Thesis

An Advanced Fuzzy-based Optimal Resource Allocation Method in NFV

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   - Fuzzy Logic
   - Covariance Matrix Adaptation – Evolution Strategy (Optimization Method)
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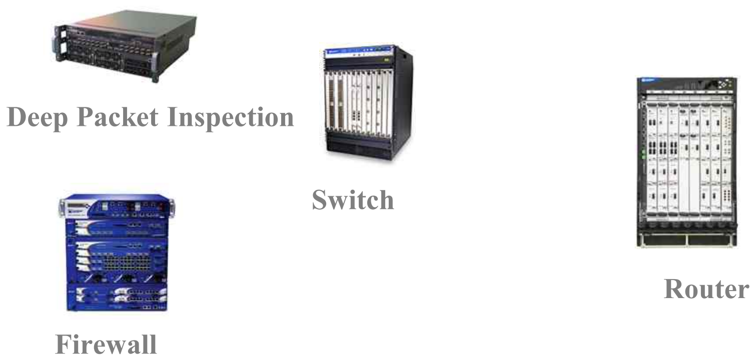
1. Introduction

1.1 Network Function Virtualization

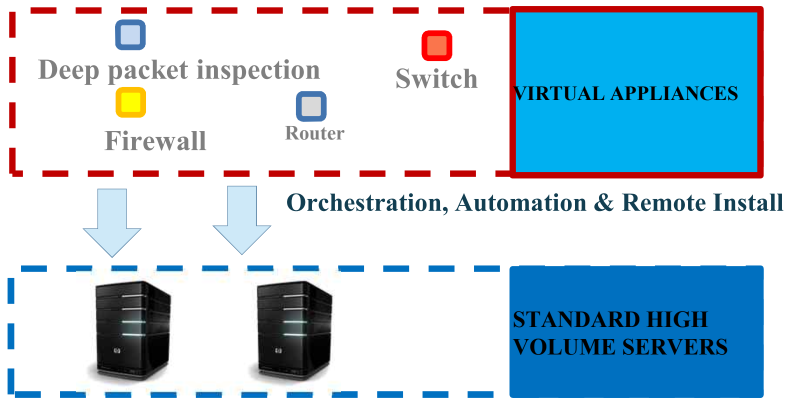
A means to make the network more flexible and simple by minimizing dependence on HW constraints.

Traditional Network Model:
APPLIANCE APPROACH



- Network Functions are **based on specific HW&SW**
- **One physical node per role**

Virtualised Network Model:
VIRTUAL APPLIANCE APPROACH

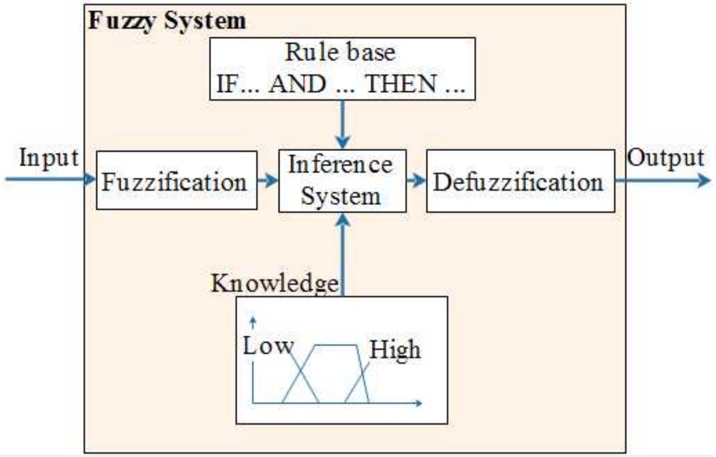


- Network Functions are **SW-based over well-known HW**
- **Multiple roles** over **same HW**

