would not ordinarily be preferred by a Shortest Path First routing calculation.

- Niven-Jenkins, Ben, et al. "Use cases for ALTO within CDNs." *Internet Engineering Task Force, draftjenkins-alto-cdn-use-cases-03* (2012).
- Penno, Reinaldo, et al. "ALTO and Content Delivery Networks." *draft-penno-alto-cdn-03 (work in progress)* (2011).

ALTO Use Case: ALTO as a Service to Select CDN Servers from Different SDN Domains

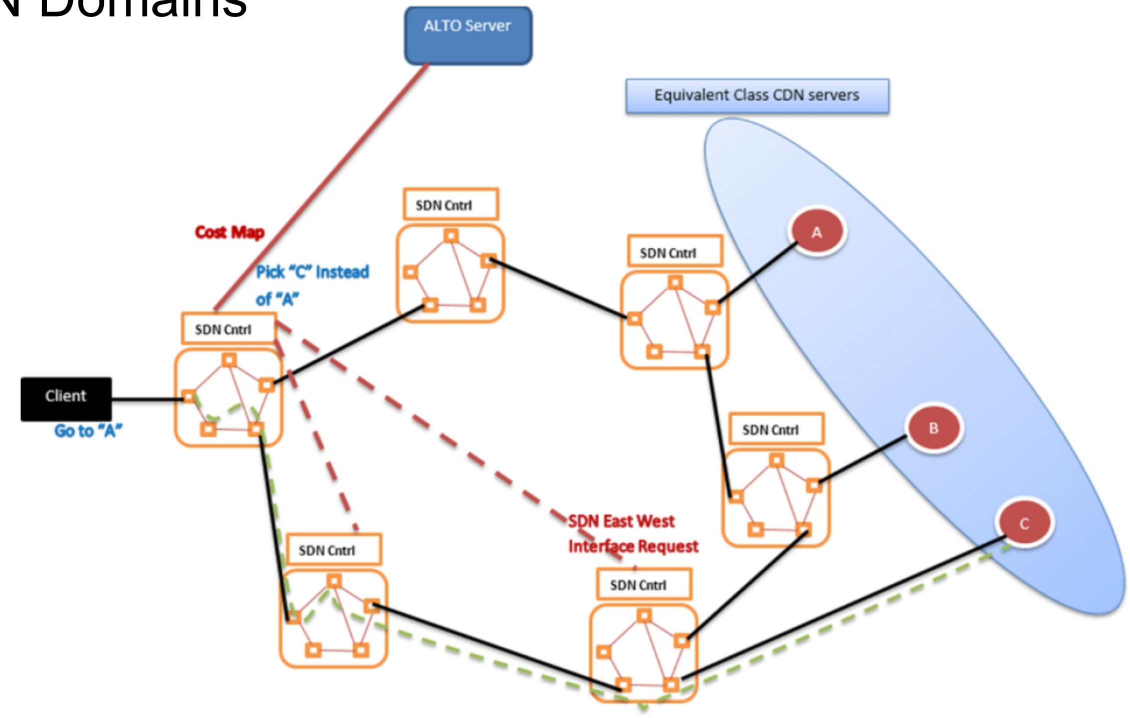
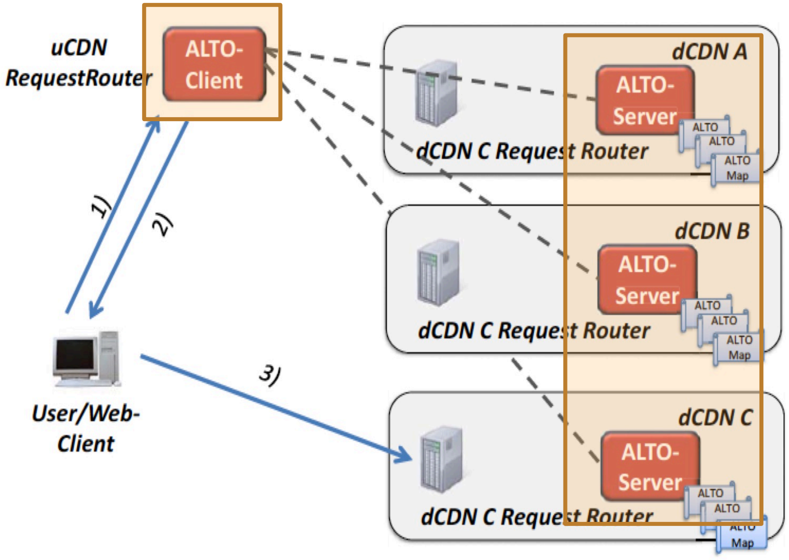


