Deploying a Content Delivery Service Function Chain on an SDN-NFV Operator Infrastructure

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IEEE ICC 2017
Objectives of the paper

- Demonstration of the CDN-as-a-vNF model.
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- Formalizing the problem Service Function Chaining Embedding optimality problem
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- Demonstration of the CDN-as-a-vNF model.
- Formalizing the problem Service Function Chaining Embedding optimality problem
- Adapt the Service Function Chain to the ISP Topology to minimize cost and increase Embedding rate
Outline

1. ISP-CDN Collaboration
2. Existing solutions
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2. Existing solutions

3. High Level Architecture

4. SFC Transformation

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Deploying vCDN as a SFC
1. ISP-CDN Collaboration

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4. SFC Transformation

5. Offline SFC Embedding

Our cache location problem can then be modeled by the following ILP: minimize

$$\sum_{(a,r)} \sum_{(i,j)} y_{a,r}^j b_{r(i,j)} + \#V_{MG} \cdot \frac{C_{V_{MG}}}{C_{net}} + \#V_{CDN} \cdot \frac{C_{V_{CDN}}}{C_{net}}$$ (1)

^Source code available at http://www.labri.fr/perso/nherbaut

6. Online Management

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The explosion of Media Streaming challenges current best-effort Internet Architecture

Over the top (OTT) Video Streaming is difficult
- Reaches 70% of Bandwidth in peak time
- Target Resolution is increasing (SD, HD, 4K, 8K, 3D...)

CDN are required
- Reduced Delivery Costs
- Improved Quality of Experience (QoE)
- Increase robustness of delivery
An ecosystem is structured around Media Delivery

Content Owner -> Content Provider -> CDN Technical Enabler -> ISP Connectivity Provider -> End-Users
But these new challenges are blurring the lines

Market Trends

- CP ↗ Network footprint (e.g. Google Global Cache)
- Large CPs + ISPs = Collaboration (e.g. Netflix Open Connect)
- ISP ⇔ Telco CDN (e.g. Level 3, BT)
- ∑ CDN = Collaboration (e.g. CDNI)
We propose a collaborative Framework

High Level Architecture

- NFV platform within the ISP Network
- vNFs are instantiated in Network Function Virtualization Infrastructure Points of Presence (NFVI-POP)
- CDN view abstracts all the underlying ISP topology
In this framework, CDN can formulate SLAs

Service Level Agreements (SLA)

- The CDN operator expresses a connectivity demand
- Specifying target Bitrate, End Users count, Content specifications, SLA duration, Client Group Nodes, CDN Exit Nodes
In this framework, CDN can formulate SLAs

Service Level Agreements (SLA)

- The CDN operator expresses a connectivity demand
- Specifying target Bitrate, End Users count, Content specifications, SLA duration, Client Group Nodes, CDN Exit Nodes
- The ISP has to embed the CDN SLA in its Network (while keeping it private)
From the SLA, we derive an Embedding Request

Best Effort Distribution

Enhanced distribution
The Embedding Request is transformed to a Service Function Chain

CDN-as-a-VNF model:
- 2 virtual functions vMG (for request), vCDN (for delivery)
- chained together & optimally embedded inside the ISP topology
- to respect the CDN provider ↔ ISP contract for collaboration
The Service Function Chain is adapted to fit the ISP Topology

- We can increase the number of vMG, vCDN or both
Service Function Chaining Embedding

Mapping a Service Function Chain to the ISP Topology

We start with the SLA from CDN. The ISP then places the Client Group Nodes and the CDN Exit Nodes. We map a service that fits the CDN's SLA constraints, with the lowest cost for the ISP.
Mapping a Service Function Chain to the ISP Topology

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**Service Mapping Algorithm**

**Data:** CDN’s provided SLA  

**Result:** a mapping $\mathcal{M}$ or rejection  

$$obj_{fun_{min}} = \infty;$$  

$$\mathcal{M}_{\text{winner}}, \mathcal{M} \leftarrow \emptyset;$$  

$$\text{req\_queue} \leftarrow \text{get\_requests}(\text{SLA});$$  

**do**  

$$(\mathcal{M}, \text{obj\_fun}) \leftarrow \text{solve}(\text{req\_queue}.\text{pop}());$$  

if $\mathcal{M} \neq \emptyset \text{ and } \text{obj\_fun} < obj_{fun_{min}}$ then  

$$\mathcal{M}_{\text{winner}} \leftarrow \mathcal{M};$$  

**while** $\text{req\_queue} \neq \emptyset;$  

if $\mathcal{M}_{\text{winner}} \neq \emptyset$ then  

$$\text{return } \mathcal{M}_{\text{winner}};$$

**Algorithm 1:** Service Mapping algorithm

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**Get the "best" mapping for each SLA**  

