Dynamic Placement of Virtual Network Functions based on Model Predictive Control

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NFV (Network Functions Virtualization)
- The virtual network functions (VNFs) are hosted by ordinary server computers.
- By placing the VNFs to the suitable server, the network services are provided efficiently

Dynamical placement of the VNFs
- Reconfigure the location of the VNFs according to the change of the required resources
- By migrating the VNFs
- By changing the configuration of the routing

1. When the required resource is large
   - VN to be placed
   - Deploy

2. When the required resource is small
   - VN to be placed
   - Reconfigure

Objective and Approach

Objective
- Establishment of a method which places the VNFs so as to follow the traffic variation
- Start migration in advance of the change of the required resources
- By considering the predicted future demands
- Allocate sufficient resources to the VNFs without migrating a large number of VNFs at the same time

Approach
- Applying MPC [1] to dynamic placement of VNFs
  - Decide the placement based on the predicted value
  - Robust control to prediction errors

Model Predictive Control (MPC) [1]
- Overview
  - Inputs setting to a system to make the output close to desired one
  - Correction of prediction error by feedback
  - Controller implements only the calculated inputs for the next time slot
  - Controller observes the output and corrects the prediction
  - Controller recalculates the inputs with the corrected prediction

Objective of Our VNF Placement

- Minimize the number of active physical node at each time
- The cost of migrations should also be considered
- Migration causes performance degradation

Placement of VNFs based on MPC (MPC-VNF-P)

- Formalization
  \[
  \text{minimize} \quad \sum_{t=0}^{T-1} \sum_{p \in \mathcal{P}} \sum_{n \in \mathcal{N}} \left( w_i^{(t)} \cdot y_{i,n}^{(t)} + \frac{(1-w_i^{(t)})}{2} \cdot \left| y_{i,n}^{(t)} - y_{i,n}^{(t-1)} \right| \right)
  \]

  - Decrease the number of active physical nodes
  - Decrease the cost of migration

  \[0 \leq y_{i,n}^{(t)} \leq 1\]

- Procedure

  \[
  \mathcal{X}^{(t)} \leftarrow \arg \min \left\{ \text{minimize} \quad \sum_{t=0}^{T-1} \sum_{p \in \mathcal{P}} \sum_{n \in \mathcal{N}} \left( w_i^{(t)} \cdot y_{i,n}^{(t)} + \frac{(1-w_i^{(t)})}{2} \cdot \left| y_{i,n}^{(t)} - y_{i,n}^{(t-1)} \right| \right) \right\} \]

- Calculation by an optimization algorithm

- Cost is defined by the largest number of migrated VNFs at the same time

Decreasing migration by introducing \( \bar{M} \)

- Before introducing \( \bar{M} \)
  \[
  \sum_{t=0}^{T-1} \sum_{p \in \mathcal{P}} \sum_{n \in \mathcal{N}} \left| y_{i,n}^{(t)} - y_{i,n}^{(t-1)} \right|
  \]

- A large number of migration may occur

- Effect of introducing \( \bar{M} \)

Evaluation: Physical network environment

- The topology is based on the Internet2 topology
- Six nodes are connected to the servers
- Only the servers have the resources to host the VNFs
- Each server has the resources whose capacity is 200
- The bandwidth of each link has a sufficiently large value

Evaluation: Virtual network environment

- The virtual network includes 8 user nodes and 17 VNFs
- Two kinds of the VNFs
  - One handles the traffic near user and is connected to user nodes
  - The other is connected to all of the VNFs
- We generate the time variations of the required resources.

Compared method

- \text{MinActiveNode}
  - Minimize the number of active physical nodes without considering the cost of migration
- \text{NoMPC}
  - The predicted required resources only at the next time slot are used, considering the cost of migration
- \text{MPC-VNF-P}
  - Proposed method

<table>
<thead>
<tr>
<th>Control parameters</th>
<th>MinActiveNode</th>
<th>NoMPC</th>
<th>MPC-VNF-P</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H = 1 )</td>
<td>( w = 0 )</td>
<td>( H = 1 )</td>
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<td>( w = 0.03 )</td>
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<td>( w = 0.03 )</td>
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Other simulation environments

- Prediction method
- Simple line fitting to past time series

Metrics
- Maximum resource utilization
  - The largest resource utilization, which is defined by
    \[ \max_{s \in S} \left( \sum_{n \in N} w_n \cdot v_n^s \right) \]
  - Number of active physical nodes
  - The number of physical nodes hosting at least one VNFs
  - The number of VNFs which are migrated at each time slot

Maximum resource utilization

- All methods map the virtual network properly
- VNFs are migrated before the lack of resources is caused by using the predicted values

Number of active physical nodes

- All methods change the number of active physical nodes according to the time variation of the required resources
- MPC-VNF-P indicates the same performance compared with MinActiveNode

- The future required resources are predicted to increase, while the actual required resources stop increasing
- MPC-VNF-P avoids the increase of the number of active physical nodes
- Correcting the prediction errors
- Calculating the locations of VNFs again

Number of migrated VNFs

- MinActiveNode and NoMPC require a larger number of migrations
- MinActiveNode does not consider the cost of migration
- NoMPC does not consider the future required resources
- MPC-VNF-P avoids a large number of migrations at any time slot
- Start migration in advance by using the predicted values

Summary and future work

- Summary
  - Proposition of MPC-VNF-P
    - We introduce the idea of placement of VNFs based on MPC
    - Our method starts migration in advance of traffic variation
    - By considering the predicted future demands
  - Evaluation of MPC-VNF-P
    - We show that MPC-VNF-P allocates sufficient resources without migrating a large number of VNFs at the same time
    - We show that our method handles the time variation of the demands
- Future work
  - The evaluation using the actual traffic traces
  - Establishing a distributed algorithm of the dynamic placement of the VNFs