User Mobility and Quality-of-Experience Aware Placement of Virtual Network Functions in 5G

Final Defense Presentation

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Overview

- Introduction
- Related Works
- Proposed Approach
- Performance Evaluation
- Conclusion & Future Works

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Introduction

- **5G**

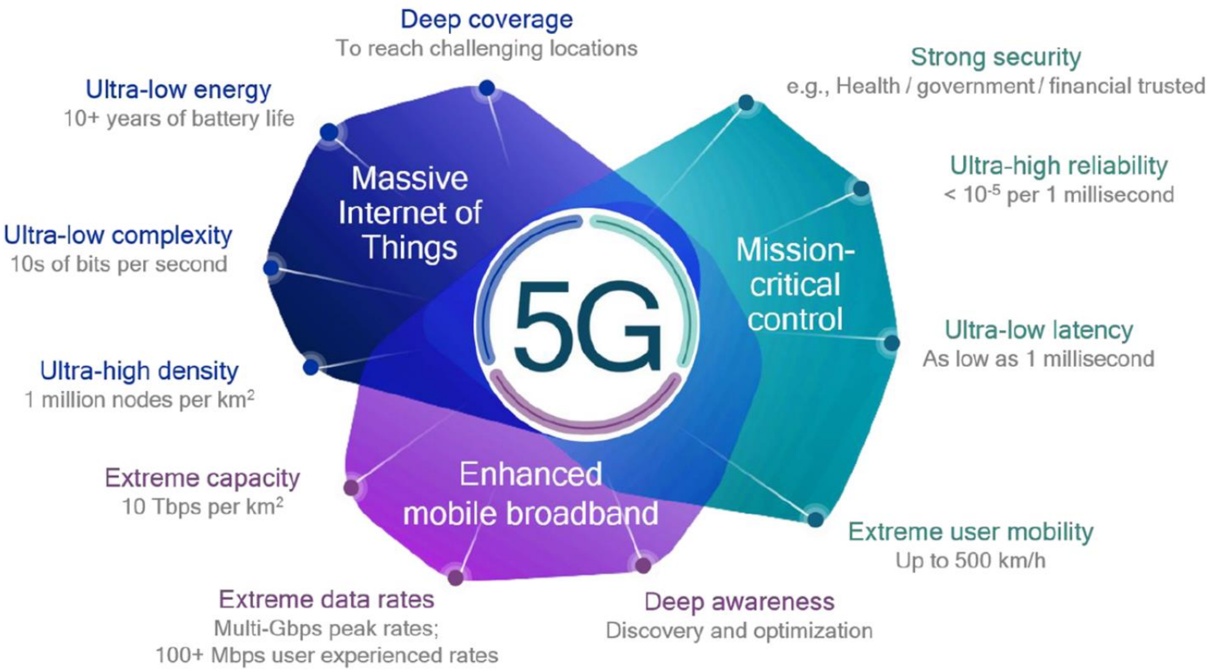


Fig: Features of 5G

Revolutionary Applications of 5G

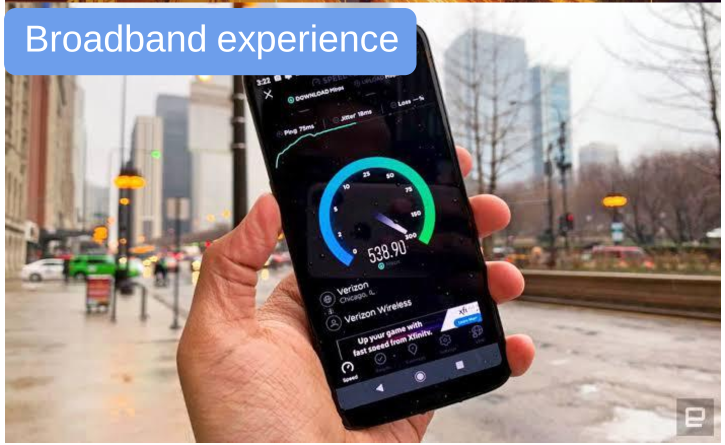
Entertainment & Media

Smart City

And many more!

Modern Agriculture

Broadband experience



Mobile Cloud Computing

- Integrated with 5G
- Uses Virtual Network Function (VNF)
- Offers high computational power

Fig 1. Mobile Cloud Computing

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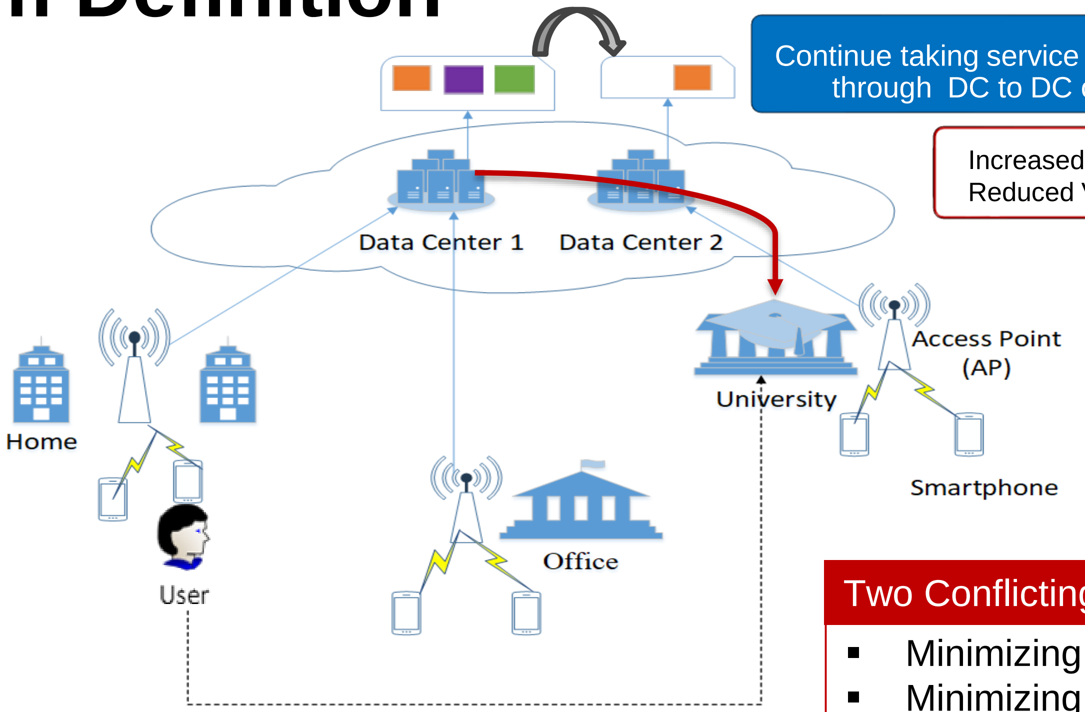
Problem Definition