1. Introduction

1.2 Fuzzy Logic

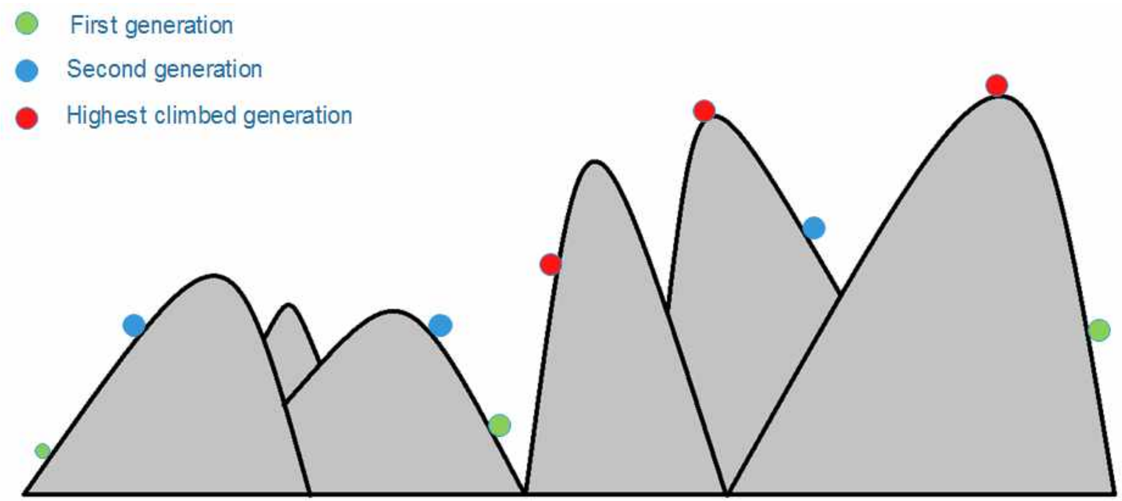
- Fuzzy logic employed to handle the concept of partial truth, where the truth value may range between completely true and completely false.
- The system itself has three processes: *Fuzzification*, *Inference*, *Deffuzzification*.
  1. **Fuzzification** : Transforming real values to fuzzy values.
  2. **Inference** : Inferring fuzzy values bases on fuzzy rules.
  3. **Deffuzzification**: Transforming fuzzy values to real values.
- Fuzzy system rules and knowledge is based on expert's estimation.



1. Introduction

1.3 Covariance Matrix Adaptation – Evolution Strategy (Optimization Method)

- CMA-ES stands for Covariance Matrix Adaptation Evolution Strategy, is stochastic, derivative-free methods for numerical optimization of *non-linear or non-convex continuous optimization problems*.
- It utilized Darwin's theory of evolution that individuals are naturally selective, and the most environmentally adapted individuals will be selected as the basis for the next generation.



Finding the highest mountain of generations

2. Resource Allocation in NFV

2.1 Network Function Virtualization - Resource Allocation

- Resource allocation in NFV requires *efficient algorithms to determine on which HVSs, VNFs are placed*, and be able to migrate functions from one server to another.

- Three stages of the resource allocation problem in NFV-based network's architectures.
  - ✓ **VNFs - Chain Composition (VNFs-CC)** → *dynamically compose chains of VNFs and strategically deploy them on a set of physical network nodes so as to achieve a predefined operator's objective.*
  - ✓ **VNF - Forwarding Graph Embedding (VNF-FGE)** → *composed by the ordered set of VNFs that the NS runs in order to fulfill service's attributes.*
  - ✓ **VNFs - Scheduling (VNFs-SCH)** → *execute each function in order to minimize the total execution time.*

2. Resource Allocation in NFV

2.2 Why we need/want to research about resource allocation problem in NFV?

- A network service is composed by a number of VNFs.
  - A packet must pass through a set of VNFs to be part of the offered network service.
  - As VNFs are software, one of the main challenges that arise is: How to allocate the set of VNFs that compose a network service in an adequate way.

  - NFV-RA is the NP-hard problem (*nondeterministic polynomial time*) so that we do not have any comprehensive optimization method to solve it.
    - ✓ Most of the proposed methods are **heuristic optimization**.

- If we can solve the problem efficiently, we could improve quality of service as well as *load balancing, reduction of capital expenditure and operational expenditure, energy saving, recovery from failures, etc*.

3. Related Works

1. Beck, Michael Till, and Juan Felipe Botero. "*Coordinated allocation of service function chains*." In Global Communications Conference (GLOBECOM), 2015 IEEE, pp. 1-6. IEEE, **2015**.
   - CoordVNF used breadth-first-search technique recursively to find all substrate nodes within a specified range that provide sufficient hosting and processing resources for a VNF request.

