Kurdistan Region Government/Iraq
Presidency of the Council of Ministers
Ministry of Higher Education & Scientific Research
Erbil Polytechnic University
Technical Engineering College
Information System Engineering Department

# Performance Study of End-user Service Separation using Network Slicing for 5G Networks

A Thesis

Submitted to the Council of the College of Technical Engineering at Erbil Polytechnic University in Partial Fulfillment of the Requirements for the Degree of Master of Information System Engineering

By

Chnar Mustafa Mohammed

B.Sc. Information System Engineering

Supervised By

Dr. Salar Kheder Shaikhah

Erbil, Kurdistan

December 2023

بسم الله الرحمن الرحيم

(أَمَّنْ هُوَ قَانِتٌ آنَاءَ اللَّيْلِ سَاجِدًا وَقَائِمًا يَحْذَرُ الْآخِرَةَ وَيَرْجُو رَحْمَةَ رَبِّهِ قُلْ هَلْ يَسْتَوِي الَّذِينَ يَعْلَمُونَ وَالَّذِينَ لَا يَعْلَمُونَ إِنَّمَا يَتَذَكَّرُ أُولُو الْأَلْبَابِ).

"سورة الزمر"، آية: 9

# DECLARATION

I declare that the Master Thesis entitled: “Performance Study of End-user Service Separation using Network Slicing for 5G Networks” is my own original work, and hereby, I certify that unless stated, all work contained within this thesis is my own independent research and has not been submitted for the award of any other degree at any institution, except where due acknowledgement is made in the text.

Signature:

Student Name: Chnar Mustafa Mohammed

Date: / /2023

# LINGUISTIC REVIEW

I certify that I have thoroughly reviewed and comprehended the thesis "Performance Study of End-user Service Separation using Network Slicing for 5G Networks". In addition, as an English linguist, I can confidently state that this thesis is devoid of grammatical and typographical errors.

Signature:

**Assistant Lecturer**: Yassen Muhammed Awla

**Email:** yassen.awla@su.edu.krd

**Phone Number:** +964 750 488 2578

**Date:** 5 / October /2023

# SUPERVISOR CERTIFICATE

This thesis has been written under my supervision and has been submitted for the award of the degree of Master of Science with my approval as supervisor.

**Signature:**

**Supervisor Name: Dr.** Salar Kheder Shaikhah

**Date:** / 12 / 2023

**I confirm that all requirements have been fulfilled.**

Signature:

**Name: Assist. Lecturer** Byad Abdulqader Ahmed

Head of the Department of Information System Engineering

**Date:** / 12 / 2023

**I confirm that all requirements have been fulfilled.**

**Postgraduate Office**

Signature:

**Name: Assist. Lecturer** Byad Abdulqader Ahmed

**Date:** / /2023

# EXAMINING COMMITTEE CERTIFICATION

We certify that we have read this thesis, “Performance Study of End-user Service Separation using Network Slicing for 5G Networks”, and, as an examining committee, examined the student “Chnar Mustafa Mohammed” in its content and what related to it. We approve that it meets the standards of a thesis for the degree of Master of Science.

**Signature:**

**Name**: **Assist. Prof. Dr.**

Reben Mohammed Salim

Member

Date: / 12 / 2023

**Signature:**

**Name: Assist.Prof. Dr.**

Jalal Jamal Hamad

Member

Date: / 12 / 2023

Signature:

**Name**: **Dr.**

Salar Kheder Shaikhah

**Supervisor**

**Date:** / 12 / 2023

Signature:

**Name**: **Assist. Prof. Dr.**

Kayhan Zirar Ghafoor

**Chairman**

**Date:** / 12 / 2023

Signature

**Name**: **Assist. Prof. Dr.** Ayad Zaki Sabr

Dean of the College of Erbil Technical Engineering

Date: / / 2023

# DEDICATION

I dedicate this thesis to

- My family.
- Erbil Polytechnic University.
- All the friends and relatives.

# ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to Allah, the Almighty, for granting me the strength and guidance to complete my research successfully. I am also deeply thankful to my supervisor, Doctor Salar Kheder Shaikhah, for his valuable advice and support throughout this study. This research would not have been possible without his encouragement and active involvement. I am genuinely grateful for his unwavering support and understanding over the years. His strict guidelines have greatly facilitated my research and writing process.

In addition, I'd like to thank the teachers and staff of the Information System Engineering Department for their helpful advice and respectful cooperation during my study time at the College. I want to thank Doctor Rojwan Sediq, the director of the Information System Engineering Department, and Assist. Prof. Dr. Ayad Zaki Sabr, the Dean of Technical Engineering College, particularly, for their encouragement and support during my studies.

I owe my parents a lot of respect and appreciation. Their love and support have inspired me to complete my work. I am thankful for my parents' love, support, and direction. My parents are a constant source of inspiration and support for me. They are in the finest place possible. I want to keep this in mind for my siblings and close friends. Due to them, I have never felt lonely in my difficult circumstances.

# ABSTRACT

Emerging fifth-generation mobile communication (5G) networks require high reliability, low latency, enhanced network capacity, and robust security. Managing Radio Access Network (RAN) infrastructure resources is challenging. Mobile service providers use Network Slicing (NS) to merge multiple services into an integrated 5G infrastructure. NS incorporates Wireless Network Virtualization (WNV) to smoothly separate services and efficiently allocate resources, ensuring optimal infrastructure utilization and network separation. However, WNV enables virtual management of NS, but the 5G network struggles to support end-user devices, causing delays in network slice selection and meeting modern telecommunications needs.

This thesis proposes a new NS architecture using virtualization to dynamically manage service selection and revenue between users and virtual operators in the 5G architecture. The virtual 5G RAN architecture includes Infrastructure Providers (InPs) and Mobile Virtual Network Operators (MVNO), serving hundreds of User Equipment (UEs). The architecture comprises sub-systems, including a wireless air-interface system, an economic system, and optimization algorithms. A new mathematical model is derived to introduce dynamic Inter-User Interference (IUI) and calculate a realized UE channel gain. In addition, integrating an economic model allows comprehensive cost and benefit analysis. The complexity of dynamic resource allocation necessitates a dual-pairing approach, pairing UEs with MVNOs and distributing InP resources to UEs through pre-selected MVNOs. For this instance, Matching Game (MG) and Particle Swarm Optimization (PSO) algorithms are introduced to optimize UE resource allocation while maximizing revenue for InPs and enhancing user throughput.

Simulation outcomes demonstrate the robustness of both algorithms in cost optimization and improved user throughput. The MG algorithm generates revenue by accurately matching user demands, while the PSO algorithm

prioritizes equitable resource distribution and offers lower prices. Both algorithms show a similar increase in convergence time as the number of UEs rises, stabilizing around 100 iterations for 300 UEs. PSO demonstrates faster convergence in 30 seconds compared to the MG's 45 seconds. In MG, the establishment of users reaches 98%, indicating a high user admission rate, and with PSO, the user engagement comes to %92. The study emphasizes the importance of considering WNV in 5G networks for resource and revenue optimization in the virtual RAN.

# TABLE OF CONTENT

# LIST OF FIGURES



# LIST OF TABLES

# LIST OF ABBREVIATIONS

| Abbreviation | Acronyms |
|---|---|
| 3GPP | 3rd Generation Partnership Project |
| 5G | fifth-generation |
| 5G-PPP | public-private partnership project |
| AI | Artificial Intelligence |
| BS | Base Stations |
| CN | Core Network |
| DSCP | Differentiated Services Code Point |
| E2E | End-to-End |
| eMBB | Enhanced Mobile Broadband |
| InP | Infrastructure Provider |
| IoT | Internet-of-Thing |
| IUI | Inter-user Interference |
| LTE | Long Term Evolution |
| MEC | Mobile Edge Computing |
| MG | Matching Game |
| mMTC | Massive Machine Type Communication |
| MVNO | Mobile Virtual Network Operator |
| NFV | Network Function Virtualization |
| NGMN | Next Generation Mobile Network |
| NS | Network Slicing |
| OAM | Open Access Manager |
| OFDMA | Orthogonal Frequency Division Multiple Access |
| PSO | Particle Swarm Optimization |
| QoS | Quality of Service |
| RAN | Radio Access Network |
| RBs | Resource Blocks |
| SDN | Software-Defined Networking |
| SDO | The Standard Developing Organization |
| SLAs | Service Level Agreements |
| TN | Transport Network |
| UEs | User Equipment |
| URLLC | Ulta Rilaibilty low latency communication |
| WNV | Wireless Network Virtualization |

# LIST OF SYMBOLS

| | |
|---|---|
| $\mathfrak{H}_1, \mathfrak{H}_2$ | Acceleration Coefficients |
| $\mathfrak{N}$ | Background Noise |
| $W$ | Channel Bandwidth |
| $d_k$ | Demand of Users |
| $\mathcal{S}_n$ | Denotes the number of slices |
| $d_{(m,k)}^{\mathcal{C}_n}$ | Distance of user k to gNode base station. |
| $\mathfrak{W}$ | Fitness function weight |
| $\text{gBS}_n$ | gNode base stations |
| $\beta_n^I$ | InPs per unit price |
| $U_m$ | Is the cardinality of UEs |
| $\mathfrak{Z}$ | Is the position of particle $\mathfrak{p}$ in time $\mathfrak{t}$ |
| $\mathcal{G}_{m,k}^{\mathcal{C}_n}$ | The sub-channel gain between the $\text{gBS}_n$ of InP $n$ and UE $k$ in The MVNO $m$ over the channel set $\mathcal{C}_n$ |
| $\mathfrak{T}_{max}$ | Maximum iteration number |
| $\mathcal{P}_{m_n}^l$ | MVNO profile preference for a set of imaginary variables $m_n$ |
| $\mathcal{N}$ | Number of InPs in the set |
| $M$ | Number of MVNOS in the system |
| $\mathcal{C}_n$ | Orthogonal channels. |
| $\mathfrak{r}_1, \mathfrak{r}_2$ | Randomly generated numbers in the range [0,1] |
| $\ell_{k,n}$ | Required channel to fulfil users' demands |
| $n$ | Set of InPs |
| $m$ | Set of MVNOS |
| $\mathcal{K}_m$ | Set of users |
| $\gamma_{m,k}^{\mathcal{C}_n}$ | Signal-to-Interference Noise Ratio (SNIR) |
| $\mathcal{BW}_n$ | The Bandwidth of each InP |
| $\mathcal{R}_{n,m,k}^{\mathcal{S}_n}$ | The data rate of user $k$ belongs to MVNO $m$ |
| $\mathfrak{T}_{\mathfrak{Q}}$ | The existing recurrence number |
| $\mathfrak{X}$ | The function of path loss. |
| $\mathfrak{B}$ | the path loss factor |
| $\mathcal{Y}_{n,m}^{\mathcal{S}_n}$ | The slice distribution variable |
| $\omega$ | the transaction between disinterest and InP income |
| $\mathcal{X}_{k,m}$ | The user Association Variable |
| $\nu_i$ | the velocity of the participle |
| $\mathcal{P}_n^{\mathcal{S}_n}$ | Transmit power |
| $\beta_m^{M}$ | unit price of MVNO $m$ |
| $P_k$ | User profile preference |

# CHAPTER ONE

# INTRODUCTION

## 1.1. Overview

The increased use of mobile communication systems by individuals and equipment has resulted in new needs for 5G networks. The Standards Development Organization (SDO) community outlines typical network requirements, such as higher data speeds, enhanced device connection, decreased power consumption, and low latency. Mobile networks have introduced new vertical applications and horizontal service improvements, benefiting healthcare, agriculture, automotive, and intelligent city users. These vertical applications cater to specific needs, such as remote patient monitoring in healthcare and autonomous vehicle communication in the automotive industry (IMT-2020, METIS-2020, 5G-PPP, FANTASTIC5G, Shaikhah and Mustafa, 2020). The Third Generation Partnership Project (3GPP) classified 5G use cases according to the characteristics, facility categories, and desires that these services required into massive Machine-Type Communications (mMTC), Ultra-Reliable Low Latency Communications (URLLC), and enhanced Mobile Broadband (eMBB) (Association, 2017).

The NS concept is a promising solution for 5G and beyond, offering an altered virtual layer over a distinct physical network frame. MVNOs can serve additional applications or isolate their services using NS techniques. Vendors provide physical infrastructure called InP, and operators become MVNOs. They buy resources from InPs and service users running a virtual network. Employing NS can increase network resource utilization and reduce costs by merging the entire services over a single physical architecture and providing dissimilar network features. (Zhang, 2019, Ma et al., 2020, Zhou et al., 2021).

A typical mobile communication system is classified into three levels based on the End to End (E2E) NS: RAN, Transport Network (TN), and Core Network (CN) (Li et al., 2020b, Lin et al., 2021, Afaq et al., 2020, Nakao et al., 2017).

Although the definition of NS is quite general, describing a method by examining how it is implemented is typical. As a result, the research community has been demonstrating the deployment of NS through the NS enablers, which are Software-Defined Networking (SDN), Network function virtualization (NFV), Mobile Edge Computing (MEC), cloud computing, network hypervisors, and more (Kazmi et al., 2019, Korrai et al., 2020, Barakabitze et al., 2020, Liu et al., 2020).

WNV is a proposed technology that allows for autonomous Virtual Networks (VNs) to coexist on the same infrastructure, addressing challenges in resource distribution. It enables VNs to have specific requirements without affecting other VNs, providing operators with comprehensive control for efficient administration and management.

Figure 1-1 shows an NS model in a 5G-RAN scenario focusing on resource allocation and financial considerations. It depicts different slices on the same physical infrastructure, each slice serving specific types of services. For example, the green slice eMBB provides high data user datarates for data-intensive applications, the blue slice mMTC caters to devices requiring high bandwidth, and the fair brown slice URLLC meets the needs of devices like critical communication systems or autonomous vehicles. The next chapters discuss the collaborative dynamics between InPs, MVNOs, and UE and propose innovative methods to address challenges and comprehensively understand the landscape and its implications for end-users.

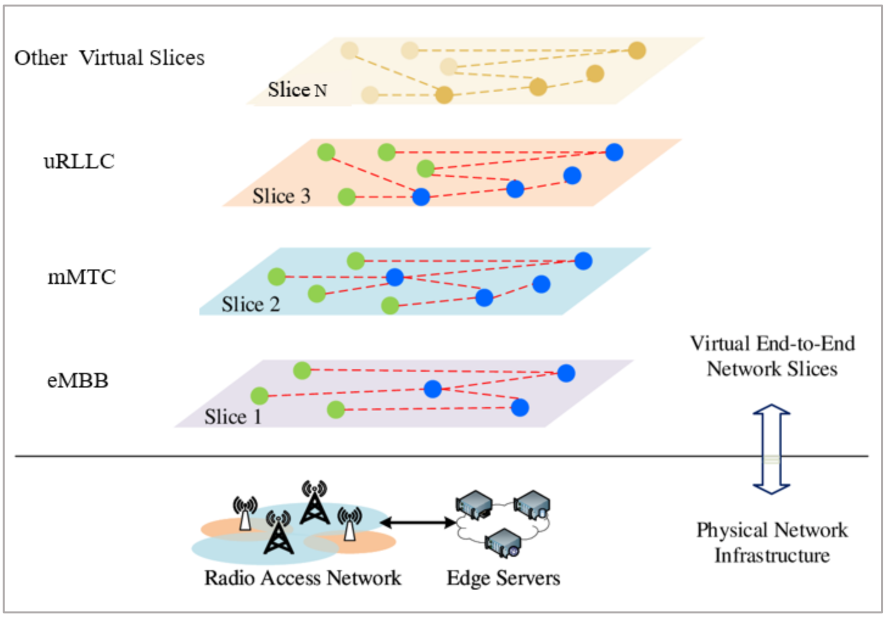



Fig. 1-1. Network Slicing Concept.

## 1.2. Motivation

WNV in 5G NS, particularly for RAN, is a revolutionary innovation that overcomes significant difficulties. The increasing need for high-speed, dependable, and low-latency connections provides a potential path towards effective administration and optimisation of network resources. Through its ability to provide the dynamic allocation and sharing of spectrum, it addresses the efficiency and availability of spectrum. Furthermore, WNV is a key enabler of NS, which allows the construction of isolated virtual networks suited to particular use cases. As a result of WNV's scalability and adaptability, network administrators may quickly and easily add or remove resources, reallocate them as required, and make other configuration changes without having to replace existing hardware completely. It reduces capital and operational expenses by optimizing resource utilization, automating network administration duties, and minimizing the need for expensive hardware enhancements. Moreover, it offers creativity and research opportunities because it offers a diverse university and industry study setting. Therefore, WNV answers crucial wireless communication difficulties like spectrum scarcity, network efficiency, and scalability while providing a productive field for innovation and research.

## 1.3. Problem Statements

The field of RAN virtualization of 5G holds immense potential but has faced challenges. Therefore, to present end-user service performance in a realistic form, the virtualized RAN system architecture should be based on practical parameters in all three sub-systems: RAN air interface, economic model and optimization methodologies. However, the research community have presented several works, but to the best of our knowledge, there is no work to consider the end-to-end system architecture. The derived models didn’t consider multi-players in the RAN air interface, including InP and MVNOs. Also, the channel gain is calculated based on many assumptions that make the system far from practical.

In addition, in the virtualized RAN networks, efficiently allocating resources while ensuring the quality of service and equitable distribution among users is a pressing issue. It involves optimizing resource allocation for various services and users, dynamically adjusting to changing demands, and maximizing overall network throughput without over-provisioning.

The economic achievability of virtualization inside 5G RANs is a significant problem. It requires motivating participation, maintaining fairness, optimizing profit functions, and maximizing revenue for all stakeholders. Facilitating involvement means developing frameworks that continually give service providers, network owners, and end users reasons to participate. Keeping the balance of fairness guarantees that everyone involved obtains the same rewards. Maximizing profit functions while reducing operational costs necessitates strategic optimization solutions that consider the unique dynamics of virtualized 5G RAN. Identifying income sources and possibilities inside the virtualized network is critical for long-term financial viability and needs to be well addressed.

## 1.4. Aims and Objectives

This thesis aims to design a comprehensive dynamic system that accommodates multiple end-users and facilitates coordination among UE, MVNOs, and InPs for service selection and resource sharing.

1- The model requires a capable architecture for dynamic resource sharing and service selection among players, implementing such objectives requiring a robust algorithm for dual pairings.
2- It also aims to create an economic model that ensures financial stability and enhances sustainability.
3- Therefore, it is essential to integrate a convex optimization framework into the economic model to tackle non-convexity and Multi Linear Integer Programming (MLIP) issues in user fees and income generation for MVNOs and InPs using optimization algorithms.

## 1.5. The Thesis Contributions

The contribution of this work concluded with the following points:

1- **New NS Architecture for Dynamic Service Selection:** This thesis introduces a New NS architecture for 5G networks, facilitating dynamic service selection and resource allocation among end-users and virtual operators. It encompasses a comprehensive virtual 5G RAN structure involving multi-InPs, multi-MVNOs, and numerous UEs, enabling dynamic resource management based on the proposed architecture.
2- **Enhanced Resource Allocation Model:** This thesis significantly improves resource allocation accuracy and system performance evaluation by developing a new mathematical model considering dynamic IUI and calculating realized channel gains for UEs. This model addresses diverse user scenarios, enhancing the precision of resource allocation strategies.

3- **Economic Integration and Optimization Techniques:** The thesis integrates an economic model with the proposed architecture, facilitating stakeholders' analysis of costs and benefits. It ensures financial stability and sustainability within the 5G network ecosystem. Innovative optimization algorithms like MG and PSO are employed alongside a dual-pairing approach that dynamically pairs UEs with MVNOs. This approach optimizes fees, enhances user throughput, and maximizes revenue for MVNOs and InPs by efficiently distributing InP resources through pre-selected MVNOs.

## 1.6. Thesis outlines

The following sections provide an overview of each chapter, outlining the main ideas, research methods, and findings of this study. This organized summary serves as a guide through all aspects of this study's relevance.

**Chapter Two** provides a theoretical foundation and a survey of the literature on NS and WNV in 5G services, examining emerging concepts and proposing a revolutionary NS architecture. It reviews current studies on resource allocation, operational efficiency, and user-responsive pricing. In addition, it discusses the integration of WNV into economic frameworks, optimizing resource deployment and user-centric pricing.

**Chapter Three** focuses on the study methodologies and system design for 5G RANs involving NS and WNV. It discusses the involvement of InPs, MVNOs, and UEs in the overall design. The chapter covers various aspects such as RAN optimizations, economic models, mathematical methods for addressing channel gain and IUI, and a combinatorial approach using Matching games and optimization algorithms for

**Chapter Four** discusses the experimental results by implementing MG and PSO algorithms, highlighting their effectiveness in enhancing performance, convergence and solution quality, addressing industry challenges, and optimizing stakeholder engagement.