Continue taking service from Data Center 1 through DC to DC communication

Increased response time but
Reduced VNF relocation

Two Conflicting Objectives!

- Minimizing VNF relocation
- Minimizing response time

Fig. 2: User Services Architecture in 5G

Objective & Contribution

- Optimal placement of Virtual Network Functions (VNFs) in DCs
- Maximizing QoE or decreasing the cost of operation
- Trade-off between minimizing VNF relocation and response time
- To study comprehensive performance of the proposed solution with the state-of-the-art works

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Related Works

User mobility-aware virtual network function placement for virtual 5g network infrastructure [1]

Contribution:

- Solution for minimizing VNF relocation
- Solution for minimizing communication delay

Limitation:

- Provide two individual solutions
- Didn’t bring trade-off among them

Related Works

Dynamic resource allocation exploiting mobility prediction in mobile edge computing [2]

Contribution:

- Proposed VM migration algorithm
- Reducing total delay compared to other algorithms

Limitation:

- Didn’t consider capacity of VM (Virtual Machines)

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System Architecture

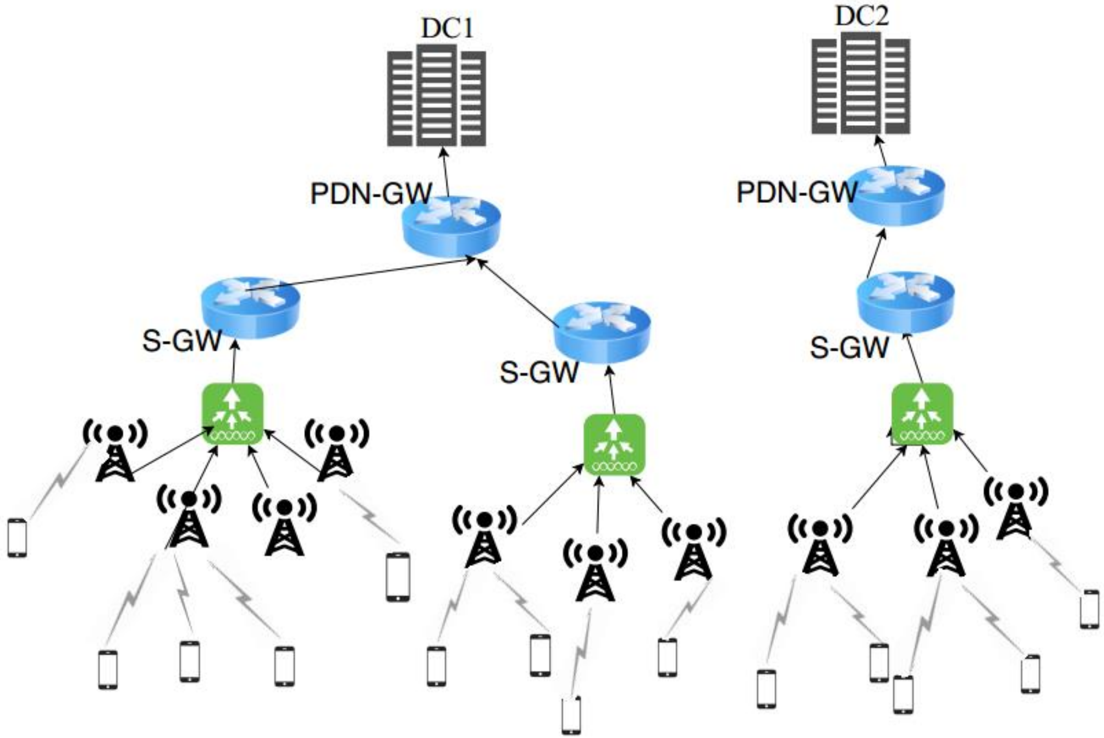

Fig 3: System Architecture of VNF services in 5G

Optimal Placement of VNFs

For placing VNF f ∈ V_j of eNB j ∈ N to DC k ∈ D:

- Relocation time:

$$R_{k,j}^f = \{(1 - p_k^f) \times b_{k,j}^f\} \times H_k^f$$

where,

$$H_k^f = (1 - n_k^f) \times \tau_f$$

- Communication Time:

$$C_{k,j}^f = b_{k,j}^f \times (t_j + t_k)$$

D = The set of data centers
N = The set of eNBs
V_j = The set of VNFs of eNB j ∈ N

$b^f_{k,j}$ = Whether VNF f of eNB j ∈ N is placed to DC k ∈ D or not.
p^f_k = Whether VNF f was previously running on DC k ∈ D or not
n^f_k = Whether DC k ∈ D contains VNF f or not
t_j = Communication time between enB j and own DC
t_k = Communication time between DC k and own DC
τ_f = Transfer time of VNF f

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Optimal Placement of VNFs

Objective Function:

$$Minimize:$$

Relocation Time

$$W = \sum_{j \in N} \sum_{f \in V_j} \sum_{k \in D} \{\gamma \times R^f_{k,j} \times \phi_k + (1-\gamma) \times C^f_{k,j} \times \sigma_k\}$$

