Knowledge-Defined Network Orchestration in a Hybrid Optical/Electrical Datacenter Network

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Outline

- Background and Motivations
- Hybrid Optical/Electrical Datacenter Network
- Knowledge-Defined Network Orchestration Mechanism
- Prediction Analytics and Decision Making
- System Implementation and Experimental Demonstration
- Conclusion
Cloud Computing Era

Cloud Computing

Servers
Virtual Desktop
Software Platform
Applications
Storage / Data

Router

Switch
End User

University of Science and Technology of China
Global Data Center Traffic

- Zettebytes per Year

25% CAGR 2016 - 2021

Global Data Center Traffic by Destination in 2021

- Data Center to User: 15%
- Data Center to Data Center: 14%
- Within Data Center: 71%

Total East-West traffic will be 85%
Network Orchestration Mechanism (NO-M)

- Resource Utilization
- Energy Consumption
- Quality of Service

![Diagram of Network Orchestration Mechanism](image)

- Web Server
- Virtual Network
- Computing Tasks
- Virtual Desktop
Challenges to Realize an Efficient NO-M

- Manage a large number of network elements

- Handle computing tasks and traffic in DCNs that are highly dynamic

“A 1-millisecond advantage in trading applications can be worth $100 million a year to a major brokerage firm”
The main idea of SDN: separating the control and data planes of a network.

The benefits of SDN: making networks be more programmable and flexible, a global review, rich telemetry information.

With SDN, Google has increased the link utilization of its inter-datacenter network from 30% to 95%.
Knowledge Defined Networking

- Predictive Analytics
- Machine Learning
- Decision Making
- Telemetry Information
- SDN Controller
- Forwarding Elements
Hybrid Optical/Electrical DCNs (H-O/E DCNs)

Electrical Inter-Rack Interconnection
- Packet-level switching granularity
- Quick response upon request
- Delay-sensitive and/or highly dynamic inter-rack traffic
- Congestion caused by oversubscription

Optical Inter-Rack Interconnection
- Wavelength-level switching granularity
- Pump high-throughput traffic through
- Bandwidth-sensitive and/or long-lasting inter-rack traffic
- Relatively long path setup latency
Knowledge-defined Network Orchestrator (KD-NO)

Knowledge-Defined Predictive Analytics and Decision Making

- DL-based Traffic Prediction Module
- DL-based VM Demand Prediction Module
- DL-based Network Reconfiguration Module

IT Resource Controller (IT-C)

- VM Deployment Module
- VM Migration Module
- IT Resource and Traffic Monitor
- VM Scaling Module

Network Controller (NET-C)

- Network Reconfiguration Module
- Flow Provisioning Module
- Network Abstract Module

Network Management Module

Network and Service Database
Deep Neural Network (DNN)

Input Layer \rightarrow \text{Hidden Layers} \rightarrow \text{Output Layer}

- \text{Input Data} \rightarrow \text{Layer 0} \rightarrow \text{Layer 1} \rightarrow \text{Layer N} \rightarrow \text{Layer N+1} \rightarrow \text{Output Data}

- Activation Function: $h_n = f(\theta_{n-1}, h_{n-1})$

$\theta_{n,i,n+1,j}$

$h_{n,i}$
Case Study: VM Migration

- **Objective:** improve energy-/resource-efficiency in the H-O/E DCN

- **Predictive Analytics**
  - Traffic matrix between VMs
  - Inter-rack traffic matrix

- **Decision Making**
  - Which VMs to be migrated?
  - Where to migrate?

---

**Input Layer**

\[ \text{Traffic Volume (t)} \]
\[ \vdots \]
\[ \text{Traffic Volume (t-i)} \]
\[ \vdots \]
\[ \text{Traffic Volume (t-T)} \]

**Layer 0**

**Activation Function**

\[ h_n = f(\theta_{n-1}, h_{n-1}) \]

**Hidden Layers**

**Output Layer**

**Prediction of Traffic**

\[ \text{Traffic Volume (t+1)} \]
\[ \vdots \]
\[ \text{Traffic Volume (t+j)} \]
\[ \vdots \]
\[ \text{Traffic Volume (t+T)} \]
Case Study: VM Scaling

- **Objective**: ensure good performance of VMs

- **Predictive Analytics**
  - IT resources demanded by VMs

- **Decision Making**
  - Which VMs to be scaled and how?