**Chapter Five** included a thesis conclusions and suggestions for further investigation.

# CHAPTER TWO

# THEORETICAL BACKGROUND AND LITERATURE REVIEW

## 2.1. Introduction

The transition from conventional network architectures to 5G and beyond has introduced NS as a transformative concept that allows the construction of virtual networks within a single physical infrastructure. These slices are personalized to specific applications, services, or use cases, facilitating optimized resource allocation, customizable performance parameters, and streamlined management. Technics like network virtualization and softwarization enable network operators to allocate resources, instantiate virtualized network functions, and orchestrate services in real time, meeting the ever-changing demands of the multifaceted 5G landscape.

Different models have emerged within NS, including service-based and resource-based slicing. Understanding these models aids in strategically deploying network slices that align with specific use cases. Architectural considerations, such as centralized designs and distributed architectures, are crucial for successful implementation. In addition to system design, NS requires a robust technological foundation in the RAN domain; therefore, WNV is critical to the 5G RAN ecosystem. WNV integrates network slicing concepts with wireless network capabilities, creating virtual RAN slices tailored to meet specific application requirements.

By comprehensively exploring these facets, stakeholders can navigate the evolving landscape of telecommunications with insight and precision, leveraging NS to shape the trajectory of communication networks in future years.

## 2.2. Network Slicing

This section highlights the NS developments, RAN architectures, fundamental concepts and enablers. The theory desires to be understood to comprehend its innovative alternatives and effects on communication networks fully.

### 2.2.1. State-of-the-Art of NS

In traditional networks, data processing, storage, and analysis are carried out through physical components such as routers, switches, access nodes, and Base Stations (BS). Services are often provided by networks to specific MVNOs. With the introduction of different services on a typical network, e.g., Long Term Evaluation (LTE) services, MVNOs have managed several services on the same infrastructure by establishing QoS for diverse sectors and services. Each service was given a Differentiated Services Code Point (DSCP). However, it was significant with the introduction of LTE, but 5G offers tens of vertical industrial applications to mobile communication systems that cannot be separated using current network strategies. In addition to the challenges of service separation, future MVNOs can simultaneously offer mMTC, URLLC, and eMBB, which is unfeasible to run on a conventional network. Emerging technologies like network virtualization and softwarization allow a single physical infrastructure to serve numerous MVNOs and their respective virtualized applications. Cloud computing, edge computing, and the hypervisor have emerged as fresh groundwork for NS (Foukas et al., 2017a).

### 2.2.2. RAN Architecture

NS enables 5G use cases concurrently on a single physical network. Adopting NS in CN is not innovative (Foukas et al., 2017a). Slicing RAN for 5G architecture was considered by the Next Generation Mobile Network (NGMN) project (Alliance, 2015). The NGMN 5G architecture has become fundamental, as shown in Figure 2-1; it consists of 3 layers:- Infrastructure Resource, Business Enablement and Business Application Layer.

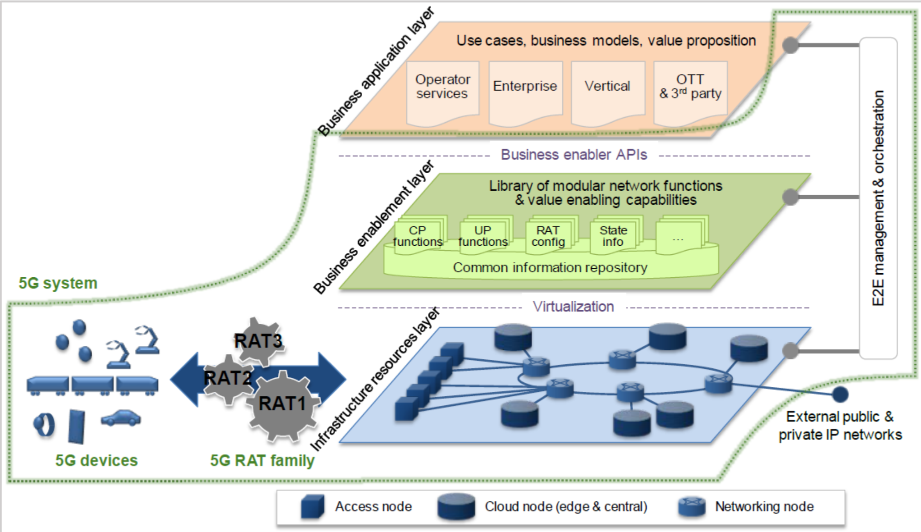



Fig. 2-1. The NGMN 5G structure presents three primary NS layers(Alliance, 2015).

The 5G architecture, proposed by the Public-Private Partnership Project (5G-PPP), consists of five layers: infrastructure, network function, orchestration, business function, and service layers. The 5G-PPP differentiates management and orchestration by having separate layers, while the NGMN's business enablement layer is split into service and business function layers. This structure allows for a more comprehensive approach to managing and controlling all processes. In (Foukas et al., 2017b), the NGMN architecture was generalized, and layer names were changed to Infrastructure, Network Function, and Service layers, as shown in Figure 2-2. The research community has adopted this generic architecture widely (Debbabi et al., 2020, ETSI, 2018, Kazmi et al., 2019).

However, as more capabilities are added to each layer, their titles have diverged among published works (Khan et al., 2020, Alliance, 2016). Therefore, NGMN has continued to use a standard 5G NS design. Most suggested designs assumed the E2E NS architecture to consist of RAN and CN, but three tiers of

RAN, TN, and CN were implemented for the E2E architecture (Li et al., 2020b, Nakao et al., 2017, Assosiation, 2021).

### 2.2.3. End-to-End NS Architecture

A traditional network is separated into three regions based on the essential capabilities of each: RAN, TN, and CN. In the present context, the term "Network Level" (NLe) is used to distinguish it from the architectural division referred to as "Network Layer" (NLa). There has been research done on E2E NS architecture (Li et al., 2020b, Afaq et al., 2020, Nakao et al., 2017, Chartsias et al., 2017, Garcia-Aviles et al., 2018, Ha and Le, 2017, Kalør et al., 2018, Li et al., 2020a, Assosiation, 2021). The E2E architecture may be broken down into three distinct parts: the RAN, the TN, and the CN, according to the consensus. Two perspectives exist on the E2E idea: the vertical view, called NLe, and the horizontal one, called NLa, as shown in Figure 2-2.

Share Layer Architecture (SLaA) and Dedicate Layer Architecture (DLaA) for each level provide another obstacle that must be overcome. In the SLaA, each NLe is shared across the RAN, the TN, and the CN; for instance, a single hardware infrastructure supplies resources for all three levels of the RAN, the TN, and the CN, as illustrated in Figure 2-2 a. However, as shown in Figure 2-2 b, in the DLaA, each NLe has its own set of three NLa. This concept is presented in the literature through the architecture diagrams.

In (Nakao et al., 2017), The foundations of the E2E design were laid out. Although discussions about horizontal and vertical layers occurred, the TN was not considered. The RAN and CN both have their dedicated layers. Notably, the architecture's most accurate description and presentation regarding NLe and NLa are given in (Li et al., 2020b). Since the E2E architecture was separated into RAN, TN, and CN as desired, DLaA for each NLe is provided as this design is more practical because implementing SLaA is not a possible assumption.

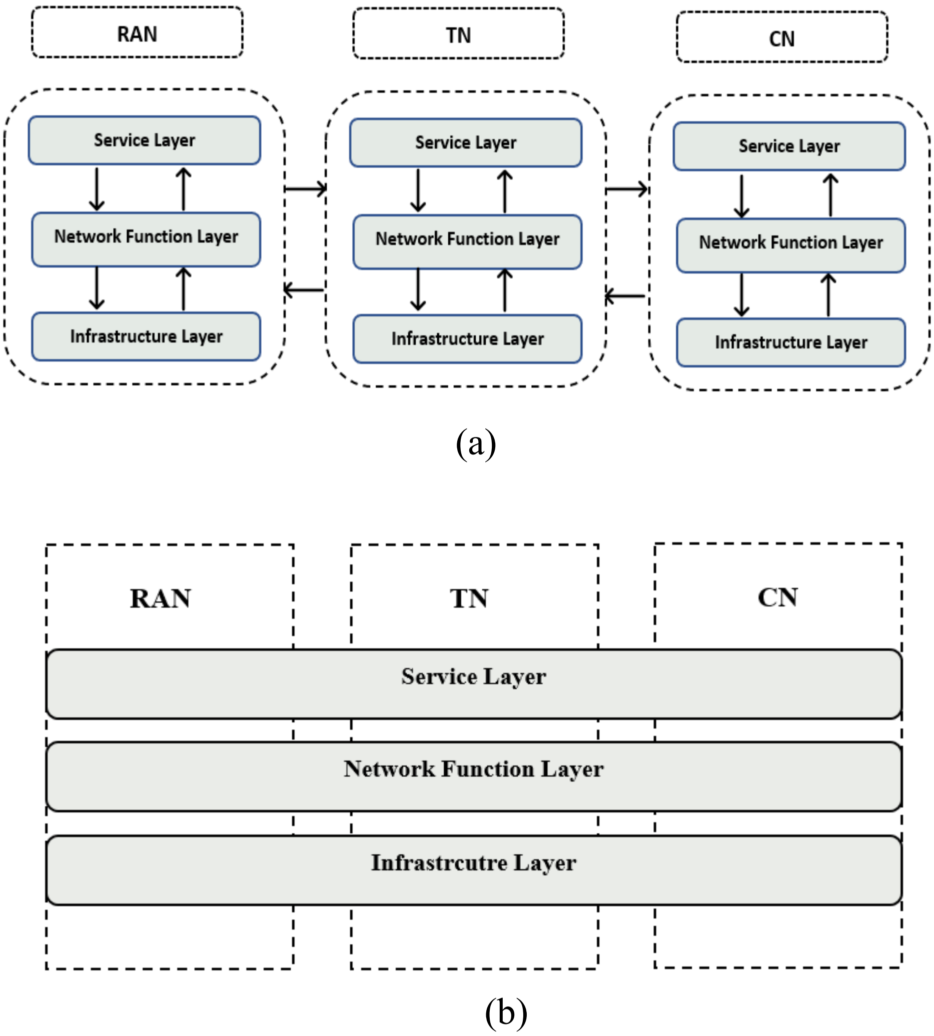



Fig. 2-2. E2E NS Architecture, (a) Dedicated Layer Architecture, (b) Share Layer Architecture.

### 2.2.4. Principles of NS

The remarkable feature known as NS enables several logical slices to coexist on the same physical network infrastructure.

Each slice is exclusive to a specific organization or enterprise, even though it is part of the same system as other users. Each network slice might customize its logical architecture, Service Level Agreements (SLAs), control and management planes, and dependability to match the demands of various services, industries, or consumers. The use of resources by NS is improved by sharing infrastructure for multiple services and MVNOs.

Demand-driven resource availability enhances user satisfaction by allowing services or MVNOs to share hardware resources based on changing procedures and client requirements, reducing operating costs and CAPEX.(Zhang, 2019, Debbabi et al., 2020, Kazmi et al., 2019, Ordonez-Lucena et al., 2017). Figure 2-3 illustrates building slices based on a single physical infrastructure. Three logical portions are created based on a hardware infrastructure dedicated to mobile broadband, healthcare and IoT services. Each service works on a piece isolated from the other two slices (Ho et al., 2018).

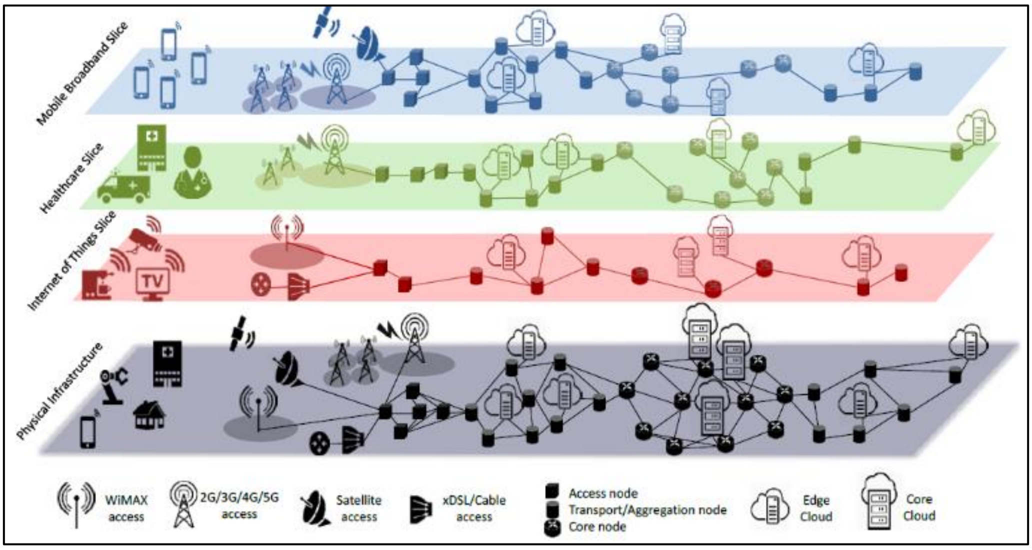



Fig. 2-3. Construct logical slices from one InP(Ho et al., 2018).

### 2.2.5. NS Enablers

This section explores virtualization technologies relevant to NS and used for slicing. Some examples of common NS enablers are shown :

1- **SDN** is a revolutionary technique that enables intelligent and flexible 5G networks. SDN allows centralized management and a comprehensive view of network components by separating a network's control and data planes and assigning a dedicated network controller to each device. This technology offers enhanced programmability and adaptability, making it suitable for various deployment scenarios and end-user requirements (Kazmi et al., 2020).

2- **NFV** is a technology framework and concept that aims to virtualize, and abstract network functions traditionally performed by dedicated hardware appliances. By separating network functions from the underlying hardware, NFV allows them to run as software on standard, virtualized servers. This technology is often associated with core network functions like firewalls, load balancers, and routers. The primary goal of NFV is to increase network flexibility, scalability, and agility while reducing hardware dependence and operational costs. In RAN architecture and network virtualization, NFV plays a crucial role in decoupling network functions from hardware components, enabling the virtualization of critical functions such as baseband processing. This flexibility enhances the RAN architecture's adaptability, scalability, and efficiency, making network deployment and management more agile and cost-effective (Barakabitze et al., 2020).

3- **Cloud/fog computing** is a calculating paradigm that enables customers to access a large pool of configurable computing and storage resources on demand. Its options include Infrastructure as a Service (IAAS), Platform as a Service (PAAS), and Software as a Service (SAAS). Anyone can access the software using a cloud service, and the user pays for their products (Korrai et al., 2020).

4- **Virtual Machines** can execute an operating system with multiple tasks. VMs in simulated settings physically virtualize the host system on the guest computer. Paravirtualization and full virtualization can exist simultaneously on hardware. Virtual machines and containers can collaborate with VNFs to offer flexible, customized network services, facilitating the system's slicing (Barakabitze and Walshe, 2022).

5- **Hypervisors** are usually recognized as network components, abstracting physical infrastructure into virtual network slices that are conceptually distinct. A genuine SDN environment offers high-level abstractions and application programming interfaces (APIs) that make creating complex network services noticeably simpler. The hypervisor enables applications to construct E2E flows by connecting several SDN providers via a standard interface or abstraction (Lozano et al., 2023).

6- **MEC** handles data in mobile networks close to data production and usage, saving costs on data transfer. It offers low delays and more effortless user connectivity in densely populated areas like shopping malls and train stops (Cruz et al., 2022).

7- **Containers (Dockers)** is a platform that enables the creation and management of containers—lightweight, isolated environments encapsulating applications and their dependencies. It uses images as blueprints for applications, containing all necessary components to run consistently across various systems. Docker simplifies development by ensuring applications run uniformly across different environments. With Docker, developers can quickly build, deploy, and manage containers, streamlining the software development and deployment lifecycle. Its efficiency and portability have revolutionized application delivery, offering a consistent and reliable way to package and run software (Azab, 2017).

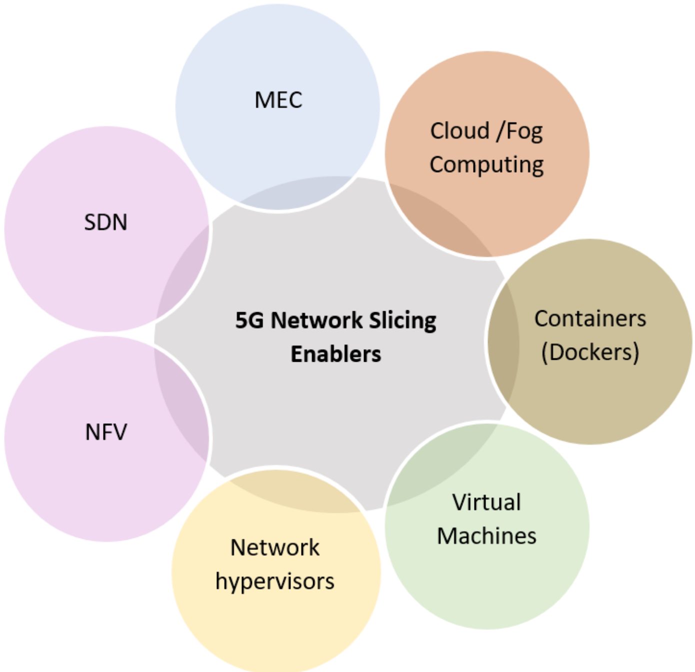



Fig. 2-4. 5G Network Slicing Enablers.

## 2.3. RAN Virtualization

In the ever-changing world of wireless communication technologies, the arrival of 5G has started a new era of connection and services at the RAN level. As the demand for various applications rises, the efficient administration of network resources becomes essential to ensure optimal performance and user satisfaction. RAN virtualization represents a revolutionary change in network architecture; it replaces the difficulty and inflexibility of previous hardware-centric designs with a more adaptable and flexible software-based architecture. With RAN virtualization (V-RAN), network operators may dynamically distribute resources, expand capacity, and offer new services without significant hardware upgrades (Yarkina et al., 2022, Jayaraman et al., 2023).

Virtualized Baseband Units (vBBUs) and virtualized Radio Units (vRUs) are essential parts of V-RAN. They handle baseband processing jobs and manage the processing and transfer of Radio frequency signals.

Cost efficiency, network flexibility, scalability, service innovation, and energy efficiency are achieved by abstracting and virtualizing network services, making them hardware-agnostic and improving resource allocation and service orchestration(Oladejo and Falowo, 2019, Oladejo et al., 2021).

Two primary forms of V-RAN are Cloud RAN (C-RAN) and Virtualized RAN (V-RAN). In contrast to V-RAN, which distributes virtualized radio units closer to cell sites to achieve reduced latency and better network resilience, C-RAN places baseband processing in data centres, where it can take advantage of centralized control and resource association, as presented in Figure 2-5.

Choosing among these methods depends on the network's needs and architecture. (Lieto et al., 2022, Awada et al., 2022) (Alevizaki).

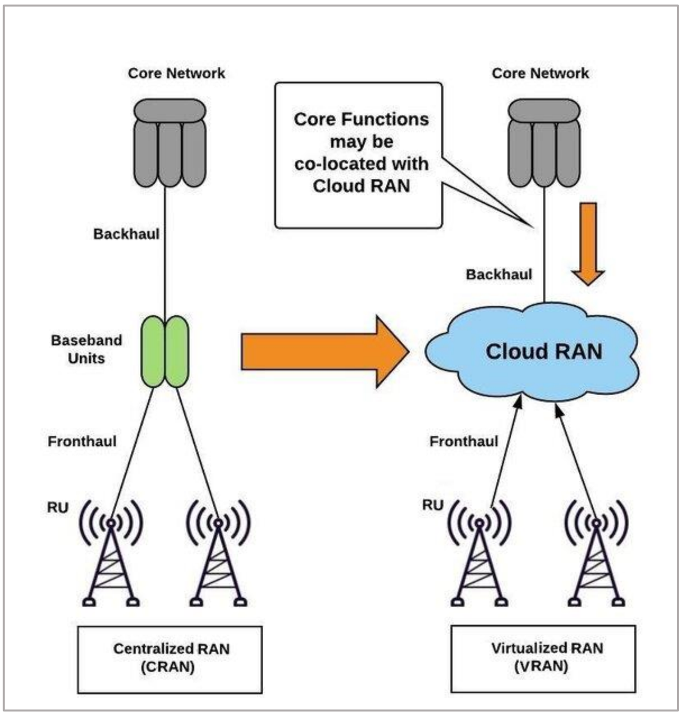



Fig. 2-5 Demonstrating C-RAN and V-RAN architecture.

## 2.4. Dynamic RAN Resource Sharing

Dynamic resource sharing is an essential feature of wireless communication networks, indicating an era of remarkable resource allocation and utilization efficiency. This vibrant and adaptive method allocates spectrum, bandwidth, and power according to real-time network circumstances, user demands, and quality-of-service requirements (Halabian, 2019). It maximizes network performance, integrates resource utilization, carefully manages interference, and consistently meets quality of service criteria. Most importantly, dynamic resource sharing allows for the wise use of spectrum and energy resources essential to wireless communication networks.