Communication Time

D = The set of data centers

N = The set of eNBs

V_j = The set of VNFs of eNB j $\in$ N

γ = Priority Factor

ϕ_k = Cost to relocate a VNF to DC k $\in$ D

σ_k = Cost of taking service from DC k $\in$ D

Optimal Placement of VNFs

Constraints:

C1: $b^f_{k,j} = \{0,1\}, \ \forall j \in N, \ \forall f \in V_j, \ \forall k \in D$

C2: $\sum_{k \in D} b^f_{k,j} = 1, \ \forall j \in N, \ \forall f \in V_j$

C3: $\sum_{f \in V_j} \sum_{k \in D} b^f_{k,j} = |V_j|, \ \forall j \in N$

C4: $\sum_{k \in D} (R^f_{k,j} + C^f_{k,j} + \varphi_f) \leq \delta_{worst}, \ \forall j \in N, \ \forall f \in V_j$

C5: $\sum_{j \in N} \sum_{f \in V_j} b^f_{k,j} \leq \zeta_k, \ \forall k \in D$

D = The set of data centers

N = The set of eNBs

V_j = The set of VNFs of eNB j $\in$ N

$b^f_{k,j}$ = Whether VNF f of eNB j is placed to DC k $\in$ D or not.

δ_{worst} = Maximum response time tolerated by the application

φ_f = Execution time of VNF f $\in V_j$

ζ_k = VNF holding capacity of DC k $\in$ D

Computation Time for Optimal Placement of VNFs

- Can be reduced to Generalized Assignment Problem (GAP)

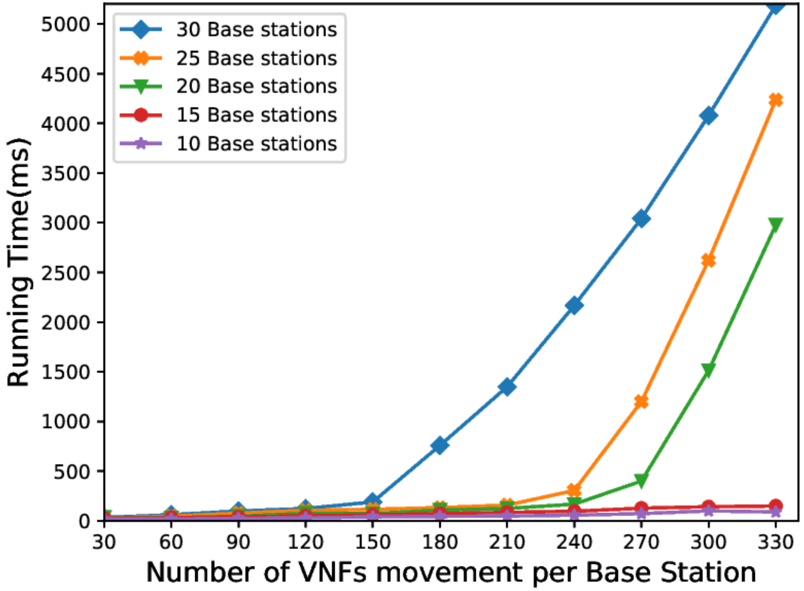

Fig. 4: Impacts of number of VNFs movement per eNB on running time

NEOS Server

2 x Intel Xeon e5-2698 @2.3 GHz

92 GB RAM

NP-Hard

a) Ant Colony Optimization (ACO) Based VNF Allocation

b) Greedy Based First-Fit VNF (FF-VNF) Allocation Problem

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First-Fit (FF) Initial Solution

Input: eNB set N, VNF set V_j for each eNB $j \in N$ and data center set D

Output: Set of VNF-DC pair for each eNB in the initial solution $\mathcal{S}_0$

$\mathcal{S}_0 \leftarrow \emptyset$
for all eNB $j \in N$ **do**
    for all VNF $f \in V_j$ **do**
        for all DC $k \in D$ **do**
            if $(X_k < \zeta_k \;\&\&\; Y_{k,j}^{f} \leq \delta_{worst})$ **then**
                $\mathcal{S}_0 \leftarrow \mathcal{S}_0 \bigcup \{(j, f, k)\}$
                $X_k = X_k + 1$
                Break
            end if
        end for
    end for
end for
return $\mathcal{S}_0$

Ant Colony Optimization (ACO) Based VNF Allocation

- Initial Pheromone Calculation
- Local Heuristic Calculation
- DC selection
- Update Local Pheromone
- Update Global Pheromone

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ACO based VNF Allocation (1/3)

- Initial Pheromone Calculation

$$\mathcal{T}_o = \sum_{j \in N} \sum_{f \in V_j} \sum_{k \in D} \frac{1}{R_{k,j}^{f} + C_{k,j}^{f}} \times \mathcal{Y}_{j,f}^{k} \quad \text{........................ (3.20)}$$

$$\mathcal{Y}_{j,f}^{k} = \begin{cases} 1, & \text{if } (j, f, k) \in \mathcal{S}_0 \\ 0, & \text{otherwise} \end{cases} \quad \text{..........................(3.21)}$$

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ACO based VNF Allocation (2/3)

- Local Heuristic Calculation

$$\mathcal{H}_{j,f}^{k} = \frac{1}{\gamma \times R_{k,j}^{f} \times \phi_k + (1-\gamma) \times C_{k,j}^{f} \times \sigma_k} \quad \text{.........} \ (3.22)$$

- Selection of Data Center

$$s = \begin{cases} \underset{k \in D_c}{\text{argmax}} \left([\mathcal{T}_{j,f}^{k}]^{\alpha} \times [\mathcal{H}_{j,f}^{k}]^{\beta} \right), \text{if q} \leq q_0 \text{ (exploitation)} \\ S, \qquad \text{otherwise (exploration)} \end{cases} \quad \text{.........} \ (3.23)$$

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ACO based VNF Allocation (3/3)