![Diagram of a neural network with input layer, hidden layers, and output layer.](Diagram)

### Historical VM Demands
- **VM**
- **CPU**(t)
- **CPU**(t-T)
- **RAM**(t)
- **RAM**(t-T)

### Input Layer

### Hidden Layers
- Layer 0
- Layer 1
- Layer N
- Layer N+1

### Output Layer

### Activation Function

\[ h_n = f(\theta_{n-1}, h_{n-1}) \]

### Predictions of VM Demands
- **CPU**(t+1)
- **CPU**(t+T)
- **RAM**(t+1)
- **RAM**(t+T)
Case Study: H-O/E DCN Reconfiguration

- **Objective**: reduce average data-transfer delay

- **Predictive Analytics**
  - Input: inter-rack traffic and DCN configuration
  - Output: average data-transfer delay

- **Decision Making**
  - Optimal DCN configuration

**Inter-Rack Traffic and DCN Configuration**

- Traffic_Volume (Rack_{1}, Rack_{2})
- Traffic_Volume (Rack_{i}, Rack_{j})
- OCS_Switch_Connection (Inport, Outport_{j})

**Predictions on Data Transfer Latency and Network Usage**

- Predictions on Data Transfer Latency
  - Average Data Transfer Latency
  - Data_Rate(Link_{i})
  - Data_Rate (EPS_Switch_{i}, Port_{j})
  - Data_Rate (OCS_Switch_{i}, Port_{j})

**Activation Function**

\[ h_{n} = f(\theta_{n-1}, h_{n-1}) \]
System Implementation: Data Plane

- Electrical Inter-Rack Interconnections

- Optical Inter-Rack Interconnections

- Servers in Racks
System Implementation: Control Plane

- IT-C: manage IT resource in a DC
  - OpenStack:
    - VM deployment and scaling
    - IT resource and traffic monitoring

- NET-C: control intra-rack and inter-rack connections
  - ONOS:
    - Flow provisioning
    - Network abstract and configuration

- KD-NO: coordinate IT-C and NET-C
  - VM and network management
  - Predictive analytics and decision making
**Results in VM Migration**

(a) Predicted and actual traffic volumes

(b) Data-transfer volumes for with and without VM migration

<table>
<thead>
<tr>
<th>Rack 1</th>
<th>Rack 2</th>
<th>Rack 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.8489</td>
<td>0.0060</td>
</tr>
<tr>
<td>0.0044</td>
<td>0.0218</td>
<td>0.8262</td>
</tr>
<tr>
<td>0.0042</td>
<td>0.9130</td>
<td>0.0506</td>
</tr>
</tbody>
</table>

(1) without VM Migration (GB)

<table>
<thead>
<tr>
<th>Rack 1</th>
<th>Rack 2</th>
<th>Rack 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.7935</td>
<td>1.0614</td>
</tr>
<tr>
<td>0.0042</td>
<td>0.0002</td>
<td>0.0090</td>
</tr>
<tr>
<td>0.0044</td>
<td>0.9130</td>
<td>1.7802</td>
</tr>
</tbody>
</table>

(2) with VM Migration (GB)
Results in VM Scaling

(a) Predicted and actual CPU usages of a VM

(b) CPU usage with and without VM scaling
Results in H-O/E DCN Configuration

(a) Average data-transfer latency

(b) Number of active switch ports
Conclusion

Knowledge-Defined Network Orchestration Mechanism

- Why? Challenges?
- Design a knowledge-defined NO-M in an H-O/E DCN system

Predictive Analytics and Decision Making

- Design three DL-based AI modules for VM migration, scaling and DCN configuration, respectively

System Implementation and Experiment Demonstration

- Implement a real network testbed to prototype the proposed design
- Achieve intelligent decision making and automatic management
- Improve the performance of service provisioning

Future Directions

- Incorporate more intelligent in the designed knowledge-defined NO-M
- Make the designed knowledge-defined NO-M application-driven