Key features of Dynamic RAN Resource Sharing include (Oladejo and Falowo, 2020, Song et al., 2020, Shi et al., 2020):

1. **Flexibility:** Resources are dynamically assigned depending on user demand, quality-of-service needs, and current network circumstances.

This adaptability enables the network to adapt to changing scenarios efficiently.

2. **Efficiency:** By distributing resources across several users or services, the network may maximize the utilization of its resources, improving overall effectiveness and capacity utilization.
3. **QoS:** Dynamic resource sharing guarantees that various services and applications get the necessary resources to maintain the required level of service. For example, it is worth noting that video streaming needs a more significant amount of bandwidth than voice conversations.
4. **Load balancing**: is a technique used to allocate resources across users or cells to mitigate network congestion and provide an equitable distribution of traffic. It prevents some network segments from becoming overwhelmed while others remain underutilized.
5. **Spectrum sharing:** Refers to constantly distributing spectrum resources inside wireless networks. This technique frequently involves sharing spectrum resources across various radio access technologies, such as 4G and 5G, or among different network operators, making it possible to use the spectrum more effectively.
6. **Management of Interference:** By modifying resource allocation in real-time, interference can be minimized, and network performance can be enhanced due to dynamic resource distribution, which helps manage interference in wireless networks.
7. **Energy Efficiency:** In circumstances where energy consumption is a problem, dynamic resource sharing helps optimize the usage of power resources, ensuring that network components run efficiently while fulfilling performance requirements.

## 2.5. Economic Models in WNV

WNV is transforming 5G RANs by dynamically partitioning physical wireless resources into virtual slices, offering opportunities for resource optimization, differentiated services, and revenue generation. Therefore, mathematical modelling helps stakeholders quantify the benefits of dynamic resource allocation, resulting in operational savings and improved service delivery (Kalogiros et al., 2021).

Economic models provide a structured framework to evaluate the financial implications of NS deployment and operation. They guide stakeholders in making well-informed decisions, ensuring that resources are allocated optimally, services are priced competitively, and investments lead to sustainable economic outcomes within the dynamic landscape of modern RANs (Esmaeily and Kralevska, 2021). This approach also helps assess risk factors and creates a framework for sound decision-making. By leveraging economic models, key players can develop strategies that harmonize resource allocation, service differentiation, pricing, investment, and risk management, paving the way for a prosperous 5G landscape.

Economic modelling plays a crucial role in the context of NS within RAN for several reasons and critical factors, such as Optimized Resource Allocation, Cost-Effectiveness, Revenue Generation, Service Differentiation, Risk Management, Strategic Decision-Making and Long-Term Viability (Darzanos et al., 2022b, Darzanos et al., 2022a, Banda et al., 2022).

## 2.6. Literature Review

This section analyzes the evolution and advancements of WNV in the context of 5G technology. It examines the development of RAN virtualization models, dynamic resource allocation WNV and economic models. The review explores previous studies in architectural designs, orchestration techniques, resource allocation algorithms, and key findings associated with related studies. This comprehensive overview highlights the progression of NS paradigms and their applications in optimizing resource efficiency, QoS, and service differentiation within the virtualized 5G RAN ecosystem.

For improving user service selection and active communication through a virtual system, many models and algorithms relating to reliable virtual resource allocation, isolation, and handoff algorithms are now being investigated and evaluated. Authors (Albonda and Pérez-Romero, 2019) proposed a low-complexity heuristic algorithm that allocates radio resources to varied parts of the RAN to optimize resource usage while ensuring that funds are available to meet traffic demands in each RAN slice. However, the system design consists of Single InPs, and the economic approach is not implemented practically, limiting its real-world scalability.(Korrai et al., 2020), To ensure QoS for diverse IoT services, the RAN resource-sharing issue was identified as sum-rate maximization with latency-related limits and a base rate restriction problem while assuring constant demand utilizing Adaptive Modulation and Coding (AMC). This research only covers one Base Station (BS); hence, it may not represent larger network structures. Researchers (Ma et al., 2020) examined WNV NS. Slices must be fulfilled by testing eMBB and uRLLC slices as downlink OFDMA systems for user requests. Thus, enhancing spectral efficiency in these two slices requires mixed-integer programming. Managing via a single BS could overlook difficulties in larger network systems. In the realm of RAN virtualization, combining MGs with PSO can result in innovative optimization methods and sophisticated tactics for allocating and managing resources (Farhat et al., 2022). The distribution of resources is essential for efficient and optimized NS in V-RAN (Adiraju and Rao, 2022, Mohammed and Shaikhah, 2022). The study's scope is limited due to its specific focus on tasks within cell slices, limiting its broader applicability.

Research communities have investigated various resource allocation algorithms that utilize game theory and PSO principles. The researchers (Kazmi et al., 2017) studied a matching game approach to allocate resources in an OFDMA virtualized wireless network. The results illustrated improved integration, better user experience, and higher bandwidth utilization, and in (Wang et al., 2019) outperformed Hierarchical matching fixed sharing techniques by 32% and 97% of the ideal solution in the average total rate for WNV. This approach disregards the interference caused by resource allocation in complex systems. A centralized design manages all slices under one controller, which may cause scalability issues in more extensive networks.

A resource pricing scheme was developed (Tun et al., 2019, Kazmi et al., 2020) to balance InP profit with network social welfare and improve resource usage and stability. The method covered dynamic network slices and used matching theory and auctions for system allocation. Simulations improved social well-being, financial pairing, and profitability. In the study (Nguyen, 2021), A generalised Kelly mechanism was proposed to solve the two-level allocation problem in network slicing, achieving efficient resource utilization and inter-slice and intra-slice isolation while maintaining high performance in addition to what is mentioned. Fixed sharing could be enhanced by considering individual interference. So far, several works (Paul et al., 2021, Sheena and Snehalatha, 2022, Wei, 2022, Waleed et al., 2021) have presented the benefits and impact of metaheuristic algorithms in WNV, such as Ant Colony Optimization, Genetics, and firefly algorithm, to improve dynamic Slicing and resource allocation in 5G networks with Pareto optimum solutions. These studies did not consider interferences in complex systems, which might affect performance. While these algorithms enhance resource allocation in 5G networks, it's essential to consider their computational complexity and applicability across various scenarios.

Table 2-I Comparison and analysis of Related work in RAN WNV models.

| Ref. | System Design for InP | | WNV-Consideration of | | Optimization Algorithms | | | Economic Model ? |
|---|---|---|---|---|---|---|---|---|
| | One | Multi | Interference | Noise | PSO | MG | Others | |
| (Kazmi et al., 2017) | ✓ | - | ✓ | ✓ | ✓ | ✓ | - | ✗ |
| (Wang et al., 2019) | ✓ | - | ✗ | ✓ | ✓ | ✓ | - | ✓ |
| (Albonda and Pérez-Romero, 2019) | ✓ | - | ✗ | ✓ | ✓ | ✓ | - | ✗ |
| (Tun et al., 2019, Kazmi et al., 2020) | - | ✓ | ✗ | ✓ | - | ✓ | - | ✓ |
| (Korrai et al., 2020) | ✓ | - | - | ✓ | ✓ | - | - | ✗ |
| (Ma et al., 2020) | ✓ | - | ✗ | ✓ | ✓ | - | - | ✗ |
| (Nguyen, 2021) | ✓ | - | ✗ | ✓ | - | | ✓ | ✗ |
| (Paul et al., 2021, Sheena and Snehalatha, 2022, Wei, 2022, Waleed et al., 2021) | ✓ | | ✓ | ✓ | - | ✓ | - | ✓ |
| (Yarkina et al., 2022, Jayaraman et al., 2023) | - | ✓ | ✗ | ✓ | - | ✓ | ✓ | ✓ |
| (Awada et al., 2022, Farhat et al., 2022) | - | ✓ | ✗ | ✓ | | ✓ | ✓ | ✓ |

# CHAPTER THREE

# METHODOLOGIES AND SYSTEM DESIGN

## 3.1. Introduction

The investigation of NS throughout WNV in the context of 5G RAN is a practical approach for improving the utilization of resources and accommodating the different demands of current wireless communication systems.

This section provides a detailed proposed comprehensive design of a new wireless network for 5G RAN. Consequently, it involves resource virtualization and channel sharing among multiple InPs, MVNOs, and UEs. The design incorporates RAN Structure optimizations and proposes a new layer for generic NS architecture, as discussed in the previous chapter. A significant contribution is a new mathematical method derived from three sub-models and integrated into a practical framework. The unique model for channel gain in the RAN's air interface is proposed, calculating user interference and termed IUI.

Furthermore, this section employs a combinatorial approach utilizing the MG and PSO. These address dual selections involving users and MVNOs for services and Resource Blocks (RBs). Pairing occurs between UEs and MVNOs for service selection, followed by dynamic MVNO-InP pairing to allocate virtual RBs. This strategy optimizes user selection, enhances resource consumption, and manages the user throughput-revenue trade-off. Practical economic frameworks are integrated to determine MVNO user expenses and InP income. Moreover, a convex optimization technique addresses MLIP challenges, achieving optimal cost-minimization and throughput improvement solutions.

## 3.2. Proposed NS Architecture for Virtual RAN

In response to the rapidly evolving 5G network landscape, it becomes imperative to reevaluate network architecture for improved reliability and flexibility and to meet the ultra-fast connectivity demands of end-users and customers. The infrastructure layer of 5G networks comprises several components that provide physical resources for processing, calculation, storage, and communication. However, the general design does not fully consider end-user devices. Although WNV effectively manages NS components virtually, it still faces the challenge of accommodating end-user devices such as mobile stations and IoT devices, causing delays in optimal network slice selection and meeting the demands of modern telecommunications.

This section presents a new NS architecture that employs virtualization as its foundation. This proposed architecture introduced a new layer to the three generic layers; the newly added layer is labelled with a “customer layer” to dynamically handle service selection and resource distribution among users and virtual operators, as depicted in Figure 3-1 and summarized in Table 3-I.

The following points discuss the proposed architecture and the new added layer:

1- **Physical layer:** This is the same as the infrastructure layer, but this naming fits its functionality.
2- **Enablers Layer:** It conducts duties similar to the network function layer, but it is referred to as the Enablers layer because this is where all NS enhancers execute their tasks. It relates the layer's name to its participants.
3- **Application Layer:** provides services to the customer as the service layer does.
4- **Customer Layer:** it ensures slice selection and implements new protocols on end-user and service provider platforms, managing a BS with three distinct service groups: mMTC, URLLC, and eMBB.

Adding a new layer to the NS architecture is essential for integrating various end-user devices and ensuring optimal performance. It also allows for dynamic service selection and revenue distribution, adapting to different requirements and models. Furthermore, the new layer enables enhanced customization of network slices, improving service quality and resource allocation. Moreover, the proposed new layer helps the dynamic two-level associations within the NS architecture. At the first level, it connects end-user devices to the appropriate network slices, ensuring each device receives the necessary resources and performance levels. At the second level, it manages the relationships between users and virtual operators, ensuring equitable revenue distribution. This two-level association is critical for maintaining a balanced and efficient network ecosystem.

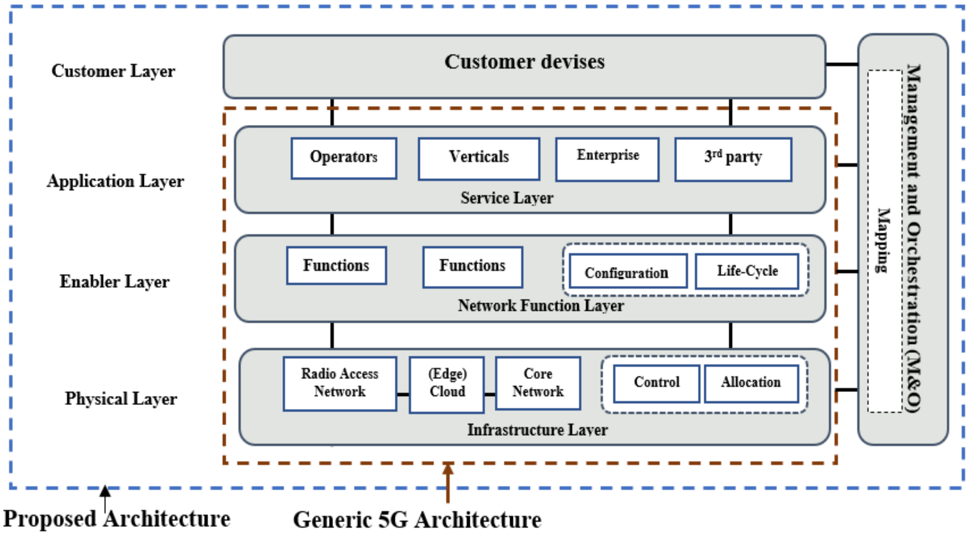



Fig. 3-1. Generic and proposed 5G NS Architecture

Therefore, a practical implementation should respond to the design and business requirements as a detailed case study in section 3.2.1.

A scenario involves individuals potentially deploying and utilizing a 5G wireless network as follows:

1- **Service Customer (SC):** A network customer, such as a subscriber of an MVNO, can be an UE in eMBB or an IoT device in mMTC.
2- **Service Provider (SP):** The MVNO provides services directly to the SC. The SP can also be considered an NS Customer (NSC). NSC is an MVNO that buys or rents a slice(s) from another company that provides NS.
3- **NS Provider (NSP):** provides a slice of a network for MVNOs and any company that has a service and wants to give it to SC. The NSP owns logical networks, but it can use the physical resources of an InP.
4- **InP:** provides a physical network.

Table 3-I Generic and Proposed NS design vs. regular scenario.

| Generic NS Architecture | Proposed NS architecture | Players in a Typical 5G network |
|---|---|---|
| Infrastructure Layer | Physical Layer | Infrastructure Provider |
| Network Function Layer | Enablers Layer | NS Provider |
| Service Layer | Application Layer | Service Provider |
| Not Available | Customer Layer | Service Customer |

This study demonstrates the practical implementation of NS through virtualization, showcasing its potential to meet modern communication demands in the 5G era. For instance, Figures 3-2 indicate that the proposed system model incorporates four InPs and vendors. Each has its unique channel set bandwidth allocation. $\mathcal{BW}_n = [5{,}10{,}15{,}20]$, the overall system offering 100 RBs = [10,20,30,40], and managing Ten virtual slices; here, MVNOs are the virtual companies measured as service providers providing facilities to 300 UEs. The user demands are assumed to display a random distribution ranging from 1 to 20 bps/Hz. The effect of path-loss and Rayleigh distribution is considered on the channel between the UEs and BS, as presented in Figure 3-

3. The pricing structures of MVNOs and InPs demonstrated a uniform distribution within the respective price ranges of MVNO $m$= (4 ~ 8) and InP $n$= (3 ~ 5) budgetary units per bps/Hz, according to some SLAs and through the proposed algorithms, these commerce interactions and block pairings practically implemented.

### 3.3. System Model

The optimization and enhancement of mobile networks' performance are crucial for stakeholders like InPs, MVNOs, and UEs. A combinatorial strategy is used to achieve this objective, integrating a hierarchical MG algorithm with an economic model and comparing it with a metaheuristic optimization algorithm using PSO techniques. The MG is run twice for service selection and resource allocation, focusing on aligning service providers with users and optimizing service distribution while maximizing revenue. The second phase distributes network resources to individuals based on their needs, maximizing network throughput. The economic model ensures that every participant operates within the most advantageous economic regions, considering profit functions, costs, and revenue. This methodology ensures the network's financial viability, providing advantages to all stakeholders.

Figure 3-2 illustrates the architecture of the proposed virtual RAN. The downlink of the system is measured to be Orthogonal Frequency Division Multiple Access (OFDMA). The designed network consists of a set of $\mathcal{N}$ InPs ($n = 1, 2, 3, \dots \mathcal{N}$), and each InP owns a bandwidth. $\mathcal{BW}_n$ and gNodeB base station ($\mathrm{gBS}_n$), as well as a set of MVNOs $M$ ($m = 1, 2, 3, \dots M$). The InPs provide services to a group of MVNOs under some individual contracts SLAs. Additionally, an MVNO $m$ offers its services to a set of UEs denoted by $\mathcal{K}_m$ ($k = 1, 2, 3, \dots \mathcal{K}_m$). Then, $k = U_m \mathcal{K}_m$indicates the total number of UEs, where $U_m$is considered a cardinality of UEs. Each InP $n$ holds a set of

Orthogonal channels. $C_n$, each channel with a bandwidth $W$. It is assumed that the transmit power on each channel of InP $n$ is $P_n$, then (Kazmi and Hong, 2017);

$$P_n = \frac{P_n^{Total}}{|C_n|} \tag{3.1}$$

Where $P_n^{Total}$ is the total transmit power of the gBS$_n$and the $C_n$denotes the number of slices that each particular InP gives.

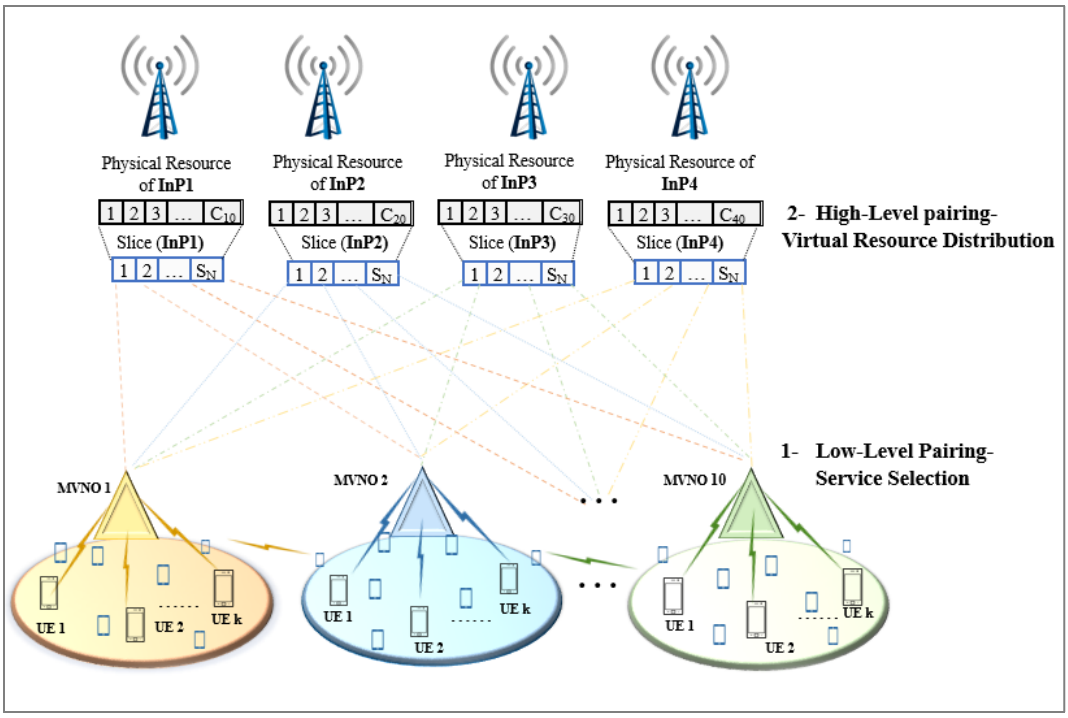



Fig. 3-2. Graphical system model for the proposed virtual RAN.

## 3.4. Proposed Dynamic Virtual RAN Models.

In the context of wireless network virtualization, resource and service allocation among diverse entities assumes a vital role. InPs emerge as essential orchestrators, facilitating continuous service distribution by allocating slices to MVNOs. This section incorporates the design details of the proposed virtual RAN downlink and investigates the strategies and variables integral to optimizing the air interface of the RAN process. This exploration encompasses a two-pairing approach, which is provided in section 3.5. Within this framework, InPs $n$ undertake the responsibility of provisioning independent services using a set of $\mathcal{S}_n$ slices. These slices are then allocated by InPs $n$ to various MVNOs $m$, each of which may require multiple channels depending on their needs.

To systematically address these allocation decisions, two binary variables are introduced:

**1-** The user Association Variable $\boldsymbol{\mathcal{X}_{k,m}}$:

$$\mathcal{X}_{k,m} = \begin{cases} 1, & \text{if user } k \text{ assosiated with MVNO } m \\ 0, & \text{otherwise} \end{cases} \tag{3.2}$$

The binary variable $\mathcal{X}_{k,m}$ signifies whether user $k$ is associated with MVNO $m$. When set to 1, it denotes that the user $k$ is connected with MVNO $m$. Conversely, a value of 0 indicates that the user is not associated with that particular MVNO $m$.

**2-** The slice distribution variable $\boldsymbol{\mathcal{Y}_{n,m}^{\mathcal{S}_n}}$:

$$\mathcal{Y}_{n,m}^{\mathcal{S}_n} = \begin{cases} 1, & \text{if slice } \mathcal{S}_n \text{ is allocated to MVNO } m \text{ from InP } n, \\ 0, & \text{otherwise} \end{cases} \tag{3.3}$$

The variable $\mathcal{Y}_{n,m}^{\mathcal{S}_n}$ indicates whether slice $\mathcal{S}_n$ is allocated from InP $n$ to MVNO $m$. A value of '1' suggests that a slice $\mathcal{S}_n$ is indeed allocated to MVNO $m$ from InP, whereas a value of '0' implies that the allocation has not occurred.