- Local Pheromone Update

$$\mathcal{T}_{j,f}^{k}(t+1) = \rho_l \times \mathcal{T}_0 + (1-\rho_l) \times \mathcal{T}_{j,f}^{k}(t) \quad \text{.............. (3.25)}$$

- Global Pheromone Update

$$\mathcal{T}_{j,f}^{k}(t+1) = \rho_g \times \Delta\mathcal{T}_{j,f}^{k} + (1-\rho_g) \times \mathcal{T}_{j,f}^{k}(t) \quad \text{.... (3.26)}$$

$$\Delta\mathcal{T}_{j,f}^{k} = \begin{cases} \mathcal{T}_{j,f}^{k}, & \text{if } (j,f,k) \in \mathcal{G} \\ 0, & \text{otherwise} \end{cases}$$

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Ant Colony Optimization based VNF Allocation

Input: eNB set N, VNF set V_j for each eNB $j \in N$ and data center set D.
Output: VNF-DC pair for each eNB

Initialize system parameters α, β, ρ_l, ρ_g
Initialize ants set A
Generate initial solution using Algorithm 2
Calculate initial pheromone value $\mathcal{T}_o$ using Eq. 3.20
Set maximum iteration MAX-IT
while ($iteration \leq$ MAX-IT) **do**
  for all ant $a \in A$ **do**
    for all eNB $j \in N$ **do**
      for all VNF $f \in V_j$ **do**
        Assign VNF $f \in V_j$ for eNB $j \in N$ to DC $k \in D$ using Eq. 3.23
      end for
    end for
    for all VNF $f \in V_j$ **do**
      Update the local pheromone value using Eq. 3.25
    end for
  end for
  Update the global pheromone value using Eq. 3.26
  $iteration = iteration + 1$
end while
return VNF-DC pairs for each eNB

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Simulation Environment

CloudSim Environment

Parameter	Value
Simulation area	2000 $\times$2000 m^2
Number of Data-Centers (DC)	12
Number of eNBs under a DC	4 - 25
Number of VNFs under an eNB	500 - 2000
Communication delay between DCs	10 - 200 msec
Communication delay between DC and eNB	2 - 5 msec
Date rate to transfer VNF between DCs	1 - 50 Mbps
Size of each Virtual Network Functions (VNFs)	100 - 300 KB
Weight factor (γ)	0.7
Importance of pheromone value (α)	5
Importance of heuristic value (β)	1
Local pheromone constant (ρ_l)	0.3
Global pheromone constant (ρ_g)	0.4
Number of ants	20
Maximum Iteration MAX-IT	200

Performance Metrics

- Quality-of-Experience (QoE)
- Number of relocations of the VNFs
- User Satisfaction
- VNF Relocation Overhead

Simulation Result

- Impact of varying number of VNFs movement
- Impact of varying number of eNB per DC
- Impact of varying number of VNF holding capacity of DC

Number of Data Centers: 12
Number of eNB per DC: 20
VNFs holding capacity of DC: 600

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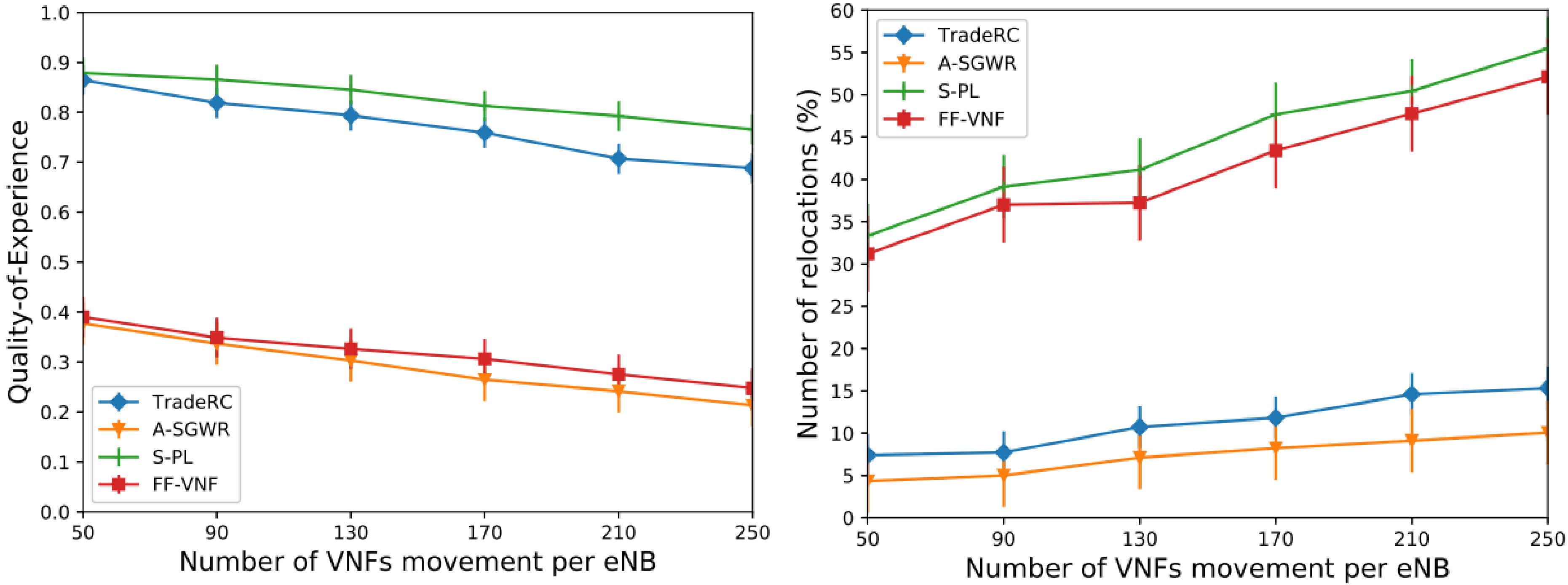
Impact of varying number of VNFs movement(1/2)



(a) (b)

Fig 5: Impacts of varying number of VNFs movement on (a) QoE (b) Number of relocations

