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Dynamic Placement of Virtual Network Functions based on Model Predictive Control

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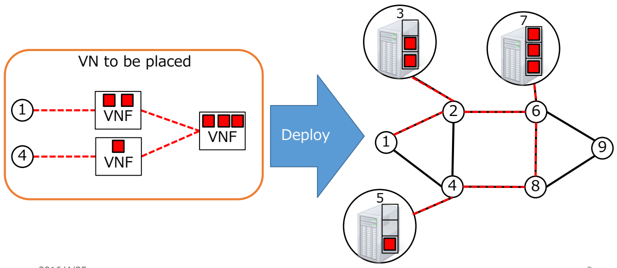
NFV (Network Functions Virtualization)

- 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



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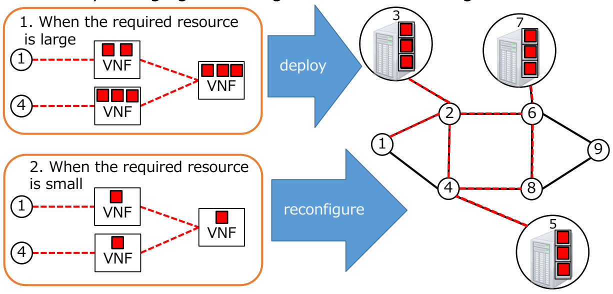
Dynamical placement of the VNFs

- 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



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The problem of existing methods

- The cost of the migration of the VNFs
  - The migration consumes network resources.
- The existing method considers only the currently required resources
  - The migration is not performed unless the necessity of the migration is detected

A large number of migrations may be required
-> Network instability

Our Method
- Detect the necessity of the migration from the predicted demands
  - Start migration in advance
  - Avoid a large number of migrations at the each time slot

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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

[1] S. J. Qin and T. A. Badgwell, "A survey of industrial model predictive control technology," *Control Engineering Practice*, vol. 11, pp. 733-764, July 2003.

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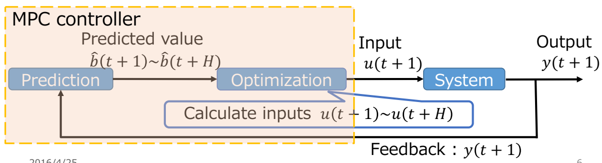
Model Predictive Control (MPC) [1]

- 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



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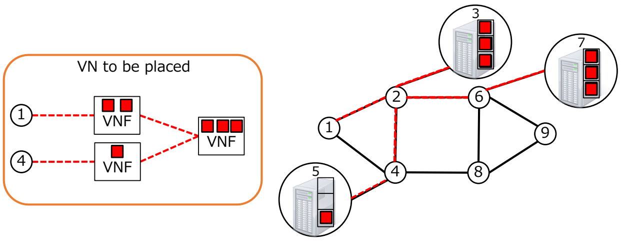
Objective of Our VNF Placement

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



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

- Formalization

$$minimize\ \frac{(1-w)}{H\cdot|N^P|}\sum_{0<t\le H}\sum_{n\in N^P} M_n^{Node}(t) + \frac{w}{2|N^{VNF}|}\bar{M}$$

Decrease the number of active physical nodes

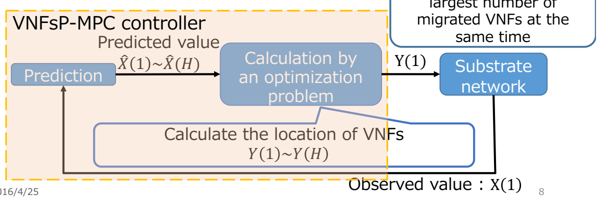
Decrease the cost of migration

w: weight for migration
H: predictive horizon
N^P: set of physical nodes
$M_n^{Node}(t)$: binary variable, that indicates the deployment of VNFs
N^{VNF}: set of VNF nodes
$\bar{M}$: variable to decrease the cost of migration
$M_{n^{vnf},n}^{Node}(t)$: binary variable, which indicates the placement of a VNF

$$St.\ 0<t\le H,\ \sum_{n\in N^P}\sum_{n^{vnf}\in N^{VNF}} |M_{n^{vnf},n}^{Node}(t) - M_{n^{vnf},n}^{Node}(t-1)| \le \bar{M}$$