Figure 2: Content Delivery Network with SDN based Network

- Deepankar, G., et al. TATA Consultancy Services. *Inter-SDN Controller Communication: Using Border Gateway Protocol*. Retrieved from http://docplayer.net/5817317-Telecom-white-paper-inter-sdn-controller-communication-using-border-gateway-protocol.html
- Xie, H., et al. "Use cases for ALTO with software defined networks." *Working Draft, IETF Secretariat, Internet-Draft draft-xie-alto-sdn-extension-use-cases-01. txt* (2012).

ALTO Use Case: ALTO as a Service to Select downstream CDN



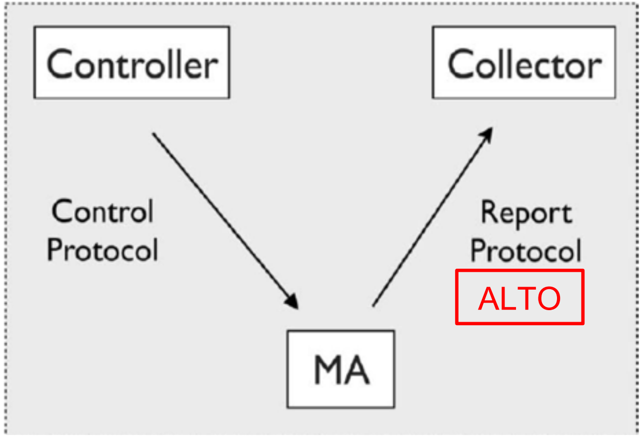
ALTO for Downstream CDN Selection
within CDNI Request Routing

would best be served by some other CDN (e.g. because the request is coming from a location where uCDN does not have caches nearby). On a high level, the scope of the CDNI Request Routing Interface contains two main tasks [2]: a) Determining if the dCDN is willing to accept a delegated content request, and b) Redirecting the content request coming from an uCDN to the proper entry point or entity in the dCDN.

ALTO can help the uCDN provider to select a proper dCDN provider for a given end user request as follows: Each dCDN provider hosts an ALTO server which provides ALTO information (i.e. ALTO network maps and ALTO cost maps [7]) to an ALTO client at the uCDN provider. A network map provided by each of the several candidate dCDNs can provide information to the uCDN provider regarding the dCDN's *footprint*, such as geographical coverage, the location of *surrogates*, or similar. In addition, an ALTO cost map can provide an uCDN provider information about the "cost" of delivering certain content via the dCDN which provided such a cost map. "Cost" in this context is a generic term; many types of costs are possible and can be useful in the context of CDNI request routing such as average link load, expected delay, load on caches, or monetary costs.

- Arumaithurai, Mayutan, et al. "Evaluation of ALTO-enhanced request routing for CDN interconnection." *Communications (ICC), 2013 IEEE International Conference on*. IEEE, 2013.
- Seedorf, J., et al. *Content Delivery Network Interconnection (CDNI) Request Routing: Footprint and Capabilities Semantics*. No. RFC 8008. 2016.
- Bertrand, Gilles, et al. *Use cases for content delivery network interconnection*. No. RFC 6770. 2012.