2. Mehraghdam, Sevil, Matthias Keller, and Holger Karl. "*Specifying and placing chains of virtual network functions*." In Cloud Networking (CloudNet), 2014 IEEE 3rd International Conference on, pp. 7-13. IEEE, **2014**.
   - considered the NFV-RA as a mixed integer quadratically constrained program (MIQCP) for finding the placement of the network functions and chaining them.

✓ Both of them did not mention calculation time as a factor to evaluate their proposed method so that it might increase calculation time in worse cases where the algorithm cannot find any solutions with limitation time.

✓ Their mathematic model employed low-performance mathematic optimization methods.

4. Proposed Method: Fuzzy-based Optimal Resource Allocation

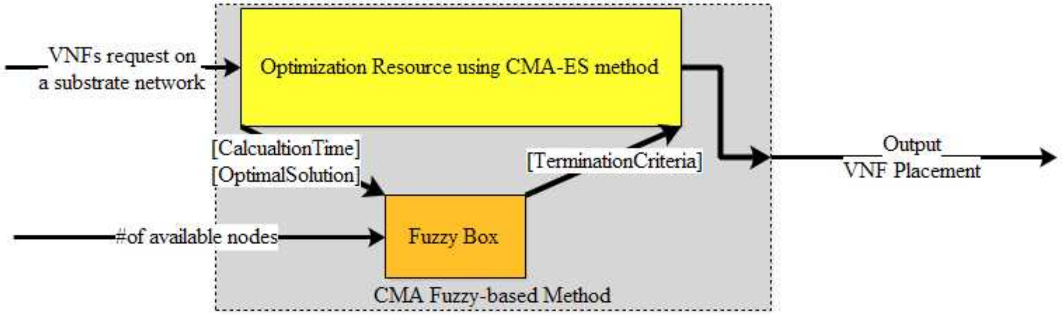
4.1 Proposed Method

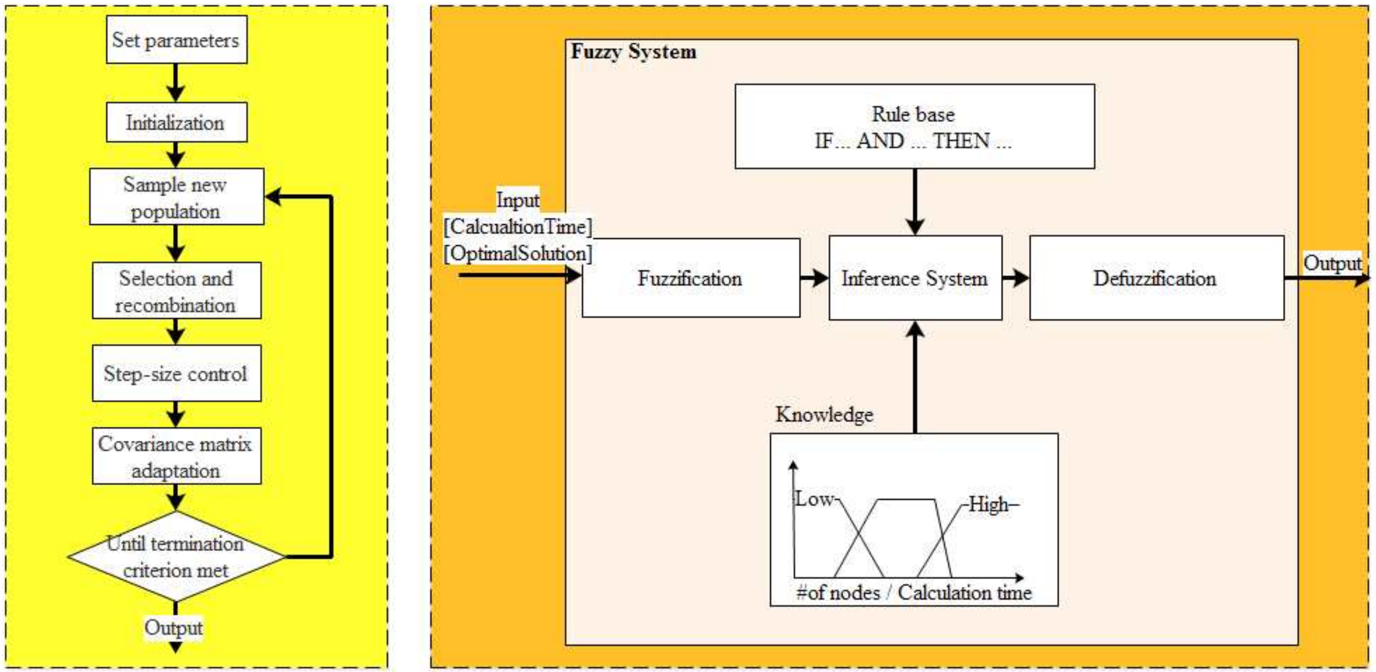
- Solving the optimization problem using heuristic methods which can deal with *non-linear or non-convex continuous* optimization problems.
  - ✓ Covariance Matrix Adaptation – Evolution Strategy is such the method.