These binary variables hold significant importance as they manage the allocation of resources and the distribution of services within the proposed virtual RAN architecture. By strategically manipulating these variables, efficient resource utilization and optimal service delivery can be achieved across the network, improving the wireless communication experience.

### 3.4.1. WNV Model

Once these decision binary variables are established, the calculation of data rates for UE $k \in \mathcal{K}_m$ belonging to MVNOs $m$ and distributed to a slice $\mathcal{S}_n$ can be executed using Shannon's formula as(Kazmi et al., 2020):

$$\mathcal{R}_{n,m,k}^{\mathcal{S}_n} = \sum\nolimits_{\mathcal{S}_n \in \mathcal{C}_n} \mathcal{W} \log_2 (1 + SINR) \tag{3.4}$$

Where $\mathcal{R}_{n,m,k}^{\mathcal{S}_n}$ is the achievable data rate of user $k$ belongs to MVNO $m$, served by InP $n$ through the slice $\mathcal{S}_n$, and $\mathcal{W}$ is the channel bandwidth of the system. The received SNIR denoted as $\gamma_{m,k}^{\mathcal{C}_n}$ relating to the transmission of MVNO $m$, and user $k$ over the $\mathcal{S}_n$ with transmit power $\mathcal{P}_n^{\mathcal{S}_n}$ is:

$$\gamma_{m,k}^{\mathcal{C}_n} = \frac{P_{n,m}^{\mathcal{S}_n}\, \mathcal{G}_{m,k}^{\mathcal{C}_n}}{\sum_{j \in M, j \neq m, e \in \mathcal{K}, e \neq k} P_{n,j}^{\mathcal{S}_n}\, \mathcal{G}_{j,e}^{\mathcal{C}_n} + \left(\sum_{u \in \mathcal{K}, u \neq k} P_{n,m}^{\mathcal{S}_n}\, \mathcal{G}_{m,u}^{\mathcal{C}_n}\right) + \mathfrak{N}} \tag{3.5}$$

Where $\mathcal{G}_{m,k}^{\mathcal{C}_n}$ is the sub-channel gain between the $gBS_n$ of InP $n$ and UE $k$ in the MVNO $m$ over the channel set $\mathcal{C}_n$that allocated for the slice $\mathcal{S}_n$.

The sub-channel gain is given by (Kazmi and Hong, 2017):

$$\mathcal{G}_{m,k}^{\mathcal{C}_n} = \mathfrak{X}\, d_{(\, d_{(m,k)}^{\mathcal{C}_n})}^{-\mathfrak{B}} \tag{3.6}$$

Where $\mathfrak{X}$ is a function of path loss and is generated randomly according to the Rayleigh distribution function. The path loss is a function of distance $d_{(m,k)}^{\mathcal{C}_n}$ which is the distance between the $gBS_n$ and user $k$ and $\mathfrak{B}$= 3 is the path loss factor.

The denominator of constrain (3.5) consists of three terms. The first term; $\sum_{j \in M, j \neq m, e \in \mathcal{K}, e \neq k} P_{n,j}^{\mathcal{S}_n}\, \mathcal{G}_{j,e}^{\mathcal{C}_n}$ , represents the UE interference of other MVNOs to the victim MVNO $m$. The second term; $\sum_{u \in \mathcal{K}, u \neq k} P_{n,m}^{\mathcal{S}_n}\, \mathcal{G}_{m,u}^{\mathcal{C}_n}$, represents UE interference of the same MVNO $m$ to the victim user $k$. The third term, $\mathfrak{N}$, is background noise.

In understanding the system architecture, it is crucial to consider all three terms in the system simulation, which is unique in this work. Most previous studies assume only background noise, an ideal case study in wireless communication that can't be applied practically.

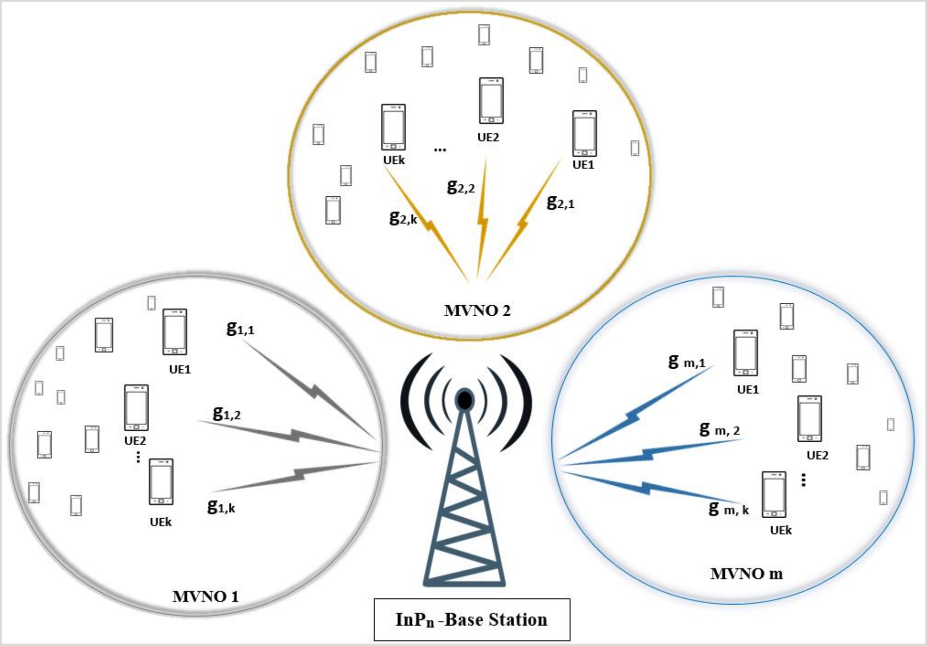



Fig. 3-3.The Channel Gain of the System model.

### 3.4.2. Economic Model

An economic model is a structured framework to analyze and comprehend the financial dynamics and interactions among various elements within a specific context. It enables representing and predicting economic behaviours, decisions, and outcomes while guided by particular assumptions and parameters.

In this design, the economic model is pivotal as a guiding tool. It examines and predicts the financial implications of decisions made by different stakeholders, particularly InPs and MVNOs. Using the economic model enables an assessment of resource allocation strategies, pricing mechanisms, and revenue distribution plans. It adopts a comprehensive understanding of how these financial components are interconnected and influenced within the context of this work.

A convex economic model has been adopted. This model type is chosen because it effectively balances UEs' diverse interests and objectives. This model aims to achieve a harmonious alignment of profit maximization for InPs and cost minimization for MVNOs, thereby contributing to an equally constructive and sustainable network ecosystem.

## 3.5. Problem Formulation

In this work, the problem focused on optimizing users' throughput while maximizing the profits of InPs and MVNOs. Within the circumstance of multi-infrastructure networks. To tackle this complex challenge, through employing convex optimization techniques, explicitly leveraging the CVX framework, to address integrally non-convex problems. This approach allows the anticipated model to maximize the interests of all parties involved by formulating and solving a convex model that encapsulates intricate relationships and trade-offs within the economic exchanges of the design framework. In this context, the UE seeks to reduce the cost incurred in the network while maximizing throughput, while MVNO $m$ should aim to minimize costs while maximizing throughput. On the other hand, InP $n$ should maximize their profits.

Here, it is defining the decision variables for each player. For the UE $k$, we can define a binary variable. $\mathcal{X}_{k,m}$ to indicate whether UE $k$ chooses to use the services of MVNO $m$. The objective function for UE $k$ should minimize the cost gained in the network while maximizing throughput (Kazmi et al., 2017).

**UE:**

$$\min_{\mathcal{X}_{k,m}\in[0,1]} \sum_{m\in M} \mathcal{X}_{k,m}\beta_m^M d_k \tag{3.7}$$

$$\text{s.t.} \sum_{m \in M} \mathcal{X}_{k,m} = 1, \tag{3.8}$$

Constrain (3.7) Where $d_k$ is the demand of users and $\beta_m^M$ is the unit price of MVNO $m$ to guarantee the viability of the proposed solution, certain limitations should be placed on the decision variables.

Condition (3.8) can be assessed by UE $k$ to determine that each UE can only be serviced by a single MVNO $m$.

The objective function for MVNO $m$ should maximize its profit, which is a function of the cost of serving its UEs and buying slices from InP $n$ (Kazmi et al., 2017, Kazmi et al., 2020).

**MVNO:**

$$\max_{\mathcal{X}_{k,m} \mathcal{Y}_{n,m}^{\mathcal{S}_n} \in [0,1]} \sum_{k \in \mathcal{K}} \mathcal{X}_{km} \beta_m^M d_k - \sum_{n \in N} \sum_{s_n \in \mathcal{S}_n} \mathcal{Y}_{n,m}^{\mathcal{S}_n} \beta_n^I |\mathcal{S}_n|, \tag{3.9}$$

$$s.t. \sum_{m \in M} \mathcal{X}_{k,m}, \leq 1, \forall k, \tag{3.10}$$

$$\sum_{k \in \mathcal{K}} \mathcal{X}_{k,m} \ell_{k,n} \leq \mathcal{Y}_{n,m}^{\mathcal{S}_n} |\mathcal{S}_n|, \forall n, \tag{3.11}$$

Where $\beta_n^I$ is InPs per unit price, $\ell_{k,n}$ is the required channel to fulfil users' demands.

Now, in (3.9), MVNOs $m$ aim to provide their users with the best possible service while keeping costs low and maximizing throughputs. To achieve this goal, they must consider various factors, including whether to accept user proposals and purchase a slice of the network infrastructure. To represent these decisions, MVNOs $m$ commonly use variables such as $\mathcal{X}_{k,m}$ $and$ $\mathcal{Y}_{n,m}^{\mathcal{S}_n} \in [0,1]$ which indicate whether a proposal has been accepted and whether a slice has been purchased, as details explained in equations 3.2 and 3.3. To ensure that each user is serviced by at most one MVNO $m$ as seen in constrain (3.10). Additionally, constraint (3.11) ensures that the number of RBs assigned to each slice is below the competency percentage provided to the MVNO $m$.

Then, computing the required channels to fulfil user demands $d_k$on InP$n$ consuming the formula:$\ell_{k,n} = d_k / \mathcal{R}_{n,m,k}^{\mathcal{S}_n}$ where $\ell_{k,n}$ is the number of channels required to serve UE $k$ on a slice $\mathcal{S}_n$ of InP $n$.

For InP $n$, it is required to confirm that allocated slices are less than the total InP slices and that the contract agreement is not unsettled. The objective should satisfy the requirements of all MVNOs concerning the contract agreements that are not desecrated. The decision variable $y_{n,m}^{\mathcal{S}_n} \in \{0,1\}$ in (3.3) indicates whether InP$n$ accepts the slice ordering offer of MVNO$m$.

The objective function for InP$n$ is (Kazmi et al., 2017, Kazmi et al., 2020).;

**InP:**

$$\max_{y_{n,m}^{\mathcal{S}_n} \in [0,1]} \sum_{m \in M} \sum_{s_n \in \mathcal{S}_n} y_{n,m}^{\mathcal{S}_n} \left( \sum_{k \in \mathcal{K}} log \;\; \mathcal{R}_{n,m,k}^{\mathcal{S}_n} \;) + \omega \beta_n^I |\mathcal{S}_n| \right) \tag{3.12}$$

$$s.t \sum_{m \in M} \sum_{s_n \in \mathcal{S}_n} y_{n,m}^{\mathcal{S}_n} \leq |\mathcal{S}_n| , \tag{3.13}$$

$$\sum_{k \in \mathcal{K}} \sum_{s_n \in \mathcal{S}_n} y_{n,m}^{\mathcal{S}_n} \mathcal{R}_{n,m,k}^{\mathcal{S}_n} \geq d_m , \forall m \tag{3.14}$$

Here, the objective function (3.12) for the InP$n$ is to raise its income, a weighted sum of the logarithm of the requested resources by the UEs and the price per unit of the slices allocated to the MVNOs. The weight $\omega$ represents the transaction between disinterest and InP income. The first term in the objective function means proportional fairness among the UEs, where the logarithm of the requested resources reflects the idea that users with higher demands have higher benefits from the network. The second term in the objective function represents the revenue earned by the InP from selling slices to the MVNOs.

Constraint (3.13) ensures that the number of slices allocated to the MVNOs by the InP $n$ does not exceed the total number of portions available.

Constraint (3.14) provides that the allocated resources to the MVNOs are sufficient to meet the demands of the UEs, where $\mathcal{R}_{n,m,k}^{\mathcal{S}_n}$ represents the number of resources allocated to the slices of the MVNO $m$ on InP $n$ used by UE $k$.

## 3.6. Proposed Methodologies

This section presents a comprehensive approach to addressing industry challenges and maximizing stakeholder profitability by applying two distinct algorithms: the MG and the PSO algorithm. Each algorithm is outlined individually, highlighting its unique strengths and potential uses, then exploring their possible integration for enhanced optimization outcomes. Figures 3-4 indicate the structural framework of the proposed system model; details are provided in sections 3.6.1 and 3.6.2

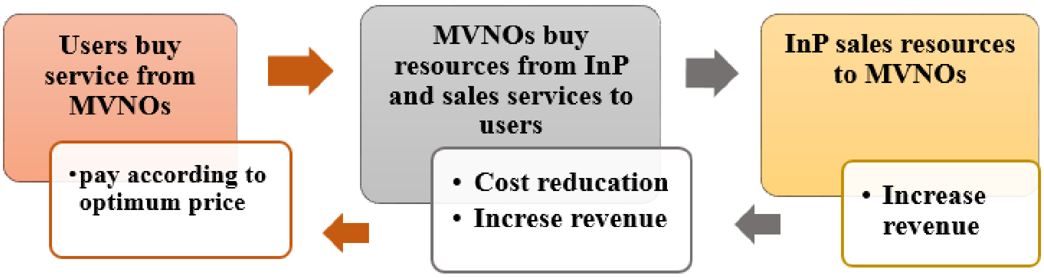



Fig. 3-4. System model workflow Framework.

### 3.6.1. Matching Game Formulation

The MG algorithm, integral to this research, addresses the NP-hard (Non-deterministic Polynomial-time hard) integer linear programming (ILP) problem, which is characterized by its computational complexity, indicating that solving it efficiently in the worst case is believed to be infeasible. Introducing a two-stage dynamic pairing approach is a notable distinction in our MG formulation. Robust selections are made in each stage, optimizing price and data rate. This dynamic selection process is achieved through utility functions, which play a pivotal role in activating our economic model within the framework of the MG. These innovations distinguish our approach by enhancing resource allocation, cost reduction, and profit maximization, setting it apart from existing methods in the field.

The proposed methodology involves a combinatorial approach that is divided into two stages. Initially, users inquire about services from the MVNOs considered buyers, which evaluate proposals based on specific criteria and forward them to the next stage as a request to various InPs, who play vendor roles at the highest level. This stage is commonly referred to as service selection. Upon acceptance of a proposal, the resulting output serves as the input (i.e., initial values) for the subsequent stage, which involves resource procurement between MVNOs and InPs. This work design corresponds to our proposed RAN architecture and is implemented practically through the utility function in the following subsections:

#### 3.6.1.1. Low-Level Pairing -Service selection

In the initial phase, the number of users requiring the service was determined based on their profile preferences and utilization functions using the user association algorithm adopted by (Kazmi et al., 2020). The MG involves pairing UEs and MVNOs, representing two distinct entities. By generating a set of $n$ imaginary variables for each MVNO, denoted by $m_n$, and considering the preferred preference profile of the UEs and MVNOs represented by $P_k$ and $\mathcal{P}^l_{m_n}$, respectively.

From constrain (3.7), a UE $k$ ranks an MVNO $m_n$, based on its accessible amount in a non-reducing instruction assumed by (Kazmi et al., 2017, Kazmi et al., 2020):

$$U_k(m_n) = \beta^M_{m_n}, \quad \forall m_n \tag{3.15}$$

Through (3.9), an MVNO $m$ ranks all UEs based on the profit they yield in a non-increasing order by:

$$U_{m_n}(k) = max\,(\beta^M_{m_n} d_k - \beta^l_n l_{n,k}, 0), \forall\, k \tag{3.16}$$

In (3.16) MVNO $m_n$ evaluate values of $d_k$ and $\mathcal{G}^{\mathcal{C}_n}_{n,k}$ determines the necessary channels (i.e., $l_{n,k}$) for a UE $k$ and places them in a preferred list according to the profit they generate in $\mathcal{P}^l_{m_n}$. Additionally, a UE is not ranked in the list if its earnings are negative in $\mathcal{P}^l_{m_n}$. Nevertheless, from (3.10), each MVNO can only assist limited UEs, i.e., through the quota $m_n$is determined as the upper limited slices for provided InP.

### 3.6.1.2. High-level pairing - Virtual Resource Distribution

MVNOs need slices from certain InPs to service their acceptable UEs. The MVNO demand signifies as $d_{m_n} = \sum_{k \in \mu(m_n)} d_k$. Now, both MVNOs and InPs define their respective preference profiles as $\mathcal{P}^{\mathcal{U}}_{m_n}$ and $\mathcal{P}_n$. Then, each MVNO targets to reduce its cost. Therefore, from (3.9), MVNO $m$ grades InPs based on their price in a non-decreasing order (Kazmi et al., 2017, Kazmi et al., 2020).:

$$U_{m_n} = \beta^I_n, \qquad \forall n \tag{3.17}$$

Through (3.17), InPs maximize expenses by exporting slices, achieving equality among UEs, and ranking purchasers non-increasingly.

$$U_n(m_n) = \sum_{k \in \mu(m_n)} log\big(\mathcal{R}^{\mathcal{S}_n}_{n,m,k}\big) + \omega\beta^I_n\, \mathcal{Y}_{m_n}, \;\; \forall m_n \tag{3.18}$$

Here, assume that the values of $d_{m_n}$ and the set of UEs matched in the low-Level (i.e., k ∈ μ($m_i$ )) are sent to the InPs in the tender phase. Then InP computes the required slice scope, i.e., $\mathcal{Y}_{m_n}$ to meet MVNO$m_n$ demand, ranking InPs based on constraints (3.18). Matching and selecting InPs under the SLA involves considering the price range, throughput, available RBs, and bandwidth.

