Availability-Aware Network Slicing and Dynamic Function Placement in Virtualized RANs with Reinforcement Learning

Amber Deshbhratar (210001003) Sushil Yadav (210001080)
Supervisor: Dr. Sidharth Sharma

Department of Computer Science and Engineering Indian Institute of Technology Indore

Contents

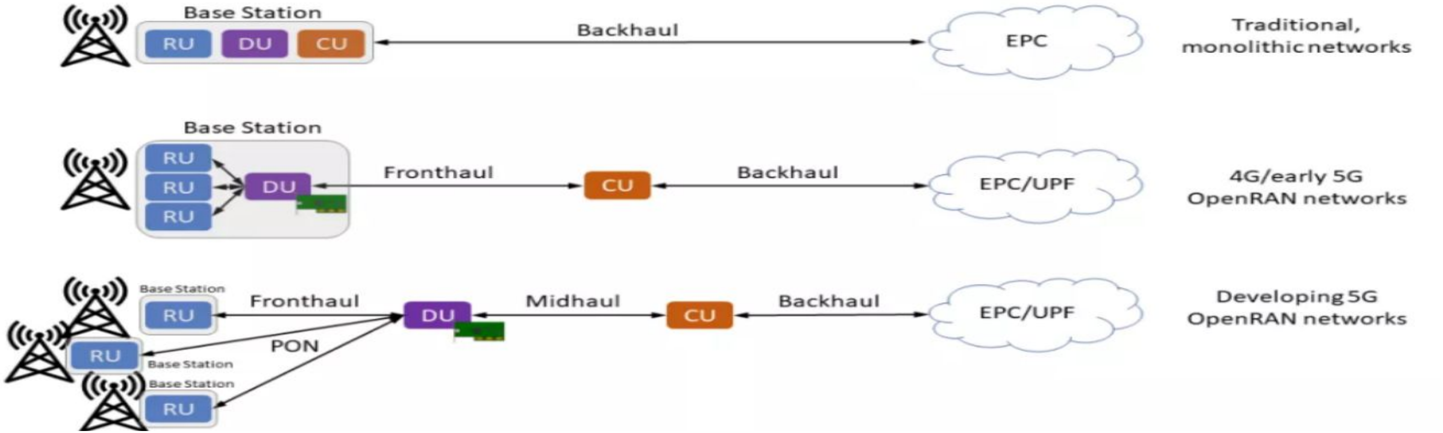
Introduction

Introduction

- **Virtualized RAN (vRAN) as a Solution**: Network softwarization via NFV and SDN supports cost-effective RAN virtualization.
- **Centralization Challenges**: While full function centralization boosts efficiency, it demands impractical bandwidth, limiting centralization to partial setups.
- **Flexible Function Placement**: 5G standards define 9 RAN function splits, deciding placement across the central (CU), distributed (DU), and radio (RU) units.
- **Network Slicing Complexity**: Diverse 5G use cases (eMBB, URLLC, mMTC) require optimized vRAN slice management, especially with limited server availability.
- **Availability and Lightpath provisioning:** need backup path mechanism for reliability Also need to provision lightpaths for DWDM networks.