- The heuristic methods might solve NFV-RA problem endlessly. If it is terminated with an amount of time, how long is enough?
  - ✓ Using fuzzy logic with two input parameters which are *current calculation duration* and *optimal solutions*, the output of the system is the *terminal criteria time*.
  - ✓ Using moving average to normalize optimal solutions, which is an input of the fuzzy system

4. Proposed Method: Fuzzy-based Optimal Resource Allocation

4.2 Overview of the proposed method

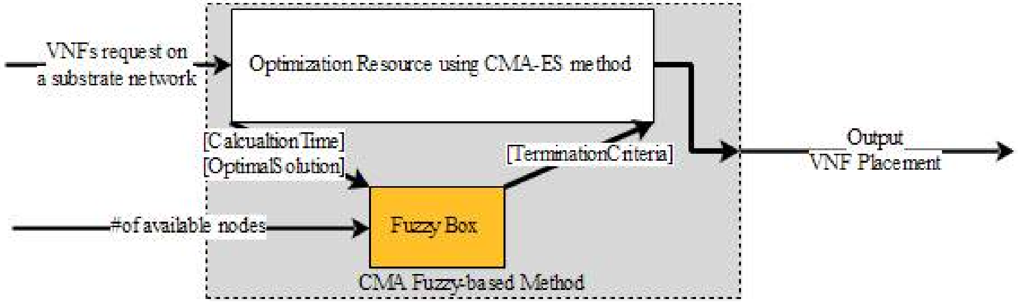


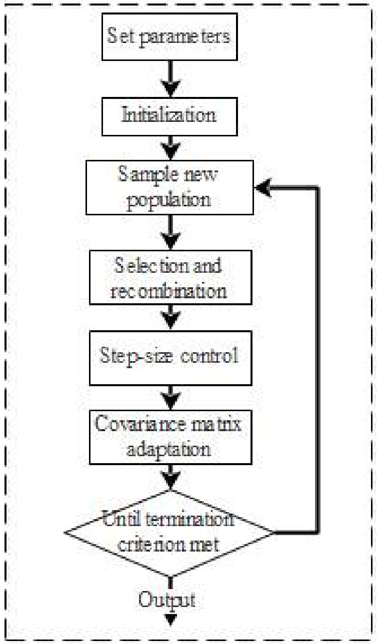


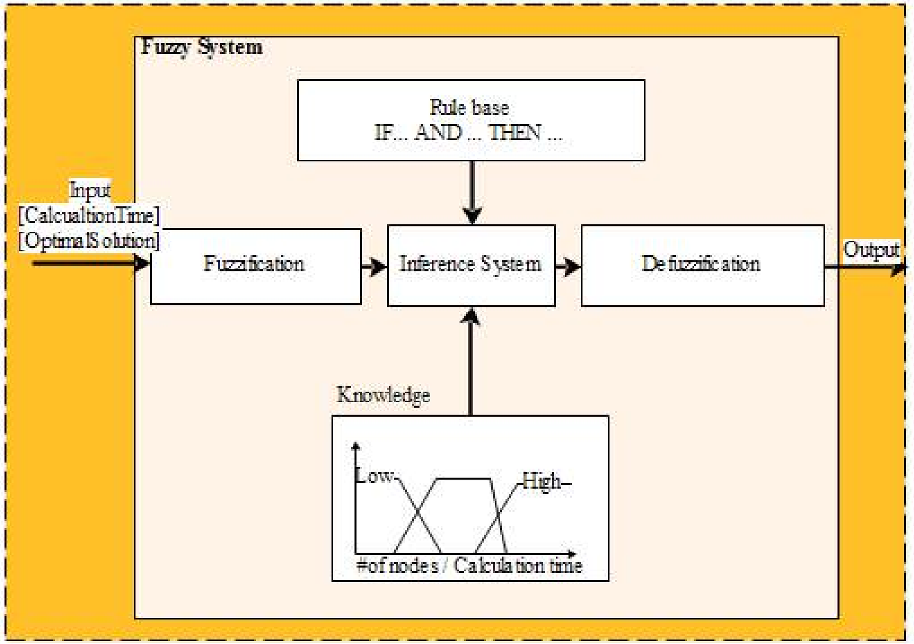
4. Proposed Method: Fuzzy-based Optimal Resource Allocation

