Design of Optical Aggregation Network with Carrier Edge Functions Virtualization

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Outline

1. Background
2. Objective
3. Proposed Method
4. Performance Evaluation
5. Conclude
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Carrier network architecture

**Aggregation network (metro):** Transport traffic from access network to backbone network, based on electronic L2 SW.

**Carrier edge function:** provides service-specific functions such as QoS and flow identification at edge router.

Access network: Connecting user premises with carrier network

Aggregation network: Concentrate user traffic and transport it to the backbone network

Backbone network: Transport long-haul traffic

OLT: Optical Line Terminal, OXC: Optical Cross-connect

※ OLT: Optical Line Terminal, OXC: Optical Cross-connect
Recent trend in aggregation networks

①: Introducing NFV for Carrier Edge functions
   • Edge functions to be relocated from edge routers to distributed pools of commodity servers

②: TDM/WDM-based Optical Aggregation Network
   • WDM ring network to accommodate large-volume traffic efficiently

VNF: Virtual Network Function
Re-optimize VNF placement according to uneven resource usage
Accommodate unpredictable traffic demand changes by NFV
① Carrier edge functions virtualization

- **Advantages:**
  - Create VNF for each OLT. The VNF can be flexibly placed on any servers among distributed pools of commodity servers.
  - Can be live-migrated from an over-loaded server to an under-utilized one in response to unpredictable traffic changes.

- **Challenges:**
  - Determine VNF placement considering traffic demand and geographical location (e.g. distance bet. OLT-Server).

Conventional network

- **Edge functions**
  - QoS
  - SBC
  - BAS
  - ACL

- **Edge routers** (dedicated hardware)

NFV

- **Commodity servers**

VNF (virtual network function): Implementation as software
② TDM/WDM-based aggregations network

- **Advantages:**
  - To cope with bursty traffic, enable the same wavelength channel to be shared by multiple OLTs through DBA or other TDM technologies.

- **Challenges:**
  - How to efficiently select route for P2MP wavelength path considering bandwidth requirement of each OLT?

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Issues in carrier edge virtualization

Conventional: Deployment of edge routers
- Edge routers accommodate fixed group of OLTs based on location. This causes congested or under-utilized routers due to unpredictable traffic demand changes

Our approach: NFV for carrier edge functions
- Can accommodate OLTs independent of location, so it can provide robustness

⇒ However, consumes more network resources if we allocate VNFs on geographically remote server.

Conventional

Our approach: NFV for edge functions

More resources are consumed if server is far distant from OLT

Degrade efficiency if traffic demand of OLTs varies widely

Improve efficiency to optimize accommodation according to demand changes

Seoul

Busan

Jeju

OLT

1 2 3 4 5

OLT

1 2 3 4 5

Edge servers (ES)
Objective

- Minimize network cost while efficiently utilizing server resources.
  - For optimal VNF placement, we need to consider resource requirements of optical network in addition to server resources.
  - In optical aggregation network, we need to consider the sharing of wavelength paths as we can use P2MP paths connecting server and OLTs.

⇒ Establish optimal design method for VNF placement and P2MP path routing.

Objective 1
- Consume 3 WDM links
- Disperse server load

Objective 2
- Consume 2 WDM links
- Server may be over-loaded
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Proposed design method

We formulate the design problem as mixed integer linear programming (MILP).

- Objective function:
  - Minimize weighted sum of network cost and max server load

- Variables:
  - P2MP wavelength paths between server and OLTs
  - VNF placement (Select ES to be accommodated)

\[
\begin{align*}
\min & \sum_{k} \sum_{mn} C_{mn}^k + \alpha \max_i \sum_{i} \sum_{j} D_{ij} \cdot x_{ij}^k \\
\end{align*}
\]  

\( \text{Network cost} \quad \text{Max server load} \quad \text{Weight parameter} \)

Total of WDM links used for P2MP paths
Network model

Logical topology design (VNF~OLT)

- Place VNFs on ES

Physical topology design (ES~OLT)

- Select ES to accommodate VNF

Problems:

1. Place VNFs on ES

Problem 2:
Compute route bet. ES and OLT.
Overview of MILP formulations

- **VNF placement**
  - Assign binary variables to candidate ES for VNF placement

- **Route for P2MP wavelength path**
  - Configure logical flow bet. VNF~OLT.
  - Find route for P2MP path minimize network cost while accommodating traffic demand of logical flows.

### Binary variable:

\[ X_1^k = \begin{cases} 1 & \text{(accommodate VNF k)} \\ 0 & \text{(no placement)} \end{cases} \]
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Objective of performance evaluation

①: Design of parameter $\alpha$
   • Parameter $\alpha$ governs the weight of network cost on server load

②: Effectiveness
   • Effectiveness regarding reduction in network cost and server load

③: Robustness against unpredictable traffic changes
   • Evaluate impact of increased variations of traffic demand

Objective function

$$\min \left( \sum_k \sum_{mn} C_{mn}^k + \alpha \max_i \sum_k \sum_j D_{ij} \cdot x_{ij}^k \right)$$  (1)
Evaluation conditions

- Topology: 10-node multi-ring
- Traffic demand: Zipf distribution $T(x) = b \cdot x^{-\beta}$
- Reference method: MinHop, RoundRobin
Result ①: Design of parameter $\alpha$

- To configure parameter $\alpha$ around 0～1, we can efficiently disperse server load while avoiding increase in network cost.
Result ②-1: Effectiveness

- Compare network cost for various traffic demand
- Proposed method reduced by up to 21%

![Graph showing network cost comparison between RoundRobin, Proposed, and MinHop methods with average traffic demand normalized by λ bandwidth.](image)

- Reduction by 21%
- 10% increase
Result ②-2 Effectiveness

- Compare max server load for various traffic demand
- Proposed method reduced by up to 30%

![Graph showing max server load compared for various traffic demands, with lines for MinHop, RoundRobin, and Proposed methods. The graph indicates a reduction by 30%.](image-url)
Result ③ Robustness

- Evaluate robustness for various traffic variations $\beta$
  - Zipf distribution $T(x) = b^*x^{-\beta}$
  - Proposed method ensures robustness against traffic variations

Traffic variations (β)

<table>
<thead>
<tr>
<th>MinHop</th>
<th>RoundRobin</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic=50</td>
<td></td>
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Sharp fluctuations
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Conclusions

• We studied the optimal design of optical aggregation networks with carrier edge function virtualization.
  • NFV improves efficiency of server resources for carrier edge functions.
  • Consider joint optimization problem that minimizes network cost and maximum server load.
  • Formulate the problem as mixed integer linear programming.

• We quantitatively evaluated effectiveness of the optimal aggregation network design with VNF placement.
  • It reduced the maximum server load and network cost by up to 30% and 21%, respectively.

Can improve resource efficiency and robustness to unpredictable demand changes.
Thank you for your kind attention.