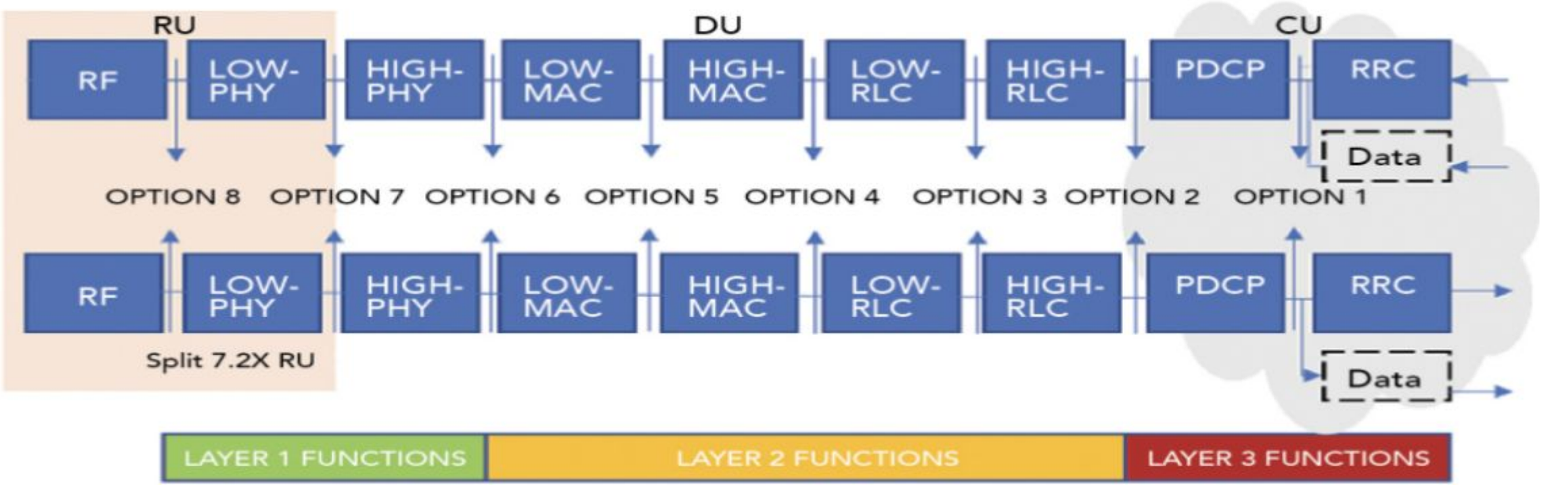
Virtualized RANs

- Refers to the deployment of radio access network functions as software instances running over commodity servers.
  - enables lower costs and more agile infrastructure for Telcos.
- Disaggregates traditional baseband units into Radio Units (RUs), Distributed Units (DUs), and Centralized Units (CUs).