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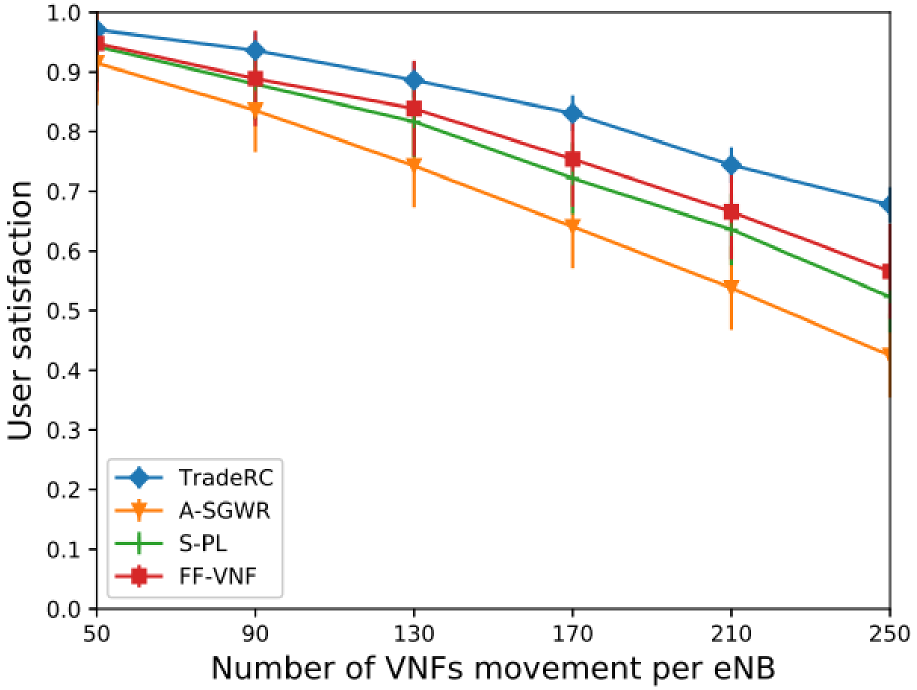
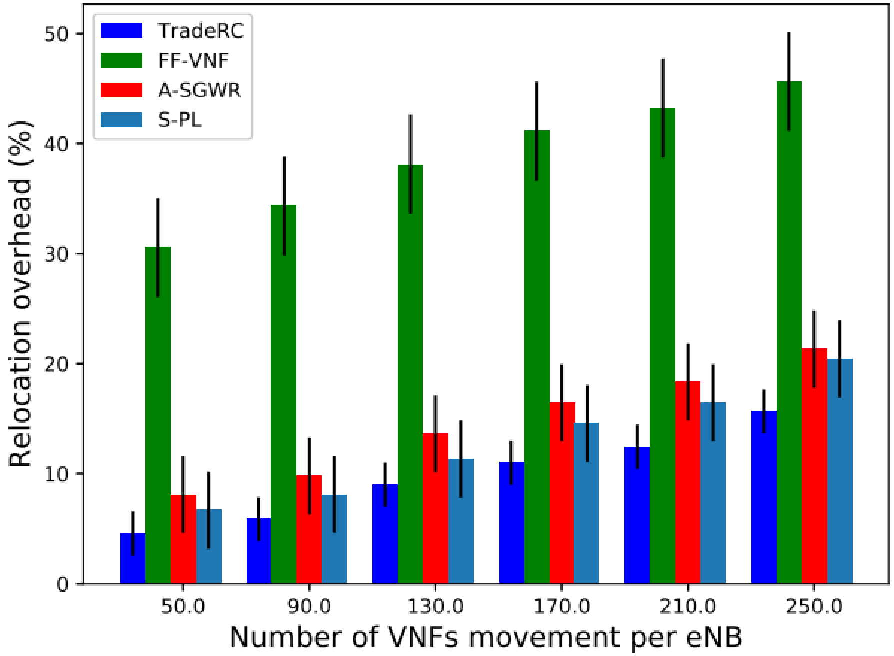
Impact of varying number of VNFs movement(2/2)



(c)



(d)

Fig 6: Impacts of varying number of VNFs movement on (a) User Satisfaction (b) Relocation Overhead

Simulation Result

- Impact of varying number of VNFs movement
- Impact of varying number of eNB per DC
- Impact of varying number of VNF holding capacity of DC

Number of Data Centers: 12
Number of VNFs movement per eNB: 250
VNFs holding capacity of DC: 600