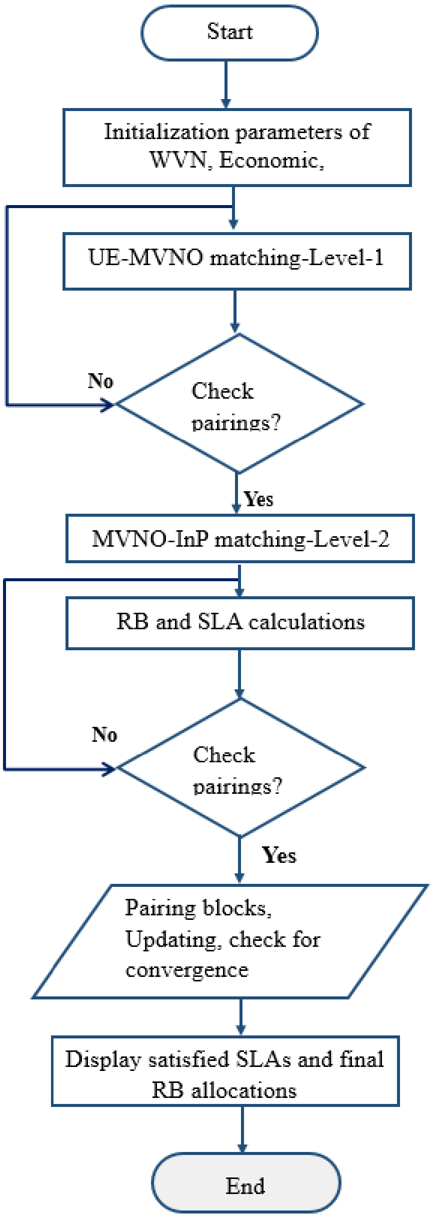



Fig. 3-5. Matching Game Algorithm Flowchart.

| Algorithm 1-A; Matching Game |
|---|
| *1: **Initialize** t_S and G(t_S,:)* |
| *2: **Initialize** Beta_M_m = unifrnd(4, 8, [M, 1])* |
| *3: **Initialize** Beta_I_i = unifrnd(2, 4, [N, 1])* |
| *4: **Initialize** Dk_k with the demand of UEs,* |
| *5: **Calculate** L_L(n,k) based on the demand per unit price **for** MVNO m and InP n* |
| *6: **Initialize** Xv = zeros(K, M)to do service selection* |

```
Initialize flag = true // Initialize flag to true
while flag is true:
    Increment t_S by 1
    Loop over all ihi from 1 to Sn:
        Loop over all jhi from 1 to K:
            Loop over all lki from 1 to M:
                If mu_mn_k(ihi,jhi,lki) < 0, then set mu_mn_k(ihi,jhi,lki) to 0
    For each UE k from 1 to 10:
        Find the most preferred MVNO-InP pair for UE k using the preference list Pk
            Do Low-Level UEs-MVNOs
        Propose to that pair by setting mu_mn_k(t,mn_ind,k) = 1,
    Update t to be min(t,5) to limit t to 15
    Pad Pk with zeros so that it has size [K, max(t-8,0), M]
    For each UE k from 1 to K:
        Sort the matrix mu_mn_k(:,k,:) in descending order and obtain the indices of
    the sorted elements
        Use the indices to update the preference list Pmn(t,:,k)
    For each MVNO-InP pair mn from 1 to M*N:
        Sort the matrix mu_mn_k(:,:,mn) in descending order and obtain the indices of
    the sorted elements
        Use the indices to update the preference list Pk(t,:,mn)
    If t > 0 and t_S > 0:
        If G(t_S,:) is not equal to G(t_S-1,:), then set flag to false
    Do high-level matching using the Gale-Shapley algorithm
    Update G(t_S,:) based on the current matching till convergence
End While
```

Algorithm 1-B; Economic Model

```
Initialize
    Set X11v to a matrix of size K x M, with all elements set to 0.
    Set q to a matrix of size M x N, with values of Q_kn for each MVNO.
    Set P_I to a matrix of size N x M, with all elements set to 1:M.
    Set P_M to a matrix of size M x N, with all elements set to 1:N.
    Set Revenue_InP and Revenue_MVNO to 0.
Perform low-level matching game:
While there exists an MVNO that is unmatched:
    For each MVNO m:
        For each UE k in MVNO m:
            Calculate the utility U_M(n) for each InP n based on R_M, C_M, and
    Beta_M_m(n).
            Calculate the utility U_I for each InP n based on Beta_I_i(n) and the number
    of matched MVNOs.
        Find the InP n that maximizes U_M(n).
        If no InP maximizes the utility function of MVNO m, remove the MVNO m from
    the game.
        Find the UE k that maximizes R_M in InP n.
        If UE k is already matched to another MVNO in InP n, remove the MVNO m
    from the game.
```

*        **Match** UE k to MVNO m in InP n and remove the old match, **if any.***
*        **Update** the demand q(m,n) of MVNO m in InP n and remove the InP n from the game **if** the demand is met.*
***    Calculate the total revenue of InPs and cost for MVNOs.***
*Check **if** matching is group stable for all InPs:*
***For** each InP n:*
*    **For** each MVNO m:*
*        **If** InP n is worse off with MVNO m than its current match, update its preference list.*
***If** matching is group stable for all InPs:*
*    **Display** the total revenue of InPs and MVNOs.*
***    Do upper matching to MVNO and InP:***
***For** each MVNO n:*
*    **For** each InP m in its preference list:*
*        **If** InP m prefers MVNO n to its current match, **update** the game.*
*    **Display** the final matching result.*

### 3.6.2. PSO Algorithm Formulation

PSO is a metaheuristic optimization method encouraged by the collective behaviour of bird clustering or fish training. It is widely used in various domains; in NS, the PSO is used to optimize the distribution of resources, such as bandwidth, computing power, and storage, among multiple InPs and their respective slices for each MVNO (Oladejo and Falowo, 2018). The fitness function uses constraints such as InP capacity, slice delay, resource allocation expenses, and MVNO profitability for assessing particles. The convergence to a globally prime result that satisfies resource allocation criteria for all MVNOs and slices is attained via iteratively updating particle locations and measuring fitness (Waleed et al., 2021).

Mathematically, the particles are employed by the subsequent equations:

$$\nu_i\,(\mathrm{t}+1) = \mathfrak{W}\mathfrak{v}_i + \mathfrak{H}_1\mathfrak{r}_1[\mathfrak{p}_i(\mathrm{t}) - \mathfrak{Z}_i(\mathrm{t})] + \mathfrak{H}_2\mathfrak{r}_2\left[\mathfrak{p}_j(\mathrm{t}) - \mathfrak{Z}_i(\mathrm{t})\right] \quad (3.19)$$

$$\mathfrak{Z}_i\,(\mathrm{t}+1) = \mathfrak{Z}_i\,(\mathrm{t}) + \nu(i)(\mathrm{t}+1) \quad (3.20)$$

$$\mathfrak{W} = \mathfrak{W}_{max} - \frac{(\mathfrak{W}_{max} - \mathfrak{W}_{min})}{\mathfrak{T}_{max}} * \mathfrak{T}_{\mathfrak{Q}} \quad (3.21)$$

Constraint (3.19) and (3.20) for finding velocity per time and best position, where $\nu_i$ is the velocity of participle $i$, $\mathfrak{H}_1$and $\mathfrak{H}_2$ are positive constants called acceleration coefficients and $\mathfrak{r}_1$and $\mathfrak{r}_2$are randomly generated numbers in the range [0,1], $\mathfrak{Z}$ is the position of particle $\mathfrak{p}$ in time $\mathfrak{t}$, and $\mathfrak{W}$ is the inertia weight defined by (3.21), where ($\mathfrak{W}_{max}$ is the initial weight, $\mathfrak{W}_{min}$ is the final weight, $\mathfrak{T}_{max}$ denotes the maximum iteration number, and $\mathfrak{T}_{\mathfrak{Q}}$ is the existing recurrence number (Tian, 2017). Below is the comprehensive PSO workflow Procedure:

1. Initialize the population of particles randomly in the search space.
2. Evaluate the fitness of each particle based on the objective function.
3. Update the personal best position and wellness of each particle.
4. Update the global best position and fitness of the swarm.
5. Update the velocity and position of each particle using the following formula:
6. velocity = inertia weight * velocity + acceleration coefficient * random number * (personal best position - current position) + acceleration coefficient * random number * (global best position - current position) position = current position + velocity
7. Repeat steps 2-5 until a stopping criterion is met (e.g., a maximum number of iterations or a satisfactory solution is found).
8. Return to the global best position and fitness as the optimal solution.

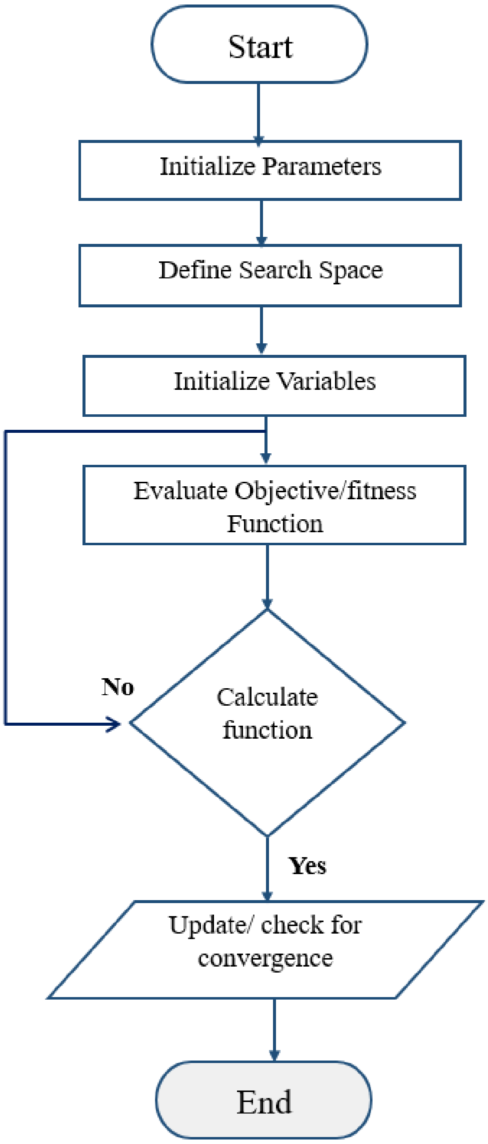



Fig. 3-6. PSO Flow Chart.

Algorithm 2:PSO

```
Define PSO parameters: nParticles, nItrations,w, c1&c2
    Define PSO search space Lower and upper boundaries
    Initialize PSO variables and cost function
    Run PSO algorithm
    for iteration = 1 to nIterations
        for particle = 1 to nParticles
            Evaluate objective function of the particle
    Run cost function and iterate for = end
            Update particle best position and cost &global best position and cost
        end
        for particle = 1 to nParticles
            Update particle velocity and position
            Enforce search space boundaries
    Iterate till convergence
        end
    end
    Print optimized results
    Calculate optimizedDataRate based on globalBestPosition
    Calculate optimizedObjective as sum of optimizedDataRate
    Print "Optimized Average Data Rate: ", optimizedObjective
    end
```

# CHAPTER FOUR

# EXPERIMENTAL RESULTS AND DISCUSSION

## 4.1. Introduction

This chapter focuses on implementing and examining the dynamics of resource allocation in WNV. The goal is to optimize the utilization of shared resources while addressing the unique challenges in a dense UE environment.

In addition, The complexity of assigning resources in such conditions is acknowledged. Therefore, to overcome this complexity, the MG and PSO are employed as two different algorithms to facilitate and cooperate in smooth communication of providing service demands and resource management among multiple UEs, MVNOs and InPs.

Additionally, these algorithms are integrated into an economic framework to evaluate the sustainability of the financial scheme. Ensuring accurate and trustworthy results requires a powerful program to be implemented; for this regard, MATLAB is preferred and supported by essential resources like the CVX libraries.

As a result, this section explores the algorithm's strengths and weaknesses during each implementation phase. MGs focus on influential association and accuracy, while PSO relies on speeds in user engagement rather than accuracy due to its randomization nature. The choice of algorithm depends on the problem at hand, available data, and desired results. Conducting a comparative experiment can provide insights into the optimal strategy for addressing industrial challenges and optimizing stakeholder profitability.

## 4.2. Simulation Setup

The proposed system architecture in Chapter Three is simulated based on realized parameters of 5G networks to present a practical case study. The parameters adopted are due to standard communities and literature. Table 4.1 illustrates the most crucial parameters in the system simulation(Kazmi et al., 2017, Kazmi et al., 2020).

The diagram in Figure 4-1 illustrates a dynamic network system comprising four InPs, ten MVNOs, and a UEs exceeding 300 individuals. The operational range of the device encompasses a circular region with a diameter of 9km. The distribution of users within this circular area is managed dynamically by calculating path loss and generating random data according to the Rayleigh fading distribution function. The route loss factor is an essential component that must be included to analyze signal attenuation over distance effectively and provide an accurate picture of wireless networks in the real world. Moreover, the circular architecture of the network system maximizes space utilization by evenly scattering users and efficiently distributing resources, demonstrating adaptability to user locations and improving visibility.

Table 4-I System Simulation Parameters.

| **Parameters** | **Values** |
|---|---|
| Carrier Frequency | 4 GHz |
| InP Bandwidth | 5,10, 15 and 20 MHz |
| No. of MVNO | 10 |
| No. of InP | 4 |
| Total no. of users | 300 |
| RB Bandwidth | 180 KHz |
| Subcarrier spacing | 15 KHz |
| No. of Subcarrier per RB | 12 |
| No. of RB in InP | 100 |
| gNodeB Noise Power | $10^{-13}$ W |
| gNodeB Tx Power | 46 dBm |
| Coverage area | Circle with a diameter of 9km |
| User distribution | Random |

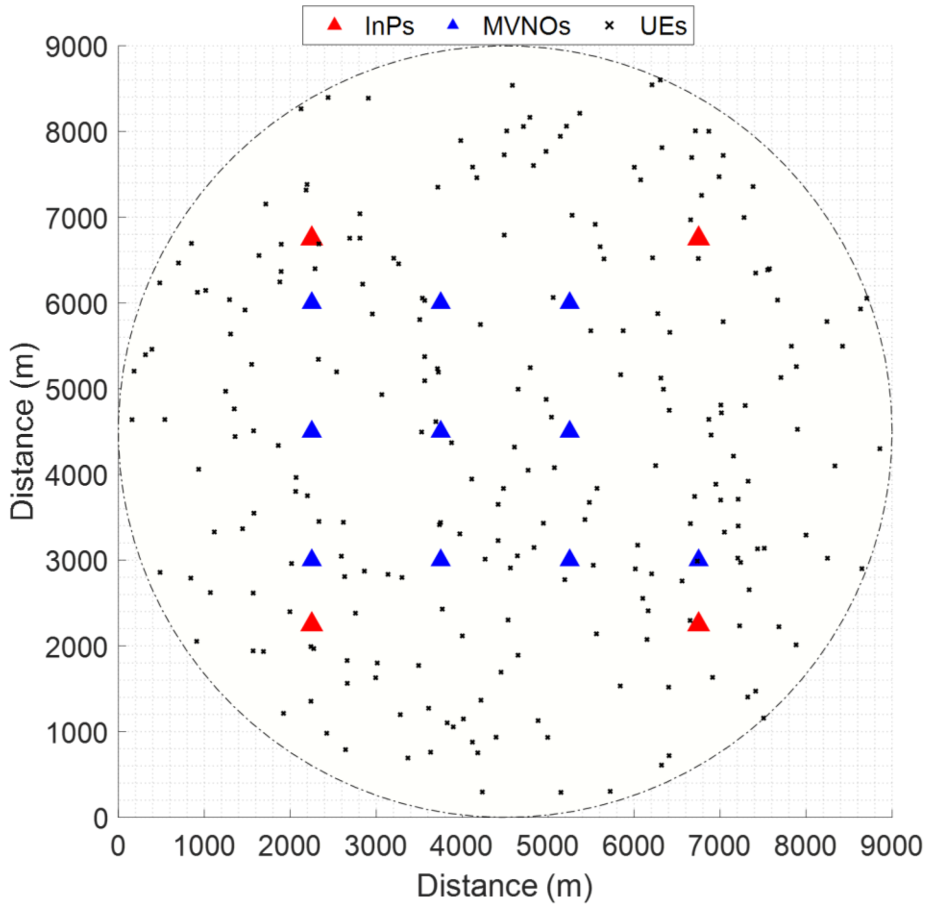



Fig. 4-1.InPs, MVNOs and UEs random distribution over a geographical area.

### 4.3. User Association in WNVs using the Matching game algorithm

To reduce resource loss and gain revenue, InPs offer limited and shared resources. Moreover, in a dense UE environment such as the proposed, designed network, UE establishment to the network and accessing services is a challenge. Therefore, user and service associations require a robust algorithm like the MG to facilitate accurate accessing through RBs and dynamic coordination among system entities.

Figure 4-2 illustrates the UE establishment over different system bandwidths of InPs with 100 available RBs for the proposed architecture. It is shown that the establishment percentage is %100 steady state for the low range of UEs up to 80 UEs for all adopted InP bandwidths. When the UEs increase to 300, the user accessing ratio drops gradually, such as stair behaviour. The ratio degrades within a transient period, then becomes a steady state for the coming range of UE increase. However, the establishment ratio for all the bands follows the same trend, but the scale of dropping this ratio is higher in low system bandwidths. The establishment percentage records 92% for the 5MHz bandwidth at 300 UEs; concurrently, it is 98% for the bandwidth of 20 MHz. It can be seen that at a low number of UEs, low bandwidth adoption is motivated as the establishment ratio is near the high bandwidth, while, at dense UE scenarios, a bandwidth lower than 5 MHz is not recommended.

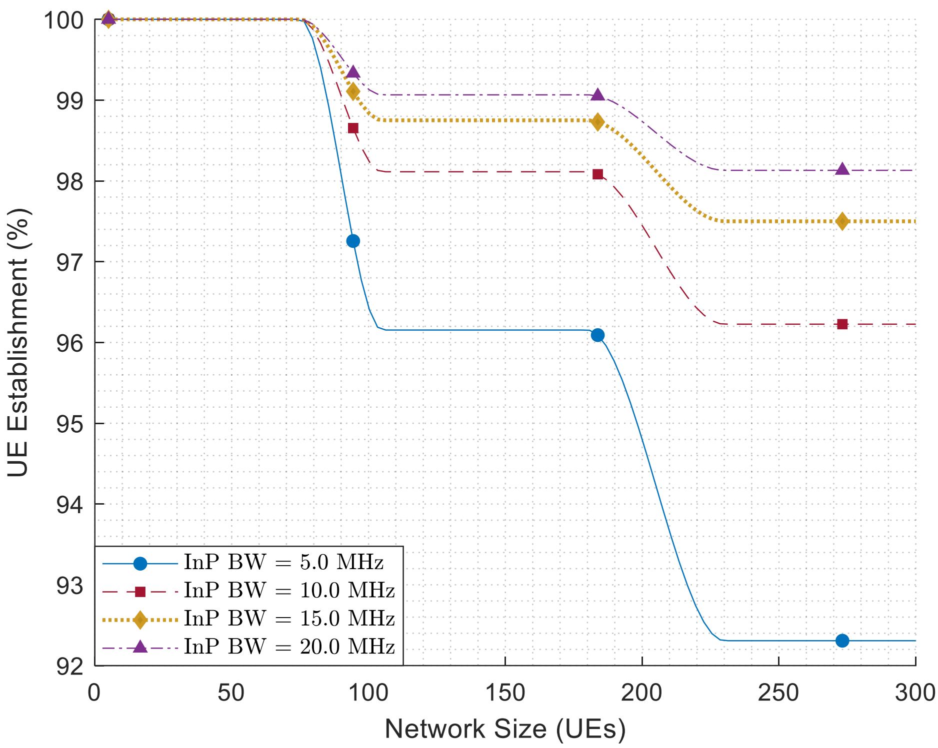



Fig. 4-2. UE establishment to the network over different InP system bandwidths.

Figures 4-3 show the average user throughput concerning established users to the network over different InP system bandwidths. Initially, when the number of associated network users is small, each user's dedicated RB is high; therefore, high user throughput is obtained. However, as more users join the network, RB per user decreases, reducing user throughput logarithmically. The trend of the throughput decreasing approaches to a steady state at high associated UEs as the free RBs approach zero.

Therefore, the system must balance capacity and user needs, highlighting the trade-off between available RBs and UEs, which the system has not yet accomplished and must be optimized using the provided methods.

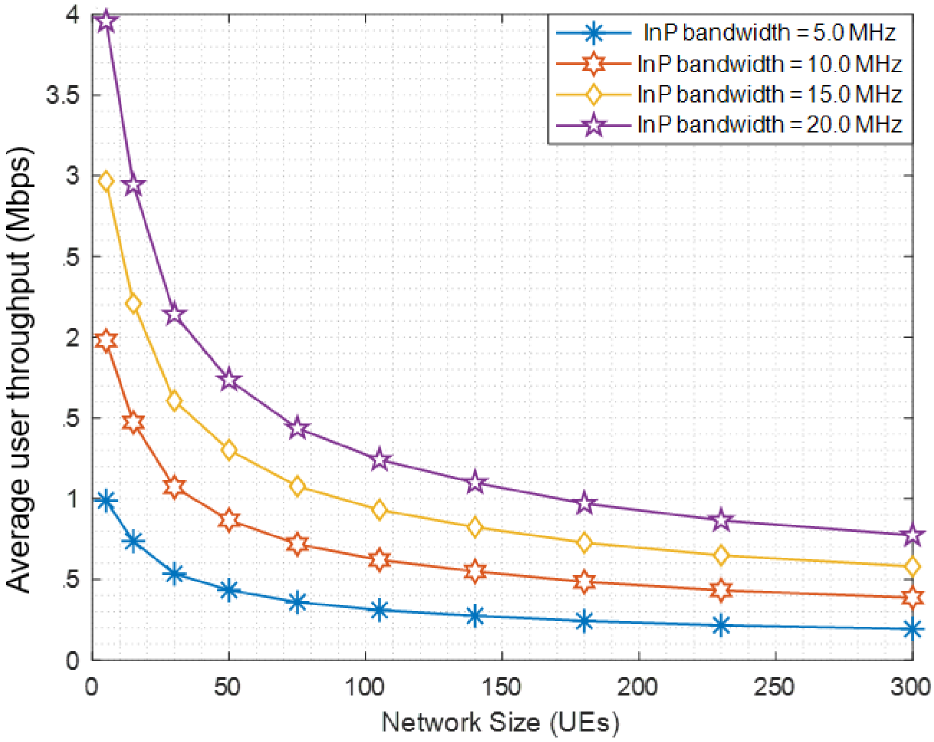



Fig. 4-3.The average user throughput with respect to UEs.

## 4.4. Matching game optimization

In order to allocate resources more effectively and prioritize popular services, the system must find a balance between the available bandwidth and the number of UEs. It is crucial for maintaining a high level of performance and continuing sustainability in such a proposed dynamic system design.

Figure 4-4 illustrates the total sum rate of each InP when the number of UEs is variable. The sum rate of InP is the summation of all UEs' associated throughput. As the MG algorithm decision requirement, profile preference is made for UEs and MVNOs considering SLA that rejects any UE under a specific data rate to maintain system performance. Users gradually join the network, adding their data rate to the total sum rate, resulting in a logarithmic increase of the sum rate. The graph shows that the data rate increases significantly at low user densest, up to 100 UEs.