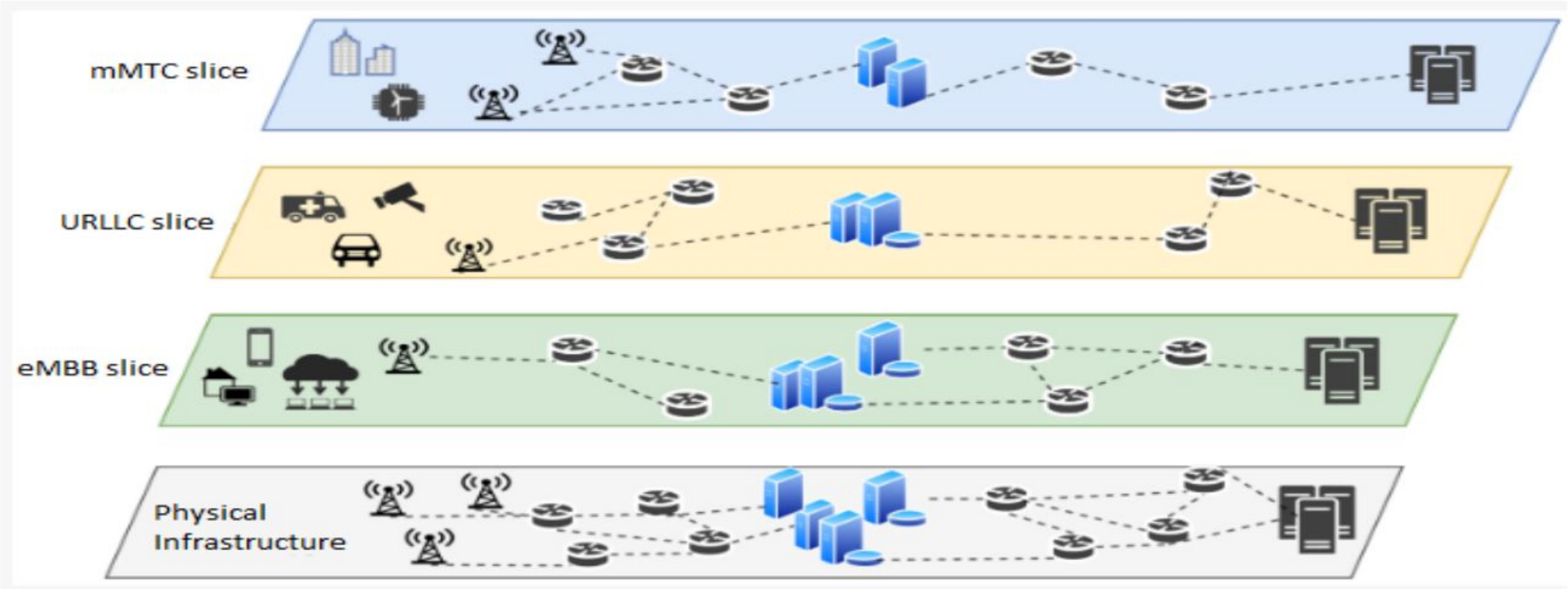


Functional Splitting

- Refers to the separation of network functions into different components (like CU, DU, and RU) that can be deployed at various locations within the network.
- 5G standards: Multiple split options- choose the degree of centralization or decentralization that best suits the current network conditions and service requirements.



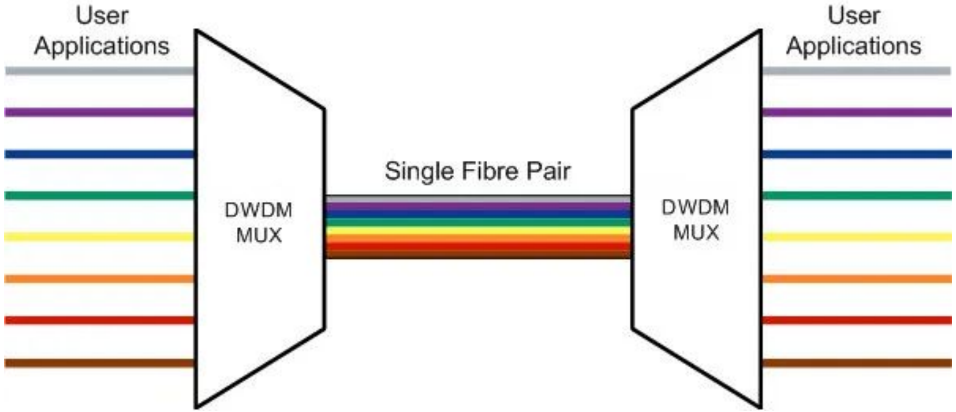
Network Slicing

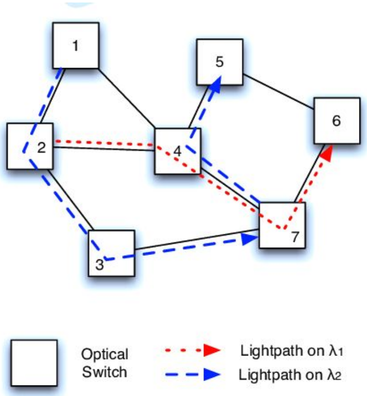


vRAN enables network slicing, allowing the same infrastructure to support diverse use cases with specific requirements.

DWDM and Lightpath Provisioning in 5G

- DWDM: allows for the efficient use of the optical spectrum by enabling multiple wavelengths to be transmitted simultaneously over a single fibre.
- Lightpath Provisioning: involves establishing optical paths (lightpaths) between nodes in the network to ensure efficient data transmission.