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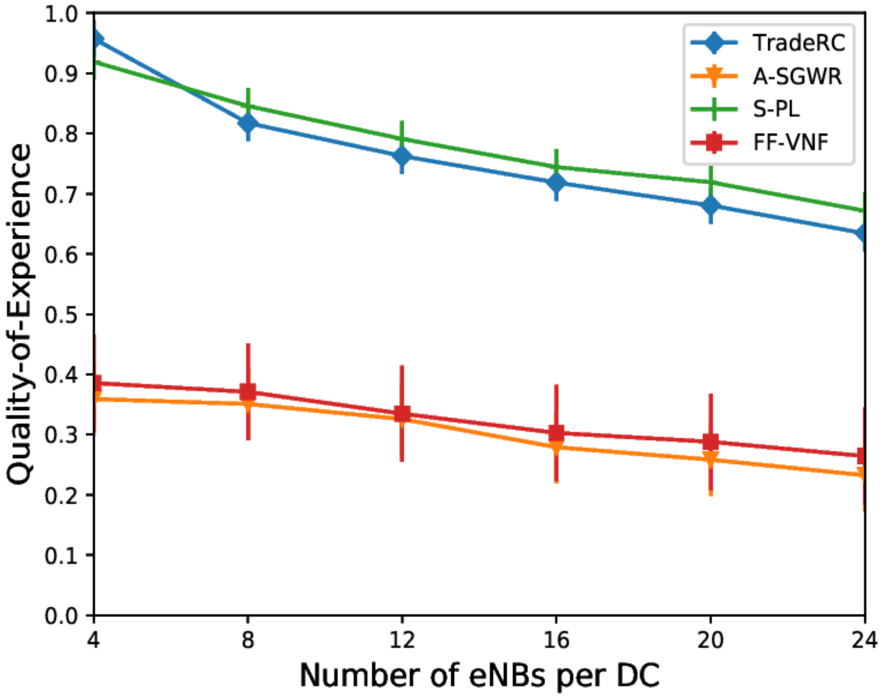
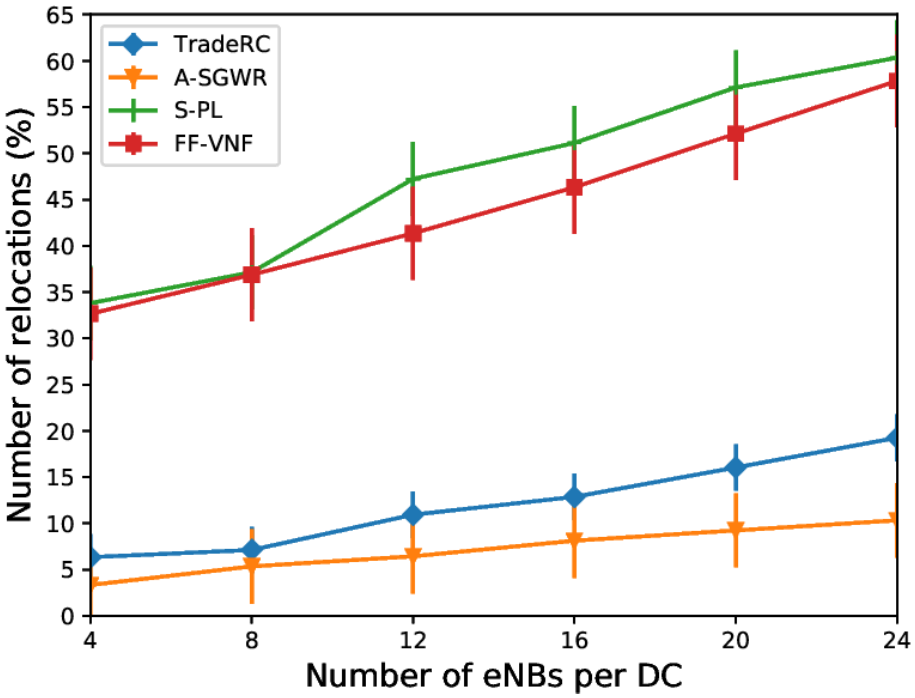
Impact of varying number of eNBs per DC(1/2)



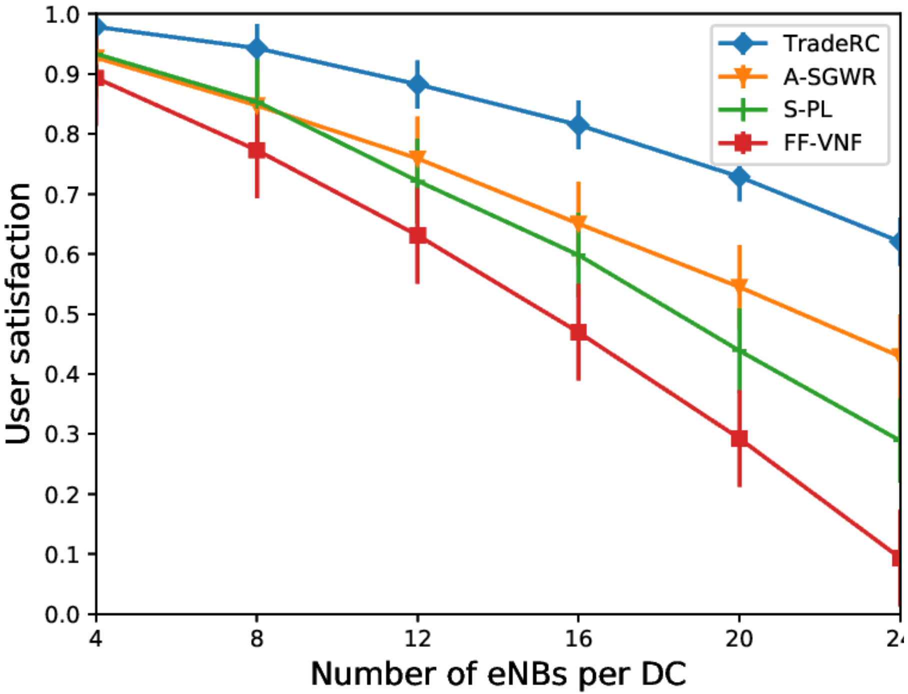
(a)



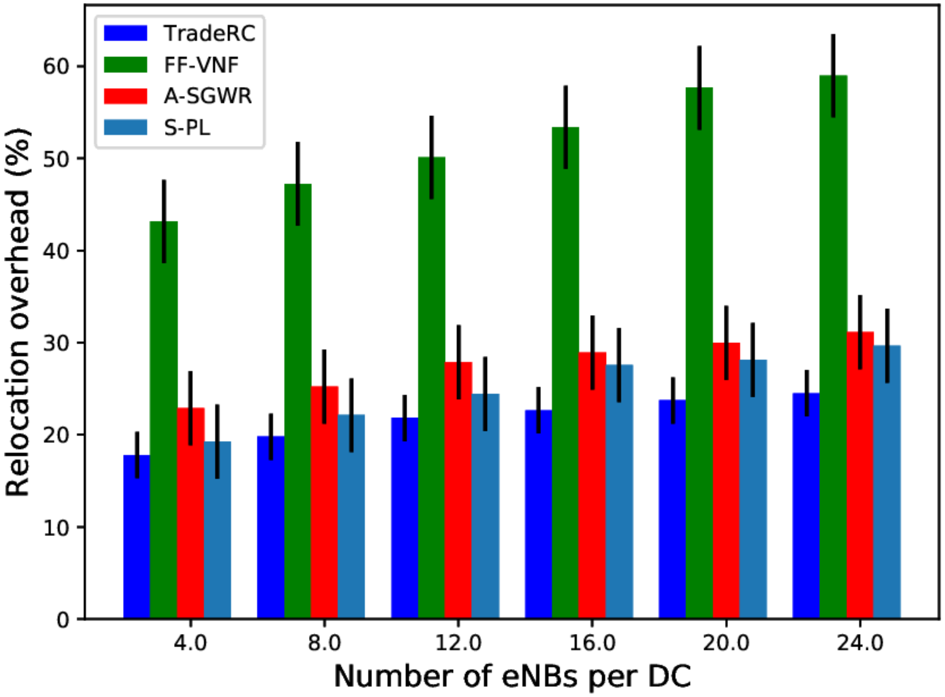
(b)