ALTO Use Case: ALTO as an Interface to Query on the LMAP measure results



LAMP Framework

discuss how an IPFIX reporting application will require a dedicated metering and exporting process on the MA and a collecting process on the collector. Application-Layer Traffic Optimization (ALTO) [123] is yet another protocol that can be used to perform queries on the LMAP measurement results repository. Jan Seedorf *et al.* in [124] discuss how ALTO provides the capability to define abstractions (network maps and cost maps) that can be used to tweak the aggregation-level of measurement results. The interaction is performed using a Representational State Transfer (REST) interface on top of HTTP while the carried data is encoded in JSON. David Goergen, *et al.* in [125] describe a methodology to derive the network topology from the FCC Measuring Broadband America dataset. The fabricated network and cost maps can then be used by an ALTO server. Marcelo Bagnulo, *et al.*

- Bajpai, Vaibhav, and Jürgen Schönwälder. "A survey on internet performance measurement platforms and related standardization efforts." *IEEE Communications Surveys & Tutorials* 17.3 (2015): 1313-1341.
- Eardley, P., et al. *A framework for Large-scale Measurement of Broadband Performance (LMAP)*. No. RFC 7594. 2015.
- Seedorf, J., and D. Goergen. *R. State, V. Gurbani, and E. Marocco,"ALTO for Querying LMAP Results," Internet Engineering Task Force*. Internet-Draft draft-seedorf-lmap-alto-02, Oct. 2013, work in Progress.[Online]. Available: http://tools. ietf. org/html/draft-seedorf-lmap-alto-02.

Outline

- Implementations
- ALTO in Literature/ Use Cases
- Ongoing and Future Use Cases

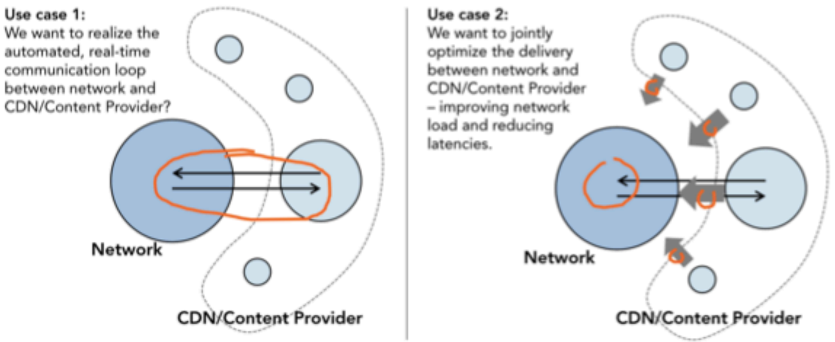
ALTO Use Case: ALTO as Network Behaviors Exchanger between Providers

Mentioned by Bell Canada in PANRG – IETF 101

Our Challenge on Path Awareness

- We Are Getting Good At Telling the Edge How to Talk with the Network
  - From BGP extended communities to Binding SID and PvDs.
  - From SRTE in the control-plane to configuration via management plane (NC/gRPC).
- There is also progress on how to exchange network behaviors between providers
  - Use of ALTO to exchange network capabilities and requirements (https://telecominfraproject.facebook.com/notes/tip-greenfield-networks-app-aware-networking/application-aware-networking-a-first-step-towards-intent-based-networking/1941364519455351/)

Use cases description:



But how can an app or a host ask for a policy ?

PANRG – IETF 101 London

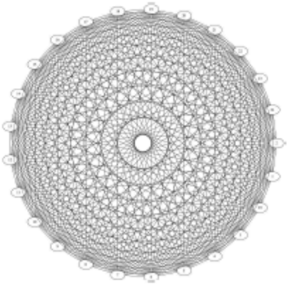
ALTO Use Case: ALTO being Used to Solving n^2 Problem

Mentioned by ESNet6 – Network Conceptual Design

Tunnels are the Key Abstraction

The Packet Core will provide a full mesh of resilient tunnels connecting all Service Edges.