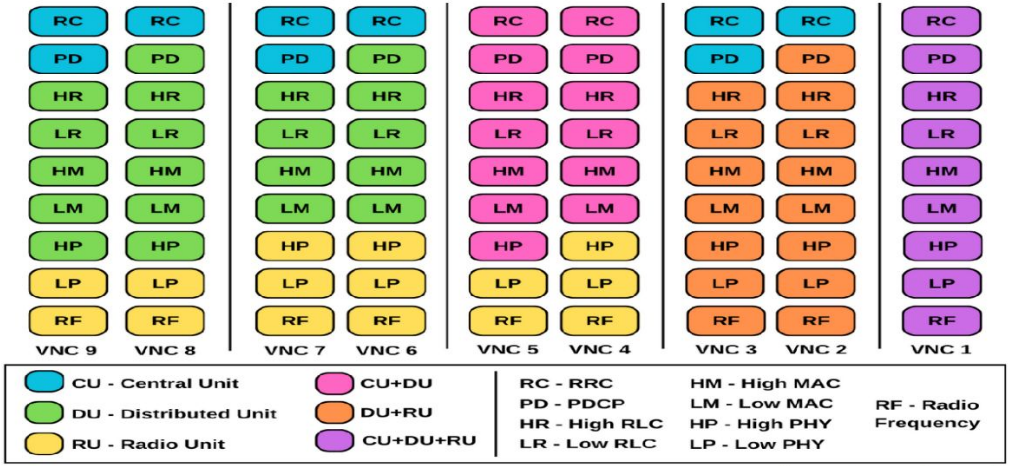
Motivation

Challenges in Optimal Placement of Radio Network Functions in vRAN

- Deciding which RAN protocol stack functions to centralize involves multiple function splits, each with distinct placement templates.
- Achieving cost efficiency requires optimal allocation of virtualized radio functions across RU, DU, and CU components.
- Lightpath provisioning requires incorporating wavelength continuity and distinct wavelength constraints (RWA problem).
- 5G network slices (URLLC, eMBB, mMTC) have distinct needs for bandwidth, latency, and availability, complicating function placement.
- Integrating availability, lightpath provisioning, delay, and bandwidth considerations for network slices increases placement complexity.

Virtual Network Configuration (VNC)

- Represents different possible placements of VNFs across CUs, DUs and RUs.
- Standardized Configurations: 9 standardized VNCs, each representing a distinct configuration of network function placement to optimize performance and resource utilization.
  - Allows for flexibility in deploying network functions based on current network conditions and service requirements.



Literature Review/ SOTA Solutions

Literature Review/ State-of-the-art Solutions

- Prior works, such as PlaceRAN [2], focused on optimizing the placement of Virtual Network Functions (VNFs) in 5G vRAN by maximizing centralization to leverage resource pooling.
- SliAvailRAN [1] extended the ILP approach to optimize vRAN resource placement while considering network slicing and reliability (e.g., primary and backup paths).
- While effective for static scenarios, its computational complexity limits scalability for dynamic and real-time 5G deployments, motivating the shift toward Reinforcement Learning (RL)-based frameworks.

ILP Formulation

ILP Formulation

- RL is a follow up of the Modified ILP (from SliAvailRAN [1]) where we try to maximize the revenue subject to the various constraints for availability, lightpath provisioning and network slicing.

Refer to the link below for detailed mathematical formulation of the ILP:

https://drive.google.com/file/d/1toqyjeolYGpwXC92yK7VUg_IG3HjIHJ1/view?usp=sharing

RL Formulation

Input Parameters

Network Topology:

- A graph representing the network infrastructure.
- Nodes: RU, CU, DU, and CN.
- Links: Connections between nodes, representing physical or logical links.

RU Groups (Beta Sets):

- A subset that represents RUs in the network.

Slice Assignments:

- Each RU is assigned a slice type, determining the quality of service (QoS) it can provide.
- Slice types: eMBB, URLLC, and mMTC.
- QoS parameters: latency, throughput, and reliability.

State Space

In this context, a state space graph is a mathematical representation of a system where:

- **Nodes:** Represent individual network elements, each characterized by:
  - **CPU Usage:** Indicates the current computational load on the node.
  - **Node Type:** Categorizes the node as one of four types: CU / DU / RU / CN.

- **Edges:** Represent the connections between nodes, with properties such as:
  - **Bandwidth:** The maximum data transfer rate between the nodes.
  - **Latency:** The time delay for data transmission between the nodes.
  - **Wavelengths Allocated:** The number of optical wavelengths assigned to the link for data transmission.