As the UE count exceeds 100, the total sum rate approaches a steady state due to reduced free channels, indicating that new users could be rejected to maintain system performance, as SLA is a crucial constraint in system design. The sum rate in different InPs changes linearly with system bandwidth.

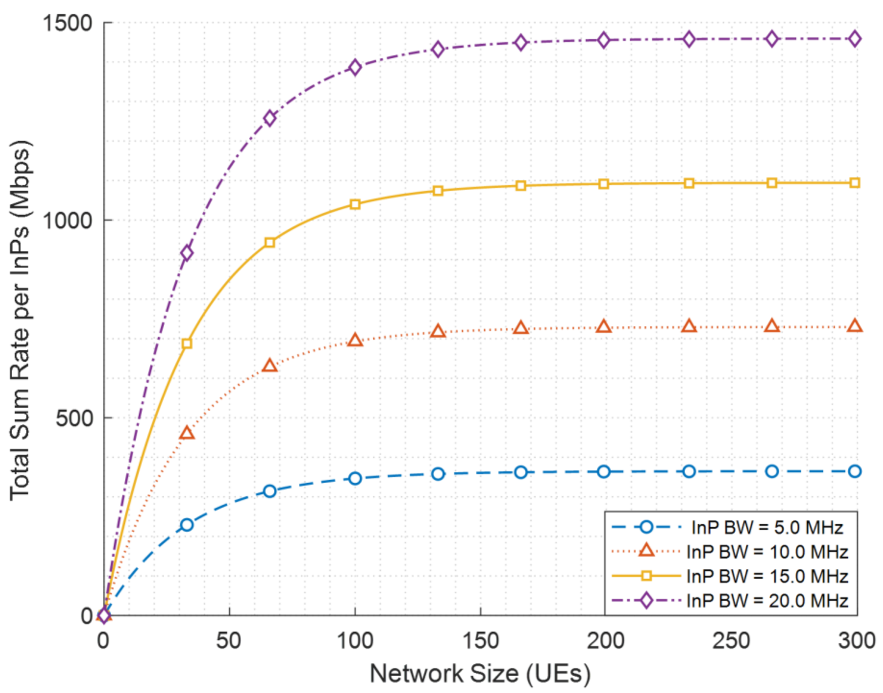



Fig. 4-4. Total sum rate per InP.

## 4.5. PSO and Matching Game Comparison in terms of throughput Optimization and System Convergence.

After evaluating MG for four InPs, a system throughput investigation is needed to compare with another algorithm to monitor their capacity to distribute resources effectively and meet user demands.

**A) Analyzing Average InPs Data Rate**

The average system data rate for the proposed algorithms MG and PSO is presented in Figure 4-5. As the UEs increase, the system data rate increases due to adding the data rate of new users to the system data rate. However, at low established UEs to the network, the system data rate in terms of both algorithms is near each other; with new UEs coming to the network, the data rate using MG has been increasing significantly. It leads to better user throughput and user experience. For example, the MG obtained 3000 Mbps for 300 UEs, while PSO offered only 1300 Mbps for the same UEs.

The superiority of the MG algorithm can be attributed to several factors. MG optimizes resource allocation by considering user-specific characteristics, resulting in higher user throughput. It prioritizes fairness and objectivity, enhancing overall system performance and leading to higher throughput.

The algorithm design principles are tailored to the network scenario, ensuring superior throughput outcomes. PSO may not be ideal for network throughput optimization due to potential issues like local optima, parameter tuning, scalability, multi-objective optimization, speed, initialization sensitivity, lack of diversity, and limited memory.

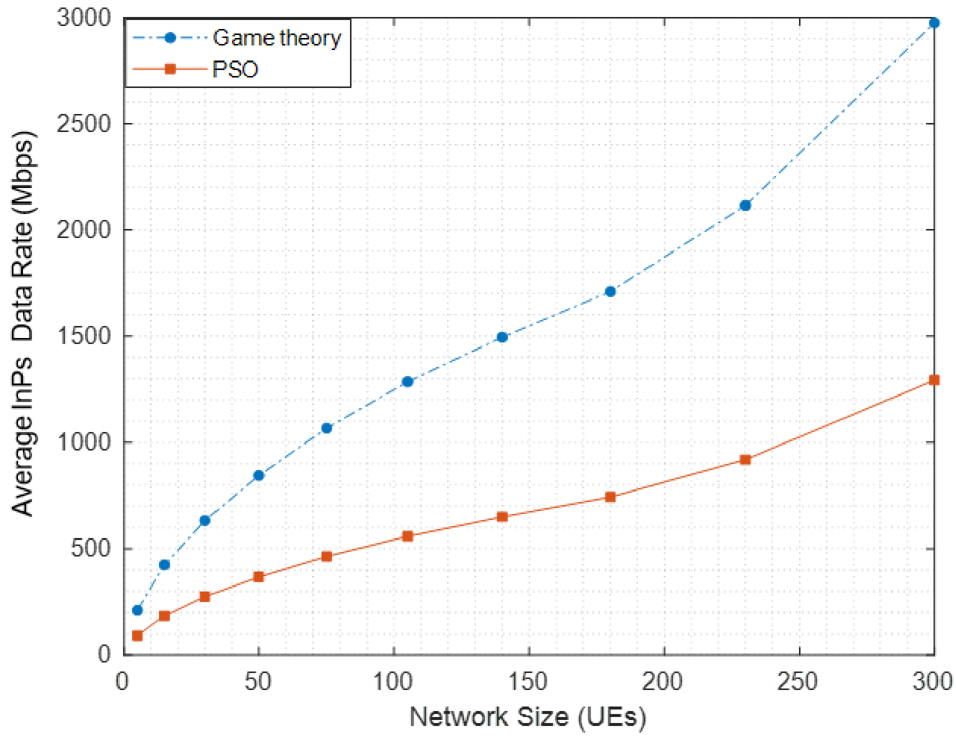



Fig. 4-5. Average InPs Data Rate

**B) System Convergence**

Figure 4-6 illustrates the proposed algorithms' convergence concerning the number of iterations. Convergence of an algorithm is the state that each user pairs with its MVNO channel to get resources. It is noted that the number of UEs in the network directly relates to the time-consuming algorithm iterations to match service providers with the users. As much as the UEs increase, the time to reach convergence is increased simi-linearly up to 100 iterations. Beyond that, increasing UEs has no significant effect on the convergence time due to the system's stability with 100 iterations for 300 UEs. PSO converges faster in 30 seconds than the MG, which takes 45 seconds for 300 users in 300 iterations. As users increase, both algorithms require more iterations and computational effort. However, once the user count reaches 300, convergence stabilizes in iteration 100 for both algorithms. PSO is a dynamic optimization method that uses particles to find solutions in a multidimensional search space, ideal for complex problems and real-time applications like route optimization or machine learning model tuning. Its rapid convergence speed makes it suitable for real-time applications. The MG, on the other hand, prioritizes user satisfaction and resource allocation decisions, ensuring higher satisfaction, but may require more complex decision-making and longer convergence times. Balancing convergence speed and user satisfaction is crucial for system stability and user experience.

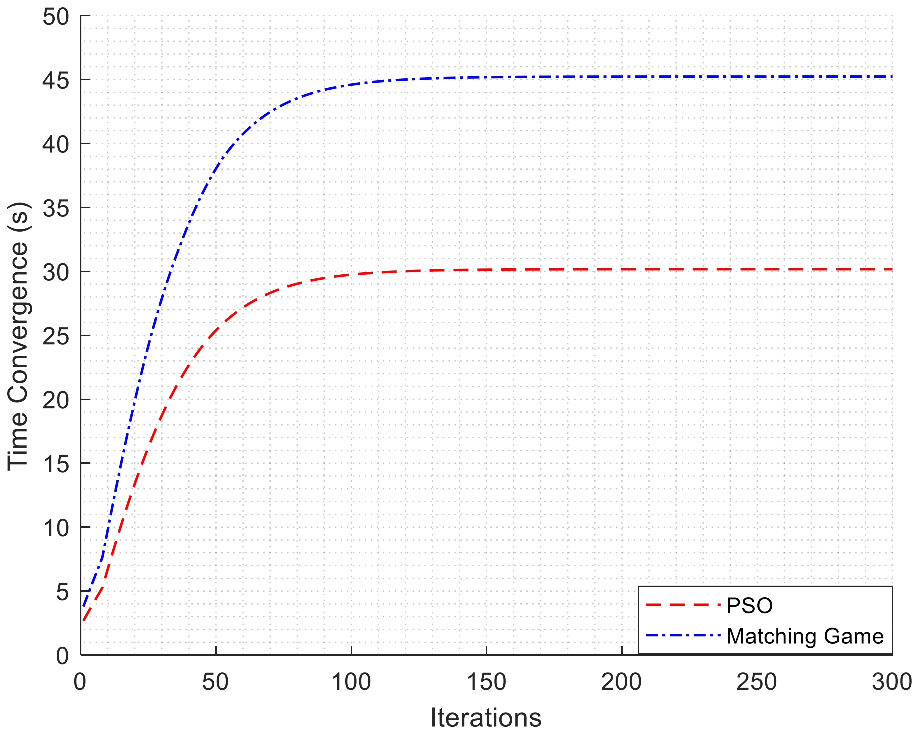



Fig. 4-6. The average convergence for all InPs per Algorithm.

## 4.6. Economic Model implementation with Matching Game and PSO

Economic models are crucial for network operators and contributors to distribute resources effectively among NS for optimal use and income generation. The model calculated each MG's objectives, utility functions, and PSO algorithm to generate an adaptable financial approach. First, the model presented a range of RB prices to all MVNO by InPs. Thus, when InP offered it, MVNO proposed a list of prices and services that fit users' demands.

### 4.6.1. InP Offered Price Range Variation for RBs

Figure 4-7 illustrates the total prices of all RBs of the InPs offered for the MVNOs. The InP RBs are 10, 20, 30 and 40 for the InP system bandwidth 5MHz, 10MHz, 15MHz and 20MHz, respectively. As the number of RBs increases, the total price increases with it. It can be shown that the offered price for each InP varies within a range due to the economic model that motivates the InP to change its price based on the supply and demand principles. The system makes preference for the demands of MVNOs and supplies of InP. Then, a repeated process defined by the algorithm matches the MVNO demands to the optimized supply of the InP. In this process, InPs change their prices within a range to guarantee optimum MVNO. As shown, the price variant is about 8% to 10%. All these processes are managed automatically and dynamically via the algorithms to optimize the requirements of both InPs and MVNOs.

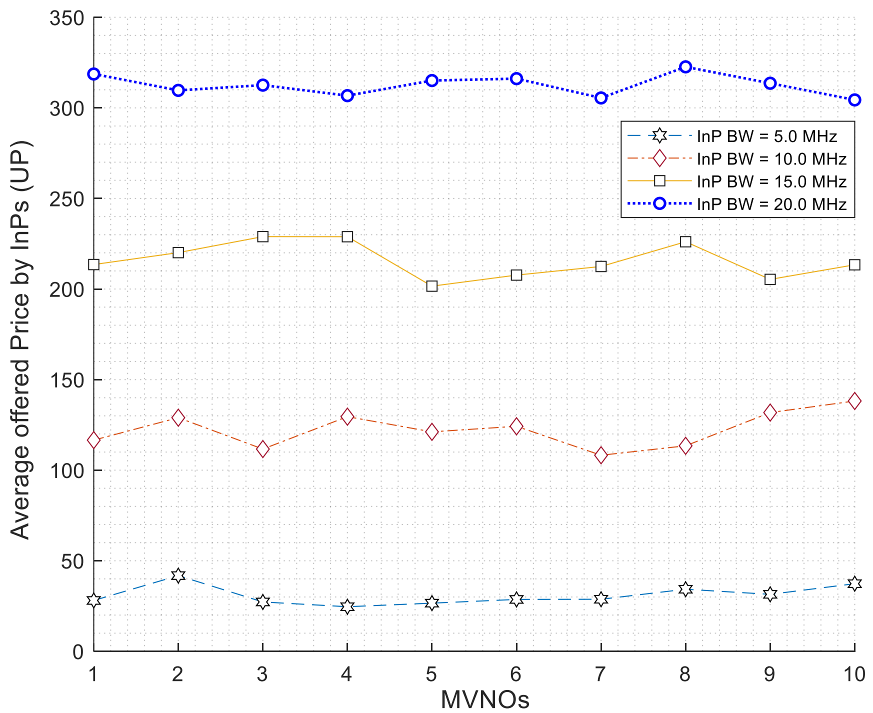



Fig. 4-7. Average Price Range Among InPs for Offered RBs

**A. Expense determination for users**

Figures 4-8 present UEs' average fee for accessing services through MVNOs. The range of prices is determined by the specific tools employed as CVX, which are linked to the data rate allocated to individual users. Higher costs are associated with users who demand more data and prioritize superior service quality. Remember that the MG and PSO algorithms find the best user pricing and fees. Optimizing user demand and prices ensures that data packages are appealing and profitable. The MG algorithm charges more than the PSO algorithm. For instance, as more MVNOs increased, the line trend increased accordingly. MG fees started at approximately 3.1 to 6.9 UP, since with PSO, the paid price starts with 0.5 to 2 UP. As a result, it can be concluded that the MG offers superior data pairing and a high data rate but gains higher costs. The PSO reduces these costs by reducing data rates and fees.

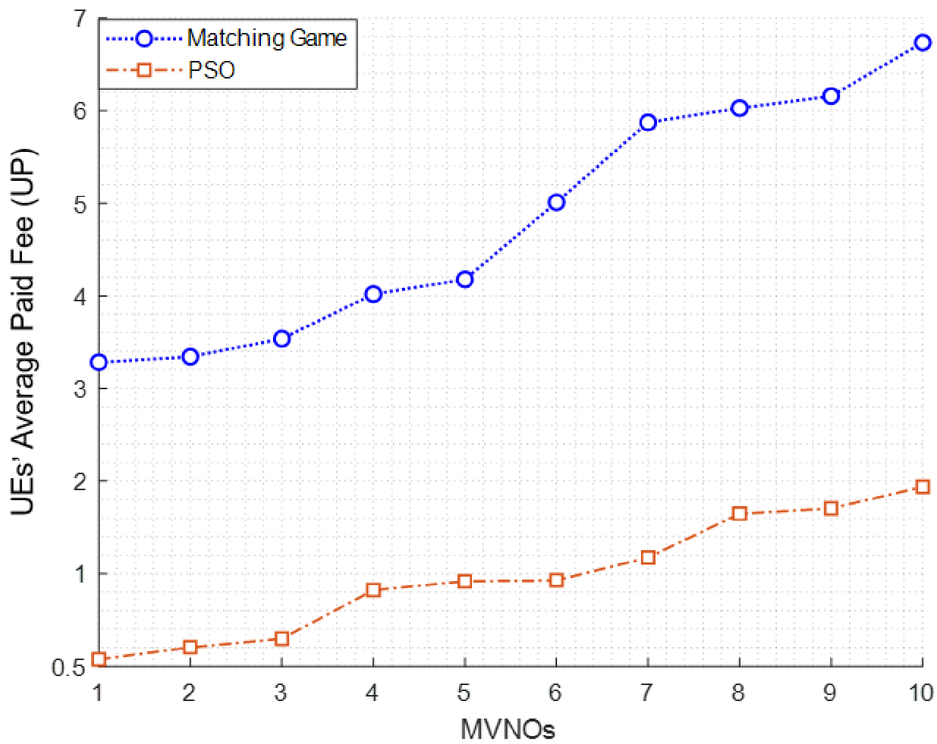



Fig. 4-8. The Average Paid fee of UEs per MVNO.

**B. MVNOs' Revenue**

Figure 4-9 illustrates the total revenue generated by MVNOs based on the number of users who required services for both algorithms. The figure demonstrates that as the number of subscribers increases, the income for the MVNOs also increases proportionally. It explicitly highlights the revenue range for MGs with a low number of users, which starts at 160 UP and gradually rises to 350 UP since PSO generates less with 10 to 90 UP.

In terms of earning more revenue, the MG outperforms PSO. MVNOs adopting the MG provide a data rate higher than the PSO, so if we consider the cost-per-bit mechanism, MVNO revenue increases by increasing air interface throughput.

It is noted that there is a direct relation between figures 4-8 and 4-9, as the MVNOs' revenue is based on the fees paid by UEs. However, there is a tradeoff between these metrics to optimize between the two players within a system.

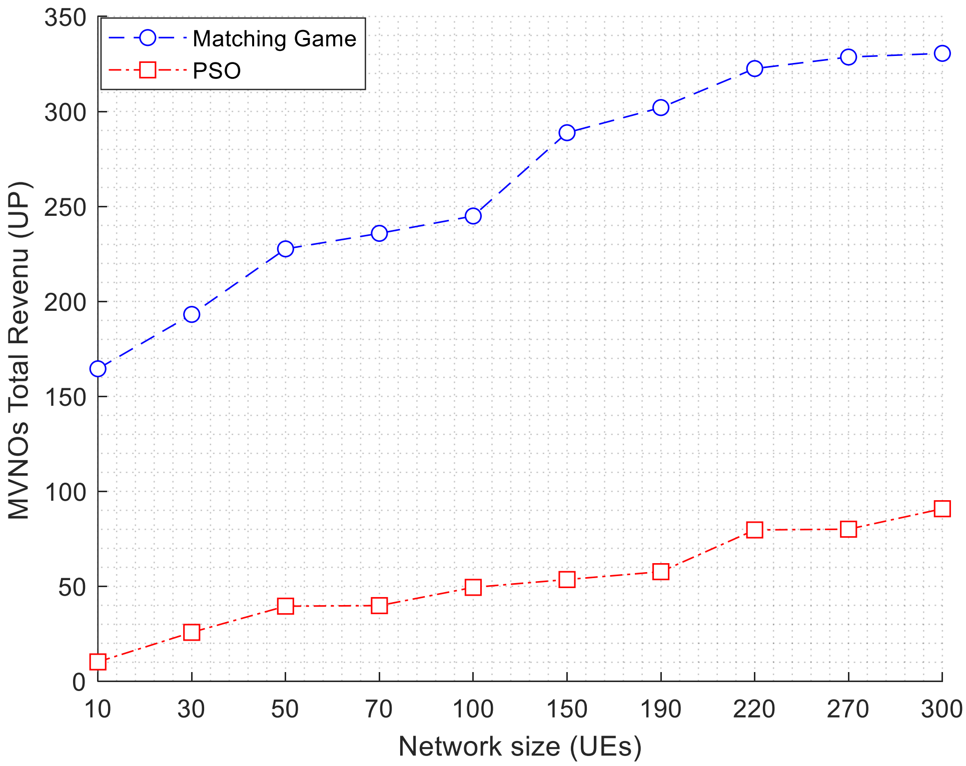



Fig. 4-9. The total Average Revenue for MVNOs from UEs per algorithm.

## C. InPs' Revenue

Figure 4-10 depicts the entire amount of InPs' revenue generated by each algorithm with respect to the utilized RBs. The graph illustrates a consistent increase in income as additional RBs are introduced to the systems. This income growth is attributed to service adjustments by MVNOs and the expanding user base. Specifically, the income outcomes for the MG and PSO approaches are presented in the figure within a system featuring 100 RBs. Remember that these data indicated system revenue, not individual InP income. For instance, selling 100 RBs yields a total revenue of 350 UP in the MG, while PSO earns 160 UP. Therefore, the average contribution per RB sold is 1.6 UP for the PSO approach, which is lower than the 3.5 UP generated by the MG. It outperforms the PSO algorithm in revenue generation and data rate services because of its configurable prices, cost-effectiveness, and efficient RB allocation. By not fully leveraging RBs, the PSO algorithm may limit the data rate. Therefore, the MG algorithm optimizes income and enhances data rate services; it could be a good option for revenue growth and customer satisfaction.

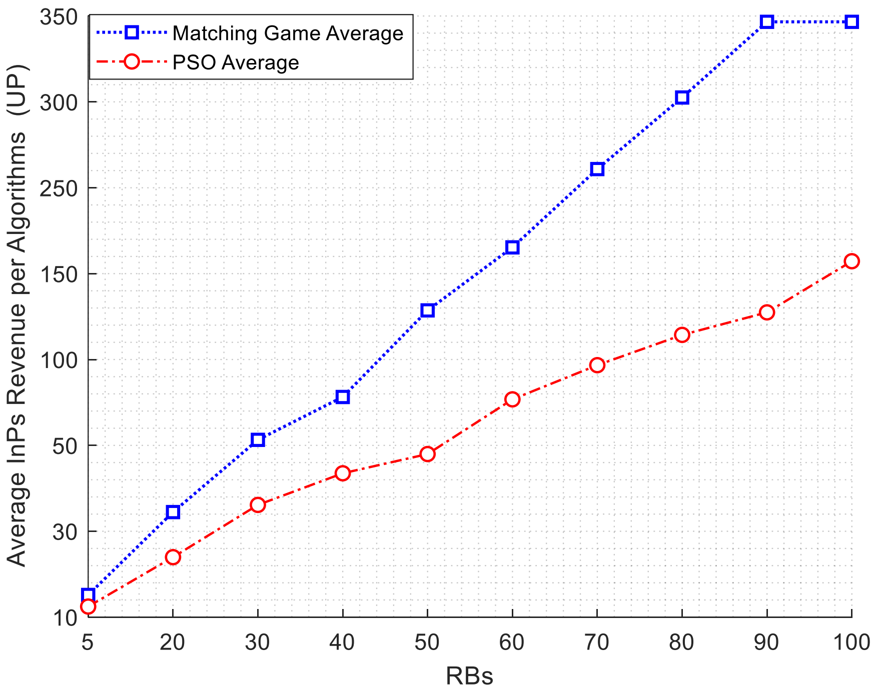



Fig. 4-10. Average Revenue of InPs per algorithm.