4.3 Fuzzy System

(1)



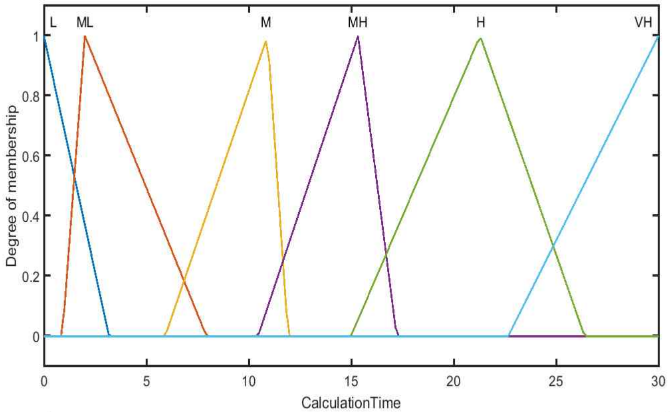


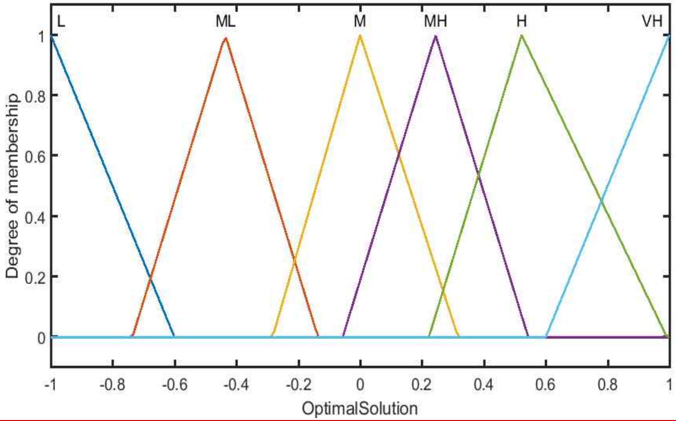


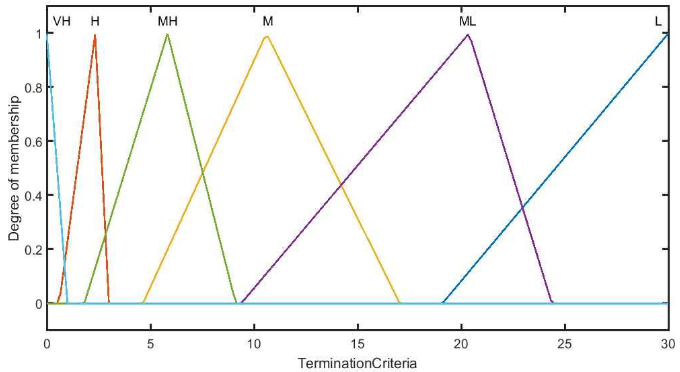
4. Proposed Method: Fuzzy-based Optimal Resource Allocation

4.3 Fuzzy System (2)

- I define six linguistic values as the following: Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H), and Very High (VH).
  - ✓ If calculation time is medium high (**MH**) and optimal solution is high (**H**), then terminal criteria is medium high (**MH**).





