Application-layer traffic optimization in software-defined mobile networks: a proof-of-concept implementation

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Motivation

- Application-layer Traffic Optimization provides better-than-random peer selection for distributed services (e.g., P2P, CDN), therefore it reduces the overhead and transport cost.

- Ranking of peers under different criteria
  - Distance-related: hops, AS, TTL, km
  - Charging-related: local, peer, transit traffic
  - Performance-related: max throughput, min RTT

- ALTO will not provide network information relevant on short time-scale. In-band measurement techniques are still needed.

- Benefits of ALTO service integration into SDN:
  - Transparent for the user (no deployment cost in the UEs)
  - Any flow can be dynamically selected (based on operator policies)
  - SDN supports redirection (easy integration)
  - ALTO client is deployed in controller. It queries network information and provides ranking of peers
  - ALTO server provides network information (network and cost maps)
ALTO

IETF ALTO WG
(https://datatracker.ietf.org/wg/alto/)

Networks 2014
Challenges

- Development of ALTO client in SDN controller, realization of ALTO Client-to-Server interface (defined in ALTO RFCs)

- Implementation of flow redirection to selected peers (transparent and non-transparent=with redirect server)

- Selection of ranking aggregation technique for ALTO guidance

- Implementation of ALTO Server-to-Network APIs, automatic network map provision, cost map provision, and merging of map information

- Implementation of routing in and beyond SDN-based network areas
ALTO server

The ALTO service must provide at least three basic functions:
- ALTO information resource directory,
- network map provision,
- cost map provision

Architectural changes compared to ALTO protocol:
- selection of the preferred endpoint (decision making) is moved from the ALTO server to the ALTO client
- ALTO server hence mainly is utilized as a pure network and cost map information service
### JSON media types specified by the ALTO protocol

<table>
<thead>
<tr>
<th>Type</th>
<th>Subtype</th>
<th>ALTO protocol [RFC 6708]</th>
</tr>
</thead>
<tbody>
<tr>
<td>application</td>
<td>alto-directory+json</td>
<td>Section 9.2</td>
</tr>
<tr>
<td>application</td>
<td>alto-networkmap+json</td>
<td>Section 11.2.1</td>
</tr>
<tr>
<td>application</td>
<td>alto-networkmapfilter+json</td>
<td>Section 11.3.1</td>
</tr>
<tr>
<td>application</td>
<td>alto-costmap+json</td>
<td>Section 11.2.3</td>
</tr>
<tr>
<td>application</td>
<td>alto-costmapfilter+json</td>
<td>Section 11.3.2</td>
</tr>
<tr>
<td>application</td>
<td>alto-endpiontprop+json</td>
<td>Section 11.4.1</td>
</tr>
<tr>
<td>application</td>
<td>alto-endpointproparams+json</td>
<td>Section 11.4.1</td>
</tr>
<tr>
<td>application</td>
<td>alto-endpointcost+json</td>
<td>Section 11.5.1</td>
</tr>
<tr>
<td>application</td>
<td>alto-endpointcostparams+json</td>
<td>Section 11.5.1</td>
</tr>
<tr>
<td>application</td>
<td>alto-error+json</td>
<td>Section 8.5</td>
</tr>
</tbody>
</table>
ALTO information resource directory request and response

GET /directory HTTP/1.1
Host: http://127.0.0.1:8080/Demo
Accept: application/alto-directory+json,application/alto-error+json

HTTP/1.1 200 OK
Content-Length: TBA
Content-Type: application/alto-directory+json

{
   "meta": {
      "cost-types": {
         "num-routing": {
            "cost-mode": "numerical",
            "cost-metric": "routingcost"
         },
         "num-del": {
            "cost-mode": "numerical",
            "cost-metric": "delay"
         }
      },
      "ord-routing": {
         "cost-mode": "ordinal",
         "cost-metric": "routingcost"
      },
      "ord-del": {
         "cost-mode": "ordinal",
         "cost-metric": "delay"
      }
   },
   "default-alto-network-map": "my-default-network-map"
}
...