## 4.7. Performance Evaluation And Analysis of Proposed Algorithms

In the context of optimizing resource allocation for network slicing, the proposed integration of PSO and MG is a significant step toward addressing the complexities of the problem. The comparison of these two algorithms underscores their distinct strengths and weaknesses, providing essential insights into their applicability in various scenarios.

The choice of Algorithm depends on the trade-offs between optimization performance, computational efficiency, and the specific problem landscape. PSO excels in continuous optimization tasks, making it ideal for scenarios where resources are best represented as constant values. On the other hand, MG's capability in discrete optimization and its ability to handle constraints and larger-scale problems positions it as a favourable choice when dealing with discrete resource allocation. As shown in Table 4-II, The MG generally outperforms PSO in several aspects, including user establishment, user throughput, InPs' and MVNOs' revenue generation, and data rate. However, PSO exhibits advantages in terms of faster convergence and lower user expenses.

Table 4-II Comparative Analysis of Proposed Algorithms.

| **Aspect** | **MG** | **PSO** |
|---|---|---|
| User Establishments (Low UE Count for all BWs) | 100% | 100% |
| User Establishments (300 UE-20 MHz) | 98% | 92% |
| Average User Throughput | 5 Mbps (300 UEs) | 4.3 Mbps (300 UEs) |
| Average InPs Data Rate (300 UEs) | 3000 Mbps | 1300 Mbps |
| Convergence Time (300 UEs) | Longer (45 seconds) | Faster (30 seconds) |
| MVNOs' Revenue (Increasing UEs) | Higher (up to 350 UP) | Lower (up to 90 UP) |
| InPs' Revenue (100 RBs) | Higher (3.5 UP per RB) | Lower (1.6 UP per RB) |
| Expense for Users | Ranges from 3.2 to 7+ | 0.5 to 2.1 |

# CHAPTER FIVE

# CONCLUSION AND FUTURE WORKS

## 5.1. Conclusion

WNV is an innovative technology that aims to revolutionize the 5G NS landscape by implementing dynamic resource allocation and separating hardware infrastructure from service providers. It offers improved network performance, significant cost savings, and enhanced resource utilization. The changing 5G network environment involves reevaluating network design to improve reliability and flexibility and fulfil end-user and customer prospects for ultra-fast connection.

This thesis suggests a new virtualized NS architecture to deal with this issue. Adding a new layer to the NS architecture is crucial for integrating end-user devices, optimizing performance, and enabling dynamic service selection and revenue distribution. Additionally, it allows the dynamics of two-level associations within the NS architecture, connecting devices to network slices and managing relationships between users and virtual operators. This two-level association is essential for maintaining a balanced and efficient network ecosystem.

This study presented a comprehensive design for a new wireless network for 5G RAN. The system includes virtualizing resources and channels provided by multiple InPs and shared among MVNOs and UEs. It proposed a new mathematical method integrating three sub-models into a practical model. A unique model for channel gain is also presented, considering interference from all users. The study utilizes a combinatorial approach, including the MG and metaheuristic optimization algorithms, to address user and MVNO selections for services and preferred Resource Blocks. The method optimizes user selection, enhances resource utilization, and manages the trade-off between user throughput and revenue for MVNOs and InPs. Economic frameworks are integrated to determine expenses and income, and a convex optimization technique is proposed to solve MLIP issues.

The study highlights the high level of user engagement achieved within acceptable timeframes, with 98% of users actively contributing to meet resource demands. Implementing the MG algorithm is characterized by its ability to foster more effective user-system interactions, resulting in higher throughput. Delivering enhanced efficiency requires more time investment to pair all users with available resources, extending the convergence period.

In contrast, PSO has a random user association getting higher throughput from the system depending on user velocity and positions; thus, the association ratio is slight to the design and varies due to its fast association.

The algorithms lead to greater resource allocation in scenarios with higher system bandwidth, boosting revenue for InPs and MVNOs and reducing end-user fees. The research highlights the importance of selecting the most suitable optimization approach tailored to specific network requirements.

Overall, the study emphasizes the relevance of WNV in the 5G landscape, particularly in resource and RAN management. It proposed that mixture techniques, merging the strengths of both algorithms, have the potential to generate higher-quality outcomes in 5G network slicing. This research contributes to the advancement of the telecommunications industry by shedding light on the possibilities of harnessing mixed methods to enhance the efficiency and effectiveness of 5G network slicing.

## 5.2. Future works and recommendations

The balance between revenue maximization and energy efficiency is crucial in network optimization. It requires exploring multi-objective strategies that adapt to dynamic network conditions, user demands, and real-time interference scenarios.

It can be concluded with these recommended points.

1- Integrating advanced machine learning techniques, like deep reinforcement learning, can refine resource allocation decisions.

2- Research should focus on strategies that bolster security without compromising optimization; therefore, addressing data security and privacy concerns is essential as network optimization progresses.

3- Transitioning from simulation environments to real-world implementations is crucial for assessing the practical feasibility of proposed methodologies. Collaborative partnerships with industry stakeholders can expedite this transition and demonstrate the tangible benefits of innovative approaches.

## REFERENCES

5g-Ppp, Accessed 20 December 2021, Online, Available At: Https://5g-Ppp.Eu.

Adiraju, P. R. & Rao, V. S. 2022. Dynamically Energy-Efficient Resource Allocation In 5g Cran Using Intelligence Algorithm. *Emitter International Journal Of Engineering Technology***,** 217-230.

Afaq, M., Iqbal, J., Ahmed, T., Islam, I. U., Khan, M. & Khan, M. S. 2020. Towards 5g Network Slicing For Vehicular Ad-Hoc Networks: An End-To-End Approach. *Computer Communications,* 149**,** 252-258.

Albonda, H. D. R. & Pérez-Romero, J. 2019. An Efficient Ran Slicing Strategy For A Heterogeneous Network With Embb And V2x Services. *Ieee Access,* 7**,** 44771-44782.

Alevizaki, V.-M. Distributed Resource Management In Converged Telecommunication Infrastructures.

Alliance, N. 2015. 5g White Paper. *Next Generation Mobile Networks, White Paper,* 1.

Alliance, N. 2016. Description Of Network Slicing Concept. Next Generation Mobile Networks, White Paper.

Association, G. 2017. An Introduction To Network Slicing.

Assosiation, G. 2021. E2e Network Slicing Architecture.

Awada, Z., Boulos, K., El-Helou, M., Khawam, K. & Lahoud, S. 2022. Distributed Multi-Tenant Ran Slicing In 5g Networks. *Wireless Networks,* 28**,** 3185-3198.

Azab, A. Enabling Docker Containers For High-Performance And Many-Task Computing. 2017 Ieee International Conference On Cloud Engineering (Ic2e), 2017. Ieee, 279-285.

Banda, L., Mzyece, M. & Mekuria, F. 2022. 5g Business Models For Mobile Network Operators–A Survey. *Ieee Access*.

Barakabitze, A. A., Ahmad, A., Mijumbi, R. & Hines, A. 2020. 5g Network Slicing Using Sdn And Nfv: A Survey Of Taxonomy, Architectures And Future Challenges. *Computer Networks,* 167**,** 106984.

Barakabitze, A. A. & Walshe, R. 2022. Sdn And Nfv For Qoe-Driven Multimedia Services Delivery: The Road Towards 6g And Beyond Networks. *Computer Networks,* 214**,** 109133.

Chartsias, P.-K., Amiras, A., Plevrakis, I., Samaras, I., Katsaros, K., Kritharidis, D., Trouva, E., Angelopoulos, I., Kourtis, A. & Siddiqui, M. S. Sdn/Nfv-Based End To End Network Slicing For 5g Multi-Tenant Networks. 2017 European Conference On Networks And Communications (Eucnc), 2017. Ieee, 1-5.

Cruz, P., Achir, N. & Viana, A. C. 2022. On The Edge Of The Deployment: A Survey On Multi-Access Edge Computing. *Acm Computing Surveys,* 55**,** 1-34.

Darzanos, G., Kalogiros, C., Stamoulis, G. D., Hallingby, H. K. & Frias, Z. Business Models For 5g Experimentation As A Service: 5g Testbeds And Beyond. 2022 25th Conference On Innovation In Clouds, Internet And Networks (Icin), 2022a. Ieee, 169-174.

Darzanos, G., Koutsopoulos, I., Papakonstantinopoulou, K. & Stamoulis, G. D. Economics Of Multi-Operator Network Slicing. 2022 20th International Symposium On Modeling And Optimization In Mobile, Ad Hoc, And Wireless Networks (Wiopt), 2022b. Ieee, 201-208.

Debbabi, F., Jmal, R., Fourati, L. C. & Ksentini, A. 2020. Algorithmics And Modeling Aspects Of Network Slicing In 5g And Beyonds Network: Survey. *Ieee Access,* 8**,** 162748-162762.

Esmaeily, A. & Kralevska, K. 2021. Small-Scale 5g Testbeds For Network Slicing Deployment: A Systematic Review. *Wireless Communications And Mobile Computing,* 2021**,** 1-26.

Etsi, G. 2018. 011:" Next Generation Protocols (Ngp). *E2e Network Slicing Reference Framework Information Model.*

Fantastic5g, Accessed 20 December 2021, Online, Available At: Http://Fantastic5g.Com/.

Farhat, S., Nasser, N. & Younis, N. Hierarchical Game For Resource Sharing And Pricing In Multi-Tenant Networks. 2022 International Conference On Smart Systems And Power Management (Ic2spm), 2022. Ieee, 91-96.

Foukas, X., Patounas, G., Elmokashfi, A. & Marina, M. K. 2017a. Network Slicing In 5g: Survey And Challenges. *Ieee Communications Magazine,* 55**,** 94-100.

Foukas, X., Patounas, G., Elmokashfi, A. & Marina, M. K. 2017b. Network Slicing In 5g: Survey And Challenges. *Ieee Communications Magazine,* 55**,** 94-100.

Garcia-Aviles, G., Gramaglia, M., Serrano, P. & Banchs, A. 2018. Posens: A Practical Open Source Solution For End-To-End Network Slicing. *Ieee Wireless Communications,* 25**,** 30-37.

Ha, V. N. & Le, L. B. 2017. End-To-End Network Slicing In Virtualized Ofdma-Based Cloud Radio Access Networks. *Ieee Access,* 5**,** 18675-18691.

Halabian, H. 2019. Distributed Resource Allocation Optimization In 5g Virtualized Networks. *Ieee Journal On Selected Areas In Communications,* 37**,** 627-642.

Ho, T. M., Tran, N. H., Le, L. B., Han, Z., Kazmi, S. A. & Hong, C. S. 2018. Network Virtualization With Energy Efficiency Optimization For Wireless Heterogeneous Networks. *Ieee Transactions On Mobile Computing,* 18**,** 2386-2400.

Imt-2020, Accessed 20 December 2021, Online, Available At: Https://Www.Itu.Int/En/Pages/Default.Aspx.

Jayaraman, R., Manickam, B., Annamalai, S., Kumar, M., Mishra, A. & Shrestha, R. 2023. Effective Resource Allocation Technique To Improve Qos In 5g Wireless Network. *Electronics,* 12**,** 451.

Kalogiros, C., Muschamp, P., Caruso, G., Hallingby, H. K., Darzanos, G. & Gavras, A. 2021. Capabilities Of Business And Operational Support Systems For Pre-Commercial 5g Testbeds. *Ieee Communications Magazine,* 59**,** 58-64.

Kalør, A. E., Guillaume, R., Nielsen, J. J., Mueller, A. & Popovski, P. 2018. Network Slicing In Industry 4.0 Applications: Abstraction Methods And End-To-End Analysis. *Ieee Transactions On Industrial Informatics,* 14**,** 5419-5427.

Kazmi, S. A., Khan, L. U., Tran, N. H. & Hong, C. S. 2019. *Network Slicing For 5g And Beyond Networks*, Springer.

Kazmi, S. A., Ndikumana, A., Manzoor, A., Saad, W. & Hong, C. S. 2020. Distributed Radio Slice Allocation In Wireless Network Virtualization: Matching Theory Meets Auctions. *Ieee Access,* 8**,** 73494-73507.

Kazmi, S. A., Tran, N. H., Ho, T. M. & Hong, C. S. 2017. Hierarchical Matching Game For Service Selection And Resource Purchasing In Wireless Network Virtualization. *Ieee Communications Letters,* 22**,** 121-124.

Kazmi, S. M. A. & Hong, C. S. A Matching Game Approach For Resource Allocation In Wireless Network Virtualization. Proceedings Of The 11th International Conference On Ubiquitous Information Management And Communication, 2017. 1-6.

Khan, L. U., Yaqoob, I., Tran, N. H., Han, Z. & Hong, C. S. 2020. Network Slicing: Recent Advances, Taxonomy, Requirements, And Open Research Challenges. *Ieee Access,* 8**,** 36009-36028.

Korrai, P., Lagunas, E., Sharma, S. K., Chatzinotas, S., Bandi, A. & Ottersten, B. 2020. A Ran Resource Slicing Mechanism For Multiplexing Of Embb And Urllc Services In Ofdma Based 5g Wireless Networks. *Ieee Access,* 8**,** 45674-45688.

Li, T., Zhu, X. & Liu, X. 2020a. An End-To-End Network Slicing Algorithm Based On Deep Q-Learning For 5g Network. *Ieee Access,* 8**,** 122229-122240.

Li, X., Ni, R., Chen, J., Lyu, Y., Rong, Z. & Du, R. 2020b. End-To-End Network Slicing In Radio Access Network, Transport Network And Core Network Domains. *Ieee Access,* 8**,** 29525-29537.

Lieto, A., Malanchini, I., Mandelli, S. & Capone, A. Dynamic Pricing For Tenants In An Automated Slicing Marketplace. International Conference On Game Theory For Networks, 2022. Springer, 278-290.

Lin, Y.-B., Tseng, C.-C. & Wang, M.-H. 2021. Effects Of Transport Network Slicing On 5g Applications. *Future Internet,* 13**,** 69.

Liu, Q., Han, T. & Moges, E. Edgeslice: Slicing Wireless Edge Computing Network With Decentralized Deep Reinforcement Learning. 2020 Ieee 40th International Conference On Distributed Computing Systems (Icdcs), 2020. Ieee, 234-244.

Lozano, S., Lugo, T. & Carretero, J. 2023. A Comprehensive Survey On The Use Of Hypervisors In Safety-Critical Systems. *Ieee Access*.

Ma, T., Zhang, Y., Wang, F., Wang, D. & Guo, D. 2020. Slicing Resource Allocation For Embb And Urllc In 5g Ran. *Wireless Communications Mobile Computing,* 2020.

Metis-2020, Accessed 20 December 2021, Online, Available At: Https://Metis2020.Com/.

Mohammed, C. M. & Shaikhah, S. K. A Survey And Analysis Of Architecture And Models Of Network Slicing In 5g. 2022 8th International Engineering Conference On Sustainable Technology And Development (Iec), 2022. Ieee, 192-198.

Nakao, A., Du, P., Kiriha, Y., Granelli, F., Gebremariam, A. A., Taleb, T. & Bagaa, M. 2017. End-To-End Network Slicing For 5g Mobile Networks. *Journal Of Information Processing,* 25**,** 153-163.

Nguyen, K. T. D. 2021. *Distributed And Parallel Metaheuristic-Based Algorithms For Online Virtual Resource Allocation.* Carleton University.

Oladejo, S. O., Ekwe, S. O. & Akinyemi, L. A. 2021. Multi-Tier Multi-Tenant Network Slicing: A Multi-Domain Games Approach.

Oladejo, S. O. & Falowo, O. E. Profit-Aware Resource Allocation For 5g Sliced Networks. 2018 European Conference On Networks And Communications (Eucnc), 2018. Ieee, 43-9.

Oladejo, S. O. & Falowo, O. E. Latency-Aware Dynamic Resource Allocation Scheme For 5g Heterogeneous Network: A Network Slicing-Multitenancy Scenario. 2019 International Conference On Wireless And Mobile Computing, Networking And Communications (Wimob), 2019. Ieee, 1-7.

Oladejo, S. O. & Falowo, O. E. 2020. Latency-Aware Dynamic Resource Allocation Scheme For Multi-Tier 5g Network: A Network Slicing-Multitenancy Scenario. *Ieee Access,* 8**,** 74834-74852.

Ordonez-Lucena, J., Ameigeiras, P., Lopez, D., Ramos-Munoz, J. J., Lorca, J. & Folgueira, J. 2017. Network Slicing For 5g With Sdn/Nfv: Concepts, Architectures, And Challenges. *Ieee Communications Magazine,* 55**,** 80-87.

Paul, M. M. R., Perarasi, T., Moses, M. L. & Rahul, P. Qos-Aware Multi-Objective Pso-Fa Based Optimizer For Uplink Radio Resource Management Of Lte-A Network. 2021 Third International Conference On Inventive Research In Computing Applications (Icirca), 2021. Ieee, 415-421.

Shaikhah, S. K. & Mustafa, S. 2020. A Robust Filter Bank Multicarrier System As A Candidate For 5g. *Physical Communication,* 43**,** 101228.

Sheena, B. G. & Snehalatha, N. 2022. Multi-Objective Metaheuristic Optimization-Based Clustering With Network Slicing Technique For Internet Of Things-Enabled Wireless Sensor Networks In 5g Systems. *Transactions On Emerging Telecommunications Technologies***,** E4626.

Shi, Y., Sagduyu, Y. E. & Erpek, T. Reinforcement Learning For Dynamic Resource Optimization In 5g Radio Access Network Slicing. 2020 Ieee 25th International Workshop On Computer Aided Modeling And Design Of Communication Links And Networks (Camad), 2020. Ieee, 1-6.

Song, F., Li, J., Ma, C., Zhang, Y., Shi, L. & Jayakody, D. N. K. 2020. Dynamic Virtual Resource Allocation For 5g And Beyond Network Slicing. *Ieee Open Journal Of Vehicular Technology,* 1**,** 215-226.

Tian, D. 2017. Particle Swarm Optimization With Chaos-Based Initialization For Numerical Optimization. *Intelligent Automation & Soft Computing***,** 1-12.

Tun, Y. K., Tran, N. H., Ngo, D. T., Pandey, S. R., Han, Z. & Hong, C. S. 2019. Wireless Network Slicing: Generalized Kelly Mechanism-Based Resource Allocation. *Ieee Journal On Selected Areas In Communications,* 37**,** 1794-1807.

Waleed, S., Ullah, I., Khan, W. U., Rehman, A. U., Rahman, T. & Li, S. 2021. Resource Allocation Of 5g Network By Exploiting Particle Swarm Optimization. *Iran Journal Of Computer Science,* 4**,** 211-219.

Wang, G., Feng, G., Qin, S., Wen, R. & Sun, S. 2019. Optimizing Network Slice Dimensioning Via Resource Pricing. *Ieee Access,* 7**,** 30331-30343.

Wei, J. 2022. Optimal Allocation Of Human Resources Recommendation Based On Improved Particle Swarm Optimization Algorithm. *Mathematical Problems In Engineering,* 2022**,** 2010685.

Yarkina, N., Correia, L. M., Moltchanov, D., Gaidamaka, Y. & Samouylov, K. 2022. Multi-Tenant Resource Sharing With Equitable-Priority-Based Performance Isolation Of Slices For 5g Cellular Systems. *Computer Communications,* 188**,** 39-51.