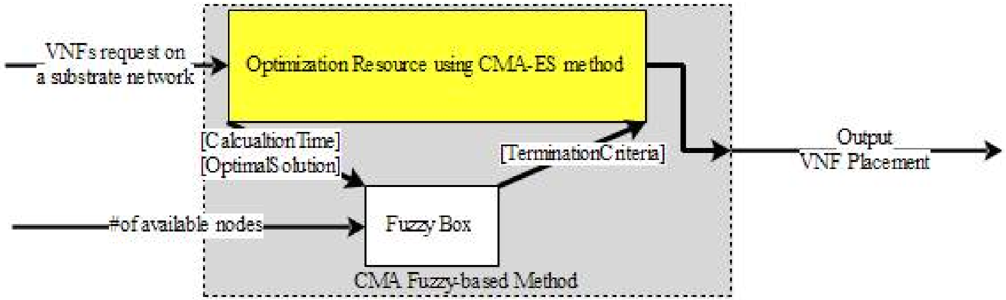


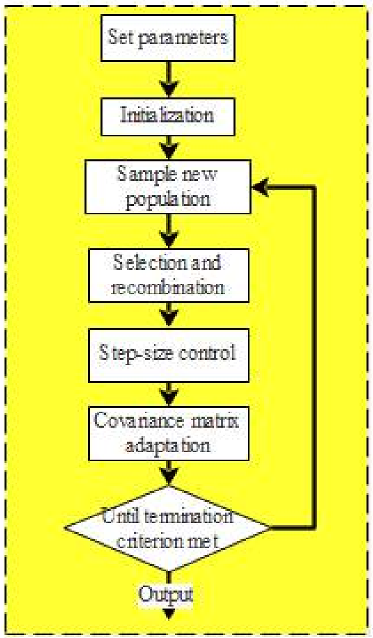
	L	ML	M	MH	H	VH
L	M	M	MH	H	H	VH
ML	M	M	M	MH	H	H
M	ML	M	M	M	MH	MH
MH	ML	ML	ML	ML	MH	MH
H	L	L	L	ML	M	M
VH	L	L	L	ML	ML	ML

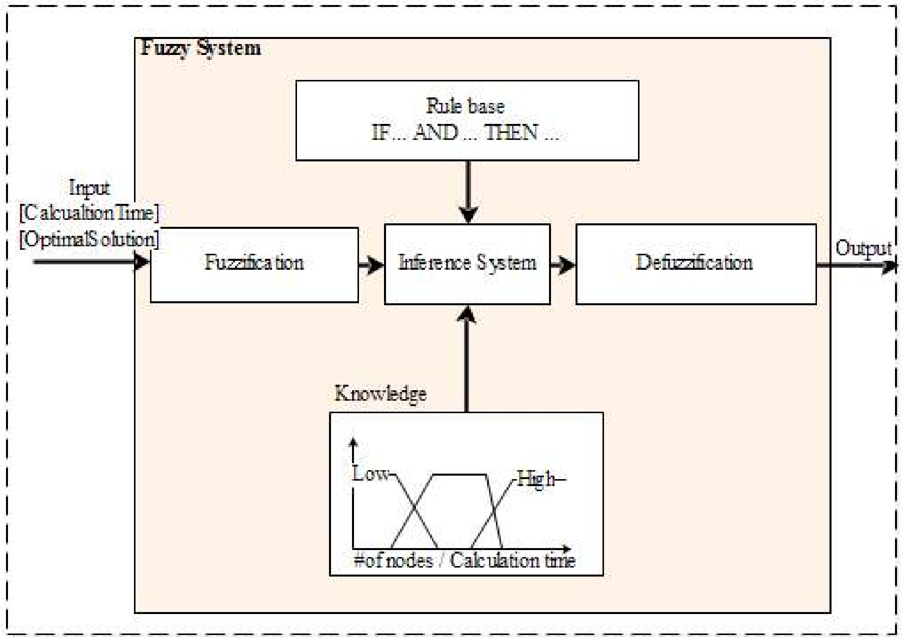
Fuzzy inference rules (Column: calculation time, Row: optimal solution)