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

- Procedure



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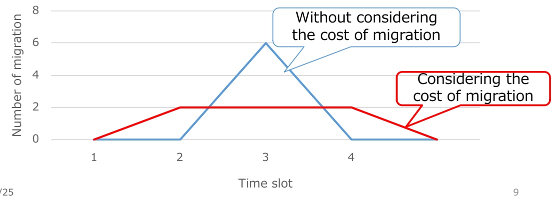
Decreasing migration by introducing $\bar{M}$

- Before introducing $\bar{M}$
  - Minimize the number of migration in predictive horizon

$$\sum_{0<t\le H}\sum_{n\in N^P}\sum_{n^{vnf}\in N^{VNF}} |M_{n^{vnf},n}^{Node}(t) - M_{n^{vnf},n}^{Node}(t-1)|$$

A large number of migration may occur

- Effect of introducing $\bar{M}$



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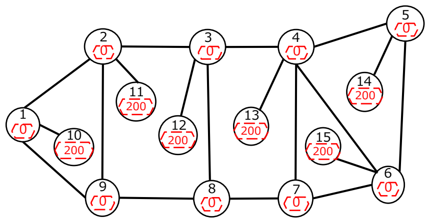
Evaluation: Physical network environment

- 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



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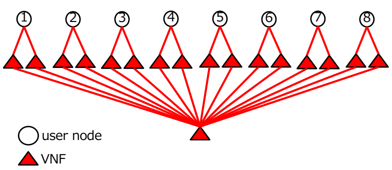
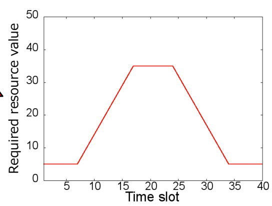
Evaluation: Virtual network environment

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





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Compared method

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

	MinActiveNode	NoMPC	MPC-VNF-P
Control parameters	$H=1$ $w=0$	$H=1$ $w=0.03$	$H=3,5$ $w=0.03$

Other simulation environments

- Prediction method
  - Simple line fitting to past time series
- Metrics
  - Maximum resource utilization
    - The largest resource utilization, which is defined by

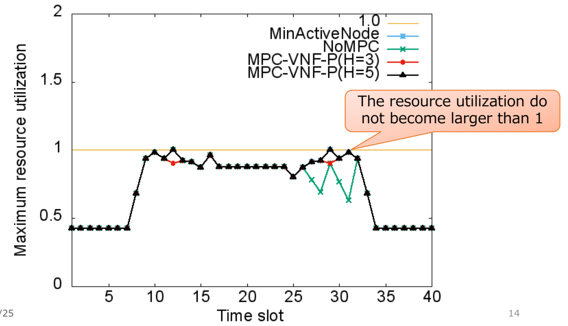
$$\max_{n^p \in N^p} \left(\frac{1}{u^p_{n^p}} \sum_{n^{vnf} \in N^{VNF}_{n^p}} u^v_{n^{vnf}} \right)$$

  - Number of active physical nodes
    - The number of physical nodes hosting at least one VNFs
  - Number of migrated VNFs
    - The number of VNFs which are migrated at each time slot

u^p_n: the resource capacity of physical node n^p
$N^{VNF}_{n^p}$: the set of virtual nodes hosted by the physical node n^p
$u^v_{n^{vnf}}$: the resource required by VNF node n^{vnf}

Maximum resource utilization

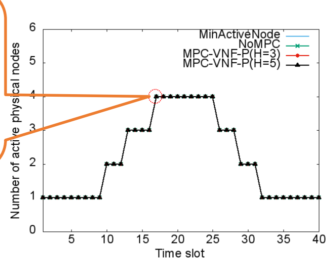
- All methods map the virtual network properly
  - VNFs are migrated before the lack of resources is caused by using the predicted values.



Number of active physical nodes

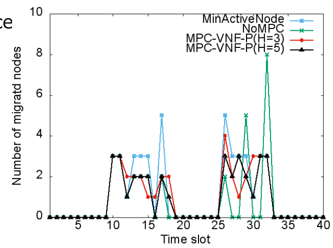
- All methods change the number of active physical nodes according to the time variation of the required resources
- MPC-VNF-P indicates the same performance compared with MinActiveNode

- 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