ESnet5: Hop-by-hop Routed along Physical Path



ESnet6: Full Mesh of **Logical** Tunnels

- **Simplifies the resiliency problem**
  - Topology changes affect dozens to hundreds of tunnels, instead of 100K+ routes.
  - So table update & synchronization will be faster
- **Provides more flexible traffic engineering controls**
  - Automatically lay-out, or individual control 1000s of tunnels, instead of just having metrics on less than 100 links.
- **Automation functions are needed to manage scale**
  - Full mesh of logical tunnels implies an n^2 problem (where ~60 < n < ~120 (single vs dual dataplane))
  - Tunnel management can be done “in-skin” as part of the router function (e.g. Segment Routing (SR)), and/or as part of external software suite (e.g. ALTO, PCEP, SDN)

Packet Core

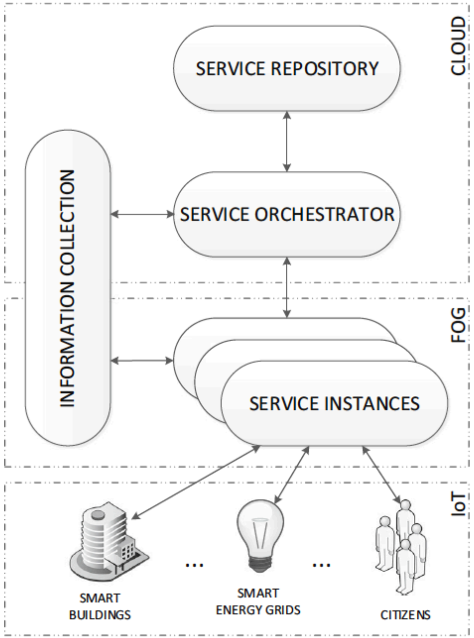
ALTO Use Case: ALTO as a Service to Guide the Peer Connection in Blockchain

- Davids, Carol, et al. "Research Topics related to Real-Time Communications over 5G Networks." (2016).

With blockchain technology as a support for Internet of Money (IoM) and an ever-increasing range of application domains ranging from asset management, IoT, insurance, and alternative coins, the underlying network protocols and network infrastructure need to address the timing requirements of blockchain-based applications. While current transaction rates in the Bitcoin network are modest, due to the design of Bitcoin itself, the extensions towards micro-payment schemes and proof-of-stake based consensus schemes require efficient peer-to-peer flooding protocols, such that blocks and transactions may efficiently reach all the corresponding peers. For the relatively simple existing protocols, with demonstrated performance only for peer sizes in the 4 digit ranges, scalability will become crucial in the future. Network assistance can be prototyped and designed in the short term, with existing approaches like Application-Layer Traffic Optimization (ALTO [4, 7]), and can guide the peer connection process thus improving the bootstrapping of the existing blockchain. Longer term strategic research is required for scaling up to millions of nodes that inter-operate through a blockchain.

ALTO Use Case: ALTO as Information Source of Service Placement in IoT

- Reference: Velasquez, Karima, et al. "Service placement for latency reduction in the internet of things." *Annals of Telecommunications* 72.1-2 (2017): 105-115.



Proposed Server Placement Architecture for IoT

3.2 Information collection

The following module is the *Information Collection* module. This module will be in charge of gathering information from the network and about the interaction among the users and the services requested. This information, together with the metadata from the services, is going to influence the future locations of the service instances. To implement this module, an option is using the Application-Layer Traffic Optimization (ALTO) protocol [20, 21]. The ALTO protocol offers a mechanism to perform better-than-random peer selection in peer-to-peer (P2P) networks, by obtaining information about the underlying network that helps to create an optimal overlay network, for instance, grouping devices that are located closer to each other, thus reducing the response time in their communication. Among the pieces of informa-