4. Proposed Method: Fuzzy-based Optimal Resource Allocation

4.4 Model resource allocation problem (1)







4. Proposed Method: Fuzzy-based Optimal Resource Allocation

4.4 Model resource allocation problem (*Maximizing bandwidth remaining allocation*) (2)

$$\text{maximize} \quad \sum_{(v,v')\in E, v\neq v'} r_{rem\ d(v,v')}, \tag{1}$$

$$r_{rem\ d}(v,v') = r(v,v') - \sum_{u,u'} r_{req}(u,u') \,.\, b_{v,v',u,u'}, \tag{2}$$

$$r(v,v') \geq \sum_{u,u'} r_{req}(u,u') \,.\, b_{v,v',u,u'}. \tag{3}$$

$$b_{v,v,u,u'} = 0, \tag{4}$$

$$b_{v,v',u,u'} + b_{v',v,u,u'} \leq 1, \tag{5}$$

$$\sum_{f\in F} m_{(f,v)} \,.\, md_{(f,v)} \,.\, d_{dem}(f) \leq d_c(v), \tag{6}$$

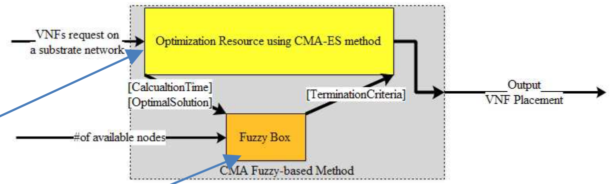
$$\sum_{f\in F} m_{(f,v)} \,.\, ms_{(f,v)} \,.\, s_{dem}(f) \leq s_c(v), \tag{7}$$

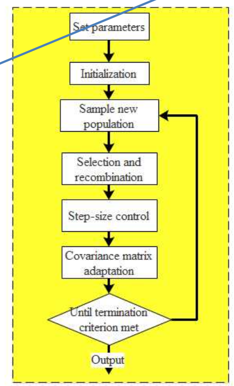
Parameter	Description
$d_c(v)$	Data center computational resources in node $v \in V$
$s_c(v)$	Switch computational resources in node $v \in V$
$d_{dem}(f)$	Datacenter demand resource for a NFV requested function $f \in F$
$s_{dem}(f)$	Switch demand resource for a requested function $f \in F$
$r(v,v')$	Data rate capacity of (v,v'), $v,v' \in E$
$r_{req}(u,u')$	Data rate demand of two mapped nodes (u,u')
$l_{lt}(u,u')$	Latency of the path between u and u'

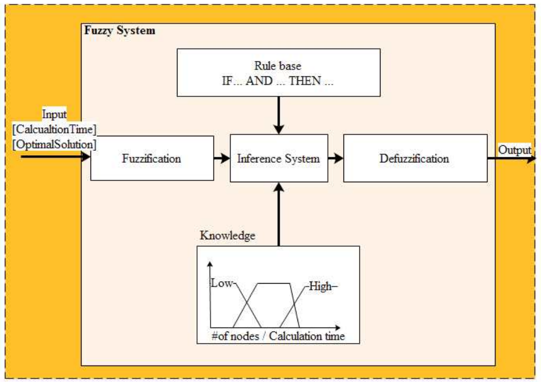
Parameter	Description
$b_{(v,v',u,u')}$	Binary number expresses that whether (u,u') belongs to the two mapped nodes (u,u')
$m_{(f,v)}$	Binary number expresses that function f mapped to v
$m_{s(f,v)}$	Binary number expresses that function f mapped to switch function on v
$m_{d(f,v)}$	Binary number expresses that function f mapped to data center function on v
$r_{rem\ d}(v,v')$	Remaining data rate of (v,v') after allocating to (u,u')