Fig 7: Impacts of varying number of BS per DC on (a) QoE (b) Number of relocations

Impact of varying number of eNBs per DC(2/2)



(c)



(d)

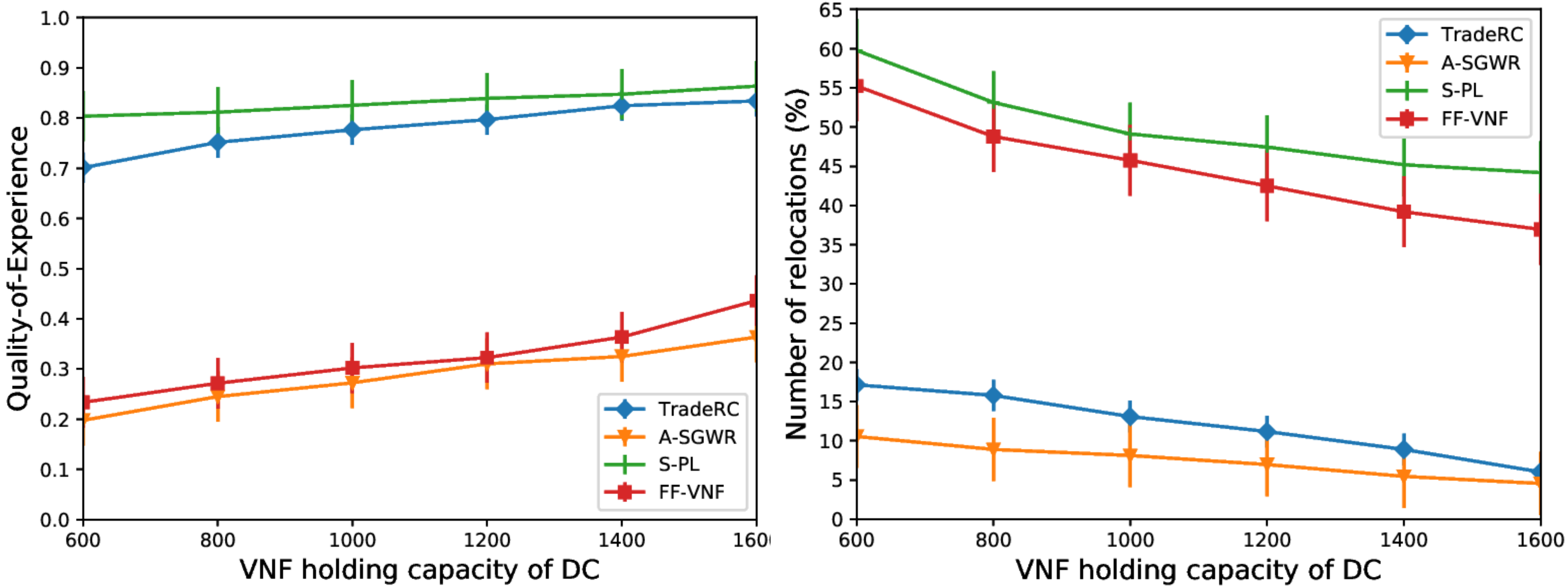
Fig 8: Impacts of varying number of BS per DC on (a) User Satisfaction (b) Relocation Overhead

Simulation Result

- Impact of varying number of VNFs movement
- Impact of varying number of eNB per DC
- Impact of varying number of VNF holding capacity of DC

Number of Data Centers: 12
Number of eNB per DC: 20
Number of VNFs movement per eNB: 250

Impact of varying number of VNF holding capacity of DC(1/2)



(a) (b)

Fig 9: Impacts of of VNF holding capacity of DC on (a) QoE (b) Number of Relocations