Action Space

1. **VNC (Virtual Network Connection):**
   - Allocating bandwidth and resources to VNCs.
2. **Primary and Backup Paths:**
   - Selecting primary and backup paths for data transmission.
   - Ensuring redundancy and fault tolerance.
3. **Wavelength Assignment:**
   - Assigning wavelengths to optical links for efficient resource utilization.

Reward function

Reward

- **Revenue** : Revenue from accepted requests.
- **Centralization** :To assign the most centralized VNC

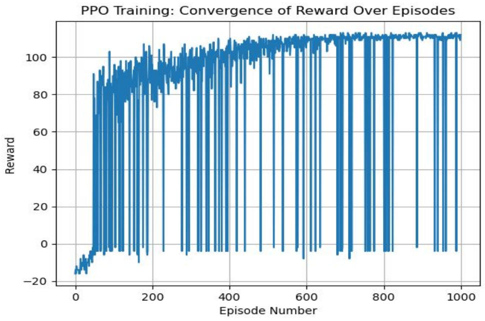
Penalty

- **Node activation** : Cost of node activation.
- **Wavelength activation** : Cost of activating wavelengths on links.

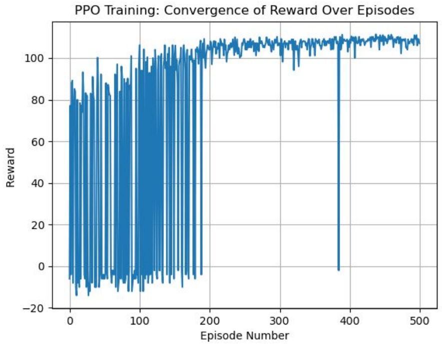
PPO Algorithm

- Chosen because it presented better results in accuracy and convergence

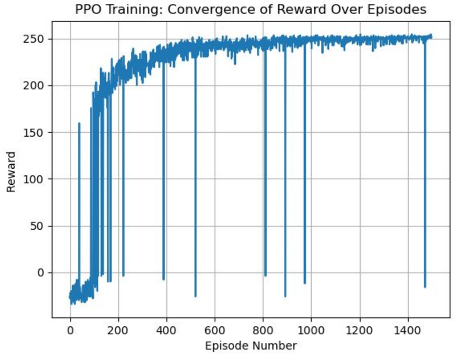
Results

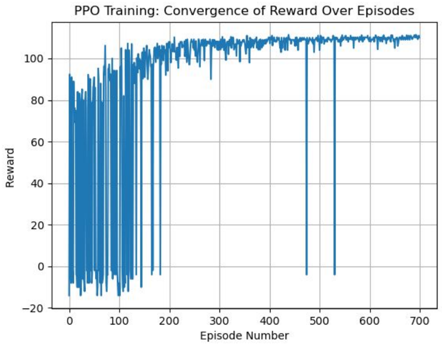


8 node topology

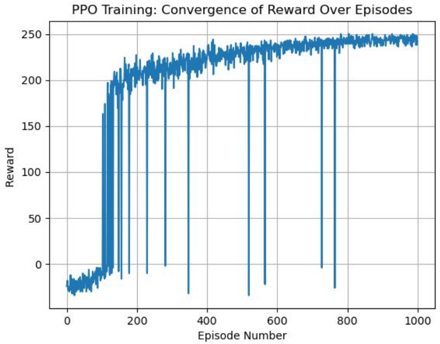