4. Proposed Method: Fuzzy-based Optimal Resource Allocation

4.5 CMA Fuzzy VNF algorithm

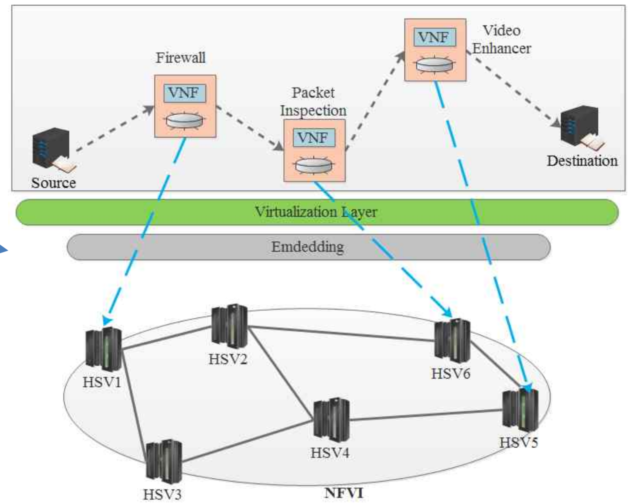






Data: A number of substrate nodes, a list of VNF requests
Result: VNF placement on the substrate network, amount of remaining resource

```
While newVNFRequest do
|   While terminalCriteriaOptimal do
|   |   solvingOptimizationProblem(); // using (1)-(7)
|   |   CalculateOptimalAverage(); // optimal average values
|   |   FuzzificationInput(); //
|   |   FuzzyInference(); // using fuzzy inference Table
|   |   outputFuzzy = Defuzzification();
|   |   terminalCriteriaOptimal = calculateTime(); //
|   end
|   calculateRemaingResource();
|   MAP_NODE_REQUEST();
|   MAP_LINK_REQUEST();
end
```

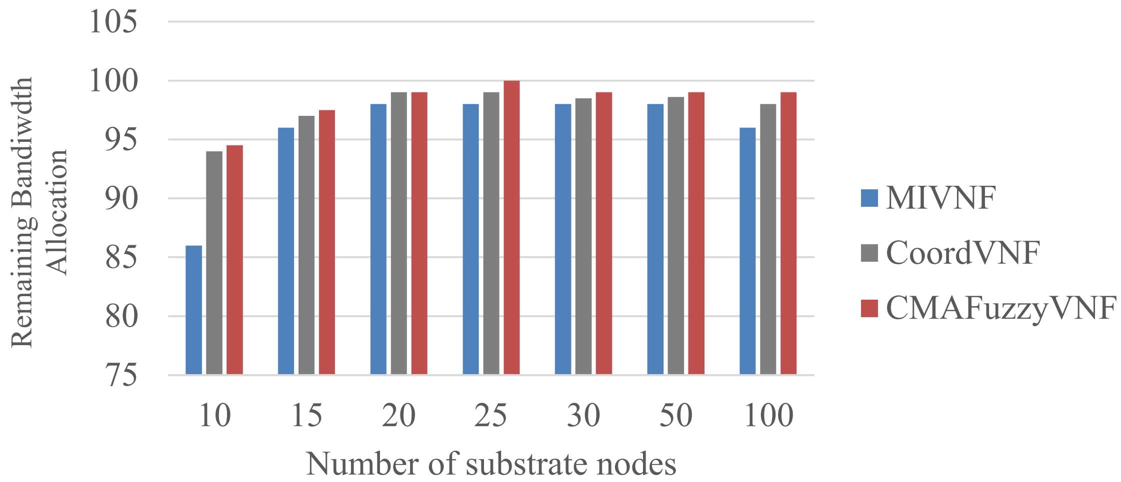


5. Experiment & Result

Runtime and Resource Allocation Comparison

Nodes	MIVNF	CoordVNF	CMAFuzzyVNF
10	2.1s	18ms	19ms
15	42.6s	15ms	14ms
20	12m02s	13ms	5ms
25	33m56s	9ms	15ms
30	12h57m	12ms	20ms
50	26h36m	16ms	18ms
100	40h37m	28ms	31ms
200	-	2m10s	1m38
300	-	5m34s	4m10s
400	-	11m24s	9m25s
500	-	18m18s	17m3s
1000	-	2h38m	30m39s

Runtime comparison between three methods



Remaining bandwidth allocation in substrate network

My proposed method saves bandwidth allocation more than CoorVNF 1% and MIVNF 3%

6. Conclusion

- I applied covariance matrix adaptation evolution strategy (CMA-ES) to solve NFV-RA optimization problem.
  - ➢ I applied fuzzy logic to deduce termination criteria based on input requirement of VNFs of the CMA-ES method.
    - ✓ NFV-RA is NP-hard problem so that we do not have any specific method to solve the problem.
    - ✓ The two compared approaches used heuristic methods, but both of the heuristic methods have *low-performance* which increases computational cost.
    - ✓ Improving remaining resource allocation up to 3% compared to existing proposed methods in NFV environment.
    - ✓ Faster calculation compared to existing methods.

- In the future research, I am going to intend to investigate the problem with *multi-objective*.
- The study of *trace-back step* will be carried out intensively to determine that how many previous optimal solutions can be used to deduce time calculation.

Q & A

Thank You