Networks 2014
ALTO information resource directory request and response

... "resources": {
  "my-default-network-map": {
    "uri": "http://127.0.0.1:8080/Demo/networkmap",
    "media-type": "application/alto-networkmap+json"
  }
},
"numerical-routing-cost-map": {
  "uri": "http://127.0.0.1:8080/Demo/costmap/num/routingcost",
  "media-type": "application/alto-costmap+json",
  "capabilities": {
    "cost-type-names": ["num-routing"]
  },
  "uses": ["my-default-network-map"]
},
"numerical-delay-cost-map": {
  "uri": "http://127.0.0.1:8080/Demo/costmap/num/delay",
  "media-type": "application/alto-costmap+json",
  "capabilities": {
    "cost-type-names": ["num-del"]
  },
  "uses": ["my-default-network-map"]
},
"ordinal-routing-cost-map": {
  "uri": "http://127.0.0.1:8080/Demo/costmap/ord/routingcost",
  "media-type": "application/alto-costmap+json",
  "capabilities": {
    "cost-type-names": ["ord-routing"]
  },
  "uses": ["my-default-network-map"]
},
"ordinal-delay-cost-map": {
  "uri": "http://127.0.0.1:8080/Demo/costmap/ord/delay",
  "media-type": "application/alto-costmap+json",
  "capabilities": {
    "cost-type-names": ["ord-del"]
  },
  "uses": ["my-default-network-map"]
}
ALTO network map request and response

GET /networkmap HTTP/1.1
Host: http://127.0.0.1:8080/Demo
Accept: application/alto-networkmap+json,application/alto-error+json

HTTP/1.1 200 OK
Content-Length: TBA
Content-Type: application/alto-networkmap+json

```
{   "meta": {       "vtag": {           "resource-id": "my-default-network-map",           "tag": "1266506139"     },       "network-map": {           "PID1": {               "ipv4": [                   "10.0.0.1/32",                   "10.0.0.4/32"               ]           },           "PID2": {               "ipv4": [                   "10.0.0.2/32",                   "10.0.0.5/32"               ]           },           "PID3": {               "ipv4": [                   "10.0.0.3/32",               ]           }       }   } }
```
ALTO costmap request and response

GET /costmap/num/routingcost HTTP/1.1
Host: http://127.0.0.1:8080/Demo
Accept: application/alto-costmap+json,application/alto-error+json

HTTP/1.1 200 OK
Content-Length: TBA
Content-Type: application/alto-costmap+json

{   "meta": {
    "dependent-vtags": [
      {"resource-id": "my-default-network-map",
       "tag": "1266506139" },
      
    "cost-type": {"cost-mode" : "numerical",
                   "cost-metric": "routingcost" }
    
    "cost-map": {
      "PID1": { "PID1": 1, "PID2": 10, "PID3": 5 },
      "PID2": { "PID1": 15, "PID2": 1, "PID3": 10 },
      "PID3": { "PID1": 10, "PID2": 20, "PID3": 1 } }
   }
}

GET /costmap/ord/delay HTTP/1.1
Host: http://127.0.0.1:8080/Demo
Accept: application/alto-costmap+json,application/alto-error+json

HTTP/1.1 200 OK
Content-Length: TBA
Content-Type: application/alto-costmap+json

{   "meta": {
    "dependent-vtags": [ {"resource-id": "my-default-network-map",
        "tag": "1266506139" }
    
    "cost-type": {"cost-mode" : "ordinal",
                   "cost-metric": "delay" }
    
    "cost-map": {"PID1": { "PID1": 1, "PID2": 2, "PID3": 3 },
                  "PID2": { "PID1": 2, "PID2": 1, "PID3": 3 },
                  "PID3": { "PID1": 3, "PID2": 2, "PID3": 1 } }
   }
}
ALTO client in SDN controller

ALTO client:
- queries network and cost maps from the ALTO service during the connection establishment phase of flows belonging to ALTO service classes.
  - caches the maps, in order to reduce signaling
  - provides ranking of endpoints
  - returns source, original destination and preferred destination to the „forwarding, redirection” module

Forwarding:
- implements transparent or non-transparent redirection

Dynamic network map and cost map provision:
- provides abstract network and cost maps to the ALTO server (one switch view)
The SDN controller must know, which service classes require ALTO service.

The schema includes:
- definition of service classes (name, IP addresses, port numbers of servers),
- network map id
- cost types, traffic direction to be considered

Reachability of:
- ALTO server
- redirect server
- (default gateway to reach external networks)
ALTO guidance

**OpenFlow Switch**
- TCP SYN to A
- What is class of A?
- Class of A: give me IRD
- IRD
- Search resources from IRD
- Available network & cost maps: give me network maps
- Network map
- Search PID's
- PID's

**Controller & ALTO Client**

**ALTO Server**

**Loop**
- Give the cost map
- Cost map
- Ranking PID's
- Rank
- Summarize ranks
- Search PID with min rank
- PID
- Search server in optional PID
- Optional server is
- Generate flow entries base
- Flow entries
- Flow entries with B
Flow redirection