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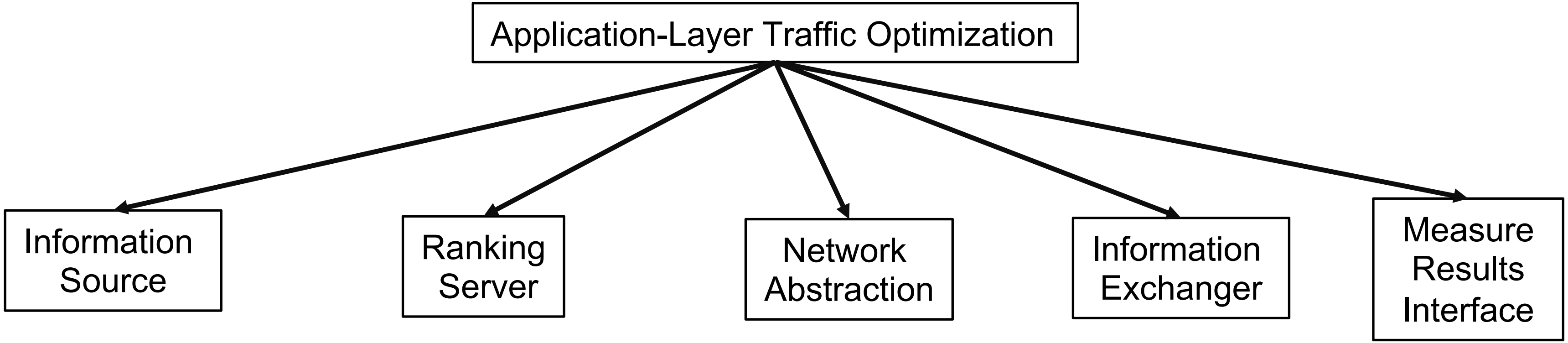
However, the mechanism employed by SNMP has been reported to have limitations [23]. Thus, ALTO represents a better option for the *Information Collection* module.

Taxonomy



Information Source

- Information Source for Path Selection in MPTS-AR
- Information Source to Locate Content in Mobile Edge Cache
- Information Source for Virtualized Service Function Chain Placement
- Information Exposure for Intelligent VM Placement
- Information Source of Service Placement in IoT

Ranking Server

- A Peer Ranking Service for P2P Streaming Information
- A Service to Select CDN Surrogate
- A Service to Select CDN Servers from Different SDN Domains
- A Service to Select downstream CDN
- A Service to Guide the Peer Connection in Blockchain

Network Abstraction

- Network Abstraction Provider in SDN
- Topology Abstraction for VPN Scale-out Decisions
- ALTO being Used to Solving n^2 Problem