- Requests are generated from SLA  
- We can add vCDN, vMG or both
Problem formulation (2)

\[
\sum_{(u,v)} \sum_{(i,j)} y_{u,v}^{i,j} b(i,j) + \#_{vMG} \cdot \frac{C_{vMG}}{C_{net}} + \#_{vCDN} \cdot \frac{C_{vCDN}}{C_{net}}
\]

\[\sum_{x_u^i = 1, \forall i \in N^S} x_u^i = 1, \forall i \in N \tag{2}\]

\[\sum_{x_i^j \times c_i^S} c_u^i \leq c_u, \forall u \in N \tag{3}\]

\[\sum_{y_{u,v}^{i,j} \times b_{i,j}^S} b_{u,v} \leq b_{u,v}, \forall (u,v) \in E \tag{4}\]

\[\sum_{(i,j) \in E^S} y_{u,v}^{i,j} \cdot d_{u,v} \leq D_M(s,t) \forall s \in S, \forall t \in T \tag{5}\]

\[\sum_{v \in N} y_{u,v}^{i,j} - y_{v,u}^{i,j} = x_u^i - x_u^j, \forall (i,j) \in E^S, \forall u \in N \tag{6}\]

\[\sum_{v \in \delta(u)} y_{u,v}^{i,j} \leq 1, \forall (i,j) \in E^S, \forall u \in N \tag{7}\]

Cost Functions

- Minimizing the total embedding cost
  - Bandwidth cost
  - Cost of the vMG
  - Cost of the vCDN

Constraints

- (2) every vNF is deployed
- (3) nodes capacities
- (4) bandwidth capacities on virtual routes
- (5) delay constraints to match target bitrate
- (6) flow conservation
- (7) loop avoiding
Problem formulation (2)

\[
\sum_{(u,v)} \sum_{(i,j)} y_{u,v}^{i,j} b_{(i,j)} + \#_v MG \cdot \frac{C_v MG}{C_{net}} + \#_v CDN \cdot \frac{C_v CDN}{C_{net}}
\]

(1)

\[
\sum_{u \in N} x_u^i = 1, \forall i \in N^S
\]

(2)

\[
\sum_{i \in N^S} x_i^j \times c_i^S \leq c_u, \forall u \in N
\]

(3)

\[
\sum_{(i,j) \in E} y_{u,v}^{i,j} \times b_{i,i}^S \leq b_{u,v}, \forall (u,v) \in E
\]

(4)

\[
\sum_{(i,j) \in E} y_{u,v}^{i,j} - y_{v,u}^{i,j} = x_u^i - x_j^i, \forall (i,j) \in E^S, \forall u \in N
\]

(6)

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(7)

Cost Functions

- Minimize the total embedding cost
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Yes the problem is NP-Hard

- Still doable for 100 nodes topologies
- We plan to introduce heuristics in future work
Offline Embedding results

- **Strategy 0**: 1 vMG and 1 vCDN.
- **Strategy 1**: adding up to \( n \) vMGs.
- **Strategy 2**: adding up to \( n \) vCDNs, and associating each vMG to one vCDN node.
- **Strategy 3**: adding up to \( \#vMG \leq n \) vMGs and up to \( \#vCDN \leq \#vMG \) vCDNs
**Offline Embedding results**

- **Strategy 0**: 1 vMG and 1 vCDN.
- **Strategy 1**: adding up to $n$ vMGs.
- **Strategy 2**: adding up to $n$ vCDNs, and associating each vMG to one vCDN node.
- **Strategy 3**: adding up to $\#v_{MG} \leq n$ vMGs and up to $\#v_{CDN} \leq \#v_{MG}$ vCDNs

**Table**: Computing time for each strategy (Geant, 28 nodes, 35 edges)

<table>
<thead>
<tr>
<th>Strategy</th>
<th>S0 (Baseline)</th>
<th>S1 (vMG)</th>
<th>S2 (vCDN)</th>
<th>S3 (vMG+vCDN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Embedding time for 1 request</td>
<td>0.27s</td>
<td>0.82 s</td>
<td>0.81 s</td>
<td>2.63</td>
</tr>
</tbody>
</table>
we have a 52% increase in request embedding rate
we have a 31% decrease in request bandwidth consumption
we have a x3 factor in node capacity consumption
We embed more requests, so we consume more resource. We did not take into account dimensioning of the extra vMGs and vCDNs, we will explore this in future work.