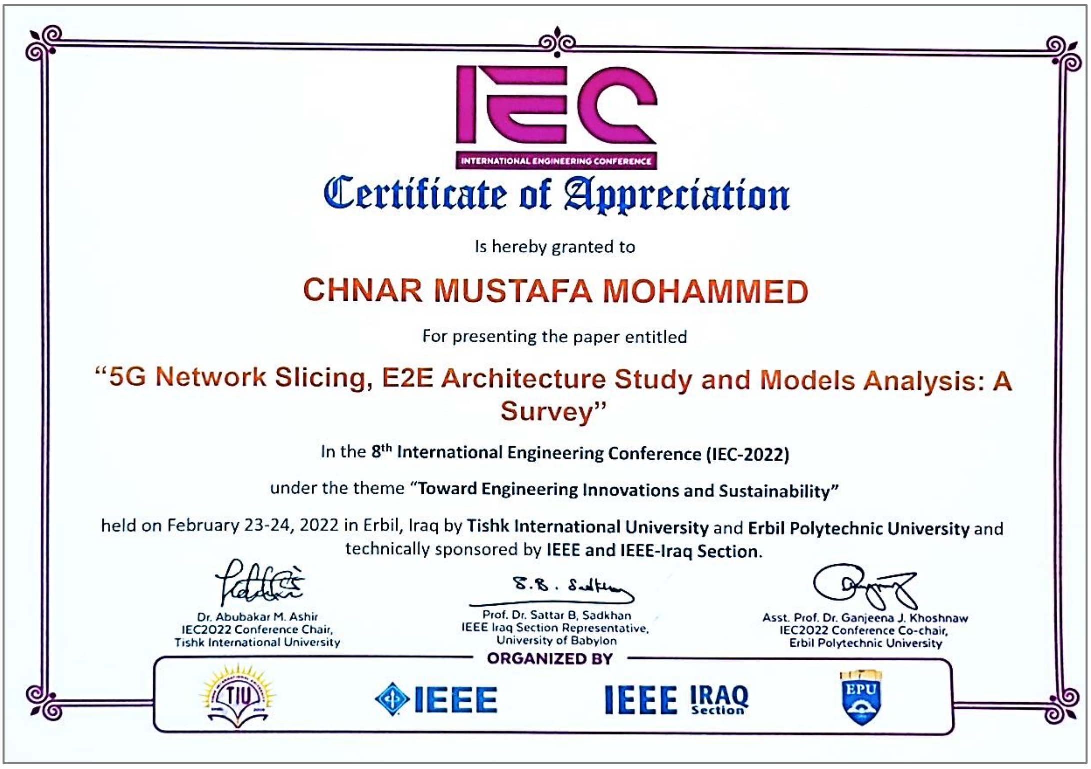
Zhang, S. 2019. An Overview Of Network Slicing For 5g. *Ieee Wireless Communications,* 26**,** 111-117.

Zhou, H., Elsayed, M. & Erol-Kantarci, M. Ran Resource Slicing In 5g Using Multi-Agent Correlated Q-Learning. 2021 Ieee 32nd Annual International Symposium On Personal, Indoor And Mobile Radio Communications (Pimrc), 2021. Ieee, 1179-1184.

# APPENDIX

**Published paper**

**Title of Paper:** A Survey and Analysis of Architecture and Models of Network Slicing in 5G
**Published in:** 2022 8th International Engineering Conference on Sustainable Technology and Development (IEC)
**Date of Conference:** 23-24 February 2022
**Date Added to IEEE Xplore:** 30 June 2022
**Electronic ISBN:** 978-1-6654-7829-8
**Print on Demand (PoD) ISBN:** 978-1-6654-7830-4
**INSPEC Accession Number:** 21846211
**DOI:** 10.1109/IEC54822.2022.9807564
**Publisher:** IEEE
**Conference Location:** Erbil, Iraq
**IEEE Paper Link:** https://ieeexplore.ieee.org/abstract/document/9807564
**Impact Factor:** 3.557



**IEC2022**

**8th International Engineering Conference**

# INVITATION

**Subject:** Acceptance Letter **Date:** February 5, 2022

**Dear Chnar Mustafa Mohammed, Salar Kheder Shaikhah**

I am pleased to inform you that your paper entitled **"A Survey and Analysis of Architecture and Models of Network Slicing in 5G"** with Paper ID: **1570786373** has been accepted for **presentation** in the 8th International Engineering Conference (IEC2022) to be held in Erbil, Kurdistan Region-Iraq on February 23-24, 2022 organized by Tishk International University and Erbil Polytechnic University and technically sponsored by IEEE and IEEE Iraq Section.

The **Opening Ceremony** will take place at **Erbil International Hotel at 10:00 am on February 23, 2022**. You are supposed to register between 8:30 am and 9:30 am.

Please be aware that all **presentation sessions** will be held on **February 23-24, 2022 at Erbil International Hotel.** Presentations will take 15 minutes plus 10 minutes for questions and answers. You can get program flow, timetable and halls of presentations online from IEC2022 Conference website:

www.tiu.edu.iq/conf/iec

We are looking forward to seeing you on the Conference Day among us.

Dr. Abubakar M. Ashir
Chair of IEC2022 Conference

**Location for Opening Ceremony:** **Erbil International Hotel**
**Date: February 23, 2022**
**Time: 10:00 am**
**Place: Erbil International Hotel / 30-meter Street, Erbil, Kurdistan Region-Iraq, Tel. +964 750 2600600**

8th International Engineering Conference on advances in Computer and Civil Engineering Towards Engineering Innovations and Sustainability, ( IEC-2022), Erbil-Iraq

# A Survey and Analysis of Architecture and Models of Network Slicing in 5G

Chnar Mustafa Mohammed
*Information Systems Engineering*
*Erbil Polytechnic university*
Erbil, Iraq
chnar.mustafa@epu.edu.iq

Salar Kheder Shaikhah
*Information Systems Engineering*
*Erbil Polytechnic university*
Erbil, Iraq
salar.shaikhah@epu.edu.iq

2022 8th International Engineering Conference on Sustainable Technology and Development (IEC) | 978-1-6654-7829-8/22/$31.00 ©2022 IEEE | DOI: 10.1109/IEC54822.2022.9807564

***Abstract*—Emerging fifth-generation (5G) networks need to fulfill high-reliability and low latency criteria and increase current and future network capacity and security requirements. To support many tenants on the same physical infrastructure, mobile service providers are searching for a virtual solution that can be used to allocate network resources on-demand and gain cost and efficiency using Network Slicing (NS) in 5G networks. NS has been considered as a promising enabler for 5G networks to meet systems ever-increasing and various performance requirements. Through "slicing" it, it is possible to adjust the functionality and performance. Resource separation and practical resource usage are also crucial features of the slicing concept. In this paper, a comprehensive survey was conducted in two directions; first, End-to-End (E2E) 5G NS architecture is studied, different available architecture scenarios are presented, and new architecture is proposed. The proposed architecture is justified by showing a 5G use case. In the second part, the most recent works on the Radio Access Network (RAN) and Transport Network (TN) NS are studied. Common models and algorithms are analyzed to show a research trend as future work. Additional to aggregating the most common topics on NS to have a comprehensive survey in this field.**

***Keywords— Network slicing principles, NS E2E-architecture, NS Enablers, RAN and TN Mathematical models.***

## I. INTRODUCTION

The rapid increase in the number of people and devices that engage with mobile communication systems (MCS) has invented new demands in recent years. The standard developing organization (SDO) community for the 5G networks summarized the basic requirements of a typical network within a set of characteristics including; 1000 times faster data rate, a dramatic increase of device connectivity, reducing power consumption, and exceptionally low latency [1]-[5]. Additional to the horizontal service improvements, new vertical applications have been introduced to the mobile networks. The 3rd Generation Partnership Project (3GPP) categorized 5G use cases based on the aspects, service types, and the requirements that these services impose into; massive Machine-Type Communications (mMTC), Ultra-Reliable Low Latency Communications (URLLC) and enhanced Mobile Broadband (eMBB) [6], [7].

Various services and applications enforce diverse requirements that cannot be implemented in a conventional network. Therefore, the concept of a single network that fits all the applications for a particular mobile network operator (MNO) is no longer efficiently workable. NS is one of the most promising key enablers for the 5G and beyond generations to address this challenge. NS provides a different virtual layer over a single physical network infrastructure. Each virtual layer can serve different applications within an MNO, or even different MNOs can use the same physical network infrastructure by isolating their services using NS technics. Adopting NS can improve the network resource utilization, reduce cost via combining all services over a single physical architecture by providing different network characteristics to address all the constraints that are introduced by the new services. As well as, it gives high flexibility to the 5G networks to service all the kinds of applications within the same network infrastructure [8]-[10].

A typical MCS can be classified into three levels based on the end-to-end (E2E) NS which are; Radio Access Network (RAN), Transport Network (TN), and Core Network (CN) [11]-[14]. NS has been studied for each of the three levels in different scenarios. However, the definition of NS is quite general, but considering how it is implemented for describing the technic is common. Therefore, the research community has been illustrating the implementation of NS via the enablers of the NS, which are SDN, NFV, Mobile Edge Computing (MEC), cloud computing, network hypervisors, and more.

Several works have reviewed 5G NS, but analyzing the overall architecture and investigating different sides of NS needs more work. In [15, 16], the most recent attempts are presented on NS. In [15], NS objects based on the SDO 3GPP, ETSI, and GSMA are described. A typical model from each organization is given, and some functional sides and workflow are shown. All three levels of NS RAN, TN, and core are considered. An aggregated end-to-end model is presented. The end-to-end slice dedication and NS consideration for a particular service increase operational cost [16], [17]. Therefore, it is preferred that the three levels of NS be investigated and analyzed separately. In [16] the authors focused on NS related to IoT applications. Several IoT applications were surveyed and analyzed, including transportation systems, smart industry, smart homes, smart grid, and smart care. Requirements for some IoT case studies are surveyed with open research challenges in the related fields.

In this review and analysis work, all the NS-related topics are studied and presented. The E2E 5G NS architecture is studied and analyzed comprehensively, common architectures are presented and the evolution trend is portrayed. A new architecture is proposed based on analyzing requirements with presenting a use case and justifying the proposed architecture. In addition, numerous earlier developed models and algorithms of RAN and TN are analyzed regarding resource allocation, isolation, and handoff. Finally, the current challenges and research trends are emphasized.

The rest of the sections are organized as; in Section II, the state of the art of NS is presented via several sub-sections. The

## Accepted for Publishing in JDU, Volume 26, Special Issue 2,2023

4th International Conference on Recent Innovations in Engineering (ICRIE2023)

### OFFICIAL ACCEPTANCE LETTER

September 5, 2023

Manuscript ID: # 1570923971

Dear Chnar Mustafa Mohammed, Salar Kheder Shaikhah

**Congratulations!** It is my pleasure to inform you that after the blind peer review, your paper entitled "An Efficient Dynamic Resource Sharing for a multi-vendor Wireless Network Virtualization" has been accepted for presentation at the 4th International Conference on Recent Innovations in Engineering (ICRIE 2023) conference which will be taking place from September 13th to 14th 2023 in Duhok city, Kurdistan Region-Iraq. Accordingly, your manuscript is accepted for publication in a Special Issue in the Journal of the University of Duhok (JUD), Volume 26, Issue 2, 2023.

You are cordially invited to present your paper at the ICRIE2023 at the Conference Hall of the University of Duhok.

Thank you for considering submitting your Research with ICRIE2023. Please do not hesitate to contact us if you have any further questions.

James H. Haido

Respectfully Yours,
Prof. Dr. James H. Haido, ICRIE2023 Chairman

https://icrie.uod.ac/ 13-14 Sept 2023 info.icrie@uod.ac

ICRIE 2023 4th INTERNATIONAL CONFERENCE ON RECENT INNOVATIONS IN ENGINEERING

UNIVERSITY OF DUHOK

University of KURDISTAN Hewlêr

CERTIFICATE OF ORAL PRESENTATION

This is to certify that

**Chnar Mustafa Mohammed**

Has successfully presented a scientific paper titled

**An Efficient Dynamic Resource Sharing for a Multi-Vendor Wireless Network Virtualization**

in the 4th International Conference on Recent Innovations in Engineering ICRIE 2023,
University of Duhok, College of Engineering,
13th – 14th September 2023.

Professor Dr. James H. Haido
Chairman of the Conference & Dean of Engineering College

# پوختە


لە میانەی دەرکەوتنی تۆڕەکانی پەیوەندی نەوەی پێنجەمی مۆبایلدا، داواکاری لەسەر بەرزیی ڕێژەی متمانە پێکراویی لە خێرایی گەیشتنی داتا، بەرزیی توانای تۆڕەکە و سکیورتی بەهێز بوونەتە جێی بایەخێکی گەورە. دەکرێت، بەهۆی ئەو خزمەتگوزارییە هەمەچەشنانەی کە لە ناو سیستمی نەوەی پێنجەمدا پێشکەش دەکرێن، ئەم پێویستییانە بەرەو پێش ببردرێت. ئەوەش سەلمێندراوە کە بەڕێوەبردنی سەرچاوە سەرەتاییەکانی تۆڕی ڕادیۆ (RAN) بۆ دابینکردنی ئەم داواکاریانە ئەرکێکی سەختە. دابینکەرانی خزمەتگوزاری مۆبایل بە شێوەیەکی سەرەکی تەکنیکی پارچەکردنی تۆڕ(NS) بەکاردێنن بۆ چارەسەرکردنی ئەم ئاڵەنگاریانە. .

پارچەکردنی تۆڕ لە نەوەی پێنجەم ،بوار دەڕەخسێنێت بۆ دابین کردنی چەندین خزمەتگوزاری جیاواز بە یەک ژێرخانی یەکگرتوو.ئەم گۆڕانکارییە بە یەکخستنی تۆڕی بێ تەلی مەجازی (WNV) لەناو پەیکەربەندی تۆڕەکەدا دەکرێت .چونکە کاتێک (WNV) دەکرێتە بەشێک لە پێکهاتەکە، خزمەتگوزارییەکان بە ئاسانیی لێک جیا دەکرێنەوە و سەرچاوەکانیش بە شێوەیەکی کاراتر دابەش دەکرێن. بەم شێوەیە، دابەش کردنی سەرچاوەکان تۆڕەکان لێک جیا دەکاتەوە و باشترین سوود وەردەگرێت لە ژێرخانەکە

هەرچەندە تۆڕی بێتەلی مەجازی بەڕێوەبردنی پێکهاتەکانی پارچە کردنی تۆڕ (NS) بە شێوەیەکی بەرچاو ئاسان دەکات؛ سەرەڕای ئەوەش، تۆڕی 5G ڕووبەڕووی ئاڵەنگاری دەبێتەوە لە جێگیرکردنی ئامێرەکانی بەکارهێنەری کۆتایی وەک وێستگەکانی مۆبایل و ئامێرەکانی IoT، ئەوەش هەڵبژاردنی پارچە کردنی تۆڕ و داواکارییەکانی پەیوەندییە هاوچەرخەکان دوادەخات.

لەم تێزەدا جێبەجێکردنی پەیکەربەندێکی نوێی بۆدابەشکردنی تۆڕپێشنیاز کراوە، بە بەکارهێنانی پرۆسەی مەجازیکردن. لە پێکهاتە پێشنیازکراوەکەدا توێژێکی نوێ خراوەتە ڕوو بۆ بەڕێوەبردن و هەڵبژاردنی خزمەتگوزاری و داهات بە شێوازێکی داینامیکی لە نێوان بەکارهێنەران و کۆمپانیای تۆرە مەجازییەکان لە پێکهاتەی 5G دا.

هەروەها پێکهاتەیەکی نوێ و گشتگیری (RAN)ی مەجازی لە نەوەی پێنجەم پەرەی پێدراوە کە چەندین کۆمپانیای دابینکەری پەیوەندی (InPs) و کۆمپانیاکانی تۆڕی مەجازی مۆبایل (MVNO) لەخۆدەگرێت کە خزمەت پێشکەشی سەدان ئامێری کۆتا-بەکاربەر (UE) دەکەن. RAN ی پەرەپێدراوی مەجازی بنەماکەی پەیکەربەندێکی پێشنیازکراوە کە سەرچاوە و داهات بە شێوەیەکی داینامیکی بەڕێوە دەبات. RANی مەجازی لە چەند سیستەمیکی لاوەکی پێکدێت: سیستەمی بەستەری هەوایی بێ وایەر، سیستەمی ئابووری و یەکگرتن لەگەڵ ئەلگۆریتمە چارەدۆزەکان. لە بەستەری هەوایی بێ وایەری 5G RAN، مۆدێلێکی بیرکاری نوێ وەرگیراوە بۆ خستنەڕووی پێکدادانی داینامیکی نێوان بەکارهێنەرانی هەمان تۆڕ (IUI) وە لە نێوان بەکارهێنەرانی تۆڕی جیاواز، وە هەژمار کردنی قازانجی کەناڵی ئامێری بەکارهێنەر (UEs) .بۆیە، یەکخستنی مۆدێلێکی ئابووری لەگەڵ سیستەمی پێشنیارکراوی WNV ڕێگە بە هەموو لایەنەکان دەدات کە تێچوون و سوودەکان بە شێوەیەکی گشتگیر شی بکەنەوە. ئاڵۆزی تەرخانکردنی سەرچاوەی داینامیکی پێویستی بە ڕێبازێکی دوو ئاست هەیە، کە ئەویش جووتکردنی ئامێرەکانی بەکارهێنەر لەگەڵ MVNO و دابەشکردنی سەرچاوەکانی InP بۆ UE

لە ڕێگەی MVNO کە پێشوەختە هەڵبژێردراون. بۆ ئەم مۆدێلە ئەلگۆریتمەکانی هاوتاکردنی پلەبەندی (Matching game)و جوڵەی گەردیلە (PSO)گەردیلە (PSO) دەخرێنە ڕوو تاوەکو دابەشکردنی سەرچاوەکان باشتر بکەن و لە هەمان کاتدا زۆرترین داهات بۆ (InPs) بەدەستبێنن و توانای بەکارهێنەرگەشە پێبدەن.

دەرئەنجامە گریمانەییەکان جەختیان لەسەر بەهێزی هەردوو ئەلگۆریتمەکە کردەوە، کە تواناییان لە باشکردنی تێچوون و باشترکردنی توانای بەکارهێنەردا نیشان دەدەن.

ئەلگۆریتمی Matching Game ناسراوە بەهۆی بەرزی توانای بەدەستهێنانی داهات و ڕازیکردنی بەکارهێنەران لە ڕێگەی بەردەست کردنی داواکارییەکانیان بە تەواوی. بەمەش ڕەوایەتی دەدات بە وەرگرتنی پارەی زیاتر بەرامبەر پێشکەشکردنی خزمەتگوزارییە بەنرخەکان کە لەگەڵ خواستاکانی بەکارهێنەردا دەگونجێن.

لە بەرامبەردا ئەلگۆریتمی PSO گرنگی سەرەکی دەدات بە دابەشکردنی سەرچاوەی دادپەروەرانە و نرخێکی کەمتر دەخاتە ڕوو لەماوەیەکی کەم بە بەراورد بە Matching Game. بەڵام ئەمە لەسەر هەژماری سازشکردن لەسەر ڕێژەی داتا و ئەزموونی بەکارهێنەردەبێت. هاوسەنگییەکی بەرچاو لە نێوان ئەلگۆریتمە پێشنیازە کراوەکاندا سەرهەڵدەدات بە زیادبوونی ژمارەی بەکارهێنەر بۆ ٣٠٠ ئامێر لەماوەی ١٠٠ خول، بەمەش PSO پێوستی بە ٣٠ چرکە دەبێت، لەکاتێکدا بۆ هەمان خول و ژمارەی بەکارهێنەر Matching Game پێوستی بە ٤٥ چرکەیە هەیە بۆ هاوسەنگبوونی سیستەمەکە . جگە لەوەش، لەگەڵ Matching Game، بەشداریکردنی بەکارهێنەر دەگاتە 98%، کە ڕێژەی وەرگرتنی بەکارهێنەری سەرنجڕاکێش لە ماوەی بەڕێوەبردندا نیشان دەدات. ، توێژینەوەکە ڕۆشنایی دەخاتە سەر ڕەچاوکردنی (WNV) لە چوارچێوەی تۆڕەکانی نەوەی پێنجەمدا، بە تایبەتی لە برەودان بە سەرچاوە و داهات لە (RAN )ی مەجازیدا.

حکومەتی هەرێمی کوردستان – عێراق
سەرۆکایەتی ئەنجومەنی وەزیران
وەزارەتی خوێندنی باڵا و توێژینەوەی زانستی
زانکۆی پۆلیتەکنیکی هەولێر
کۆلیژی تەکنیکی ئەندازیاری
بەشی ئەندازیاری سیستەمی زانیاری

# توێژینەوەی ئەدای جیاکردنەوەی خزمەتگوزاری بەکارهێنەری کۆتایی بە بەکارهێنانی تۆڕی پارچەکردن بۆ تۆڕەکانی نەوەی پێنجەم (5G)

## نامەیەکە

پێشکەشی ئەنجومەنی کۆلێژی تەکنیکی ئەندازیاری کراوە لە زانکۆی پۆلیتەکنیکی هەولێر وەکو بەشێك لە پێداویستیەکانی بەدەست هێنانی پلەی ماستەرلە ئەندازیاری سیستەمی زانیاری

لەلایەن
چنار مصطفى محمد
بەکالۆریۆس لە ئەندازیاری سیستەمی زانیاری

بەسەرپەرشتیاری
دکتۆرسالار خدر شێخە

هەولێر- کوردستان
١٢/ ٢٠٢٣