Information Exchanger

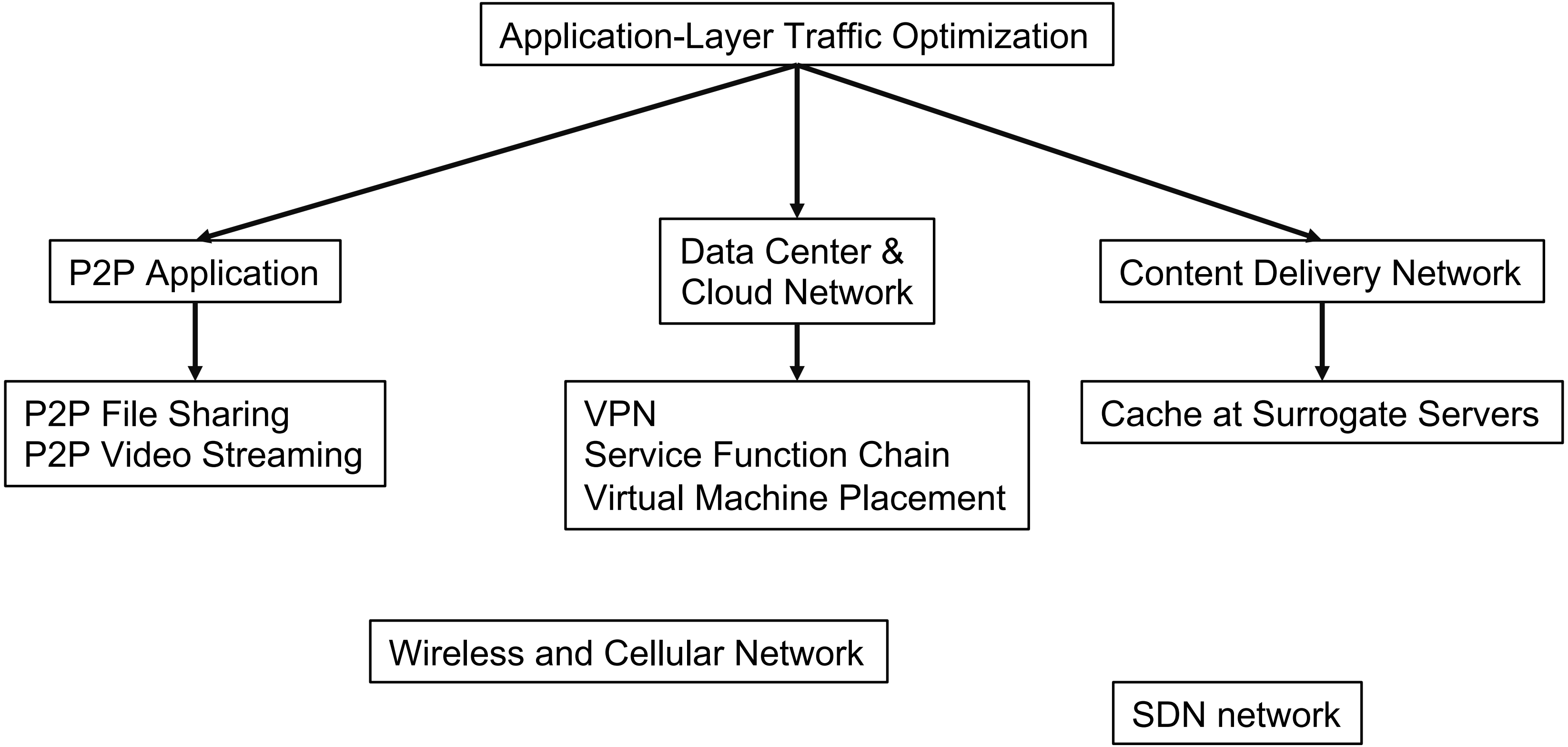
- Network Behaviors Exchanger between Providers