- Two types of redirection operations should be supported by the SDN-ALTO service:
  - Transparent redirection:
    - uses flow rewrite rule during the entire period of the service session
    - the client believes that it communicates with the initially requested service endpoint
  - Non-transparent redirection:
    - redirection towards a HTTP redirect server
    - the HTTP redirect server signals to the client the new location of the service.
    - the redirected connection is closed by the client
    - client reconnects to the preferred endpoint
      - using default routing mechanism implemented in the SDN network or virtual network.
A, B = service endpoints

Transparent redirection
A, B = service endpoints
R = redirect server

Non-transparent redirection
Selection of ranking aggregation technique

- Multi-attribute decision making (MADM) methods appear in many disciplines including telecommunication
  - dynamic context-aware access network selection.
  - algorithm selection for user authentication.
  - context-aware media independent handover services

- **ALTO requires** the application of MADM techniques for the **ranking the endpoints based on multiple cost types**, such as routing costs, link utilization costs, available capacity, round-trip times for E-E paths.
MADM

- Normalization (ranking, grade assignment, performance category assignment):
  - max, min, min-max, sum, vector norm

- Ranking aggregation methods:
  - weighted sum (WS),
  - weighted product (WP),
  - analytic hierarchy process (AHP),
  - grey relational analysis (GRA),
  - distance of ideal alternatives (DiA),
  - technique for order preference by similarity to ideal solution (TOPSIS), etc.

\[
\begin{align*}
\text{Alt}_1, \text{Alt}_2, \ldots, \text{Alt}_N \\
\begin{bmatrix}
\text{Cr}_1, & \text{Cr}_2, & \ldots, & \text{Cr}_M \\
X_{1,1}, & x_{1,2}, & \ldots, & x_{1,M} \\
\vdots & \vdots & \ddots & \vdots \\
X_{N,1}, & \ldots, & \ldots, & X_{N,M}
\end{bmatrix} \\
\end{align*}
\]

- Ranking aggregation methods:
  - weighted sum (WS),
  - weighted product (WP),
  - analytic hierarchy process (AHP),
  - grey relational analysis (GRA),
  - distance of ideal alternatives (DiA),
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\[
\begin{align*}
\text{Alt}_j \text{ alternative j} \\
\text{Cr}_i \text{ criterion i} \\
x_{ij} \text{ performance of Alt}_i \text{ under } \text{Cr}_i \\
\bar{x}_{ij} \text{ normalized performance values} \\
c_i \text{ criteria weights} \\
t_j \text{ terminal score of } \text{Alt}_j
\end{align*}
\]
Clustering ranking aggregation methods based on the similarities of their ranking

- the simple WS method can substitute most of the methods, including AHP, DIA, GRA, WP methods.
- we recommend to apply the Weighted Sum method in the ranking aggregation phase of service endpoint selection in ALTO-SDN use case on ordinal costs
ALTO network-to-server API

- ALTO server requests dynamically network information from the ALTO client,
- ALTO server will provide a single-node network view over REST API with JSON media type.
- Content-type: application/singlenodeview+json

```json
{"topology":{
  "10.0.0.1":{"10.0.0.2":{"num-routing":2, "num-delay":0},"10.0.0.3":{"num-routing":6, "num-delay":0},"10.0.0.4":{"num-routing":6, "num-delay":0}},
  "10.0.0.2":{"10.0.0.1":{"num-routing":2, "num-delay":0},"10.0.0.3":{"num-routing":6, "num-delay":0},"10.0.0.4":{"num-routing":6, "num-delay":0}},
  "10.0.0.3":{"10.0.0.1":{"num-routing":6, "num-delay":0},"10.0.0.2":{"num-routing":6, "num-delay":0},"10.0.0.4":{"num-routing":2, "num-delay":0}},
  "10.0.0.4":{"10.0.0.1":{"num-routing":6, "num-delay":0},"10.0.0.2":{"num-routing":6, "num-delay":0},"10.0.0.3":{"num-routing":2, "num-delay":0}}},
  "pidMask":"255.255.255.255",
  "mapName":"my-default-network-map"}
```
Validation plans for the ALTO-SDN use case

Objective:
- elaborate and demonstrate an ALTO-SDN use case where HTTP streaming server selection is orchestrated by ALTO client deployed in SDNs using Redirect server

Proof-of-concept demonstration of the following functionalities:
- Automatic redirection of video service connection requests to the best service endpoint based on ALTO server guidance, without the need of deployment of ALTO client in endhosts
- Demonstration of the ALTO client and server configuration possibilities
- Automatic ALTO network map creation driven by the policies of network operators
Validation environment

For the demonstration of the ALTO-SDN service, we need the following tools:

- Video content servers providing HTTP video streams using the VLC application
- SDN data layer using Open vSwitch for SDN switches,
- Mininet [5] for the emulation of SDN network areas and the endhosts
- SDN controller is the FloodLight controller extended with ALTO client and updated functionalities
- ALTO Server is an own Java-based servlet deployed over Apache Tomcat 6.0 Server
- HTTP Redirect server is an own Java-based servlet deployed over Apache Tomcat 6.0 Server.
- Legacy network using Ethernet switches and legacy routers.
Floodlight controller extensions

REST Applications
The ALTO Server uses the following core services: Device Manager, Topology Manager, Link Discovery

REST API

Core services of common interest to SDN applications
* Interfaces defined only & not implemented: FlowCaches, NoSql

Module Applications
- VNF
- Static Flow Entry Pusher
- FireWall
- PortDown Reconciliation
- Hub
- Forwarding Switch
- Learning Switch
- Redirect

Java API
- VNF
- Static Flow Entry Pusher
- FireWall
- PortDown Reconciliation
- Hub
- Forwarding Switch
- Learning Switch
- Redirect

OpenFlow Services
- Switches
- Controller Memory
- PerfMon
- Trace
- Counter Store

Floodlight Controller
- Module Manager
- Thread Pool
- Packet Streamer
- Python Server
- Web UI
- Unit Test
- Storage
- Memory
- NoSql
- Link Discovery
- Flow Cache
- Topology Manager/Routing

ALTO Applications
- ALTO Server
- ALTO Client

Applications with higher bandwidth communication

Networks 2014
A scenario with in-network caches (no traffic)
Service request without ALTO

TCP flow entries
Service request with ALTO

Client

Local cache

Content server

TCP flow entries
Periodic network and costmap update

Networks 2014

Network map:
- "PID1" : { "ipv4" : ["10.0.0.8/30"]},
- "PID2" : { "ipv4" : ["10.0.0.4/30"]},
- "PID3" : { "ipv4" : ["10.0.0.0/30"]},
- "PID4" : { "ipv4" : ["10.0.0.252/30"]}

Cost-map:
- "PID2" : {"PID1" : 1,"PID2" : 0,"PID3" : 1,"PID4" : 1},
- "PID3" : {"PID1" : 1,"PID2" : 1,"PID3" : 0,"PID4" : 1},
- "PID4" : {"PID1" : 1,"PID2" : 1,"PID3" : 1,"PID4" : 0}
Periodic network and costmap update

Network map:

```
"PID1" : { "ipv4" : ["10.0.0.8/30"]},
"PID2" : { "ipv4" : ["10.0.0.4/30"]},
"PID3" : { "ipv4" : ["10.0.0.0/30"]},
"PID4" : { "ipv4" : ["10.0.0.252/30"]}
```

Cost-map:

```
"PID2" : {"PID1" : 1,"PID2" : 0,"PID3" : 9,"PID4" : 1},
"PID3" : {"PID1" : 1,"PID2" : 1,"PID3" : 0,"PID4" : 1},
"PID4" : {"PID1" : 1,"PID2" : 1,"PID3" : 9,"PID4" : 0}
```

UDP traffic from PID 4 to PID 3

Networks 2014
Service request with ALTO in loaded network

1) UDP traffic utilizes a considerable amount of the capacity of red links
Service request with ALTO in loaded network

2) Client requests service from content server

Controller: - provides redirect information to Redirect server based on ALTO guidance,
- transparent redirection of the TCP syn of the client to the Redirect server,
- establishes flow entries bw. client and regional cache
Service request with ALTO in loaded network

3) Client re-connects to regional-cache
ALTO client-to-server API

„One-switch topology view“ (ALTO server requests it from ALTO client)
Client side

Client “thinks” to be redirected by the content server.
ALTO client-to-server API

ALTO protocol messages
Redirect server side

- Controller-to-Redirect server:
  - Information on which incoming request (source, destination) to redirect where (new destination)
- Client’s HTTP GET request
Conclusions

- We have implemented
  - ALTO Client-to-Server interface, only part of JSON media types defined in the RFC of ALTO protocol is implemented
  - Flow redirection to selected peers, transparent and non-transparent mode, based on learning switch module or the forwarding module
  - ALTO Server-to-Network APIs, automatic network map provision, cost map provision
  - Routing in and beyond SDN-based network areas: based on „learning switch” and „forwarding"

- We proposed a new method for the selection of ranking aggregation technique for ALTO guidance

- Next step
  - Moving from Mininet environment to real testbed, software-defined mobile network testbed of AALTO university
Thank you for your attention!
Any questions?