We have at most a x3 factor in node capacity consumption.
Loaded a simple topology on Mininet, and used the ISP network API to control request routing.

Example: CDN’s customers have 3 profiles: HD Premium, HD Free, and SD. Only vCDN can deliver HD, while legacy CDN delivers SD. We want to provide HD to both HD Profile. It is possible, otherwise, downgrading HD Free to SD to save on vCDN Bw.
Loaded a simple topology on Mininet, and used the ISP network API to control request routing.
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Example

- CDN’s customers have 3 profiles: **HD Premium**, HD Free and SD
- Only vCDN can deliver **HD**, while legacy CDN delivers SD
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Online Management Results

Virtual Route Configuration

50 100 150 200

Virtual Route User Bandwidth

CDN vCDN

50 100 150 200

# buffer starvation per minute

vCDN Max Bandwidth

1 100 100 200 200

Streaming Sessions

400 MB/s

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Online Management Results

Streaming Sessions

Virtual Route User Bandwidth

Virtual Route Configuration

HD Streaming Buffer Starvation

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Deploying vCDN as a SFC
Conclusion and future work

Advantages of our approach

- Promotes tight collaboration
- SFC Transformation increases embedding rate and decrease network costs
- Online vCDN management is possible.

Future Work

- Investigate heuristics
- Proof of concept implementation ongoing in a FUI project with Tier-1 ISP
- ”Updatable” and more flexible SLAs
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Questions?
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Online Management Evaluation testbed

Online vCDN TestBed

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### CDN-ISP SLA example

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>unit</th>
<th>example value</th>
<th>Simulation Hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit rate</td>
<td>Movie target bitrate</td>
<td>Mbps</td>
<td>2Mbps</td>
<td>randomly chosen between 2Mbps, 5Mbps and 10Mbps</td>
</tr>
<tr>
<td>Count</td>
<td>Movie download count</td>
<td>#</td>
<td>15000</td>
<td>randomly chosen from a normal distribution with mean 1000 and std dev 100</td>
</tr>
<tr>
<td>Content Duration</td>
<td>Movie average duration</td>
<td>minutes</td>
<td>90 min</td>
<td>randomly chosen from a normal distribution with mean 1h and std dev 10 min</td>
</tr>
<tr>
<td>SLA duration</td>
<td>Start and stop of the SLA</td>
<td>date range</td>
<td>From 00:00 01/01/2017 to 23:59 01/03/2017</td>
<td>randomly chosen from a normal distribution with mean 10h and std dev 1h</td>
</tr>
<tr>
<td>Client Group nodes (CG)</td>
<td>Identifiers for where the users connect</td>
<td>IP address/net-mask</td>
<td>10.10.10.10/16</td>
<td>up to 4 random nodes in the substrate</td>
</tr>
<tr>
<td>CDN Exit routes</td>
<td>CDN Peering point</td>
<td>IPX ID</td>
<td>netflix.franceix.net</td>
<td>up to 2 random nodes in the substrate</td>
</tr>
</tbody>
</table>
Existing Collaboration models

Managed CDN

- The CDN installs an appliance in the ISP AS
- Users stream media from the appliance
- Cross AS traffic is reduced
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Telco CDN
- ISPs own the software and the hardware
- It deploys it
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CDN Interconnection
- Standardization effort by IETF, ETSI...
- Interconnect 2 or more CDNs
  - Increase footprint
  - Small CDN can compete with global CDN
Existing Collaboration models

**Managed CDN**
- The CDN installs an appliance in the ISP AS
- Users stream media from the appliance
- Cross AS traffic is reduced

**Telco CDN**
- ISPs own the software and the hardware
- It deploys it

**These solutions have caveats**
- They don’t promote tight collaboration (MCDN, TCDN)
- There’s no implementation ready (CDNI)
- Quality of Service is not guaranteed

- Increase footprint
- Small CDN can compete with global CDN