16 node topology





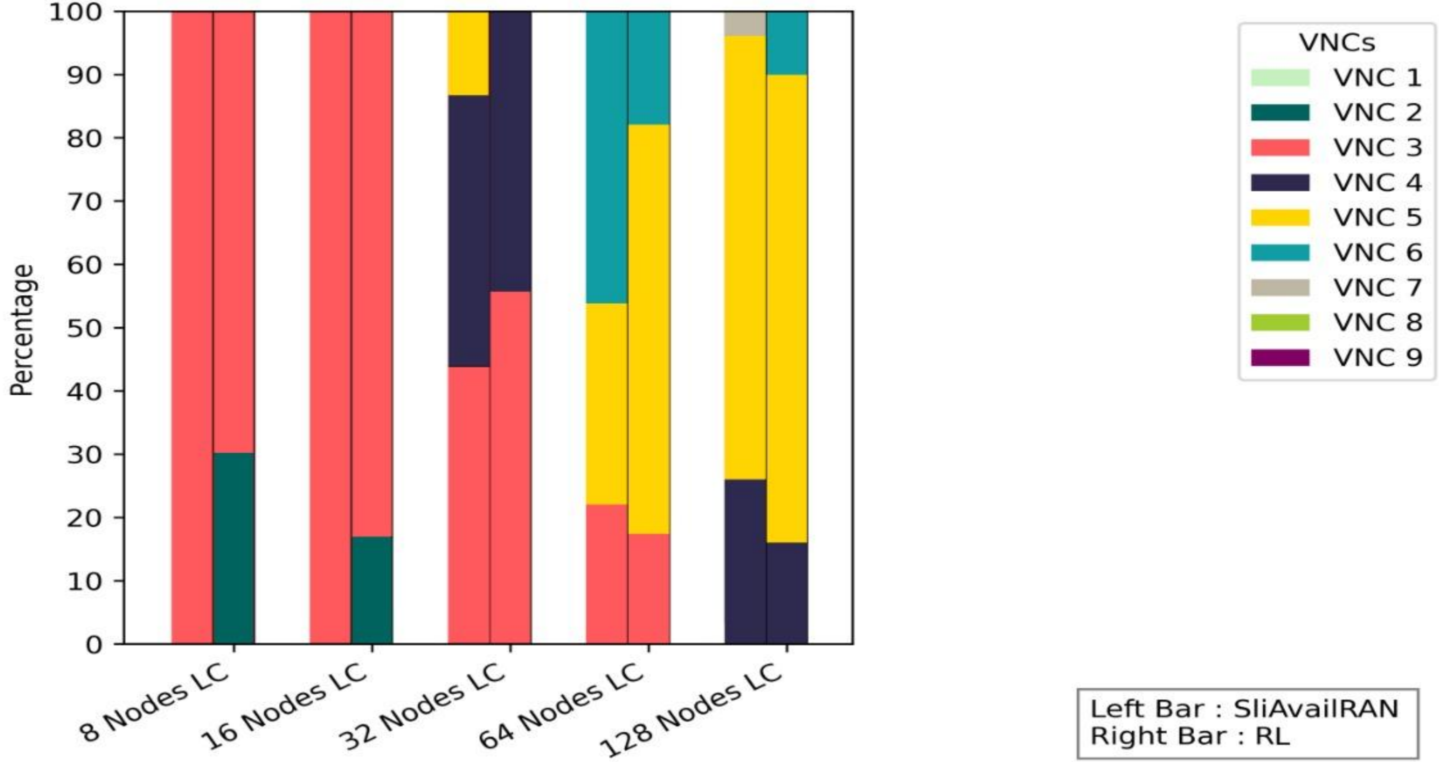
64 node topology



32 node topology

128 node topology

Results



100
90
80
70
60
50
40
30
20
10
0
Percentage
8 Nodes LC
16 Nodes LC
32 Nodes LC
64 Nodes LC
128 Nodes LC
VNCs
VNC 1
VNC 2
VNC 3
VNC 4
VNC 5
VNC 6
VNC 7
VNC 8
VNC 9
Left Bar : SliAvailRAN
Right Bar : RL

References

[1] Saad Ahmed, Mayank Ramnani, and Sidharth Sharma. Sliavailran: Availability-aware slicing and adaptive function placement in virtualized rans. In 2024 IEEE 25th International Conference on High Performance Switching and Routing (HPSR), pages 112–117. IEEE, 2024.

[2] Fernando Zanferrari Morais, Gabriel Matheus F de Almeida, Leizer Pinto, Kleber Vieira Cardoso, Luis M Contreras, Rodrigo da Rosa Righi, and Cristiano Bonato Both. Placeran: Optimal placement of virtualized network functions in beyond 5g radio access networks. IEEE Transactions on Mobile Computing, 22(9):5434–5448, 2022.