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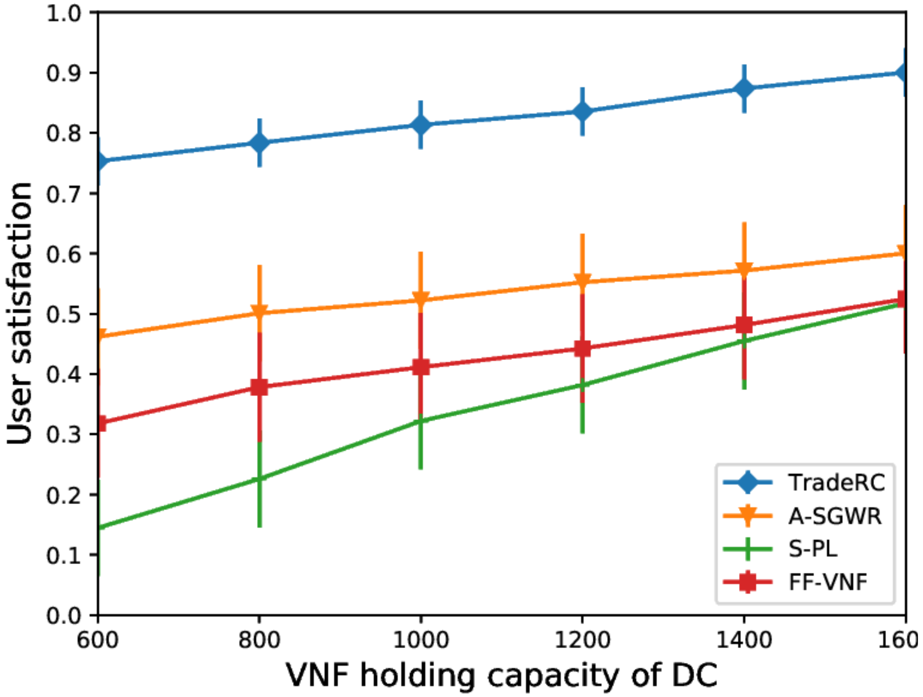
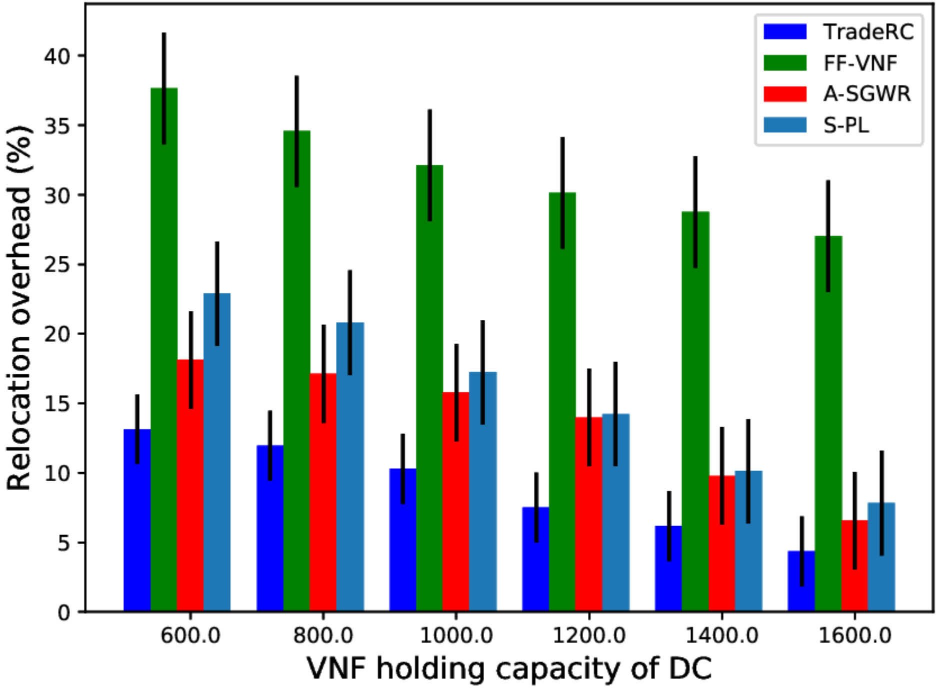
Impact of varying number of VNF holding capacity of DC(2/2)



(c)



(d)

Fig 10: Impacts of VNF holding capacity of DC on (a) User Satisfaction (b) Relocation Overhead

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Conclusion

- Optimal Placement of VNF
- Trading off between VNF relocation and QoE
- NP-hard problem
- Ant Colony Optimization (ACO) based VNF placement
- Maximizes user satisfaction (as high as 25%)
- Minimizes VNF relocations overhead (as high as 15%)

Future Research Scope

- Mathematical modeling & analysis
- Load balance among the DCs

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1. J. Plachy, Z. Becvar, and E. C. Strinati, “Dynamic resource allocation exploiting mobility prediction in mobile edge computing,” in 2016 IEEE 27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), Sep. 2016, pp. 1–6.
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1. Min Chen, Yixue Hao, Hamid Gharavi, and Victor C.M. Leung. Cognitive information measurements: A new perspective. Information Sciences, 505:487 - 497, 2019

1. M. Chen, Y. Hao, L. Hu, K. Huang, and V. K. N. Lau. Green and mobility aware caching in 5g networks. IEEE Transactions on Wireless Communications, 16(12):8347{8361, Dec 2017

List of Publications

1. Palash Roy, Anika Tahsin, Sujan Sarker, Tamal Adhikary, Md. Abdur Razzaque, Mohammad Mehedi Hassan, “User mobility and Quality-of-Experience aware placement of Virtual Network Functions in 5G", **Elsevier Computer Communications Journal 2019**, vol. 150, pages. 367 - 377, January 2020. doi: https://doi.org/10.1016/j.comcom.2019.12.005.

Any Question ?

Thank You

Proof of NP-Hardness

- **Generalized Assignment Problem (GAP):**

Minimize:

$$\sum_{i\in M}\sum_{j\in T} C_{ij}X_{ij}$$

Subject to,

$$\sum_{j\in T} A_{ij}X_{ij} < B_i, \quad \forall i \in M$$

$$\sum_{i\in M} X_{ij} = 1, \quad \forall j \in T$$

$$X_{ij} \in \{0,1\}, \quad \forall i \in M, \forall j \in T$$

T = Set of tasks
M = Set of agents

C_{ij} = Cost of assigning task j to agent i

X_{ij} = Capacity of agent i used to assign task j

A_{ij} = Whether task j is assigned to agent i

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Proof of NP-Hardness

- **Optimal VNF Placement Problem Reduced to GAP:**

Minimize:

$$\sum_{f \in V_j} \sum_{k \in D} Z_{kf} b_k^f$$

Subject to,

$$\sum_{f \in V_j} b_k^f \leq \zeta_k, \ \forall k \in D$$

$$\sum_{k \in D} b_k^f = 1, \quad \forall f \in V_j$$

$$b_k^f \in \{0, 1\}, \quad \forall f \in V_j, \forall k \in D$$

D = The set of data centers

V_j = The set of VNFs of eNB j

b_k^f = Whether VNF f is placed to DC k or not

$$Z_{kf} = H_k^f (1 - p_k^f) \times \gamma \times \phi_k$$

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