Measure Results Interface

- An Interface to Query on the LMAP measure results

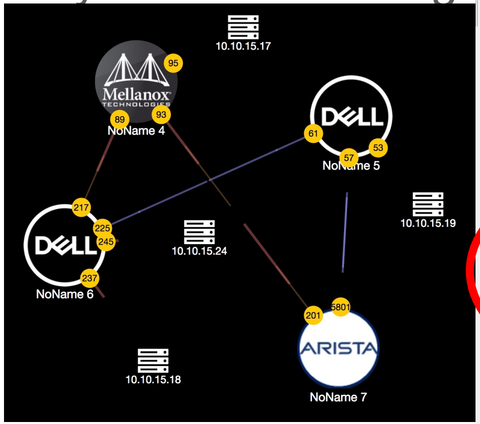
Backup Slides

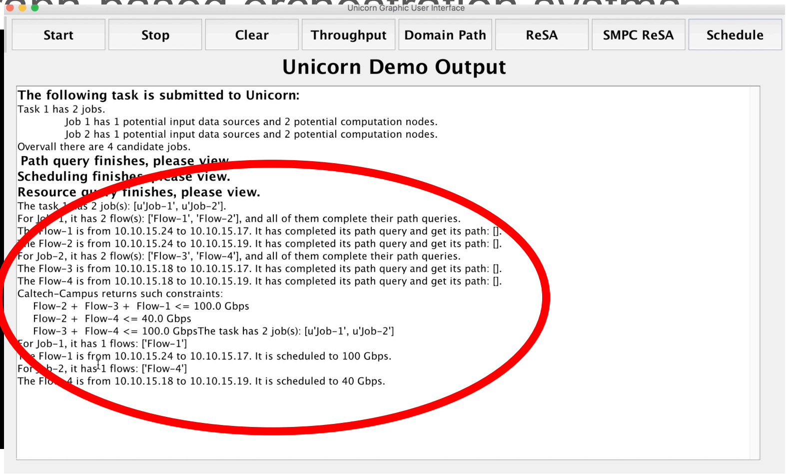
Taxonomy


Application-Layer Traffic Optimization
P2P Application
Data Center & Cloud Network
Content Delivery Network
P2P File Sharing
P2P Video Streaming
VPN
Service Function Chain
Virtual Machine Placement
Cache at Surrogate Servers
Wireless and Cellular Network
SDN network

Unicorn Demo: Resource Discovery

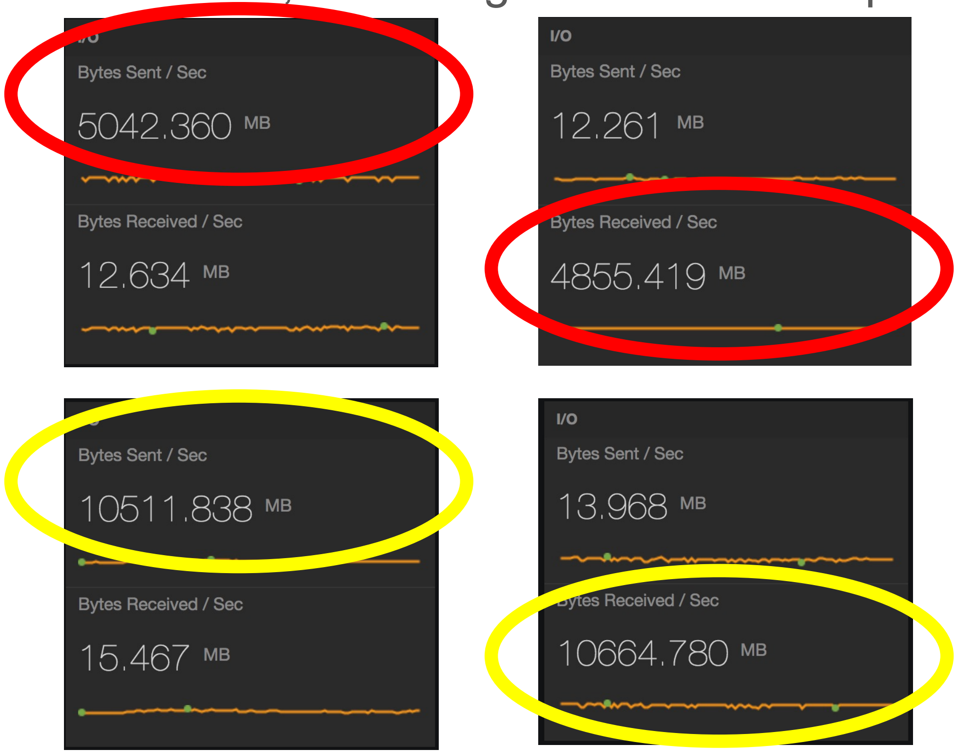
- A diamond topology with 4 DTNs, 4 OpenFlow switches, 6 100Gbps links and 2 40Gbps links.
- Two data analytic job with four candidate flows.
- Unicorn achieves a 67.5% reduction on information exposure than the commonly used resource-graph based orchestration systms.





Unicorn Demo: Resource Orchestration

- The Unicorn orchestrator makes the optimal scheduling decision, achieving a total of 140Gbps throughput.



Server 1 to Server 3 is allocated to job 1 with a **40Gbps** bandwidth.

Server 2 to Server 4 is allocated to job 2 with a **100Gbps** bandwidth.